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Testing the Temporal Stability of the Climate Response of Tree Species at Norris Dam State Park, Tennessee, U.S.A.

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To the Graduate Council:

I am submitting herewith a thesis written by Allison Elizabeth Ingram entitled "Testing the Temporal Stability of the Climate Response of Tree Species at Norris Dam State Park, Tennessee, U.S.A.." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Geography.

Henri D. Grissino-Mayer, Major Professor

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Testing the Temporal Stability of the Climate Response of Tree Species at Norris Dam State Park, Tennessee, U.S.A.

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Abstract

Temporal stability of the climate-tree growth relationship means that over time, tree species were responding to a specific climate variable and continue to respond to that variable into the present. The stability of this response is important to test prior to attempting to reconstruct past climate. In this study, I sampled oaks (white oak = *Quercus alba* L. and chestnut oak = *Quercus montana* Willd.) and pines (Virginia pine = *Pinus virginiana* Mill. and shortleaf pine = *Pinus echinata* Mill.) growing in Norris Dam State Park in eastern Tennessee and tested the temporal stability of these species and their potential for reconstructing past climate. The cores were mounted and sanded, and the tree rings were crossdated and measured. I created chronologies in ARSTAN and analyzed my tree-ring data with DENDROCLIM2002 using regional climate data, which with the use of response and correlation functions and forward and backward evolutionary intervals, tested the temporal stability of the climate-tree growth relationship. Oak was positively correlated with late spring (June) precipitation and pine was positively correlated with spring (May-June) precipitation. Both species were positively correlated with growing season Palmer Drought Severity Index (PDSI), oak with late growing season (June-October) PDSI and pine with early growing season (May-July) PDSI. Oak had a negative relationship with temperature in late spring (June). These relationships are consistent from 1895 to 2015 in correspondence with the instrumental record. The chronologies formed can be used to reconstruct these past climate variables. In the southeast, both stable and unstable relationship between climate and tree growth have been found, which confirms the need to assess temporal stability on a site by site and chronology by chronology basis before reconstructions are attempted.

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Chapter One

Introduction

1.1 Background

Norris Dam State Park (NDSP) in eastern Tennessee consists of over 1,600 ha of old-growth and secondary-growth Appalachian oak-pine forest and is situated on the shores of Norris Lake (Figure 1.1). The park features over 1,280 km of shoreline, a marina, 15 hiking trails, 19 historic rustic cabins built by the Civilian Conservation Corps (CCC) in the 1930s, and 10 deluxe cabins along with two campgrounds (Maher 2008). The construction of Norris Dam began in 1933 and was completed in 1936 by the Tennessee Valley Authority (TVA). The purpose of this dam was to control flooding and bring electricity through hydroelectric power and economic development to the Tennessee Valley. The city of Norris was developed as a planned city along with the creation of the dam. The original purpose of Norris was for housing the workers on the dam (McDonald and Muldowny 1982). NDSP was built by the CCC in the 1930s (Maher 2008) and named for Nebraska senator George William Norris, the “father of the TVA” (McDonald and Muldowny 1982). Today, NDSP is managed by the Tennessee Department of Environment and Conservation and contains trees with old-growth traits that could be used by tree-ring scientists to better understand past climate.

1.2 Reconstructing Past Climate

Proxy reconstructions of past climate are important because the instrumental record becomes sparser and less reliable the further back in time you go (Wilson *et al*. 2007). For example, climate data available from the National Oceanic and Atmospheric Administration’s National Centers for Environmental Information, such as precipitation, temperature, and Palmer

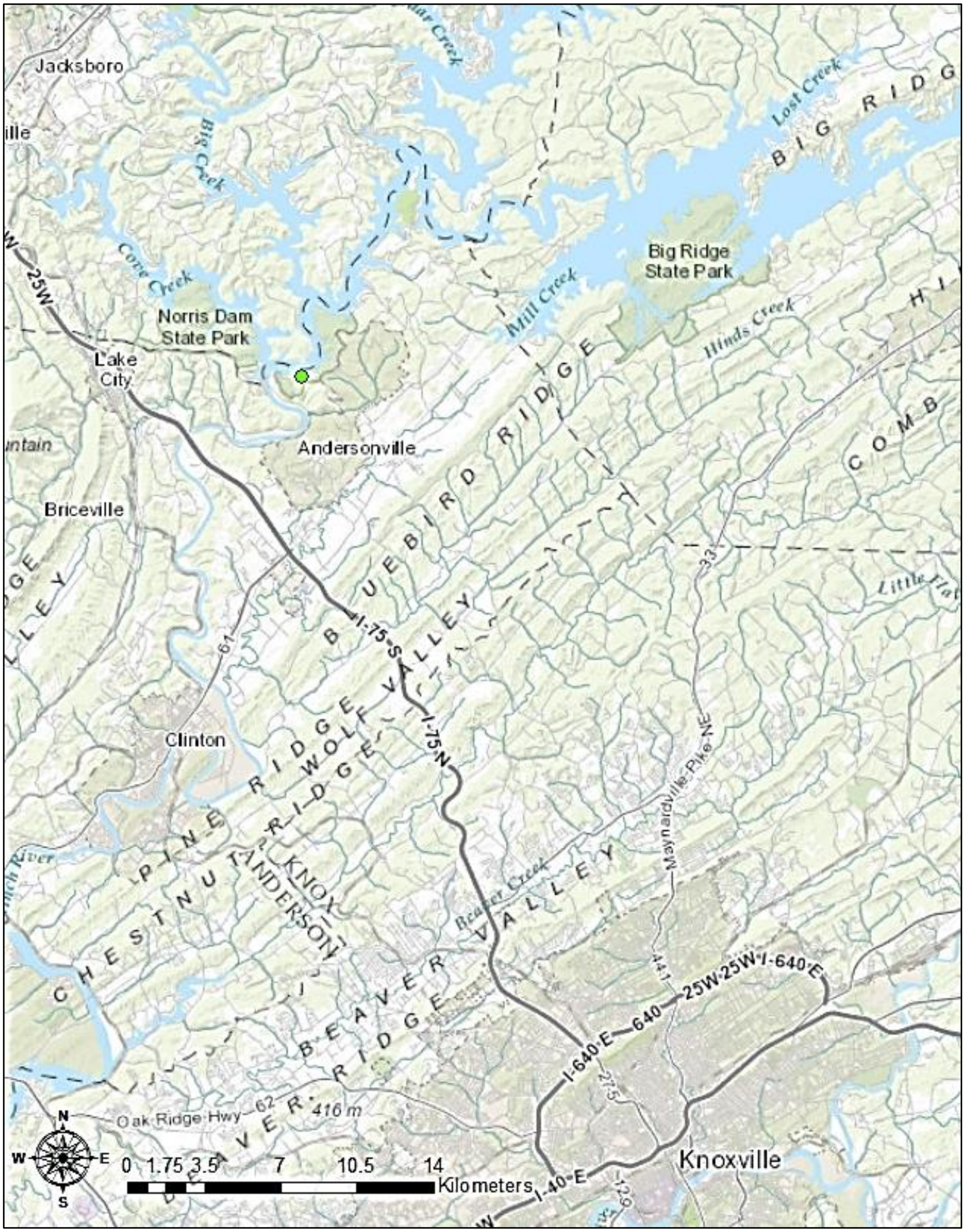

Figure 1.1. Map showing the location of Norris Dam State Park (84°5’24’’W, 36°13’12’’N), created using ArcMap.

Drought Severity Index (PDSI), only go back to 1895. To understand climate prior to 1895, we can use proxies for past climate, such as tree rings. The variability of tree-ring widths and the sensitivity to changes in year-to-year climate make it possible to identify to which climate variable the tree species are most responsive and which climate factor most drives tree growth. To reconstruct past climate, we need long-term tree-ring data to better understand both high- and low-frequency climate episodes across multiple time scales (Jacoby and D'Arrigo 1997). Tree rings are ideal because they have a resolution from the sub-annual to seasonal to century time scales (Biondi and Waikul 2004) and can be collected from sites where climate may be particularly limiting to tree growth (Coppola *et al*. 2012).

A principle that has become common in dendroclimatology is the uniformitarian principle, which states that the way trees are responding to climate during the present is how they responded to climate in the past. For this principle to hold, the tree species must be found to have a temporally stable response to climate. Testing for temporal stability has therefore become an important and necessary step in reconstructing past climate because it is also a test for the reconstruction potential of the tree species. If the tree species is unstable at site level and does not respond to the same climate variable over time, the climate reconstruction developed from this species would not be representative of past climate (D'Arrigo *et al.* 2008). Prior to developing a reconstruction of some climatic variable, we must first verify that the climate-tree growth relationship has remained stable over at least the modern period, i.e. 1895 to present.

1.3 The Divergence Problem

In recent studies, dendroclimatologists have identified a phenomenon termed the divergence problem that could put the uniformitarian principle in doubt. Divergence is the tendency for tree growth at climate-limited sites (i.e., sites where a specific climate variable limits tree growth) to reflect a weakening in response to climate over time, causing a divergence in trend where a climate variable (such as temperature) increases over time, but tree growth decreases over time (Wilson *et al*. 2007). Ideally, both variables should track similarly over time. A loss in temperature sensitivity means that trees are not responding as strongly or at all to seasonal temperature changes in recent decades (Briffa *et al*. 1998). This has mainly been observed with trees that grow at high latitudes and elevations (Lebourgeois *et al*. 2012). Mid- and low-latitude sites and trees do not experience divergence as much or at all; however, these forests also are more sensitive to drought rather than temperature (Lebourgeois *et al*. 2012). The influence of divergence in the mid- and lower latitudes cannot be determined based only on what has been observed occurring in the higher latitudes (D'Arrigo *et al*. 2008). Divergence could be due to another climate variable becoming the main driver of tree growth at the site or regional level (Lebourgeois *et al*. 2012, D'Arrigo *et al.* 2008). Divergence has been observed since only the mid-20th century and is likely anthropogenic in origin (Briffa *et al*. 1998, D'Arrigo *et al.* 2008), but divergence is not present in all temperature-sensitive sites (Wilson *et al*. 2007).

The divergence problem is the primary reason why testing for temporal stability between climate and tree-growth is important. If a site and tree species show divergence, the climate-tree growth relationship is unstable over time and the tree-ring data cannot be used to reconstruct past climate. A temporally unstable relationship calls into question the reliability of using tree rings to determine earlier warm and cold periods (Wilson *et al*. 2007). We need to verify that chronologies are free from divergence and temporally stable before we can reconstruct climate (Wilson *et al*. 2007).

1.4 Research Questions

I will examine the climate response of white oaks and yellow pines growing in Norris Dam State Park in eastern Tennessee and test the temporal stability between climate and tree growth during the 20th and 21st centuries. My hypotheses are:

H_o = The climate-tree growth relationships in these tree species are temporally stable over the past 120 years (1895 to 2015).

H_A = The climate-tree growth relationships in these tree species are not temporally stable over the past 120 years.

To evaluate my null hypothesis, I will address the following research questions:

1. To which climate variables are oak and pine species responding?
2. Were the climate-tree growth relationships temporally stable?
3. Can the oak and pine chronologies be used to reconstruct past climate?
4. What are the implications of the results for past and future climate reconstructions?

If the climate-tree growth relationships are temporally stable, reconstructions of past climate can be developed from these chronologies at NDSP in eastern Tennessee in the southeastern United States. If the climate-tree growth relationship is not temporally stable, a basic assumption in dendroclimatology is violated and any reconstructions from these species would be inaccurate.

Chapter Two

Literature Review

2.1 Mitigating the Divergence Problem

In addition to or instead of ring widths, other properties of tree-ring data (such as maximum latewood density or isotopic composition) can be helpful in reconstructing climate (Büntgen *et al*. 2012). Creating a successful proxy that can be used to reconstruct climate is important and has many requirements. These requirements are: (1) a stable relationship with climate; (2) being comprised of long-lived species that will not affect the segment length and restrict the reconstruction; (3) not being affected by statistical divergence due to detrending and standardization; and (4) not being affected by calibration methods that cause variance loss, which underestimates climate variability (Anchukaitis et al. 2013). The choice of detrending method is a major concern with tree-ring reconstructions and may have inadvertently contributed to creating tree-ring data that would be prone to the divergence issue. To detrend tree-ring data, dendrochronologists use lines or curves mathematically fit to the original raw data. These lines or curves can artificially introduce divergence if the fits greatly over-estimate or under-estimate tree growth, which happens occasionally towards the end of longer tree-ring sequences (D’Arrigo *et al*. 2008). This causes reconstructed temperatures to be over- or under-estimated (Briffa *et al*. 1998).

2.2 Possible factors that cause divergence in the Northern Hemisphere

Researchers are attempting to understand the factors that determine how tree species respond to divergence; however, the possible causes are uncertain and could be climatic, non-climatic, anthropogenic, or a combination. These causes could be: (1) increasing moisture stress (i.e. “overtaking” the temperature response); (2) threshold responses (i.e., trees respond to temperature only up to a certain level); (3) delayed snow melt (which would impact the temperature response); (4) changes in the seasonal response to climate (i.e., a shift from spring to summer responses); (5) local pollution (masking the temperature response); (6) responses to minimum and maximum temperatures (rather than the commonly-used mean temperature); (7) detrending effects (i.e., applying curves to tree-ring data that actually cause an underestimation of temperature); and (8) human factors (again, masking the natural climate response) (D'Arrigo *et al*. 2008).

Divergence could be a function of changes on the hemispheric scale, not the local or regional scale, such as higher UV-B levels and lower solar radiation, increased CO_2, increased acid deposition, or increased ozone and climate variability (Briffa *et al*. 1998). For example, global dimming is a large-scale process and occurs when the amount of solar radiation received at ground level for photosynthesis and plant growth is reduced, possibly due to increasing pollutants. An increase in ozone affects photosynthesis and decreases productivity (D'Arrigo *et al*. 2008). Finally, the number of proxy data sets used, low replication, limited recording stations and data that result in an unreliable instrumental record could also be contributing factors (Wilson *et al*. 2007).

2.3 Statistical methods for testing temporal stability

Calibration identifies climatic factors (such as precipitation and temperature) that affect tree growth, and is a prerequisite for reconstructing climate from tree rings (Biondi 1997). In addition, trees integrate responses from climate conditions outside the growing season and dendroclimatologists calibrate climate with tree growth by including climate data from the previous growing season and dormant season rather than using monthly climate data from just the growing season (Wilson *et al*. 2007). In the calibration process, we conduct correlation analyses for a single calibration interval, e.g. 1895 to 1950. Moving and evolutionary response function analyses, however, use multiple calibration intervals. Moving response functions (MRF) have a fixed number of years (e.g., 35 years) advanced across time by one year (either forward or backward) to calculate the correlation coefficients between tree growth and climate for moving intervals. For example, the most recent period would be 1981–2015; the next would be 1980–2014, then 1979–2013, and so on, in a MRF analysis backward in time. Evolutionary response function (ERF) analysis uses a longer number of years to calculate the response coefficients and also allows for both forward and backward calculations, having either a fixed start year or fixed end year, and adding one year additionally to the period forward or backward and calculating a new correlation coefficient. These techniques are useful for examining non-linear climate-tree growth relationships in which multiple climate predictors may exist. Moving and evolutionary response functions are an improvement on standard linear response function analyses (Biondi 1997).

DENDROCLIM2002 is a Windows-based program developed by dendroclimatologists that calibrates tree-ring chronologies against instrumental data over the historical period and estimates the significance of the response and correlation coefficients (Biondi and Waikul 2004). DENDROCLIM2002 uses bootstrapped confidence intervals and evolutionary and moving intervals to test for temporal changes in climate-tree growth relationships. To compute response and correlation coefficients, DENDROCLIM2002 uses 1000 bootstrapped samples to compute confidence intervals and tests significance at $p < 0.05$. To be deemed significant, median correlation and response coefficients must be greater than half the difference between the 97.5th and 2.5th quantiles (Biondi and Waikul 2004).

This software has been used in many recent climate analyses to determine which climate variables are most important for tree growth and for evaluating whether climate and tree growth relationships have been stable over the 20th–21st centuries. For example, Levanič and Eggertsson (2008) used DENDROCLIM2002 for testing the temporal stability of the climate response of birch in northern Iceland. They used both response functions and forward evolutionary intervals and found that above average temperatures in both June and July had a positive effect on tree growth and that this was a stable relationship over time. Koprowski *et al.* (2010) investigated climate-tree growth relationships of Scots pine in northern Poland with the use of DENDROCLIM2002. They investigated both temperature and precipitation and reconstructed past climate with the use of February-March temperature, which was stable over time. Maxwell *et al.* (2012) used correlation function analysis in DENDROCLIM2002 to identify a period for reconstructing precipitation from eastern red cedar in the mid-Atlantic region of the U.S. They used previous May to current October as the time frame to examine the lag effect of climate on tree growth. The researchers found that May precipitation was suitable for reconstruction through moving evolutionary analysis. May precipitation was stable with tree growth over time. Roibu *et al.* (2011) assessed dying beech stands on the Dragomirna plateau in Suceava county in Romania. The researchers tested the influence of precipitation and temperature on tree growth and used DENDROCLIM2002 to assess climate-tree growth relationships using the previous June to current August as the time frame. The researchers found that current May precipitation was positively correlated with tree growth. The relationship between May precipitation and tree growth was stable over time.

2.4 Research on temporal stability in the Northern Hemisphere

Many researchers have studied temporal stability and the ability of certain tree species to be used to reconstruct past climate. For example, Biondi (1997) found that Torrey pines (*Pinus torreyana* Parry) growing in California were temporally stable, but Douglas-fir trees (*Pseudotsuga menziessii* (Mirb.) Franco) growing in Idaho were not. Douglas-firs showed a negative response to July temperature and a positive response to April to June precipitation, especially May precipitation. Over time, though, the precipitation signal shifted from a June response to a May response and eventually to just an April response. Douglas-fir growth is most affected by moisture stress based on the negative response to summer temperature and positive response to spring/summer precipitation, which could be due to lack of soil and steep slopes found where these trees were collected. As the signal shifted in recent decades, the onset of this moisture stress in Douglas-fir occurred earlier in the growing season. This study again demonstrates that some tree species can show the effects of divergence while others may not.

Wilson *et al*. (2007) used tree-ring and local and regional temperature data that did not show any effects of divergence to develop a new, independent reconstruction of extratropical Northern Hemisphere annual temperature from 1750 to 2000. This reconstruction fared well in tracking trends in the instrumental data, even through the recent period, although it still slightly under-predicted temperatures. Choosing divergence-free sites can reduce the effects of divergence in the reconstruction; however, it is not something that can be done prior to field sampling, and can only be conducted on a tree-by-tree basis in the laboratory.

Kipfmueller (2008) conducted research in the northern Rocky Mountains and found that whitebark pine (*Pinus albicaulis* Engelm.) has a weak summer temperature signal and is showing divergence to temperature and not responding proportionally. This species is widespread in the northern Rockies and should be able to be used to reconstruct past climate because it is found at the upper treeline and should be sensitive to climatic fluctuations. Subalpine larch (*Larix lyallii* Nutt.), however, is a species found in the same region, but does not show divergence (Kipfmueller 2008). This research demonstrates that not all species in a site may show divergence and more studies are needed to better understand why.

Biermann (2009) found that the growth of yellow pines in Great Smoky Mountains National Park (GSMNP) is influenced by both precipitation and temperature, but is mainly moisture sensitive, with the strongest response to spring precipitation. However, she also found that winter mean minimum temperature influenced the growth of yellow pines. Biermann found temporally unstable climate-tree growth relationships at GSMNP in which the response of yellow pine to moisture conditions during the growing season weakened and the response to mean minimum temperatures in winter strengthened. This makes yellow pine growing in GSMNP unsuitable for climate reconstructions.

Fish *et al*. (2010) investigated whether Scots pines (*Pinus sylvestris* L.) growing in Glen Affric, Scotland were reaching a senescent stage in which they would no longer respond to the dominant climate signal. They found a positive response to mean summer temperature and also a positive response to winter temperature, but a stronger response was found for summer temperature. Surprisingly, the strongest response to mean temperature was observed for trees in the older age groups. However, this group also showed the greatest weakening in the climate signal, suggesting that senescence had a strong effect on the strength of the climate response as well as the level of divergence that was occurring.

Trindade *et al*. (2011) investigated air temperature and precipitation during the growing season and the growth of two spruce species (*Picea mariana* B.S.P. and *P. glauca* (Moench)

Voss) at four sites across central Labrador in eastern Canada and tested for temporal stability. They found that the climate-tree growth relationships were unstable over time, likely due to changes in moisture availability, precipitation, temperature, or other site-specific factors. Moist sites often had less stable climate-tree growth relationships, while those at drier sites were more stable. Insect outbreaks have been recorded at times corresponding to insensitivity in the climate-tree growth relationship; however, these climate sensitivity shifts and reversals do not always correspond to lower tree growth. The shifts and reversals have more to do with changes in precipitation, and therefore moisture availability. Therefore, high moisture levels, caused by an increase in precipitation, can reduce climate sensitivity.

Li (2011) also found that pines in the southeastern U.S. responded both to precipitation and temperature. In her study site from eastern North Carolina to eastern Tennessee, she found that winter temperature was the limiting factor for pines on the western mountain site and moisture was the limiting factor for pines on the eastern mountain and coastal sites. Winter North Atlantic Oscillation (NAO) had positive correlations with tree growth. However, she found that tree growth and climate exhibited an unstable relationship, shown by a shift from a precipitation signal to a temperature signal in the mid-20th century.

Coppola *et al*. (2012) found that temperature influenced growth of European larch more than precipitation in the Italian Central Alps. The influence of temperature also depended on elevation, with stronger climate signals found at higher elevations. June temperature had the greatest influence on larch growth, but the relationship was somewhat unstable and variable. Since the 1960s, a loss in the June temperature signal was observed in these larch chronologies, especially at lower altitude sites. An emerging and increasing trend between August temperature and tree growth indicated a prolonged growing season. This phenomenon was mainly observed at high elevations where temperature was the strongest driving factor. At lower-elevation sites, precipitation was more important for tree growth, especially during late spring to early summer, but Coppola *et al*. (2012) found a negative influence of June precipitation at higher elevations. Although they found that high altitude chronologies were valuable in the study of climate, the responses to climate varied over time and temporal instability was apparent in the climate-tree growth relationships.

Büntgen *et al*. (2012) extended a one-thousand-year long European larch (*Larix decidua* Mill.) chronology from the French Alps out to 2007 (it previously ended in 1974) for calibration and verification because the original chronology showed only weak correlations with summer temperature. Comparing the new, updated data set with temperature, precipitation, and drought, they found weak and temporarily inconsistent climate responses. They found that temperature sensitivity decreased with decreasing latitude. These findings call into question the reliability of temperature reconstructions based on tree-ring widths in the Mediterranean region overall. They stressed the need to create chronologies instead from maximum latewood density and stable isotope ratios, which are not as affected by divergence. They also stressed the need to collect data from lower latitudes and evaluate site conditions before compiling the local data into a regional network.

2.5 Climate Oscillations

In this study, we will not only be analyzing climate variables such as temperature, precipitation and PDSI, but also climate oscillations, which may also have an effect on tree growth. The Atlantic Multidecadal Oscillation (AMO) is a climate oscillation of sea surface temperature (SST) between Greenland and the equator. It has warm and cool phases lasting around 20–40 years with a range of 0.4 °C and operates across a 65 to 80 year cycle (Enfield et al. 2001). Over the instrumental period, from 1856 to the present (Gray et al. 2004), warm phases have occurred from around 1860 to 1880 and 1940 to 1960 and cool phases have occurred from around 1905 to 1925 and 1970 to 1990. Warm or positive phases of the AMO are characterized by increased rainfall over Florida and the Pacific Northwest and decreased rainfall over the rest of the U.S. Cool or negative phases are characterized by increased drought in Florida and the Pacific Northwest, causing an increase in wildfires and an increase in rainfall over the rest of the U.S. (Enfield et al. 2001). Since the mid-1990s, we have been in another warm phase (Gray et al. 2004).

The El Niño-Southern Oscillation (ENSO) operates on a 2 to 10 year cycle of shifting pressure and SST in the Pacific Ocean (Philander 1983). ENSO alternates between warm phases (El Niño) and cold phases (La Niña). The Southern Oscillation index (SOI) is an index of pressure across the tropical Pacific used to monitor ENSO conditions (Mccabe and Dettinger 1999), and is the difference in sea level pressure (SLP) between Tahiti and Darwin. ENSO events persist for 6 to 18 months (Mantua and Hare 2002). During a warm El Niño phase, sea level pressure is higher at Darwin and lower at Tahiti, making the SOI negative (Stenseth et al. 2003). This would be reversed during La Niña (McCabe and Dettinger 1999). El Niño causes warm surface waters in the central and eastern Pacific and cold waters in the western Pacific. The west coast of South America experiences warm, wet winters during an El Niño event (Wu et al. 2004), while the American Midwest and Northwest experience warmer winters and the American Southwest experiences wetter winters (Ropelewski and Halpert 1986). La Niña is the cool phase consisting of high sea level pressure and cold sea surface temperatures in the eastern Pacific (Philander 1983). La Niña causes the opposite effects of El Niño.

The North Atlantic Oscillation (NAO) is an oscillation of atmospheric mass between the Azores high and the Icelandic low and is most pronounced in the winter (Hurrel and van Loon 1997). It was first identified as the seesaw in winter temperature between Greenland and northern Europe (van Loon and Rogers 1978). The NAO consists of positive and negative phases (Stenseth et al. 2003) and is associated with pressure over the Northern Hemisphere (van Loon and Rogers 1978). The positive phase is associated with low pressure over the Icelandic low and high pressure over the Azores high (Rogers 1984). Since the 1980s, the NAO has been in a positive phase, which shifts storms northward and brings warm, wet conditions over northern Europe and Eurasia, cool conditions to the North Atlantic and dry conditions to southern Europe and the Mediterranean (Hurrel and van Loon 1997). Negative phases of the NAO have a reduced pressure difference between the Azores high and Icelandic low and are characterized by weaker storms on a southerly track. Northern Europe experiences much colder winters, the Mediterranean and northern Canada experience moist and mild winters, and the eastern U.S. experiences cold and snowy conditions (Rogers and van Loon 1979, Hurrell and van Loon 1997, van Loon and Rogers 1978, Hurrell 1996).

The Pacific Decadal Oscillation (PDO) operates on 20 to 30 year cycles with alternating warm and cool phases with abrupt transitions. It is similar to the El Niño pattern (Mantua and Hare 2002); however, the PDO alone does not have a great effect on the Southeastern U.S, unless combined with another climate oscillation, such as the AMO. When a positive phase of the PDO is combined with a positive phase of the AMO, major drought occurs in the U.S. (McCabe et al. 2004). In a warm or positive phase of the PDO, cool sea surface temperatures (SST) are found in the central north pacific and warm SST on the west coast of North and South America. Warm or positive phases are characterized by cooler temperatures in the eastern U.S.

and Midwest and warmer temperatures in the western U.S. and Canada. Warm or positive phases also include increased precipitation in the American Southwest and Mexico and decreased precipitation in the Pacific Northwest, Midwest, Great Lakes and Southeastern U.S. Cool or negative phases of the PDO are the reverse of the warm or positive phases with regards to SST, temperature, and rainfall. Since 1998, we are believed to have entered a cool phase of the PDO (Mantua and Hare 2002).

2.6 The Norris Dam chronology as a master chronology

The Norris Dam white oak chronology, developed by Dr. Daniel Duvick of Oak Ridge National Laboratory in 1981 (Duvick 1981), has been used as a master chronology for many dendroarchaelogical studies in the Southeast (Mann 2002, Reding 2002, Blankenship et al. 2009, Grissino-Mayer et al. 2009, Slayton et al. 2009), due to the geographical proximity of Norris Dam State Park to the study sites. In these cases, the chronologies shared a similar climate signal because they were comprised of white oak species, or trees that correlated well with the white oak chronology. For example, the Norris Dam white oak chronology was used for dating the year of harvest for trees used to build the Swaggerty Blockhouse located in Cocke County, Tennessee. The same climate responses were present at both the Norris Dam site and the site from where the trees grew used in the blockhouse. The two chronologies had a correlation of 0.56 and the blockhouse was dated to 1860 (Mann 2002). The NDSP chronology was also used to date log structures to evaluate settlement patterns in Grainger, Jefferson, Hamblen, and Union counties in Tennessee (Reding 2002). Although none of the buildings sampled were made of oak, the Norris Dam chronology was still suitable for dating. To determine when saltpeter (used to make gunpowder) was mined at Cagle Saltpetre Cave, timbers from abandoned wooden leaching vats were sampled (Blankenship et al. 2009). The researchers used the Piney Creek Pocket

Wilderness and Norris Dam chronologies as reference chronologies because of their close proximity to the saltpeter cave. The final chronology was highly correlated with the Norris Dam chronology with a correlation of 0.49 (Blankenship et al. 2009). To date undated samples from the Rocky Mount Historic Site in Piney Flats, Tennessee, Grissino-Mayer et al. (2009) used five white oak chronologies from the International Tree-Ring Data Bank (ITRDB), one of which was the Norris Dam chronology, to create a regional composite chronology. Two structures at the Marble Springs Historic Site in Knox County, Tennessee, were dated using the Piney Creek Pocket Wilderness and Norris Dam chronologies, but only the Norris Dam chronology was used to anchor the series in time with a correlation of 0.61 (Slayton et al. 2009).

Chapter Three

Testing the Temporal Stability of the Climate Response in Tree Species at Norris Dam State Park, Tennessee, U.S.A.

This chapter is intended for publication in a peer reviewed journal. This research topic was originally developed by me and my advisor, Dr. Henri Grissino-Mayer. The use of "we" throughout the text refers to me, Dr. Grissino-Mayer, who assisted with site selection, field work, guidance of project development, and editing, and my field and lab assistants, who assisted with field work, sample preparation and processing. My contributions to this chapter include field work, processing and dating of samples, data analysis, interpretation and graphic displays of results, and writing.

Abstract

Temporal stability of the climate-tree growth relationship means that over time, tree species were responding to a specific climate variable and continue to respond to that variable into the present. The stability of this response is important to test prior to attempting to reconstruct past climate. In this study, I sampled oaks (white oak = *Quercus alba* L. and chestnut oak = *Quercus montana* Willd.) and pines (Virginia pine = *Pinus virginiana* Mill. and shortleaf pine = *Pinus echinata* Mill.) growing in Norris Dam State Park in eastern Tennessee and tested the temporal stability of these species and their potential for reconstructing past climate. The cores were mounted and sanded, and the tree rings were crossdated and measured. I created chronologies in ARSTAN and analyzed my tree-ring data with DENDROCLIM2002 using regional climate data, which with the use of response and correlation functions and forward and backward evolutionary intervals, tested the temporal stability of the climate-tree growth relationship. Oak was positively correlated with late spring (June) precipitation and pine was positively correlated with spring (May-June) precipitation. Both species were positively correlated with growing season Palmer Drought Severity Index (PDSI), oak with late growing season (June-October) PDSI and pine with early growing season (May-July) PDSI. Oak had a

negative relationship with temperature in late spring (June). These relationships are consistent from 1895 to 2015 in correspondence with the instrumental record. The chronologies formed can be used to reconstruct these past climate variables. In the southeast, both stable and unstable relationship between climate and tree growth have been found, which confirms the need to assess temporal stability on a site by site and chronology by chronology basis before reconstructions are attempted.

3.1 Introduction

Proxy reconstructions of past climate are important because the instrumental record becomes sparser and less reliable the further back in time you go (Wilson *et al*. 2007). For example, climate data, available from the National Oceanic and Atmospheric Administration's National Centers for Environmental Information, go back only to 1895. To understand climate prior to 1895, we can use tree rings, which are good proxies of past climate. The variability of tree-ring widths and the sensitivity to changes in year-to-year climate make it possible to identify to which climate variable the tree species is most responsive and which factor most drives tree growth. Tree-ring chronologies are usually collected from climate-limited sites, such as high elevations and high latitudes, which are usually temperature sensitive (Trindade *et al.* 2011, Büntgen *et al.* 2012, Lebourgeois *et al.* 2012, D'Arrigo *et al.* 2008, Kipfmueller *et al.* 2008, Briffa *et al.* 1998, Coppola *et al*. 2012). Chronologies can also be collected from mid-latitude sites or low elevation sites, which would be more sensitive to drought (Lebourgeois *et al.* 2012), Even moist sites are possible for tree-ring analyses because these sites could be more sensitive to drought (Stahle and Cleaveland 1992, Briffa *et al.* 1998, Friedrichs *et al.* 2009).

An underlying principle in dendroclimatology is the uniformitarian principle, which states that the way trees are responding to climate during the present is how they responded to climate in the past. For this principle to hold, the relationship between tree growth and climate must be found to be temporally stable over the 20th and 21st centuries. Testing for temporal stability has, therefore, become an important and necessary step for reconstructing past climate because it is also a test for the reconstruction potential of the tree species. If the relationship is temporally unstable at the site level and does not respond to the same climate variable over time, the climate reconstruction developed from the species may not be representative of past climate (D'Arrigo *et al.* 2008). Because tree-ring data have been used in hundreds of reconstructions of past climate, it is important that these reconstructions be re-evaluated to determine whether or not the climate-tree growth relationship has been stable over time.

In recent years, a phenomenon termed divergence has been identified which describes the tendency for tree growth at climate-limited sites to show a weakening in response to climate in recent years, essentially a loss in climate sensitivity. This causes a divergence in trends where a climate variable (such as temperature) increases while tree growth decreases (Wilson *et al*. 2007). This loss in temperature sensitivity indicates that trees did not respond as much or at all to changes in temperature in the most recent decades of the 20th century (Briffa *et al*. 1998). This has mainly been observed with trees that grow at high latitudes and elevations (Lebourgeois *et al*. 2012). Mid- and low-latitude sites and trees do not experience divergence as much or at all; however, these forests also are more sensitive to drought than to temperature (Briffa *et al*. 1998, Pederson *et al*. 2001, Peng *et al.* 2011, Lebourgeois *et al*. 2012). Divergence could be due to another climate variable becoming the main driver of tree growth at the site or regional level (D'Arrigo *et al.* 2008, Lebourgeois *et al*. 2012) because divergence has been observed only since the mid-20th century, some speculate the cause to be anthropogenic in origin (Briffa *et al*. 1998, D'Arrigo *et al.* 2008).

The divergence problem is one reason testing for temporal stability is important. If a site and tree species show divergence, the climate-tree growth relationship is unstable over time and the tree-ring data cannot be used to reconstruct past climate. If a tree species shows a weakening in the correlation between tree rings and temperature over time, but once showed a strong correlation, the trees are likely responding to a different climate variable (Biondi 1997). A temporally unstable relationship calls into question the reliability of using tree rings to determine earlier warm and cold periods (Wilson *et al*. 2007). We need site chronologies to be free from divergence and to be temporally stable before we can reconstruct climate (Wilson *et al*. 2007).

In 1981, Dr. Daniel Duvick of Oak Ridge National Laboratory sampled white oak species at Norris Dam State Park and developed an oak chronology spanning from 1633 to 1980 from 71 crossdated series (Grissino-Mayer et al. 2009). This Norris Dam white oak chronology has been used as the master reference chronology for many dendroarchaeological studies in eastern Tennessee because of the close proximity of the historic structures to Norris Dam State Park and because the tree rings found in these structures came from trees that share a similar climate response (Mann 2002, Reding 2002, Blankenship et al. 2009, Grissino-Mayer et al. 2009, Slayton et al. 2009). I will examine the climate response of white oaks and yellow pines growing in Norris Dam State Park (NDSP) in eastern Tennessee and test the temporal stability of these tree species with climate over the 20th and 21st centuries. Another objective of my study is to extend Dr. Daniel Duvick's white oak chronology out to 2014 by sampling oaks from the same study site that he sampled in 1981. I will determine if the resultant chronology is temporally stable and can continue to be confidently used as a proxy for past climate. My null and alternative hypotheses are:

H_o = The climate-tree growth relationship in these tree species is temporally stable over the past 120 years (1895 to 2015).

H_A = The climate-tree growth relationship in these tree species is not temporally stable over the past 120 years.

If the climate-tree growth relationship is temporally stable, reconstructions of past climate can be developed from these chronologies. If the climate-tree growth relationship is not temporally stable, a basic assumption in dendroclimatology is violated and any reconstructions from these species would be inaccurate.

3.2 Study Site

Norris Dam State Park consists of over 1,600 ha of old-growth and secondary-growth Appalachian oak-pine forest situated on the shores of Norris Lake. The park consists of 15 hiking trails and 19 historic rustic cabins built by the Civilian Conservation Corps (CCC) in the 1930s, and 10 deluxe cabins along with two campgrounds. The trail my field assistants and I used, Lake View Trail, has its trailhead behind the rustic cabins (Figure 3.1). The site was on either side of the trail (Figure 3.2). We were specifically searching for old-growth white oaks and were initially wishing to focus on analyzing only one hardwood species. We were not looking for pines, but found very large pine trees in NDSP that appeared to be of considerable age and decided to include conifers as well. The study site was selected by Dr. Henri Grissino-Mayer. He cored oaks at NDSP along this trail in October 2014 along with Dr. Daniel Duvick, currently of Iowa State University.

3.3 Methods

3.3.1 Field Methods

The trees we cored were selected based upon species identification, location, size and presence of large lower limbs and other physical attributes that indicated great age (Schulman 1937). Because we initially sampled in March before the trees had broken winter dormancy, we identified the white oaks based on the bark and leaves on the ground around the tree. Pines were easily identified as these were the only tree species easily visible because of its green foliage in the stark winter landscape. We cored the trees with Haglof increment borers. WD-40 was sprayed on the inside and outside of the shaft of the borer. We started with the oaks and found that they were extremely hard to core. On almost every tree, the borer could not be extracted.

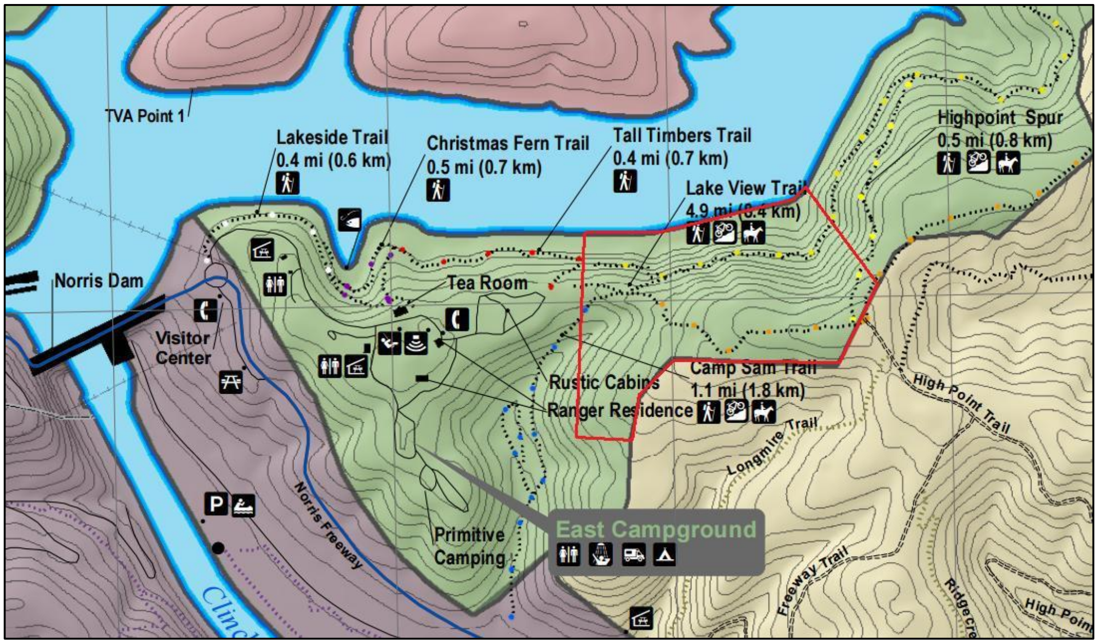

Figure 3.1. Partial map of Norris Dam State Park including the sampling area (red outline) and surrounding topography (taken from the Tennessee State Parks website, http://tnstateparks.com/parks/about/norris-dam).

Figure 3.2. Site on slope at Norris Dam State Park and view of Norris Lake (Photograph by Kyle Landolt).

This required we wrap a tow strap around the shaft of the borer and tie the tow strap to the rope and the rope around a nearby tree directly in line with the stuck borer (Figure 3.3). We then backed the borer out until the borer threads caught in the wood, which then allowed us to undo the rope and tow strap and back the borer out normally. Once extracted from the tree, each core was placed in a paper straw with the ID number written on it. The straws were placed in a map tube for protection and transportation. A GPS point was recorded at every tree and written in a field notebook to create a digital map showing locations of all sampled trees (Figure 3.4). Diameter at breast height was taken for each tree using a DBH tape. I sampled 30 oaks and 32 pines for a total of 62 trees.

Figure 3.3. Use of a tow strap and rope to remove a stuck borer from a tree (Photograph by Kyle Landolt).

3.3.2 Laboratory Methods

The cores were dried in the laboratory for five days, then mounted onto wooden core mounts using wood glue and held in place with masking tape. Once dry, the cores were sanded with progressively finer sandpaper (ANSI 80, 120, 220, 320 and 400 grit) until a smooth surface was achieved and the cell boundaries were clearly visible (Orvis and Grissino-Mayer 2002). The rings on the cores were crossdated using the list method (Yamaguchi 1991) then measured to 0.001 mm accuracy with the use of a dissecting scope and Measure J2X measuring software interfaced with a Velmex measuring stage.

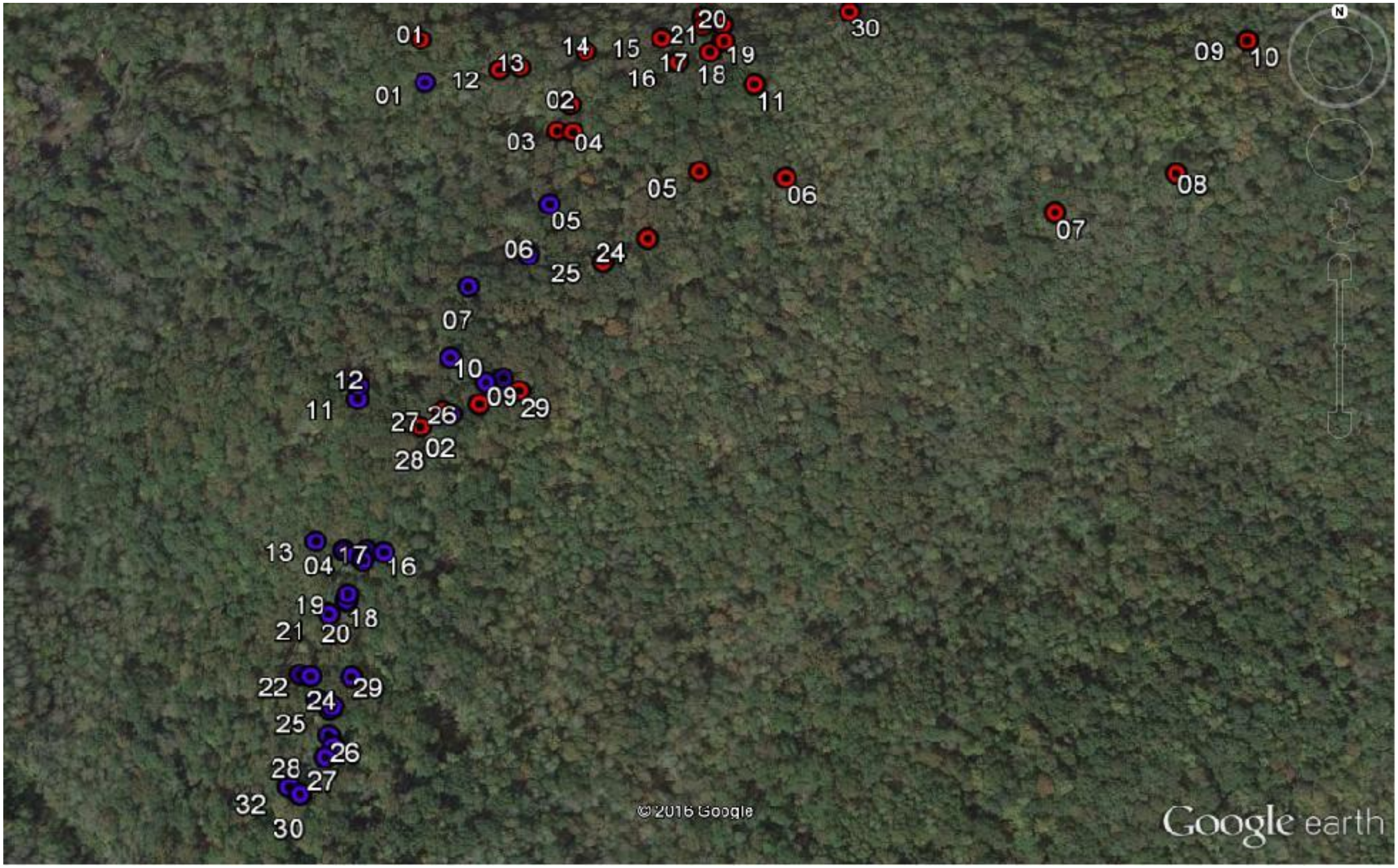

Figure 3.4. Close up of study area with sampled oaks (red) and pines (blue). Points show every sampled tree, totalling 62 trees (30 oaks and 32 pines).

3.3.2.1 Assessing Crossdating Accuracy

I used COFECHA to ensure proper crossdating and measuring (Holmes 1983; Grissino-Mayer 2001). COFECHA first produces a master chronology and then checks each measured series against it once the series being tested has been removed. I used 40-year segments with 20-year overlaps to test the correlation between a measured series and the master chronology created from all other series. COFECHA flagged potential crossdating errors below the critical threshold of 0.3665 which is the 99% confidence interval ($p < 0.01$) and identified, if possible, a position (i.e. shifting the segment by ±10 years) yielding a higher correlation. This allowed for visual rechecking and remeasuring, if necessary. Flagged samples with low correlation values ($p > 0.01$) that were rechecked, but could not be corrected, were removed from further analyses to ensure a strong climate signal. These trees were not responding to the macroclimate signal, but to some other disturbance or microclimate signal (such as crown or trunk damage from windthrow).

To evaluate crossdating quality, I used the interseries correlation, which is the correlation coefficient calculated for each series when compared to the chronology calculated from all other series in the dataset. A correlation coefficient of 0.40 and above is desired both for every individual core and the master chronology and indicates a strong regional climate signal (Grissino-Mayer 2001). I also evaluated the strength of the climate signal using mean sensitivity, which is a measure of the strength of the year-to-year variability in the ring widths (Grissino-Mayer 2001). Average values for tree-ring data from the Southeast may be as low as 0.15 to 0.2, with values of 0.25 to 0.35 being exceptional and best for crossdating and climate analyses (Biermann 2009).

3.3.2.2 Standardization

To remove possible non-climatic effects that may have affected tree growth, detrending by standardization is first conducted. Using ARSTAN, detrending was performed by first choosing a negative exponential or linear regression if the negative exponential curve does not fit the measurement data for each series (Cook and Holmes 1986). The detrending curves were visually inspected with the interactive detrending option in ARSTAN to determine which class of detrending option best fit the raw tree-ring data (Cook and Holmes 1986) and to remove trends unrelated to climate. If this class did not fit the data, then another class was chosen, such as different cubic smoothing spline lengths ranging from 10 to 100 years (Speer 2010). A spline length of 10 is very flexible, while a spline length of 100 is very rigid and smooth. Other detrending classes that I inspected were the Friedman Variable Span Smoother and the Hugershoff Growth Curve. In each detrending option, ARSTAN fits a line or curve to the ring-width data. The ring widths were then converted to unitless indices, which were generated based on the predicted versus actual growth. This removed the noise and isolated the desired signal and allowed all trees to contribute equally to the final chronology (Cook 1985, Cook et al. 1990). When converted to unitless indices, the chronology fluctuated around a mean of 1.0. A final chronology was developed once all the measurements had been converted to unitless indices, and then averaged together across all series by year.

Three chronologies are produced in ARSTAN: standard, residual, and ARSTAN. The standard chronology has major autocorrelation retained that is thought to be climatic in origin, but has biological autocorrelation as well. The residual chronology has no autocorrelation and all low frequency trends have been removed, even trends that could have been climatic in origin. Reincorporating the pooled model of autocorrelation back into the residual chronology produces the ARSTAN chronology. The pooled model of autocorrelation contains persistence both common and synchronous across the site that is attributed to climate (Cook 1985). The ARSTAN chronology is ideal to use in dendroclimatological analyses because this chronology has the climate signal built back in (Cook 1985) and is intended to have the strongest climate signal out of all the chronology types (Cook and Holmes 1986).

I detrended both tree species in ARSTAN using cubic smoothing spline lengths of 10, 15, 20, 25, 30, 35, 40, 45, 50, 75, and 100 years, as well as using the Friedman Variable Span Smoother and the Hugershoff Growth Curve. I ran ARSTAN for each detrending method and obtained an ARSTAN chronology for each one. By visually inspecting the resulting graphed tree-ring indices and by comparing the rbar and EPS, I was able to narrow down the best detrending techniques for each species to four each. I chose the detrending classes that displayed the highest rbar and EPS values back in time. The rbar is a measure of the strength of the common signal in the chronology and a measure of chronology reliability. The critical threshold for southeastern trees is at least 0.40 for a strong signal (ITRDB 2016). The EPS estimates the desired forcing signal, which should be common in all chronologies, and uncorrelated noise within and between individual trees (Mäkinen and Vanninen 1999) and is based on a correlation matrix of all the tree-ring series. The EPS should be > 0.85 for an acceptable level of chronology confidence (Wigley *et al.* 1984).

For oaks, I determined that a 30-year spline, 40-year spline, 50-year spline, and the Friedman Variable Span Smoother best reduced the high-frequency trends in the data, while maintaining the low-frequency (and hopefully climatic) trends. For pines, I determined that a 20-year spline, 25-year spline, 30-year spline, and the Friedman Variable Span Smoother best reduced the high-frequency trends in the data, while maintaining the low-frequency trends.

3.3.2.3 Climate Response

After narrowing down the possible detrending techniques to four for each species, I ran standardization trials in DENDROCLIM2002 to ensure the best detrending class was chosen, i.e. the class that retained the strongest climate signal. I tested a 20-year spline, a 25-year spline, a 30-year spline, a 40-year spline, a 50-year spline and the Friedman Variable Span Smoother for my standardization trials. This analysis also served to determine to which climate variables the oaks and pines at NDSP were responding most significantly. I downloaded climate data (climate division 01 for East Tennessee) from the National Oceanic and Atmospheric Administration's National Centers for Environmental Information (NCEI, formerly the National Climatic Data Center). I conducted the analysis spanning July of the previous year to October of the current year and from the year 1896 to 2014. I used a lagged effect to include influences from the previous year on current growth (Rochner 2014) because trees may integrate responses from climate conditions outside of the growing season (Wilson *et al.* 2007). I analyzed precipitation, Palmer Drought Severity Index (PDSI), and temperature data, as well as North Atlantic Oscillation (NAO), Pacific Decadal Oscillation (PDO), Southern Oscillation Index (SOI), and Atlantic Multidecadal Oscillation (AMO) data for each of the detrended chronologies to determine (1) which chronology had statistically significant ($p < 0.05$) correlations with climate and (2) which climate variables were most significant to tree growth. The final chronology for each species was chosen based on the statistically significant ($p < 0.05$) correlations with climate variables.

3.3.2.4 Tests for Temporal Stability

After the final detrended chronology was chosen for each species, I tested the temporal stability of the climate response. While the chronologies were chosen based on significant (p <

0.05) correlations, this first test is required to determine whether the correlations were stable over time. DENDROCLIM2002 uses evolutionary interval analysis to test for temporal changes in the climate-tree growths relationships over time (Biondi and Waikul 2004). I used both forward evolutionary analysis, which fixes the first year of growth and adds one year forward each time, and backward evolutionary analysis, which fixes the last year of growth and adds one year back in time. I ran DENDROCLIM2002 twice for each climate variable, once for forward evolutionary analysis and once for backward evolutionary analysis using an initial base length of 32 years, and then compared the results from the forward and backward evolutionary analyses. If the correlations were significant over time in both the forward and backward evolutionary analyses, then climate and tree growth have a temporally stable relationship.

3.4 Results

I collected a total of 124 cores from 62 trees across the site, but used only 95 measured ring-width series from 50 trees to develop the chronologies. Some cores were omitted due to breaks in the core or lost bark and/or rings, while I was unable to date the tree rings on some cores due to severe growth suppression. Once the series were measured, they were only removed from subsequent analyses if they displayed very low correlations with the other series in the dataset and could not be corrected. In these cases, the trees were responding to something other than the overarching climate signal, such as some disturbance process or competition (Grissino-Mayer 2001). The final oak chronology consisted of 55 series from 28 out of the original 30 trees collected and the pine chronology consisted of 40 series from 22 out of the original 32 trees collected.

3.4.1 Crossdating

The final tree-ring chronology for oak spanned the years 1840 to 2014. The series retained for chronology development were significantly correlated with an average interseries correlation of 0.62 and an average mean sensitivity of 0.19. In the southeastern U.S., a mean sensitivity of 0.15 to 0.20 is common, with a mean sensitivity of 0.25 to 0.30 being exceptional (ITRDB 2016). The 0.19 value suggests the ring widths are sensitive to changes in year-to-year climate. Five percent of the segments were flagged (15 segments out of 324).

The chronology for pine spanned the years 1781 to 2014. The series retained for chronology development were significantly correlated with an average interseries correlation of 0.60 and an average mean sensitivity of 0.27. This value falls within the exceptional category for this region and suggests that yellow pines have a high sensitivity to changes in year-to-year climate (ITRDB 2016). Four percent of the segments tested by COFECHA were flagged (12 segments out of 275). All flagged segments for both oak and pine were re-evaluated under the microscope. The flagged segments occurred mostly in the inner or outer portions of the core, where the tree could have been responding more to internal stand dynamics than to climate. This causes tree rings in these flagged segments to contain some noise unrelated to the common climate signal. The flagged segments had lower correlations than the rest of the core, but occasionally a higher correlation could be found shifting the segment to an alternate temporal position. If a higher correlation was found, it was only slightly higher than the original position and shifting the segment was not possible without also shifting the remaining segments that were not flagged (Grissino-Mayer 2001). I therefore deemed these segments to be correctly placed in time.

3.4.2 Standardization

I determined that a 30-year spline was the best detrending option for oak species (Figure 3.5) and a 20-year spline was best for pine species (Figure 3.6) because these spline options retained the strongest climate signal based on the number of significant relationships and the higher correlations compared to the other detrending options (Tables 3.1 and 3.2) and had high rbar and EPS values (Tables 3.3 and 3.4). Once the chronologies were detrended with a 30- and 20-year spline, both high frequency and low frequency trends in the data unrelated to climate were mostly removed both at the individual core level and in the final chronology consisting of all cores (Figures 3.7 and 3.8). The running rbar and EPS statistics further substantiated using the 30- and 20-year splines to develop the final chronologies. The running rbar was above 0.40, which is the critical threshold for a strong signal in the southeastern United States (ITRDB 2016) for most of the oak chronology length and the expressed population signal (EPS) was above 0.85, which is the acceptable level of chronology confidence (Wigley *et al.* 1984) for all of the chronology length (Table 3.3). These statistics give confidence in using the 30-year spline and the oak chronology because they show that a strong climate signal is retained.

The rbar for the pine chronology was above 0.40 for most of the chronology length (the critical threshold) (ITRDB 2016) and the EPS was above 0.85 (the level of chronology confidence) (Wigley *et al.* 1984) (Table 3.4). These statistics give confidence in using the 20-year spline and the pine chronology because they show that a strong climate signal is retained. The pine chronology had a stronger climate signal than the oak chronology and had more significant relationships with climate (Table 3.2). Both ARSTAN chronologies were graphed to show trends in tree growth over time (Figures 3.9 and 3.10).

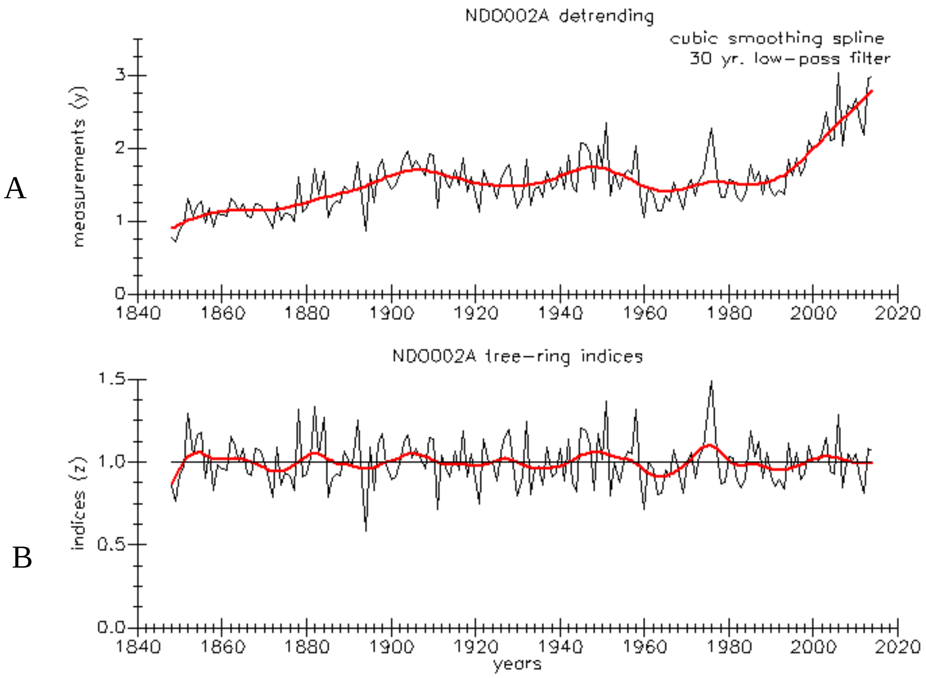

Figure 3.5. An example of a 30-year spline applied to oak core NDO002A. (A) shows the 30-year spline applied to the measurement series and (B) the resulting tree-ring indices.

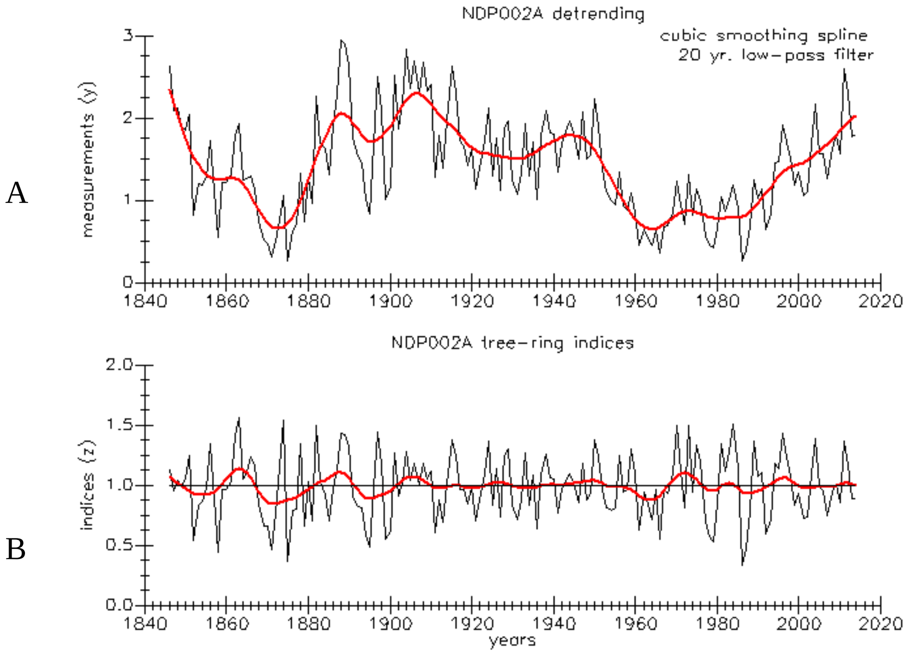

Figure 3.6. An example of a 20-year spline applied to yellow pine core NDP002A. (A) shows the 20-year spline applied to the measurement series and (B) the resulting tree-ring indices.

Table 3.1. Significant ($p \leq 0.05$) correlations found in the detrending tests between climate data and the oak measurement data. Months listed in all capital letters represent the previous year while lower case letters are the current year. Highlighted cells indicate the highest correlation per monthly variable for each of the detrending methods. The 30-year and 40-year splines were very similar. The correlations were the same or different by 0.01. The 40-year spline had a March precipitation variable that was not present in the 30-year spline, however, the 30-year spline was chosen based on the number of significant relationships and the high correlations.

Climate Variable	**30-year spline**	**40-year spline**	**50-year spline**	**Friedman**
May Temp	–0.28	–0.27	–0.27	–0.27
Jun Temp	–0.33	–0.32	–0.32	–0.31
Jul Temp	–0.17	–0.17	0.23	–
Sep Temp	–0.20	–0.20	–	–0.20
DEC Precip	0.20	0.19	0.18	0.18
Mar Precip	–	0.20	0.19	–
May Precip	0.30	0.30	0.29	0.29
Jun Precip	0.38	0.37	0.37	0.37
DEC PDSI	0.20	0.20	0.19	0.19
Jan PDSI	0.19	0.19	0.19	0.18
Feb PDSI	0.19	0.20	0.20	0.19
Mar PDSI	0.25	0.25	0.25	0.23
May PDSI	0.37	0.37	0.37	0.36
Jun PDSI	0.43	0.44	0.43	0.42
Jul PDSI	0.46	0.47	0.46	0.45
Aug PDSI	0.49	0.49	0.49	0.48
Sep PDSI	0.44	0.45	0.44	0.43
Oct PDSI	0.38	0.38	0.38	0.37
Aug NAO	0.28	0.29	0.29	0.27
DEC PDO	–0.18	–0.17	–0.17	–0.17
Jan PDO	–0.18	–0.18	–0.17	–0.17
Feb PDO	–0.16	–0.16	–0.16	–0.16

Table 3.2. Significant (p ≤ 0.05) correlations found in the detrending tests between climate data and the pine measurement data. Months listed in all capital letters represent the previous year while lower case letters are the current year. Highlighted cells indicate the highest correlation per monthly variable for each of the detrending methods. The 20-year spline was chosen based on the number of significant relationships and the higher correlations.

Climate Variable	20-year spline	25-year spline	30-year spline	Friedman
NOV Temp	–	–0.22	–0.23	–0.23
Apr Temp	–0.20	–0.19	–0.19	–0.19
Jul Temp	–0.19	–	–	–
Sep Temp	–0.20	–0.18	–	–
DEC Precip	–	0.21	0.22	0.20
May Precip	0.38	0.35	0.35	0.33
Jun Precip	0.31	0.31	0.30	0.30
Oct Precip	–0.18	–	–0.17	–0.19
JUL PDSI	0.18	0.17	0.18	–
SEP PDSI	0.17	–	–	–
OCT PDSI	0.18	0.17	0.18	–
NOV PDSI	0.18	–	0.17	–
DEC PDSI	0.24	0.23	0.23	0.22
Feb PDSI	0.22	0.17	0.18	0.18
Mar PDSI	0.23	0.19	0.20	0.20
Apr PDSI	0.24	0.22	0.22	0.21
May PDSI	0.38	0.37	0.37	0.34
Jun PDSI	0.42	0.41	0.41	0.39
Jul PDSI	0.40	0.39	0.39	0.37
Aug PDSI	0.31	0.31	0.31	0.29
Sep PDSI	0.33	0.31	0.31	0.30
Oct PDSI	0.25	0.24	0.24	0.22
OCT NAO	–0.24	–	–	–
NOV NAO	–0.26	–0.31	–0.32	–0.33
Feb NAO	0.23	–	–	–
Jun NAO	–0.32	–0.32	–0.32	–0.35
Aug NAO	–	0.23	0.23	
JUL SOI	0.26	0.23	0.23	0.24
DEC SOI	0.27	0.24	0.24	0.25
May SOI	0.39	0.36	0.35	0.33
Jul SOI	0.26	–	–	–

Table 3.3. rbar and EPS values for the oak chronology detrended with a 30-year spline.

Year	rbar	EPS
1865	0.43	0.89
1900	0.41	0.96
1925	0.43	0.97
1950	0.39	0.97
1975	0.33	0.96

Table 3.4. rbar and EPS values for the pine chronology detrended with a 20-year spline.

Year	rbar	EPS
1806	0.68	0.84
1840	0.47	0.89
1865	0.32	0.91
1890	0.41	0.96
1915	0.51	0.97
1940	0.47	0.97
1965	0.40	0.96
1990	0.37	0.96

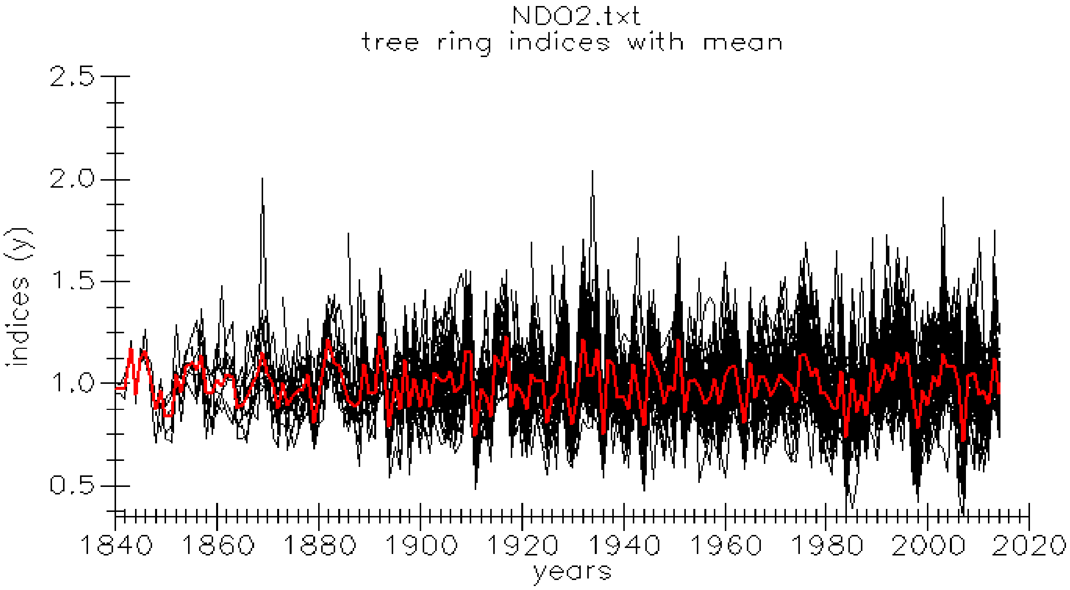

Figure 3.7. Tree-ring indices calculated for all oak measurement series once the 30-year spline was applied. The darker red curve is the average of all indices by year.

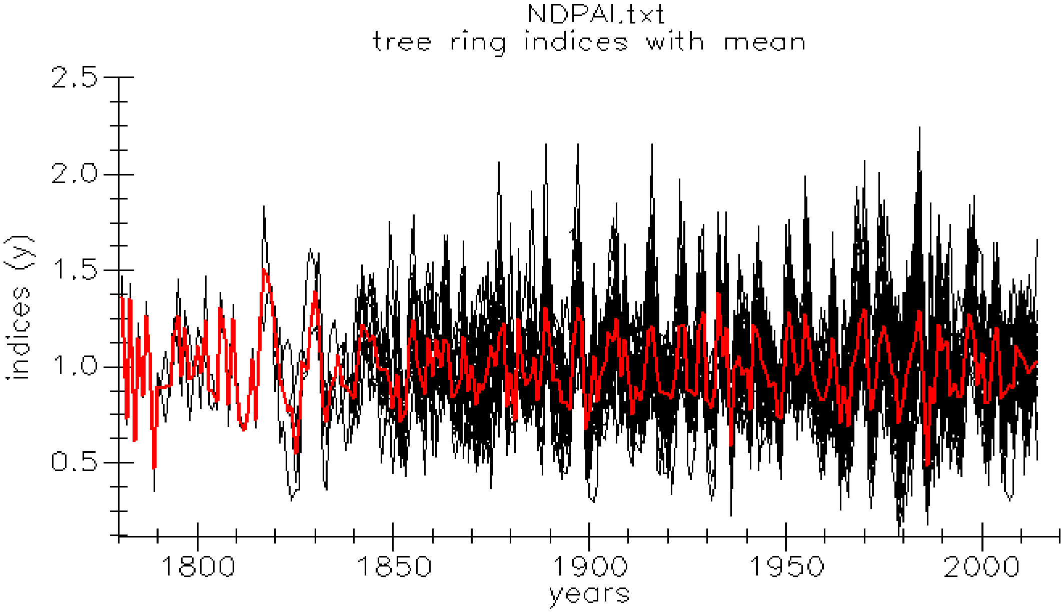

Figure 3.8. Tree-ring indices calculated for all pine measurement series once the 20-year spline was applied. The darker red curve is the average of all indices by year.

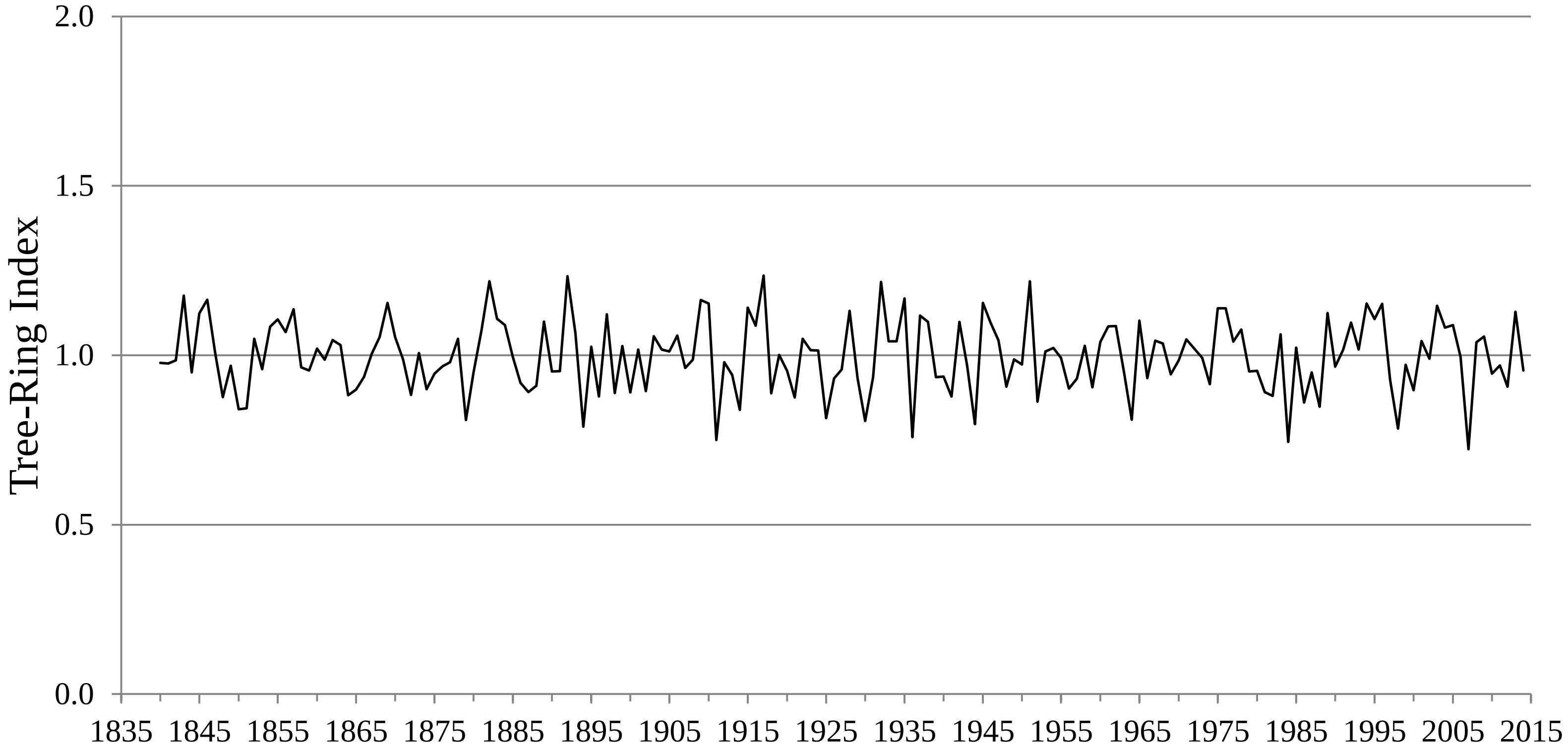

Figure 3.9. The tree-ring chronology developed from 28 oak trees growing in Norris Dam State Park.

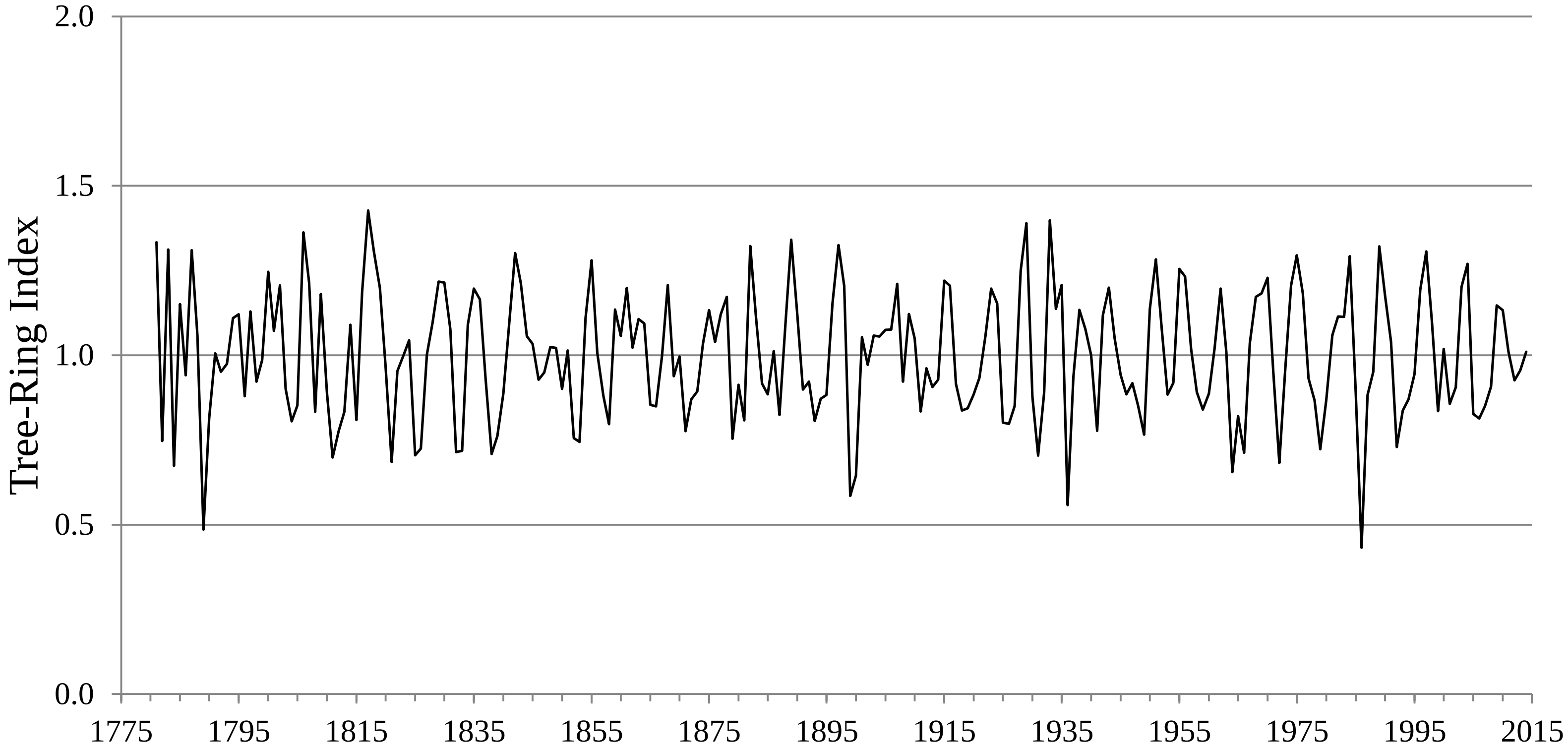

Figure 3.10. The tree-ring chronology developed from 22 pine trees growing in Norris Dam State Park.

3.4.3 Climate-Tree Growth Relationships

3.4.3.1 Oaks

I found that precipitation in December of the previous year (r = 0.20), and May (r = 0.30), and June (r = 0.38) of the current year were statistically significant ($p < 0.05$) with oak growth (Figure 3.11). PDSI in the consecutive months of previous December through October, with the exception of April, was statistically significant with tree growth with coefficients ranging from 0.19 to 0.49 (Figure 3.11). May (r = –0.28), June (r = –0.33), July (r = –0.17), and September (r = –0.20) temperature were negatively correlated with tree growth. August NAO (r = 0.28) was statistically significant with tree growth (Figure 3.12). Previous December (r = –0.18) and current January (r = –0.18) and February (r = –0.16) PDO were negatively correlated with tree growth (Figure 3.12).

The precipitation signal for oaks shifted from May-June to only June. The forward evolutionary interval (Figure 3.13A) shows a May precipitation signal, but a stronger and more consistent June signal. The backward evolutionary interval (Figure 3.13B), also shows a strong June signal, but the May signal drops off. For both forward and backward evolutionary intervals, the June precipitation signal was the same (Figure 3.13A, B). The PDSI signal for the growing season is strong (Figure 3.14A), although May PDSI drops off some in the backward evolutionary interval (Figure 3.14B). The June through October PDSI signal was the same for both forward and backward evolutionary intervals (Figure 3.14A, B). I also found a late spring temperature signal for oak species, which shifted from a May-June signal to just a June signal (Figure 3.15A, B). The June temperature signal was the same for both forward and backward evolutionary intervals. When I investigated the longer-term ocean-atmosphere climate oscillations, I found a shift in the NAO signal from an August signal to a June signal, but this was not consistent over time in both the forward and backward evolutionary intervals (Figure

3.16A, B). Lastly, I found that previous December to current February PDO was not consistent over time in both the forward and backward evolutionary intervals (Figure 3.17A, B).

3.4.3.2 Pines

I found that precipitation in May ($r = 0.38$), June ($r = 0.31$), and October ($r = –0.18$) were statistically significant ($p < 0.05$) with tree growth (Figure 3.18). PDSI in the consecutive months from previous July through current October (with the exception of previous August and current January) was statistically significant ($p < 0.05$) with tree growth with coefficients ranging from 0.17 to 0.42 (Figure 3.18). April ($r = –0.20$), July ($r = –0.19$), and September ($r = –0.20$) temperature were statistically significant ($p < 0.05$) with tree growth. February ($r = 0.23$) NAO was positively correlated with tree growth and June ($r = –0.32$), previous October ($r = –0.24$) and previous November ($r = -0.26$) NAO was negatively correlated with tree growth (Figure 3.19). May ($r = 0.39$), July ($r = 0.26$), previous December ($r = 0.27$) and previous July ($r = 0.26$) SOI were statistically significant ($p < 0.05$) with tree growth (Figure 3.19).

The May precipitation signal was strong and consistent in both the forward and backward evolutionary intervals, but the June precipitation signal picked up and became strong in the backward evolutionary interval (Figure 3.20A, B). A May through July PDSI signal was consistently strong in both the forward and backward evolutionary intervals (Figure 3.21A, B). I found no temporally stable relationships for monthly temperature in either the forward or backward evolutionary intervals (Figure 3.22A, B). The April and previous November temperature signals become strongly negative in the backward interval (Figure 3.22B). I also found no temporally stable relationships for NAO or SOI. June and previous October NAO are not consistent in both the forward and backward evolutionary intervals (Figure 3.23) and May SOI only became significant in the backward evolutionary interval (Figure 3.24B).

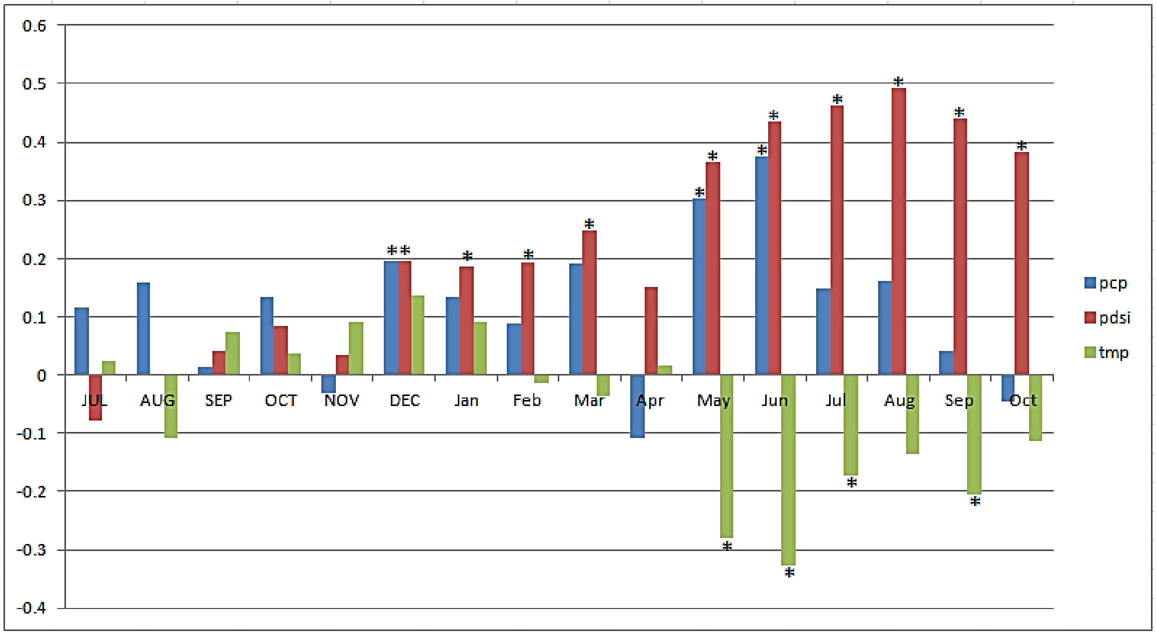

Figure 3.11. Correlation coefficients between precipitation (pcp), PDSI, and temperature (tmp) and the oak tree-ring chronology. Asterisks indicate a significant relationship ($p < 0.05$).

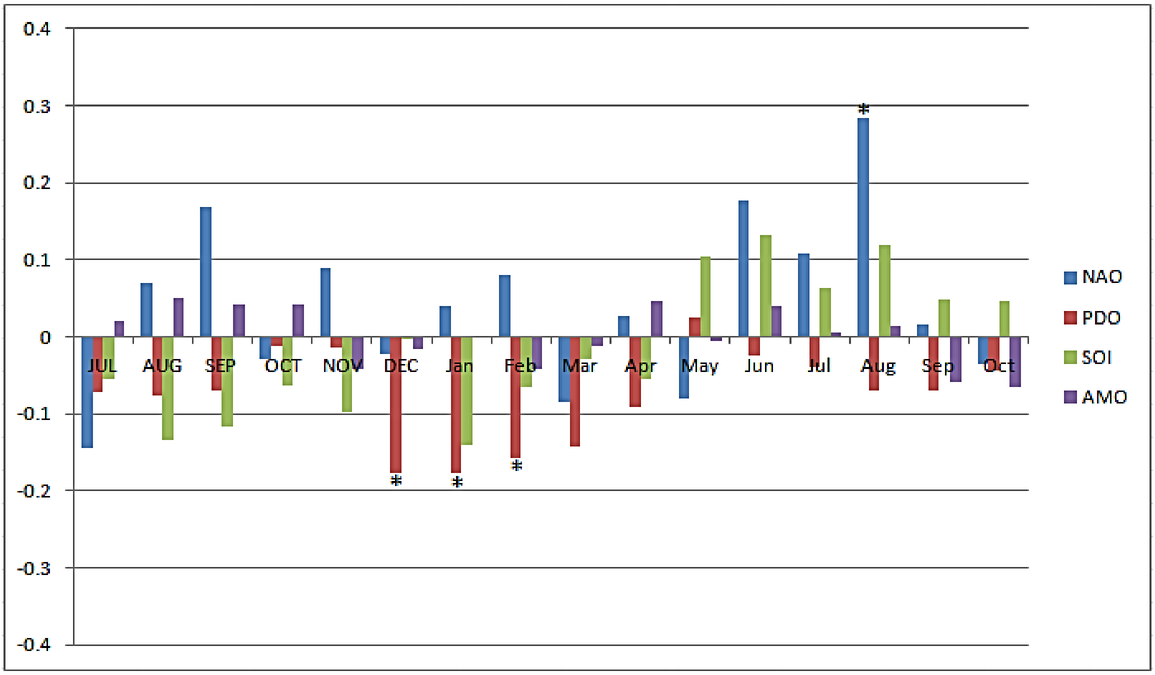

Figure 3.12 Correlation coefficients between climate oscillations NAO, PDO, SOI, and AMO and the oak tree-ring chronology. Asterisks indicate a significant relationship ($p < 0.05$).

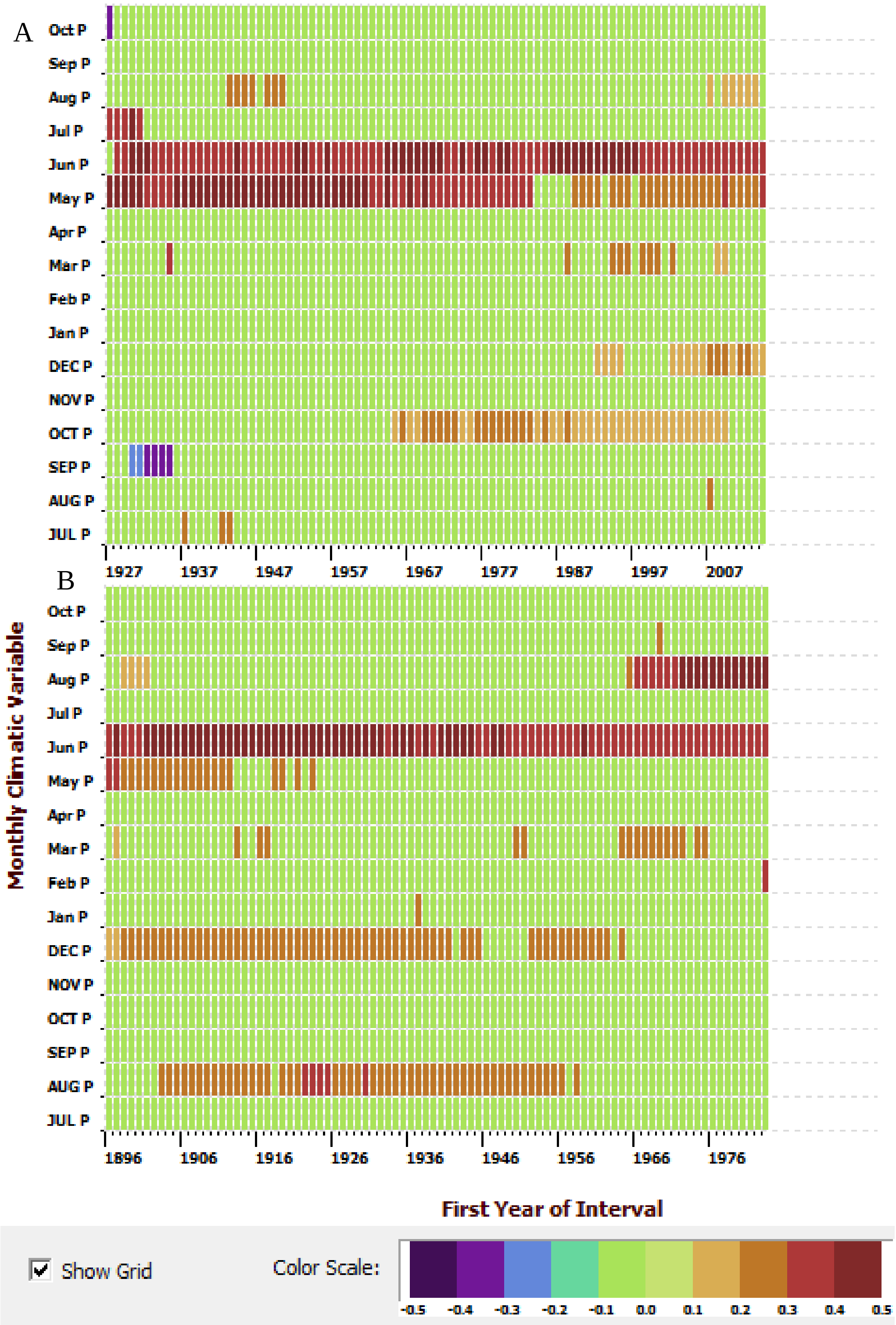

Figure 3.13. Forward (A) and backward (B) evolutionary interval analyses between precipitation and oak. The color scale indicates a significant positive or negative relationship. Green signifies no statistically significant ($p < 0.05$) relationship. The June precipitation signal is positive in both the forward and backward evolutionary intervals and a shift occurred from a May-June signal to just a June signal.

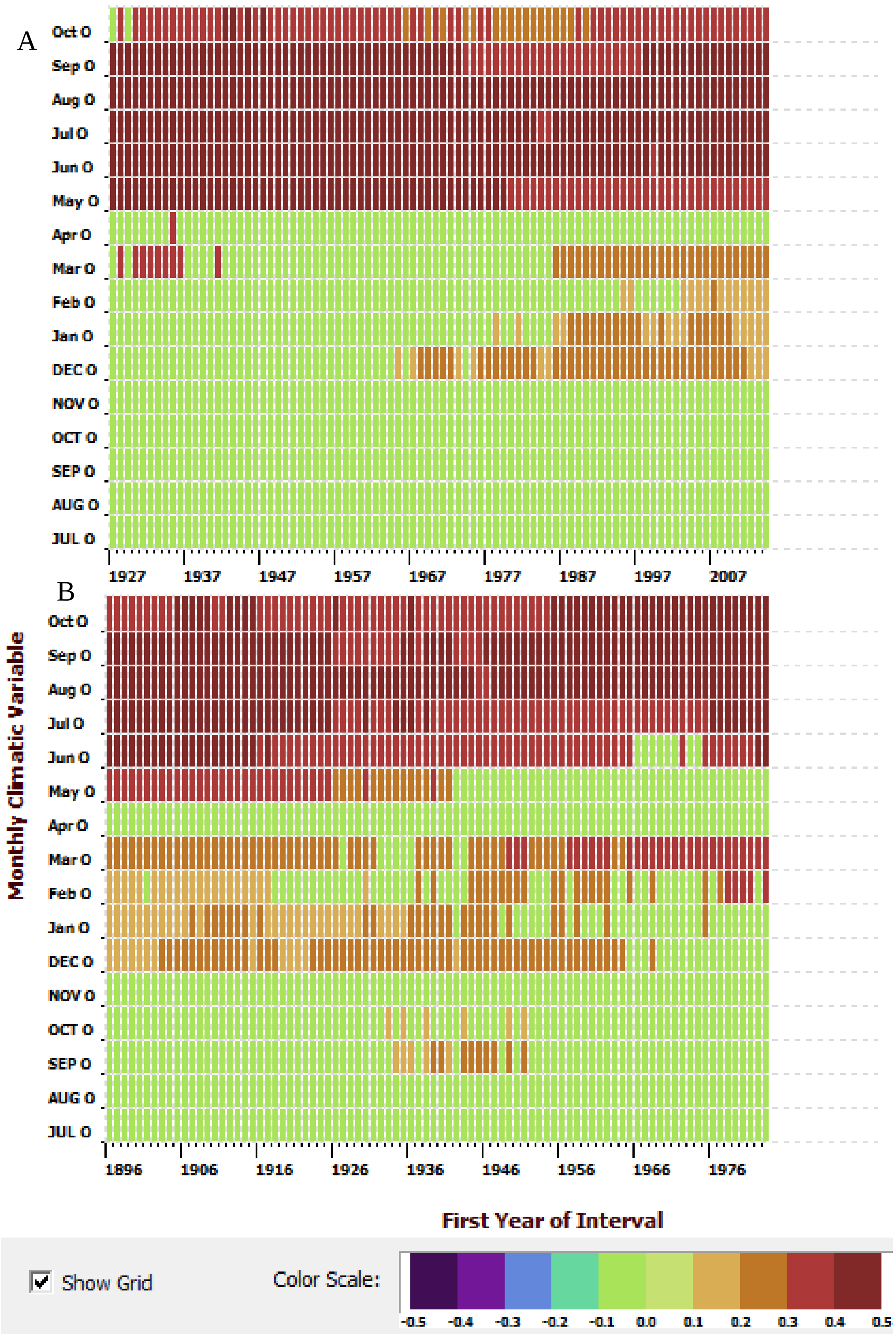

Figure 3.14. Forward (A) and backward (B) evolutionary interval analyses between PDSI and oak. The color scale indicates a significant positive or negative relationship. Green signifies no statistically significant ($p < 0.05$) relationship. The growing season PDSI signal is strongly positive in both the forward and backward evolutionary intervals. May and June drop off from forward to backward analyses, but current July through October remain strong in both analyses.

Figure 3.15. Forward (A) and backward (B) evolutionary interval analyses between temperature and oak. The color scale indicates a significant positive or negative relationship. Green signifies no statistically significant ($p < 0.05$) relationship. The June temperature signal is strongly negative in both the forward and backward evolutionary intervals and there was a shift from a May to June signal.

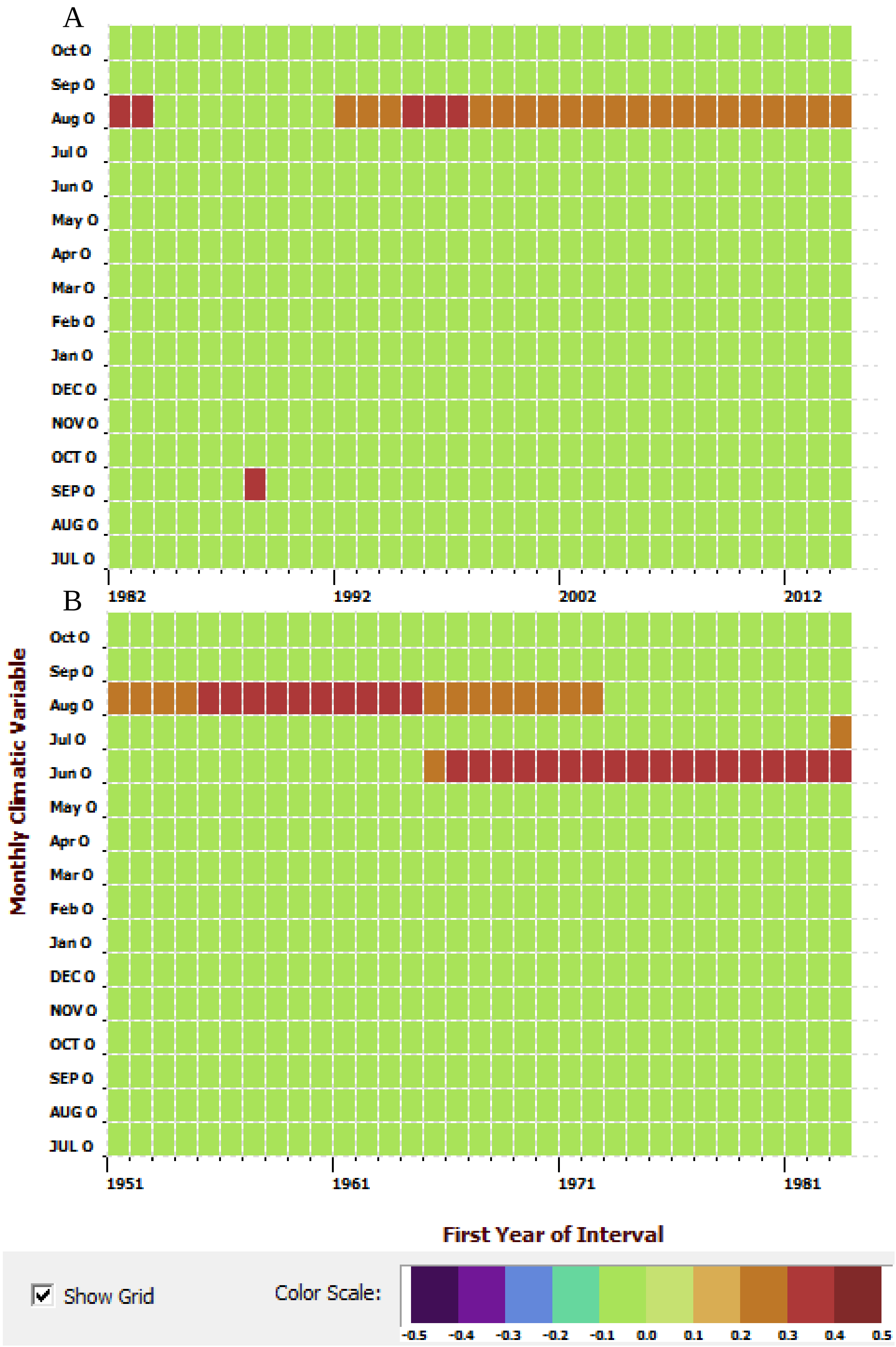

Figure 3.16. Forward (A) and backward (B) evolutionary interval analyses between NAO and oak. The color scale indicates a significant positive or negative relationship. Green signifies no statistically significant ($p < 0.05$) relationship. The August NAO signal is positive in both the forward and backward evolutionary intervals, but was not stable over time.

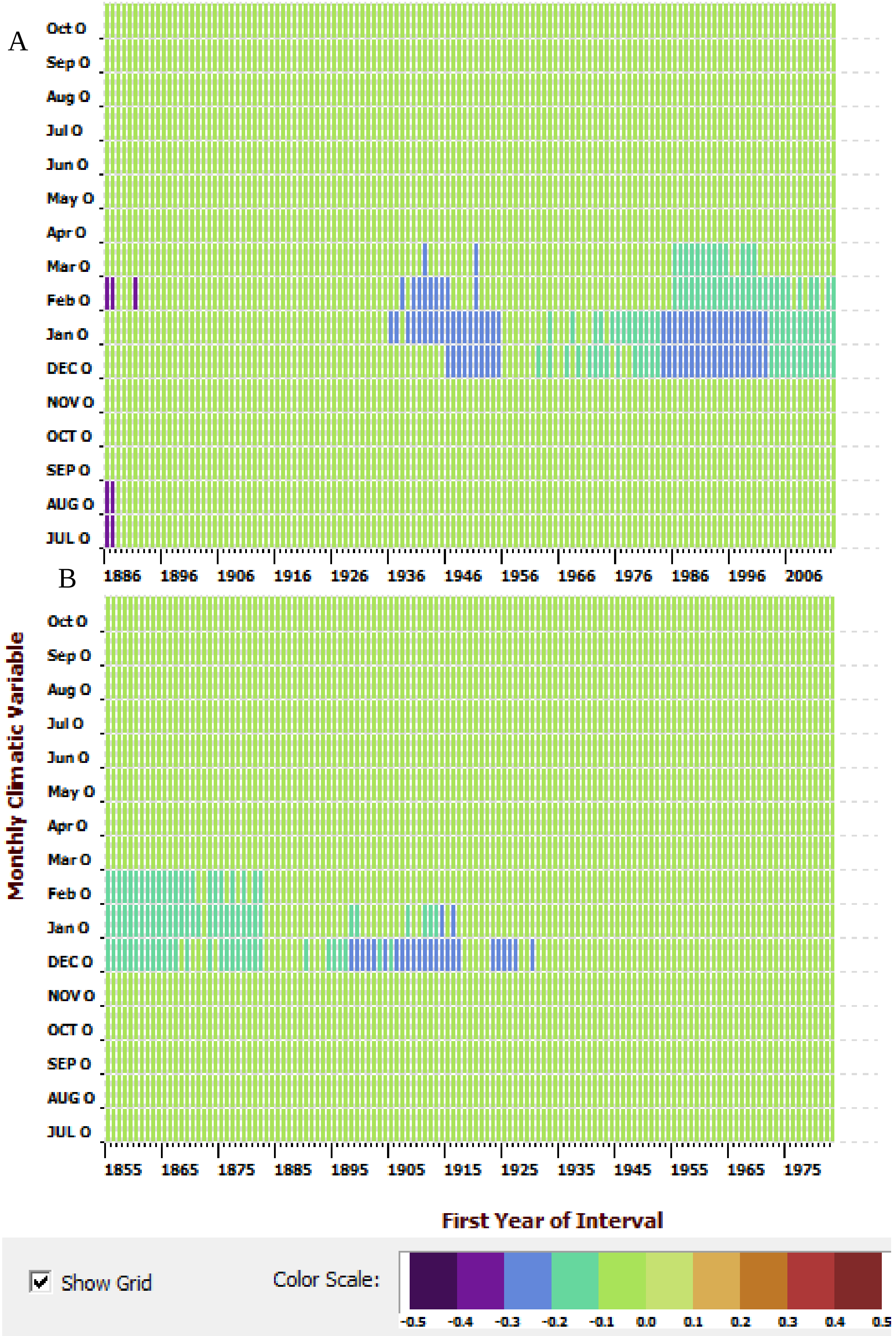

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Figure 3.17. Forward (A) and backward (B) evolutionary interval analyses between PDO and oak. The color scale indicates a significant positive or negative relationship. Green signifies no statistically significant ($p < 0.05$) relationship. The previous December, January and February PDO signals are negative in both the forward and backward evolutionary intervals, but were not stable over time.

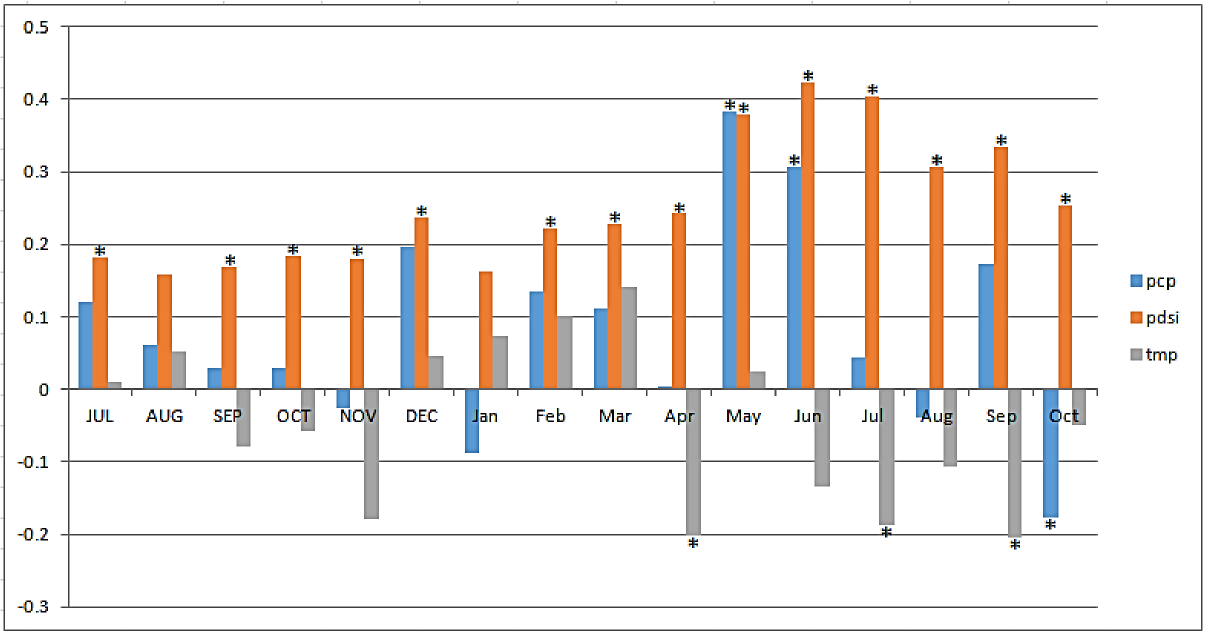

Figure 3.18. Correlation coefficients between precipitation (pcp), PDSI, and temperature (tmp) and the pine tree-ring chronology. Asterisks indicate a significant relationship ($p < 0.05$).

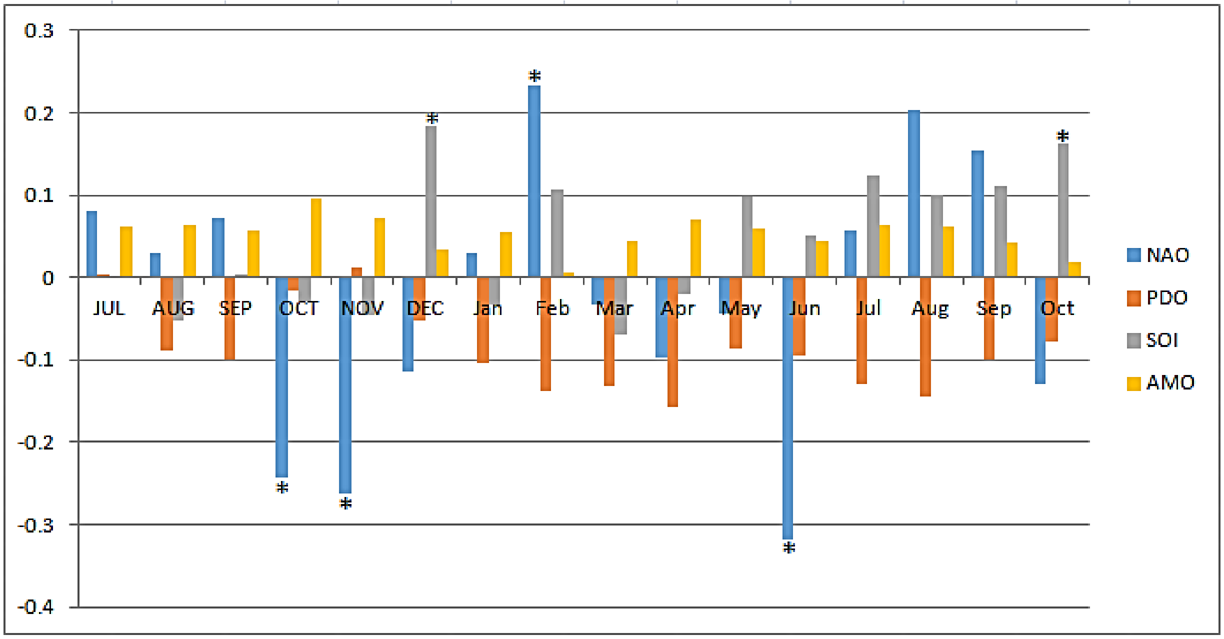

Figure 3.19. Correlation coefficients between climate oscillations NAO, PDO, SOI and AMO and the pine tree-ring chronology. Asterisks indicate a significant relationship ($p < 0.05$).

Figure 3.20. Forward (A) and backward (B) evolutionary interval analyses between precipitation and pine. The color scale indicates a significant positive or negative relationship. Green signifies no statistically significant ($p > 0.05$) relationship. The May precipitation signal is positive in both the forward and backward evolutionary intervals. A shift occurred from a May to a May-June signal.

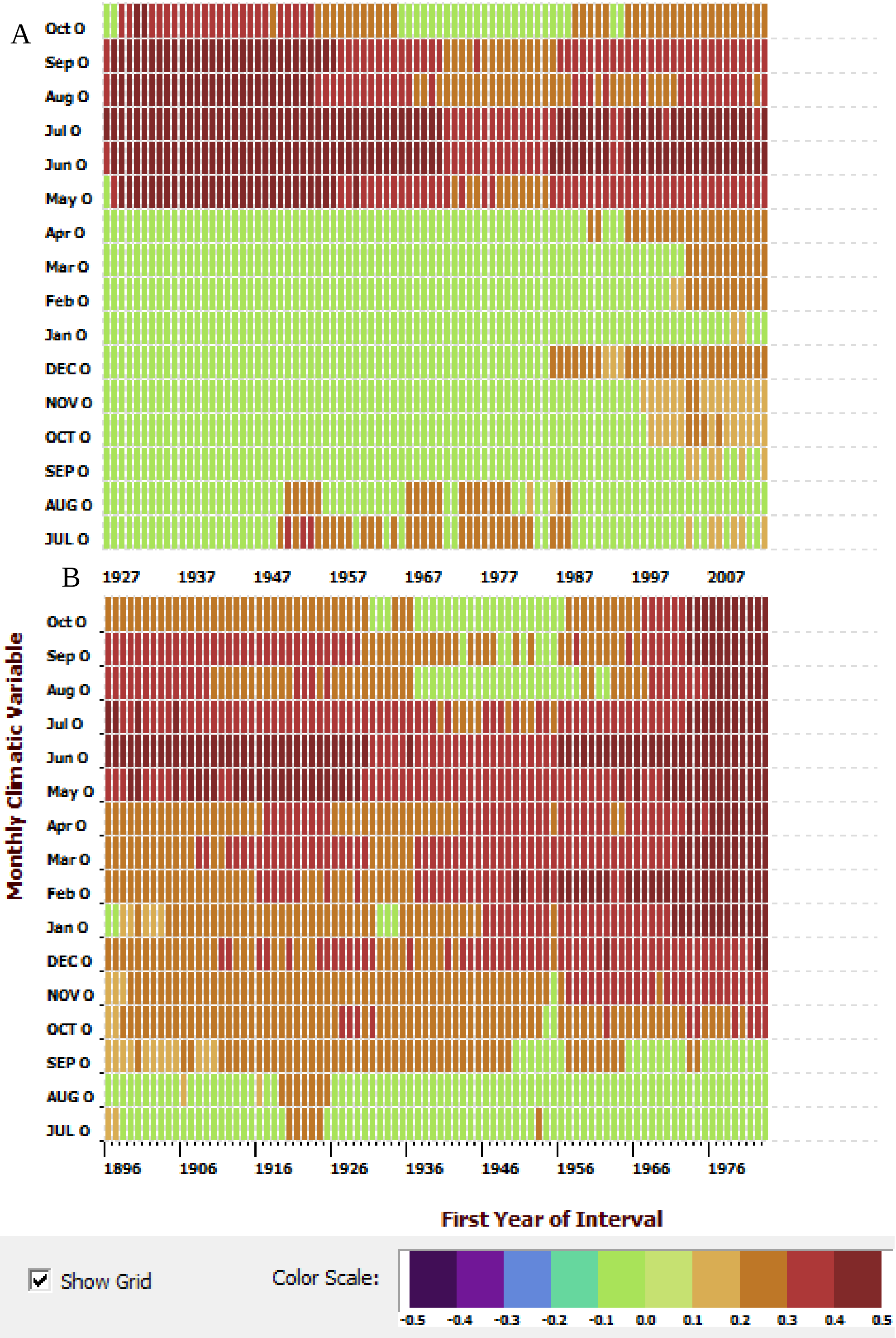

Figure 3.21. Forward (A) and backward (B) evolutionary interval analyses between PDSI and pine. The color scale indicates a significant positive or negative relationship. Green signifies no statistically significant ($p > 0.05$) relationship. The PDSI signal for May through July is positive in both the forward and backward evolutionary intervals.

Figure 3.22. Forward (A) and backward (B) evolutionary interval analyses between temperature and pine. The color scale indicates a significant positive or negative relationship. Green signifies no statistically significant ($p > 0.05$) relationship. The temperature signals for previous November and April are negative in the backward evolutionary interval.

Figure 3.23. Forward (A) and backward (B) evolutionary interval analyses between NAO and pine. The color scale indicates a significant positive or negative relationship. Green signifies no statistically significant ($p > 0.05$) relationship. The NAO signals for previous October and June are negative in both the forward and backward evolutionary intervals.

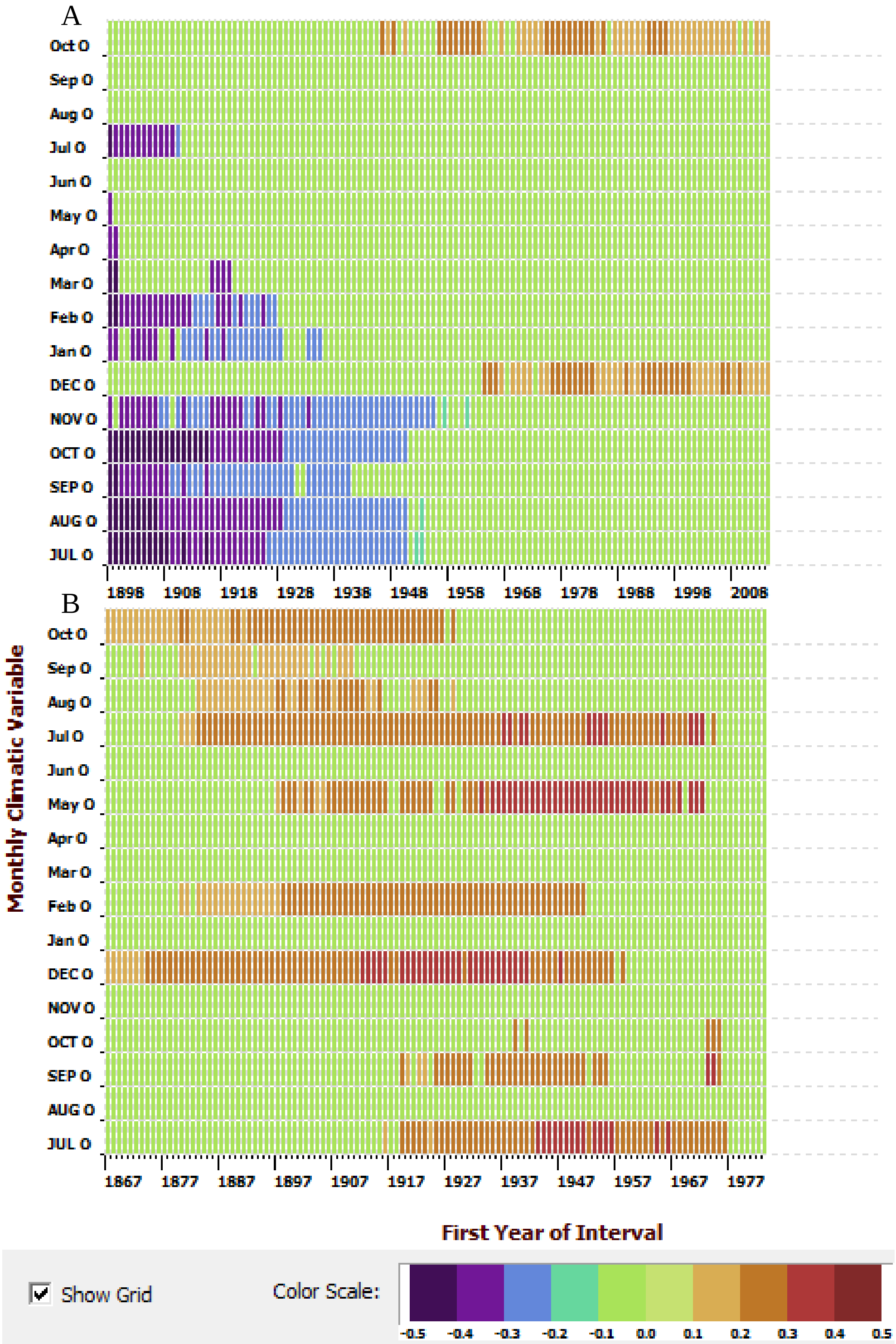

Figure 3.24. Forward (A) and backward (B) evolutionary interval analyses between SOI and pine. The color scale indicates a significant positive or negative relationship. Green signifies no statistically significant (p > 0.05) relationship. The SOI signals for previous December and current October are positive in both the forward and backward evolutionary intervals.

3.5 Discussion

3.5.1 Oak

I failed to reject my null hypothesis that the climate-tree growth relationships in oak species are temporally stable over the past 120 years (1895 to 2015), but only for some of the climate variables. Oak at NDSP responded most to June precipitation, late growing season (June-October) PDSI, and June temperature. These climate variables were all temporally stable with tree growth because oak tree growth responded similarly to these climate variables in both the forward and backward evolutionary interval analyses. Although I found a shift from a May-June to only a June precipitation signal, the June precipitation signal was strong in both the forward and backward evolutionary analyses. The June signal was already present when the May signal was dropping off, which shows the dominance of June precipitation. The June precipitation signal for oak has reconstruction potential because it was both statistically significant ($p < 0.05$) and temporally stable with tree growth.

I also found a shift from a current May-October to June-October PDSI signal. May PDSI was significant in the forward evolutionary interval, but was not significant in the backward evolutionary interval. Because the May PDSI signal was not significant in both the forward and backward evolutionary intervals, May PDSI was not temporally stable; however, current June through October PDSI signals were significant in both the forward and backward evolutionary intervals. The current June through October PDSI signal has reconstruction potential because it was both statistically significant ($p < 0.05$) and temporally stable with tree growth.

June temperature was consistently negative and most significant for oak in both the forward and backward evolutionary interval analyses. I found a shift from a May-June to only June temperature signal. The May temperature signal was significant in the forward evolutionary interval, but the June signal was stronger. In the backward evolutionary interval, the June signal remains significant, but the May signal drops off. The June temperature signal has reconstruction potential because it was both statistically significant ($p < 0.05$) and temporally stable with tree growth.

No climate oscillations (NAO, AMO, PDO, or SOI) showed temporally stable relationships between climate and tree growth for oak. The NAO signal for August was statistically significant ($p < 0.05$), but was not temporally stable. August NAO was positive in both the forward and backward evolutionary intervals, but was not consistent over time. In the backward evolutionary interval, the August NAO signal drops off and the June NAO signal picks up, but this signal was not statistically significant ($p > 0.05$). A shift may have occurred from an August to June signal, but the June signal did not become significant. Because the August signal dropped off in the backward evolutionary interval and the June signal picked up, neither the August NAO signal nor the June NAO signal is temporally stable. They were not the same in both the forward and backward intervals and neither has reconstruction potential.

The previous December to current February PDO signals were statistically significant ($p < 0.05$), but were not temporally stable because they were not consistent in both the forward and backward evolutionary interval analyses. In both the forward and backward analyses, these months fluctuate and drop off. March PDO picks up some, but this climate variable is not statistically significant ($p > 0.05$). Because of the fluctuations of these climate variables, previous December to current February PDO are not temporally stable and therefore do not have reconstruction potential. Neither AMO nor SOI showed any statistically significant relationships with tree growth for oak species.

For the climate oscillation analyses, longer timescales for data may be necessary to pick up a strong and temporally consistent signal. My timeframe for the oscillations was not consistent as it was for the other climate variables (precipitation, temperature, and PDSI), which ran from 1895 to 2014. PDO was longest, spanning 1854 to 2015 and this oscillation also showed the most significant correlations out of all four oscillations. This could suggest that I need longer climate data to pick up more statistically significant values; however, even though PDO was statistically significant, it was not temporally stable. My AMO data span 1856 to 2015, my SOI data span 1866 to 2014, and my NAO data only span 1950 to 2015. I might be able to find a stronger and consistent NAO signal with a longer dataset, but the relationship may or may not be temporally stable. AMO and SOI appear not to affect oak growth in the Southeast and their longer datasets had no effect on whether or not I found statistically significant relationships. Datasets extending into the mid- to late 1800s for all climate oscillations (NAO, AMO, PDO, or SOI) would make my datasets more consistent with the other climate variables (precipitation, temperature, and PDSI) and could possibly aid in identifying more statistically significant relationships, whether those relationships would be temporally stable or not.

Additional analyses may help identify more statistically significant relationships in the climate oscillations. Many studies have used wavelet analyses (Larocque and Smith 2004, MacDonald and Case 2005, Biermann 2009), which can be used to identify changing periodicities over time in my chronologies, which can then be compared to potential changes in periodicities in the climate oscillations to evaluate if they correspond and if they are stable over time (Torrence and Compo 1998). Wavelet analyses would complement the evolutionary interval analyses I already conducted and could be conducted on the longer datasets for testing the climate-tree growth relationship for climate oscillations. The few statistically significant relationships I found indicated that relationships between tree growth and NAO and PDO are present in oak, but these relationships need to be investigated further. Further investigation would also be able to rule out any relationships between NAO, AMO and tree growth for oak species.

For example, Larocque and Smith (2004) used wavelet analyses on high elevation tree species from the southern British Columbia Coast Mountains, Canada, including yellow cedar, Douglas-fir, whitebark pine, subalpine fir, and mountain hemlock, that shared a common growth response. Chronologies were created for each species that showed the regional signal. Wavelet analyses were used on the reconstructions to determine the dominant frequencies in these species over time. All the reconstructions showed high frequency variability at less than 8 years and medium frequency variability at 23–25 years, which correspond to ENSO and PDO signals, respectively. MacDonald and Case (2005) performed wavelet analyses on the reconstruction of two moisture sensitive limber pine chronologies from California and Alberta. Both chronologies were significantly correlated with the PDO. They used 1940–1998 as the period for calibration and verification and produced a reconstruction of annual PDO from January to December extending from AD 993 to 1996. They used wavelet analyses on the detrended reconstruction to examine PDO variability in multidecadal spectral bands. They found significant 50–70 year variability corresponding to the PDO and weakly significant 4–7 year variability corresponding to ENSO.

Biermann (2009) also performed wavelet analyses on yellow pine tree-ring data from Great Smoky Mountains National Park (GSMNP) to determine the dominant frequencies in the pine chronologies over time. She then compared the results to the periodicities of the climate oscillations (AMO, PDO, ENSO, and NAO) to determine if they matched up and if they were stable over time. Wavelet analysis was used as an additional technique along with correlation, response function, and moving correlation analyses, to identify climate oscillation signals present in the chronology. Biermann found low frequency 55–90 year oscillations in most of her chronologies, which could be associated with the AMO, which operates on a 65–80 year cycle.

In all of the temporally stable climate variables for oak (June precipitation, June-October PDSI, and June temperature), I found a shift from a May-June to only a June signal. This was interesting because the June signal in each case was temporally stable in both the forward and backward evolutionary interval analyses, but the May signal was only consistent in the forward evolutionary analyses and dropped off in the backward evolutionary analyses. The June signal was stronger than the May signal in the forward evolutionary analyses in each case. The shifting of the signal does not seem to have affected the temporal stability of the June signal, which is consistent. For the shift to have occurred in all three climate variables, suggests that June is the critical month to which oak trees most respond. Temperature, precipitation, and PDSI may be more important in June because of the higher temperatures oaks experience in the middle part of the growing season. Tree growth was negatively correlated with temperature for June, meaning that lower temperatures meant more growth. In the middle of the growing season, lower temperatures would not stress the tree that higher temperatures would. In addition, oak growth was positively correlated with June precipitation. Higher amounts of precipitation mean more growth. Increased soil moisture would allow the tree to grow more during this month. Tree growth was positively correlated with June to October PDSI. Lower instances of drought due to lower temperatures and higher amounts of precipitation would limit the stress on the trees and allow for more growth. June must be the time in the growing season at which oaks reach a threshold and respond most strongly to temperature, precipitation, and PDSI.

3.5.2 Pine

Temperature was statistically significant ($p < 0.05$) for pine growth in April, June, and September of the current year, which indicates that lower temperatures in the growing season mean more growth for pines. Lower temperatures suggest the tree is not under stress and can grow more because moisture can remain in the soil longer and be used by the pines to form new wood. In the forward and backward evolutionary interval analyses, however, none of the relationships with monthly temperature were temporally consistent. Although the relationships in the monthly and seasonal temperature were not temporally stable, the relationship is ecologically tenable.

Pine responded most strongly to the PDSI signal in the early growing season (May-July) and this climate variable was temporally stable with tree growth because pines responded similarly to May-July PDSI in both the forward and backward evolutionary interval analyses. In the forward evolutionary analyses, May-September was significant, but in the backward evolutionary analyses, only May-July was found to be significant. The PDSI signal for May through July was temporally stable with tree growth and has reconstruction potential. The statistically significant PDSI signal in the growing season (May-September) and the temporally stable PDSI signal in the early growing season (May-July) indicate that very wet conditions are important for pine growth. Higher PDSI values signify periods of exceeding moisture and enhanced pine growth. Drought during the growing season, however, would put stress on pines.

The precipitation signal for pines shifted from a May precipitation signal to a May-June precipitation signal. The May precipitation signal was dominant in the forward evolutionary interval, with the positive June and negative October signals present. In the backward evolutionary interval, the October signal drops off, the May signal is still dominant, the June signal becomes dominant, and the February signal picks up. The May precipitation signal was the same in both the forward and backward evolutionary interval analyses, but the June signal became dominant in the backward evolutionary interval. For reconstruction purposes, we could possibly use a May-June precipitation signal because of the possible shift from a May to a May-June signal, but because the May signal is consistent in both the forward and backward evolutionary interval analyses, the May precipitation signal is temporally stable for pine species and has the best reconstruction potential.

Previous October and current June NAO were consistently negative in the forward evolutionary interval but dropped off in the backward evolutionary interval. February was positive in the forward evolutionary interval but dropped off in the backward evolutionary interval. Previous July, previous December, current May, and current July SOI were all statistically significant ($p < 0.05$) with pine growth, but none were the same in both the forward and backward evolutionary interval analyses.

Neither AMO nor PDO was statistically significant ($p < 0.05$) with pine growth. Neither of these oscillations could affect pine species in the Southeast or perhaps we did not have a long enough dataset for the oscillations and a signal was not picked up. Other analyses could be used to attempt to pick up a signal, such as wavelet analyses. I found more statistically significant relationships between climate oscillations and tree growth for the pine species than for oak species. This could occur because pine species have a higher mean sensitivity and are more likely sensitive to changes in climate than the oaks. There was also an elevation difference in the location of the sampled oaks and pines. The oaks were at higher elevations on the slope and the pines were lower in the valley.

3.5.3 Implications of Climate Reconstructions

Many researchers have conducted dendroclimatological studies and have reconstructed past climate, but many earlier studies did not focus on testing the temporal stability of the climate-tree growth relationship because this was not an issue in dendroclimatology until the last 10 years. Stahle and Cleaveland (1992) reconstructed spring rainfall for the past 1000 years using bald cypress tree-ring chronologies from North Carolina, South Carolina, and Georgia. The April-June precipitation signal from North Carolina and the March-June precipitation signal from South Carolina and Georgia were combined to form a spring precipitation signal. I found that my oak and pine chronologies from NDSP in Tennessee were temporally stable with spring precipitation. This finding gives confidence in the usage of this variable for climate reconstruction, but tests should be conducted on the bald cypress chronologies to determine if they have a stable relationship with climate. My data, while temporally stable with spring precipitation, were from oak and pine species in eastern Tennessee, not bald cypress in North Carolina, South Carolina, or Georgia.

Cook *et al.* (1999) used a network of 425 climate sensitive tree ring chronologies and PDSI data to reconstruct past summer drought from 1700 to 1978. Summer PDSI, from June to August, related better to tree rings. Dr. Duvick's NDSP white oak chronology was included in this network. For my white oak chronology, I found that summer PDSI from June to October was temporally stable. This gives confidence to the inclusion of Dr. Duvick's NDSP white oak chronology in the network, however, Cook *et al.*'s reconstruction was for the entire 48 states. A total of 424 other chronologies were used in addition to Dr. Duvick's, which were not tested for temporally stable climate-tree growth relationships. The other chronologies should be tested for temporally stable climate-tree growth relationships to ensure that this reconstruction is still valid and able to be used.

Druckenbrod *et al.* (2003) used senesced white oak trees from James Madison's Montpelier plantation to create two reconstructions of monthly precipitation, one from early summer (June) precipitation, using latewood ring widths, and one from prior fall (prior September) precipitation, by removing the measured latewood from the annual growth rings. The researchers compared the reconstructions with precipitation records and meteorological diaries kept by James Madison. I found oak growth at Norris Dam State Park to be temporally stable with June precipitation. My results give confidence in the summer reconstruction by Druckenbrod *et al.* of early summer precipitation, but I did not find a prior fall precipitation signal. James Madison's Montpelier plantation is in Virginia and my research was done in eastern Tennessee; therefore, different sites and topography could affect climate signals.

Pederson *et al.* (2012) reconstructed April to August PDSI from 1665 to 2010 based on the common response of the multispecies tree-ring network from the headwaters of the Apalachicola-Chattahoochee-Flint river basin. This network was geographically dense and diverse and consisted of chronologies spanning AD 929–2009. My oak chronology was temporally stable with June to October PDSI and my pine chronology was temporally stable with May to July PDSI. Based on varying species response and location, my findings do support the use of a reconstruction of summer PDSI, but the temporal stability of summer PDSI for oak and pine in eastern Tennessee does not support a reconstruction from Alabama, Georgia, and Florida.

In eastern Tennessee alone, studies have found both temporally stable and temporally unstable relationships with climate. In my study, I found some temporally stable relationships at NDSP for oak and pine species that could be used to reconstruct past climate, but others have found temporally unstable climate-tree growth relationships from eastern North Carolina to eastern Tennessee (Biermann 2009, Li 2011). This confirms that we need to assess temporal stability on a site by site and chronology by chronology basis before reconstructions are attempted. Reconstructions that have already been created should be tested for temporally stable climate-tree growth relationships in order to be confidently used. In the case of large networks used to create a reconstruction, if unstable climate-tree growth relationships are found, those chronologies could be removed and the reconstruction redone to ensure the temporal stability of the climate response.

Chapter Four

Conclusions and Future Research

4.1 Major Conclusions

I found that both oak and pine species crossdate well and are sensitive to changes in climate. Oak species crossdated with a correlation coefficient of 0.62, which is above the accepted threshold of 0.40, and displayed a mean sensitivity of 0.19, which is in the common range for oaks in the Southeast. Pine species crossdated with a correlation coefficient of 0.60 and a mean sensitivity of 0.27, both values being exceptional for pines in the Southeast. Both oak and pine species were correlated with climate and respond to specific climate variables.

4.1.1 To which climate variables are oak and pine species responding?

Oaks respond positively to June precipitation, negatively to June temperature, and positively to June-October PDSI. Increased precipitation in the growing season contributes to enhanced tree growth for oaks because of the increased soil moisture. Lower temperatures in the middle of the growing season meant higher growth for oaks because of decreased stress. Lower temperatures mean less soil moisture is evaporated, keeping more moisture in the soil for tree growth. Higher PDSI values mean fewer droughts and fewer droughts mean increased oak growth.

Pine species respond positively to May-June precipitation, positively to May-July PDSI, negatively to previous October and current June NAO, and positively to May SOI. Positive relationships with precipitation in the growing season suggest that increased precipitation during the growing season leads to enhanced growth in pines due to an increase in soil moisture. Higher PDSI values mean fewer droughts. Fewer droughts during the growing season lead to increased growth in pines, due to less stress and less evaporation of soil moisture. Lower temperatures and increased precipitation contribute to higher PDSI values. Negative phases of the NAO indicate cold air and colder winters. In years when the NAO was negative, cold air in the early winter causes decreased growth in pines in the following growing season. Positive phases of the SOI index indicate a cool phase or La Niña. This causes decreased rainfall in the south and warmer winters in the southeast. In years when the SOI was positive, warmer winters and less rainfall caused increased growth during the following growing season for pines.

4.1.2 Were the climate-tree growth relationships temporally stable?

I fail to reject my null hypothesis that oak and pine species are temporally stable with climate for some of the climate variables. Oak species are temporally stable with June precipitation, June temperature, and June-October PDSI. Pine species are temporally stable with May-June precipitation, May-July PDSI, previous October and current June NAO, and May SOI. These climate variables showed statistically significant and temporally consistent responses in both the forward and backward evolutionary analyses. Using both forward and backward evolutionary analyses to determine if oak and pine species were temporally stable with climate is better than using just forward or backward evolutionary analyses. Some climate variables were only temporally stable in the forward evolutionary interval, but not in the backward. In the backward evolutionary interval, they dropped off some or completely, even if that variable was statistically significant, it was found not to be temporally stable because it was not consistent in both the forward and backward evolutionary analyses.

4.1.3 Can the oak and pine chronologies be used to reconstruct past climate?

The oak and pine chronologies can be used to reconstruct past climate for the climate variables that showed temporally stable relationships. Because the relationships between oak and pine species and these climate variables were found to be stable over the 20th and 21st centuries, we can assume they have been stable over longer periods of time. The oak chronology can be used to reconstruct June precipitation, June to October PDSI, and June temperature. The pine chronology can be used to reconstruct May-June precipitation, May to July PDSI, previous October and current June NAO, and May SOI for Norris Dam State Park. These climate-tree growth relationships are not transferrable to another region or to another tree species from this region.

4.1.4 What implications come of this research?

The oak chronology I created was an extension of the research first performed by Dr. Daniel Duvick. His oak chronology extended to 1980. By coring trees at his original field site and creating my own oak chronology, I both replicated his research and extended his chronology out to 2014. His chronology has been used as the master chronology in many studies and has been used in climate reconstructions. By testing the temporal stability of my oak chronology, we can confirm that the oaks at NDSP are temporally stable for some climate variables. My oak chronology validates the use of his oak chronology in climate reconstructions for certain climate variables.

The pine chronology I created is a new chronology for this region and is the first pine chronology from NDSP. This chronology can be used in future reconstructions of climate because the pines were found to be temporally stable for some climate variables at NDSP. In addition, the pine chronology is useful because pine trees responded to different climate variables than the oaks. The pines responded more to climate variables earlier in the growing season and showed temporally stable relationships with the climate oscillations, while the oaks responded more to climate variables later in the growing season. The pine chronology was highly sensitive to changes in climate, much more so than the oak chronology, which could have contributed to the different climate response. The pine chronology was comprised of pine trees located in the valley. Differences in topography and elevation could have contributed to the pines response to climate.

4.2 Future Research

This study revealed the importance of testing the temporal stability of the climate response before reconstructions are created. Some climate-tree growth relationships were stable over time, however, some were unstable. The ITRDB includes many chronologies used in reconstructions whose temporal stability has not been tested. These existing chronologies and future chronologies should have their temporal stability examined prior to use in any future reconstruction to ensure their validity. Previous dendroclimatic studies should be redone and include tests for temporal stability.

More research should be conducted at NDSP on both oak and pine species. These species are both sensitive to changes in climate and are correlated with many climate variables including the climate oscillations. More data could be collected including developing chronologies that extend further back in time and using climate oscillation data that extend back to the mid-1800s; however, NAO data are only available from 1950 onward. Future research should include more and different analyses, such as wavelet analysis. This technique would be used in addition to forward and backward evolutionary interval analyses and would be especially helpful in identifying trends related to climate oscillations.

My oak and pine chronologies could also be extended back further in time with more sampling. I measured one oak core that extended back to 1674, but I had no other cores to check it against; therefore, the early years were not included in any further analyses. A longer chronology would allow for further investigation into climate responses back in time, although the instrumental climate record only goes back to the mid-1800s. Investigation into other tree species might also be insightful since oaks and pines were found to respond to different climate variables, some of which were temporally stable. Depending on the responses of other tree species, a multispecies climate response could be determined.

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Appendices

Appendix 1. Oak COFECHA Output Summary Statistics

```
[]  Dendrochronology Program Library                                        Run NDOAI  Program COF  17:37  Mon 27 Jul 2015  Page   1
[]
[]  P R O G R A M      C O F E C H A                                                                      Version 6.06P    29429
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 QUALITY CONTROL AND DATING CHECK OF TREE-RING MEASUREMENTS

 File of DATED series:   NDOAI.txt

 CONTENTS:

    Part 1:  Title page, options selected, summary, absent rings by series
    Part 2:  Histogram of time spans
    Part 3:  Master series with sample depth and absent rings by year
    Part 4:  Bar plot of Master Dating Series
    Part 5:  Correlation by segment of each series with Master
    Part 6:  Potential problems: low correlation, divergent year-to-year changes, absent rings, outliers
    Part 7:  Descriptive statistics

 RUN CONTROL OPTIONS SELECTED                             VALUE

         1  Cubic smoothing spline 50% wavelength cutoff for filtering
                                                            32 years
         2  Segments examined are                           40 years lagged successively by  20 years
         3  Autoregressive model applied                     A  Residuals are used in master dating series and testing
         4  Series transformed to logarithms                 Y  Each series log-transformed for master dating series and testing
         5  CORRELATION is Pearson (parametric, quantitative)
            Critical correlation, 99% confidence level   .3665
         6  Master dating series saved                       N
         7  Ring measurements listed                         N
         8  Parts printed                               1234567
         9  Absent rings are omitted from master series and segment correlations  (Y)

 Time span of Master dating series is  1674 to  2014   341 years
 Continuous time span is               1674 to  2014   341 years
 Portion with two or more series is    1781 to  2014   234 years


                                       ****************************************
                                       *C* Number of dated series        56 *C*
                                       *O* Master series 1674 2014  341 yrs *O*
                                       *F* Total rings in all series   8333 *F*
                                       *E* Total dated rings checked   8226 *E*
                                       *C* Series intercorrelation     .590 *C*
                                       *H* Average mean sensitivity    .184 *H*
                                       *A* Segments, possible problems   28 *A*
                                       *** Mean length of series      148.8 ***
                                       ****************************************

 ABSENT RINGS listed by SERIES:            (See Master Dating Series for absent rings listed by year)

              No ring measurements of zero value
```

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PART 2:  TIME PLOT OF TREE-RING SERIES:                                                            17:37  Mon 27 Jul 2015  Page   2
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PART 2:  TIME PLOT OF TREE-RING SERIES:                                                            17:37  Mon 27 Jul 2015  Page   3
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PART 3:  Master Dating Series:                                                                     17:37  Mon 27 Jul 2015  Page   4
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                        1701  -.029   1       1751  -.440   1       1801   .441   3       1851 -1.731  18       1901   .180  46
                        1702  -.440   1       1752  -.485   1       1802  1.198   3       1852   .245  19       1902  -.687  46
                        1703 -1.102   1       1753 -3.715   1       1803  1.608   3       1853  -.507  20       1903   .642  46
                        1704   .084   1       1754  -.795   1       1804 -1.501   3       1854   .026  20       1904   .318  46
                        1705  1.032   1       1755 -1.013   1       1805  -.183   4       1855   .222  20       1905   .162  46
                        1706  -.587   1       1756   .584   1       1806  -.688   5       1856   .031  20       1906   .573  46
                        1707   .860   1       1757  1.173   1       1807  -.536   5       1857   .741  20       1907  -.303  46
                        1708  -.330   1       1758   .532   1       1808   .831   5       1858  -.265  22       1908   .064  47
                        1709  2.845   1       1759   .498   1       1809  -.118   5       1859  -.818  22       1909  1.168  48

                        1710  2.107   1       1760   .782   1       1810  -.108   5       1860   .563  25       1910  1.058  48
                        1711  1.103   1       1761  1.148   1       1811  -.174   5       1861   .364  25       1911 -1.947  48
                        1712  -.244   1       1762 -3.754   1       1812   .703   5       1862   .690  26       1912   .069  48
                        1713 -1.499   1       1763  1.267   1       1813 -1.501   5       1863   .376  26       1913  -.231  50
                        1714   .486   1       1764  -.523   1       1814 -1.416   5       1864  -.734  27       1914 -1.172  50
                        1715  -.973   1       1765 -1.389   1       1815   .460   6       1865  -.562  27       1915  1.100  50
                        1716  -.854   1       1766  -.686   1       1816  -.703   7       1866  -.318  27       1916   .591  50
                        1717  -.156   1       1767  1.379   1       1817   .596   7       1867   .513  28       1917  1.502  50
                        1718 -1.416   1       1768   .636   1       1818   .747   7       1868   .179  28       1918  -.762  50
                        1719 -1.446   1       1769   .833   1       1819   .531   7       1869  1.266  28       1919   .102  50

                        1720 -2.056   1       1770   .706   1       1820  1.577   9       1870   .776  29       1920  -.294  51
                        1721  -.575   1       1771  1.627   1       1821  -.566   9       1871  -.108  29       1921  -.924  51
                        1722  -.340   1       1772  1.500   1       1822   .385   9       1872 -1.072  30       1922   .451  51
                        1723 -1.275   1       1773   .366   1       1823   .917   9       1873  -.183  30       1923   .227  51
  1674  -.058   1       1724   .115   1       1774 -1.630   1       1824   .792   9       1874  -.867  30       1924   .113  51
  1675  1.461   1       1725  1.350   1       1775  -.232   1       1825  -.227   9       1875  -.345  31       1925 -1.393  51
  1676 -1.522   1       1726  1.511   1       1776  -.488   1       1826 -2.001   9       1876  -.171  31       1926  -.259  51
  1677  1.615   1       1727  1.422   1       1777   .454   1       1827  -.536   9       1877  -.099  31       1927  -.231  52
  1678   .988   1       1728   .726   1       1778  1.522   1       1828 -1.367   9       1878   .289  31       1928   .966  53
  1679   .325   1       1729  1.021   1       1779 -2.658   1       1829  -.075   9       1879 -1.327  31       1929  -.356  53

  1680  1.511   1       1730  1.083   1       1780 -1.195   1       1830  -.008  10       1880  -.313  33       1930 -1.408  53
  1681  -.531   1       1731   .564   1       1781  -.433   2       1831   .055  10       1881   .598  33       1931  -.293  53
  1682 -3.173   1       1732  -.251   1       1782  1.348   2       1832  -.210  11       1882  1.497  33       1932  1.521  53
  1683   .088   1       1733   .833   1       1783  1.756   2       1833  -.550  11       1883  1.077  33       1933   .361  53
  1684   .326   1       1734   .273   1       1784   .189   2       1834   .112  11       1884   .664  33       1934   .468  53
  1685 -1.070   1       1735  -.707   1       1785   .140   2       1835   .475  13       1885   .014  33       1935  1.056  53
  1686  -.472   1       1736 -3.866   1       1786   .626   2       1836   .653  13       1886  -.469  34       1936 -1.804  53
  1687 -2.258   1       1737  -.142   1       1787  -.337   2       1837   .092  13       1887  -.630  35       1937   .865  53
  1688  -.909   1       1738  -.522   1       1788  -.819   2       1838  -.090  13       1888  -.353  37       1938   .659  53
```

```
  1689  -.201    1       1739  1.722    1       1789 -1.053    2       1839 -1.519   14       1889   .790   37       1939  -.266   54

  1690 -1.135    1       1740  1.846    1       1790 -2.013    2       1840   .267   15       1890  -.340   37       1940  -.362   54
  1691  -.198    1       1741  1.172    1       1791  -.964    2       1841   .088   15       1891   .028   37       1941  -.797   55
  1692  1.417    1       1742  1.529    1       1792 -1.175    2       1842   .584   15       1892  1.449   37       1942   .775   55
  1693  -.358    1       1743  -.614    1       1793  1.189    2       1843  1.024   16       1893   .581   38       1943   .042   55
  1694  2.326    1       1744  -.587    1       1794   .023    2       1844  -.206   16       1894 -1.691   40       1944 -1.591   55
  1695  1.781    1       1745  1.850    1       1795   .652    2       1845  1.052   16       1895   .150   43       1945  1.223   55
  1696   .861    1       1746  -.266    1       1796   .235    3       1846  1.174   16       1896 -1.010   44       1946   .753   56
  1697   .908    1       1747  -.016    1       1797  1.043    3       1847   .112   17       1897   .859   45       1947   .400   56
  1698   .103    1       1748   .604    1       1798   .837    3       1848  -.764   17       1898  -.979   46       1948  -.728   56
  1699 -2.839    1       1749  -.959    1       1799  -.019    3       1849  -.049   17       1899   .204   46       1949   .024   56

PART 3:  Master Dating Series:                                                                          17:37  Mon 27 Jul 2015  Page   5
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  Year  Value  No Ab     Year  Value  No Ab     Year  Value  No Ab     Year  Value  No Ab     Year  Value  No Ab     Year  Value  No Ab
  ------------------     ------------------     ------------------     ------------------     ------------------     ------------------
  1950  -.240  56        2000  -.563  56
  1951  1.634  56        2001   .385  56
  1952 -1.187  56        2002   .027  56
  1953   .152  56        2003  1.112  56
  1954   .272  56        2004   .585  56
  1955  -.014  56        2005   .700  56
  1956  -.741  56        2006   .040  56
  1957  -.487  56        2007 -2.275  56
  1958   .313  56        2008   .370  56
  1959  -.868  56        2009   .415  56

  1960   .370  56        2010  -.305  56
  1961   .701  56        2011  -.112  56
  1962   .769  56        2012  -.557  56
  1963  -.339  56        2013   .911  56
  1964 -1.789  56        2014  -.245  55
  1965   .880  56
  1966  -.497  56
  1967   .444  56
  1968   .371  56
  1969  -.420  56

  1970   .010  56
  1971   .633  56
  1972   .285  56
  1973   .000  56
  1974  -.563  56
  1975  1.149  56
  1976  1.153  56
  1977   .361  56
  1978   .759  56
  1979  -.286  56

  1980  -.230  56
  1981  -.760  56
  1982  -.824  56
  1983   .524  56
  1984 -2.014  56
  1985   .246  56
  1986  -.945  56
  1987  -.243  56
  1988 -1.116  56
```

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  1989   .809  56

  1990  -.147  56
  1991   .145  56
  1992   .795  56
  1993   .133  56
  1994  1.092  56
  1995   .721  56
  1996  1.037  56
  1997  -.326  56
  1998 -1.585  56
  1999  -.033  56
------------------------------------------------------------------------------------------------------------------------------------

PART 4:  Master Bar Plot:                                                                          17:37  Mon 27 Jul 2015  Page   6
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   Year Rel value  Year Rel value  Year Rel value  Year Rel value  Year Rel value  Year Rel value  Year Rel value  Year Rel value
                   1700--b         1750f           1800----a       1850-d          1900-d          1950----a       2000--b
                   1701-----@      1751---b        1801-------B    1851g           1901------A     1951----------G 2001------B
                   1702---b        1752--b         1802---------E  1852------A     1902--c         1952-e          2002-----@
                   1703-d          1753o           1803----------F 1853--b         1903--------C   1953------A     2003---------D
                   1704-----@      1754--c         1804f           1854-----@      1904------A     1954------A     2004-------B
                   1705---------D  1755-d          1805----a       1855------A     1905------A     1955-----@      2005--------C
                   1706--b         1756-------B    1806--c         1856-----@      1906-------B    1956--c         2006-----@
                   1707--------C   1757---------E  1807--b         1857--------C   1907---a        1957--b         2007i
                   1708---a        1758-------B    1808--------C   1858---a        1908-----@      1958------A     2008------A
                   1709----------K 1759-------B    1809----@       1859-c          1909---------E  1959-c          2009-------B
                   1710----------H 1760--------C   1810----@       1860-------B    1910---------D  1960------A     2010---a
                   1711---------D  1761---------E  1811----a       1861------A     1911h           1961--------C   2011----@
                   1712----a       1762o           1812--------C   1862--------C   1912-----@      1962--------C   2012--b
                   1713f           1763---------E  1813f           1863------B     1913----a       1963---a        2013---------D
                   1714-------B    1764--b         1814f           1864--c         1914-e          1964g           2014----a
                   1715-d          1765f           1815-------B    1865--b         1915---------D  1965--------D
                   1716-c          1766--c         1816--c         1866---a        1916-------B    1966--b
                   1717----a       1767----------F 1817-------B    1867-------B    1917----------F 1967-------B
                   1718f           1768-------C    1818--------C   1868------A     1918--c         1968------A
                   1719f           1769--------C   1819-------B    1869---------E  1919-----@      1969---b
                   1720h           1770--------C   1820----------F 1870--------C   1920---a        1970-----@
                   1721--b         1771----------G 1821--b         1871----@       1921-d          1971-------C
                   1722---a        1772----------F 1822------B     1872-d          1922-------B    1972------A
                   1723-e          1773------A     1823---------D  1873----a       1923------A     1973-----@
   1674-----@      1724-----@      1774g           1824--------C   1874-c          1924-----@      1974--b
   1675----------F 1725----------E 1775----a       1825----a       1875---a        1925f           1975---------E
   1676f           1726----------F 1776--b         1826h           1876----a       1926----a       1976---------E
   1677----------F 1727----------F 1777-------B    1827--b         1877----@       1927----a       1977------A
   1678---------D  1728--------C   1778----------F 1828-e          1878------A     1928---------D  1978--------C
   1679------A     1729---------D  1779k           1829-----@      1879-e          1929---a        1979---a
   1680----------F 1730---------D  1780-e          1830-----@      1880---a        1930f           1980----a
   1681--b         1731-------B    1781---b        1831-----@      1881-------B    1931---a        1981--c
   1682m           1732----a       1782----------E 1832----a       1882----------F 1932----------F 1982-c
   1683-----@      1733--------C   1783----------G 1833--b         1883---------D  1933------A     1983-------B
   1684------A     1734------A     1784------A     1834-----@      1884--------C   1934-------B    1984h
   1685-d          1735--c         1785-----A      1835-------B    1885-----@      1935---------D  1985------A
   1686--b         1736o           1786-------C    1836--------C   1886---b        1936g           1986-d
   1687i           1737----a       1787---a        1837-----@      1887--c         1937--------C   1987----a
   1688-d          1738--b         1788-c          1838----@       1888---a        1938--------C   1988-d
   1689----a       1739----------G 1789-d          1839f           1889--------C   1939---a        1989--------C
   1690-e          1740----------G 1790h           1840------A     1890---a        1940---a        1990----a
   1691----a       1741---------E  1791-d          1841-----@      1891-----@      1941--c         1991-----A
```

```
   1692----------F 1742----------F 1792-e          1842-------B    1892----------F 1942--------C   1992--------C
   1693---a        1743--b         1793---------E  1843---------D  1893-------B    1943-----@      1993-----A
   1694----------I 1744--b         1794-----@      1844----a       1894g           1944f           1994---------D
   1695----------G 1745----------G 1795--------C   1845---------D  1895------A     1945---------E  1995--------C
   1696--------C   1746---a        1796------A     1846---------E  1896-d          1946--------C   1996---------D
   1697---------D  1747-----@      1797---------D  1847-----@      1897--------C   1947-------B    1997---a
   1698-----@      1748-------B    1798--------C   1848--c         1898-d          1948--c         1998f
   1699k           1749-d          1799-----@      1849-----@      1899------A     1949-----@      1999-----@

PART 5:  CORRELATION OF SERIES BY SEGMENTS:                                                        17:37  Mon 27 Jul 2015  Page   5
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 Correlations of  40-year dated segments, lagged  20 years
 Flags:  A = correlation under   .3665 but highest as dated;  B = correlation higher at other than dated position

 Seq Series  Time_span   1780 1800 1820 1840 1860 1880 1900 1920 1940 1960 1980
                         1819 1839 1859 1879 1899 1919 1939 1959 1979 1999 2019
 --- -------- ---------  ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
   1 NDO001B  1887 2014                            .45  .39  .53  .49  .48  .67
   2 NDO002A  1840 2014                  .39  .62  .77  .75  .66  .54  .34A .42
   3 NDO002B  1674 2014   .58  .58  .44  .28A .44  .77  .74  .73  .54  .19A .17A
   4 NDO003A  1888 2014                            .73  .74  .70  .62  .51  .61
   5 NDO003B  1806 2014        .33A .30A .44  .66  .70  .74  .67  .50  .51B .54
   6 NDO003C  1862 2014                       .75  .83  .64  .33A .37  .35A .38
   7 NDO004A  1781 2014   .30A .41  .60  .60  .65  .69  .71  .70  .62  .50  .49
   8 NDO004B  1893 2014                            .53  .67  .65  .54  .61  .60
   9 NDO005A  1853 2014                  .59  .67  .84  .74  .70  .67  .71  .77
  10 NDO005B  1927 2014                                      .76  .71  .67  .72
  11 NDO006A  1908 2014                                 .79  .62  .49  .73  .67
  12 NDO006B  1913 2013                                 .82  .74  .71  .86  .83
  13 NDO007A  1875 2014                       .42  .47  .70  .67  .45  .47  .56
  14 NDO007B  1928 2014                                      .57  .46  .46  .46
  15 NDO009A  1835 2014             .52  .42  .46  .48  .44  .56  .42  .39  .55
  16 NDO009B  1946 2014                                           .39  .56  .66
  17 NDO010A  1880 2014                            .69  .56  .41  .45  .69  .66
  18 NDO010B  1870 2014                       .65  .71  .64  .35B .19B .52  .63
  19 NDO011A  1805 2014        .49  .52  .28A .35A .54  .67  .73  .72  .85  .85
  20 NDO011B  1888 2014                            .75  .74  .67  .66  .81  .85
  21 NDO012A  1939 2014                                      .66  .69  .86  .75
  22 NDO012B  1898 2014                            .69  .75  .58  .55  .64  .73
  23 NDO013A  1843 2014                  .46  .46  .65  .65  .59  .64  .52  .43
  24 NDO013B  1920 2014                                      .62  .54  .67  .78
  25 NDO013C  1847 2014                  .37  .37  .66  .77  .72  .71  .82  .76
  26 NDO014A  1860 2014                       .46  .61  .49  .55  .60  .61  .76
  27 NDO014B  1867 2014                       .58  .72  .68  .64  .59  .65  .72
  28 NDO015A  1872 2014                       .68  .66  .67  .66  .63  .69  .78
  29 NDO016B  1860 2014                       .39  .49  .62  .65  .60  .55  .64
  30 NDO017A  1839 2014             .58  .60  .51  .63  .68  .73  .63  .50  .51
  31 NDO017B  1820 2014             .47  .37  .52  .49  .61  .74  .72  .48  .52
  32 NDO018A  1895 2014                            .36A .41  .59  .60  .47  .35B
  33 NDO018B  1880 2014                            .60  .71  .67  .63  .54  .53
  34 NDO019A  1886 2014                            .57  .60  .51  .58  .74  .66
  35 NDO019B  1896 2014                            .70  .74  .48  .29A .56  .58
  36 NDO021A  1864 2014                       .67  .69  .76  .68  .57  .60  .56
  37 NDO021B  1851 2014                  .38  .44  .57  .62  .57  .56  .47  .46
  38 NDO022A  1815 2014        .29B .33A .49  .52  .37  .40  .62  .60  .58  .59
  39 NDO022B  1796 2014   .59  .66  .61  .53  .51  .51  .46  .60  .43  .45  .68
  40 NDO023A  1816 2014        .54  .55  .52  .65  .46  .32B .52  .46  .71  .64
  41 NDO023B  1852 2014                  .38B .64  .83  .75  .47  .40  .57  .46
  42 NDO024A  1895 2014                            .60  .80  .76  .59  .59  .61
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  43 NDO024B  1913 2014                                 .76  .72  .67  .53  .62
  44 NDO025A  1897 2014                            .87  .84  .68  .64  .68  .72
  45 NDO025B  1894 2014                            .51  .66  .72  .78  .66  .59
  46 NDO026A  1895 2014                            .29B .35B .64  .65  .73  .80
  47 NDO026B  1858 2014                  .63  .64  .71  .78  .76  .76  .78  .77
  48 NDO027A  1858 2014                  .39  .43  .52  .68  .72  .67  .68  .66
  49 NDO027B  1832 2014             .56  .41  .58  .62  .57  .63  .65  .76  .68
  50 NDO028A  1835 2014             .42B .45B .61  .77  .80  .76  .61  .49  .53
  51 NDO028B  1820 2014             .61  .41  .61  .75  .75  .70  .60  .34B .52
  52 NDO029A  1894 2014                            .74  .78  .76  .70  .43  .39
  53 NDO029B  1941 2014                                           .67  .50  .41
  54 NDO029C  1909 2014                                 .74  .66  .62  .44  .36A
  55 NDO030A  1860 2014                       .67  .71  .65  .58  .62  .72  .74
  56 NDO030B  1830 2014             .25A .48  .58  .73  .82  .79  .79  .78  .70
 Av segment correlation   .49  .47  .48  .45  .55  .63  .66  .64  .58  .59  .61

PART 6:  POTENTIAL PROBLEMS:                                                                       17:37  Mon 27 Jul 2015  Page   7
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 For each series with potential problems the following diagnostics may appear:

 [A] Correlations with master dating series of flagged  40-year segments of series filtered with  32-year spline,
     at every point from ten years earlier (-10) to ten years later (+10) than dated

 [B] Effect of those data values which most lower or raise correlation with master series
     Symbol following year indicates value in series is greater (>) or lesser (<) than master series value

 [C] Year-to-year changes very different from the mean change in other series

 [D] Absent rings (zero values)

 [E] Values which are statistical outliers from mean for the year
====================================================================================================================================

 NDO001B   1887 to  2014     128 years                                                                                    Series   1

 [B] Entire series, effect on correlation (  .513) is:
       Lower   1964> -.022   1907< -.021   1960< -.009   1890> -.007   1932< -.006   1943< -.005  Higher   2007  .016   1975  .008

 [E] Outliers     4   3.0 SD above or -4.5 SD below mean for year
       1890 +3.1 SD;    1922 +5.0 SD;    1964 +3.5 SD;    1968 +4.2 SD
====================================================================================================================================

 NDO002A   1840 to  2014     175 years                                                                                    Series   2

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1960 1999    0    .04  .13  .08  .09 -.04  .21  .12 -.10 -.05 -.15  .34*-.01  .01 -.07  .06  .05 -.04  .00 -.29  .05 -.02

 [B] Entire series, effect on correlation (  .558) is:
       Lower   1960< -.020   1898> -.015   1847< -.008   1984> -.008   1983< -.008   1992< -.007  Higher   1911  .031   1894  .023
     1960 to 1999 segment:
       Lower   1960< -.078   1983< -.026   1992< -.024   1986> -.023   1974> -.019   1984> -.017  Higher   1964  .053   1975  .042

 [E] Outliers     6   3.0 SD above or -4.5 SD below mean for year
       1878 +3.1 SD;    1898 +3.7 SD;    1958 +3.1 SD;    1960 -4.7 SD;    1976 +3.4 SD;    2006 +4.3 SD
====================================================================================================================================

 NDO002B   1674 to  2014     341 years                                                                                    Series   3
```

```
 [*] Early part of series cannot be checked from 1674 to 1780 -- not matched by another series

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1840 1879    0   -.02  .03  .06  .03 -.10 -.10  .00 -.25 -.24 -.16  .28* .09  .23  .19 -.05  .15 -.19 -.02 -.01 -.02 -.26
    - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1960 1999    0    .08 -.02 -.25  .11 -.16  .05  .17 -.03  .05 -.11  .19* .10  .00  .11  .02  .11 -.28 -.11 -.40 -.24  .16
    1975 2014    0   -.07  .02 -.32  .13 -.17  .06  .13  .04  .07 -.20  .17*   -    -    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .465) is:
       Lower   1863< -.049   1983< -.016   1984> -.013   1995< -.010   2007> -.009   1781> -.007  Higher   1936  .018   1804  .017
     1840 to 1879 segment:
       Lower   1863< -.220   1864> -.026   1845< -.025   1858> -.015   1871> -.010   1843< -.006  Higher   1872  .077   1879  .031
     1960 to 1999 segment:
       Lower   1983< -.075   1984> -.053   1995< -.045   1982> -.028   1967< -.023   1990> -.018  Higher   1988  .063   1989  .025
     1975 to 2014 segment:
       Lower   1983< -.077   1995< -.047   1984> -.040   2003< -.031   1982> -.025   2001< -.021  Higher   1988  .064   1989  .025

 [E] Outliers     9   3.0 SD above or -4.5 SD below mean for year
       1852 +3.6 SD;    1863 -7.7 SD;    1926 +4.6 SD;    1969 -5.1 SD;    1982 +3.2 SD;    1983 -4.6 SD;    1990 +3.3 SD;
       2007 +3.2 SD;    2008 +3.0 SD
==================================================================================================================================

 NDO003A   1888 to  2014     127 years                                                                                Series   4

 [B] Entire series, effect on correlation (  .664) is:
       Lower   1965< -.019   1998> -.019   1922< -.017   1993< -.011   1992< -.008   1959> -.007  Higher   1984  .030   1936  .024

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1998 +3.1 SD
==================================================================================================================================

 NDO003B   1806 to  2014     209 years                                                                                Series   5

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1806 1845    0    .07  .20 -.13  .28 -.11 -.08 -.17 -.02  .18 -.10  .33*-.15 -.21 -.09 -.23  .22 -.04  .01  .03 -.13  .09
    1820 1859    0   -.14  .04  .14  .25 -.01 -.05 -.12  .09  .08 -.14  .30*-.15 -.21 -.22 -.10  .22 -.05  .01 -.17 -.04 -.09
    - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1960 1999   -7    .06 -.04 -.21  .52*-.19  .03  .03  .04  .08 -.15  .51|-.27 -.04 -.12 -.06 -.08 -.10  .19 -.13  .28  .02

 [B] Entire series, effect on correlation (  .554) is:
       Lower   1826> -.020   1991< -.015   1812> -.014   1942< -.011   1976< -.008   1892< -.008  Higher   1911  .024   2007  .020
     1806 to 1845 segment:
       Lower   1826> -.079   1812> -.067   1844> -.026   1840< -.024   1820< -.012   1842< -.011  Higher   1839  .040   1828  .030
     1820 to 1859 segment:
       Lower   1826> -.080   1844> -.028   1840< -.025   1855< -.016   1850> -.016   1854< -.013  Higher   1839  .044   1843  .035
     1960 to 1999 segment:
       Lower   1991< -.075   1976< -.042   1982> -.028   1974> -.024   1975< -.020   1994< -.015  Higher   1984  .083   1988  .032

 [E] Outliers     6   3.0 SD above or -4.5 SD below mean for year
       1812 +7.6 SD;    1826 +3.1 SD;    1843 +3.3 SD;    1849 +3.6 SD;    1870 +3.4 SD;    1915 +3.2 SD
==================================================================================================================================

 NDO003C   1862 to  2014     153 years                                                                                Series   6

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
```

```
   1920 1959    0   -.14 -.11  .24  .15 -.35  .10  .14  .32 -.27 -.45  .33* .23  .07 -.18 -.16  .06 -.05 -.06  .10  .06 -.07
   - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
   1960 1999    0   -.21 -.10 -.13 -.02 -.33  .11  .11 -.04  .07 -.16  .35* .26  .13  .26 -.10  .02 -.11 -.25 -.21 -.05  .11

 [B] Entire series, effect on correlation (  .534) is:
      Lower   1984> -.024   1951< -.014   1928< -.013   1870< -.012   2007> -.011   1974> -.010  Higher   1911  .041   1894  .019
    1920 to 1959 segment:
      Lower   1928< -.054   1951< -.052   1934< -.039   1959> -.032   1943< -.020   1921> -.018  Higher   1945  .065   1932  .054
    1960 to 1999 segment:
      Lower   1984> -.082   1974> -.046   1978< -.033   1996< -.033   1968< -.030   1990> -.014  Higher   1975  .044   1965  .042

 [E] Outliers     3   3.0 SD above or -4.5 SD below mean for year
      1911 -4.7 SD;    1974 +3.9 SD;    1984 +3.3 SD
=====================================================================================================================================

 NDO004A   1781 to  2014     234 years                                                                                    Series   7

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------   ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1781 1820    0   -.11 -.14 -.03 -.18 -.16  .07 -.22 -.04  .11  .17  .30* .22  .19  .10  .02  .01 -.34 -.15 -.29  .05 -.06

 [B] Entire series, effect on correlation (  .522) is:
      Lower   1804> -.012   1803< -.011   1998> -.011   1796> -.008   1812< -.008   2007> -.006  Higher   1951  .007   1911  .006
    1781 to 1820 segment:
      Lower   1803< -.046   1796> -.041   1812< -.040   1781< -.030   1799> -.029   1816> -.022  Higher   1813  .041   1790  .039

 [E] Outliers     9   3.0 SD above or -4.5 SD below mean for year
      1796 +3.4 SD;    1799 +3.3 SD;    1800 +3.1 SD;    1803 -4.8 SD;    1839 -6.1 SD;    1857 +3.4 SD;    1970 +3.6 SD;
      1998 +3.6 SD;    2008 +3.3 SD
=====================================================================================================================================

 NDO004B   1893 to  2014     122 years                                                                                    Series   8

 [B] Entire series, effect on correlation (  .577) is:
      Lower   1906< -.027   1940< -.027   1894> -.018   1964> -.011   1962< -.011   1896> -.010  Higher   1984  .026   1911  .017

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
      1895 +4.5 SD
=====================================================================================================================================

 NDO005A   1853 to  2014     162 years                                                                                    Series   9

 [B] Entire series, effect on correlation (  .712) is:
      Lower   1929> -.009   1983< -.008   1871> -.008   1868< -.006   1925> -.005   2002> -.005  Higher   2007  .022   1984  .018

 [E] Outliers     5   3.0 SD above or -4.5 SD below mean for year
      1871 +3.1 SD;    1899 +3.3 SD;    1929 +3.1 SD;    1978 +3.0 SD;    2002 +3.2 SD
=====================================================================================================================================

 NDO005B   1927 to  2014      88 years                                                                                    Series  10

 [B] Entire series, effect on correlation (  .721) is:
      Lower   1964> -.014   1941> -.011   1932< -.010   1985< -.010   1970< -.007   1979> -.007  Higher   2007  .023   1944  .008

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
      2007 -5.1 SD
=====================================================================================================================================

 NDO006A   1908 to  2014     107 years                                                                                    Series  11
```

```
 [B] Entire series, effect on correlation (  .641) is:
       Lower   2007> -.016   1959> -.014   2010< -.014   1957> -.011   2004< -.009   1956> -.008  Higher   1984  .021   1952  .011

 [E] Outliers     3   3.0 SD above or -4.5 SD below mean for year
       1955 +3.1 SD;    1957 +4.0 SD;    1998 -4.8 SD
=====================================================================================================================================

 NDO006B   1913 to  2013     101 years                                                                                    Series  12

 [B] Entire series, effect on correlation (  .787) is:
       Lower   1954< -.012   1936> -.009   1988> -.007   1963< -.006   1941> -.005   1950> -.005  Higher   1984  .022   1964  .010

=====================================================================================================================================

 NDO007A   1875 to  2014     140 years                                                                                    Series  13

 [B] Entire series, effect on correlation (  .537) is:
       Lower   1894> -.015   1906< -.014   1885< -.012   1896> -.011   1964> -.011   1984> -.010  Higher   1936  .035   1911  .019

 [E] Outliers     5   3.0 SD above or -4.5 SD below mean for year
       1875 +3.7 SD;    1896 +3.2 SD;    1913 +3.2 SD;    1966 +3.0 SD;    2006 +3.2 SD
=====================================================================================================================================

 NDO007B   1928 to  2014      87 years                                                                                    Series  14

 [B] Entire series, effect on correlation (  .512) is:
       Lower   1947< -.041   1998> -.028   1995< -.019   1956> -.019   2010> -.017   1984> -.011  Higher   1936  .055   2007  .026

 [E] Outliers     4   3.0 SD above or -4.5 SD below mean for year
       1956 +4.0 SD;    1957 +3.9 SD;    1998 +3.8 SD;    2010 +4.2 SD
=====================================================================================================================================

 NDO009A   1835 to  2014     180 years                                                                                    Series  15

 [B] Entire series, effect on correlation (  .482) is:
       Lower   1964> -.013   1920< -.013   1963< -.012   1911> -.010   1864> -.009   1873< -.009  Higher   1936  .021   1894  .021

 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
       1861 +3.0 SD;    1941 +3.1 SD
=====================================================================================================================================

 NDO009B   1946 to  2014      69 years                                                                                    Series  16

 [B] Entire series, effect on correlation (  .528) is:
       Lower   1960< -.040   1979< -.027   1952> -.025   1964> -.024   2003< -.023   1948> -.011  Higher   1998  .041   2007  .018

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1960 -4.7 SD
=====================================================================================================================================

 NDO010A   1880 to  2014     135 years                                                                                    Series  17

 [B] Entire series, effect on correlation (  .578) is:
       Lower   1927< -.026   1938< -.017   2007> -.015   1944> -.014   2009< -.011   1964> -.008  Higher   1984  .039   1894  .026

 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
       1915 +3.4 SD;    1927 -4.7 SD
=====================================================================================================================================
```

```
 NDO010B   1870 to  2014     145 years                                                                                    Series  18

 [A] Segment   High  -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1920 1959   -9   -.15  .36*-.12 -.10  .15  .13  .22 -.33 -.11 -.22  .35|-.07 -.10 -.14  .15  .08 -.11  .01  .09 -.16  .19
    1940 1979    4    .05 -.02  .08  .10 -.06 -.11  .11 -.03 -.02 -.18  .19|-.02 -.11  .21  .31*-.18 -.08  .16  .06 -.20 -.09

 [B] Entire series, effect on correlation (  .526) is:
       Lower   1944> -.018   1946< -.012   1945< -.012   1921> -.011   1911> -.009   1974> -.009  Higher   1984  .044   1894  .029
     1920 to 1959 segment:
       Lower   1944> -.063   1946< -.055   1945< -.049   1921> -.038   1941> -.022   1934< -.021  Higher   1936  .129   1937  .040
     1940 to 1979 segment:
       Lower   1944> -.058   1945< -.038   1946< -.038   1974> -.029   1941> -.021   1976< -.020  Higher   1966  .043   1948  .032

 [E] Outliers     3   3.0 SD above or -4.5 SD below mean for year
       1944 +4.2 SD;    1946 -5.2 SD;    1974 +3.6 SD
==================================================================================================================================

 NDO011A   1805 to  2014     210 years                                                                                    Series  19

 [A] Segment   High  -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1840 1879    0   -.06 -.19 -.05 -.05 -.02  .05  .05 -.06  .26  .08  .28* .00 -.14  .01  .03 -.11 -.14 -.02 -.37 -.21  .15
    1860 1899    0    .12  .14  .20 -.16 -.11 -.01  .07 -.05  .31  .07  .35*-.42 -.12 -.27 -.20 -.27 -.02  .10 -.20  .02  .14

 [B] Entire series, effect on correlation (  .620) is:
       Lower   1871> -.023   1944> -.015   1894> -.013   1900< -.009   1816> -.008   1842> -.006  Higher   1984  .019   2007  .015
     1840 to 1879 segment:
       Lower   1871> -.145   1872> -.026   1859> -.016   1855< -.015   1861< -.014   1854< -.013  Higher   1879  .058   1851  .041
     1860 to 1899 segment:
       Lower   1871> -.159   1894> -.053   1881< -.026   1872> -.023   1890> -.016   1861< -.013  Higher   1892  .076   1879  .050

 [E] Outliers     9   3.0 SD above or -4.5 SD below mean for year
       1815 +3.3 SD;    1816 +3.5 SD;    1842 +5.2 SD;    1871 +6.5 SD;    1872 +3.6 SD;    1894 +3.2 SD;    1900 -5.7 SD;
       1914 -6.0 SD;    1944 +3.8 SD
==================================================================================================================================

 NDO011B   1888 to  2014     127 years                                                                                    Series  20

 [B] Entire series, effect on correlation (  .763) is:
       Lower   1959< -.022   1927< -.009   1934< -.006   1903< -.006   1975< -.005   1952> -.005  Higher   1984  .018   2007  .013

==================================================================================================================================

 NDO012A   1939 to  2014      76 years                                                                                    Series  21

 [B] Entire series, effect on correlation (  .709) is:
       Lower   2006< -.037   1948> -.015   1962< -.014   1945< -.013   1950> -.010   1939> -.010  Higher   1984  .048   1964  .020

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1989 +3.3 SD
==================================================================================================================================

 NDO012B   1898 to  2014     117 years                                                                                    Series  22

 [B] Entire series, effect on correlation (  .650) is:
       Lower   1898> -.018   1956> -.017   1929> -.016   1940< -.013   1961< -.013   1996< -.012  Higher   1911  .030   2007  .029
```

```
 [E] Outliers     4   3.0 SD above or -4.5 SD below mean for year
       1898 +3.2 SD;    1929 +4.2 SD;    1956 +4.0 SD;    2005 +3.1 SD
=====================================================================================================================================

 NDO013A   1843 to  2014     172 years                                                                                    Series  23

 [B] Entire series, effect on correlation (  .532) is:
       Lower   1952> -.011   1981> -.011   1989< -.011   1907< -.010   1876< -.009   1850> -.008  Higher   1911  .032   1964  .014

 [E] Outliers     7   3.0 SD above or -4.5 SD below mean for year
       1849 +4.0 SD;    1850 +3.0 SD;    1861 +4.4 SD;    1907 -4.6 SD;    1981 +4.1 SD;    1983 +3.2 SD;    2000 +3.3 SD
=====================================================================================================================================

 NDO013B   1920 to  2014      95 years                                                                                    Series  24

 [B] Entire series, effect on correlation (  .673) is:
       Lower   1921< -.027   1979> -.013   1974< -.013   1954< -.009   1975< -.009   1966> -.009  Higher   1984  .036   2007  .030

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1979 +3.5 SD
=====================================================================================================================================

 NDO013C   1847 to  2014     168 years                                                                                    Series  25

 [B] Entire series, effect on correlation (  .664) is:
       Lower   1861< -.016   2013< -.012   2012> -.010   1847> -.008   1894> -.007   1864> -.007  Higher   2007  .024   1984  .021

 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
       2007 -8.1 SD;    2012 +3.4 SD
=====================================================================================================================================

 NDO014A   1860 to  2014     155 years                                                                                    Series  26

 [B] Entire series, effect on correlation (  .586) is:
       Lower   1921> -.043   1864> -.011   1962< -.011   1932< -.010   1894> -.009   1915< -.007  Higher   2007  .038   1984  .015

 [E] Outliers     4   3.0 SD above or -4.5 SD below mean for year
       1864 +3.0 SD;    1882 +3.1 SD;    1891 +3.2 SD;    1921 +7.5 SD
=====================================================================================================================================

 NDO014B   1867 to  2014     148 years                                                                                    Series  27

 [B] Entire series, effect on correlation (  .655) is:
       Lower   1879> -.015   1977< -.010   1872> -.009   1915< -.009   1948> -.008   1873< -.006  Higher   2007  .029   1911  .014

 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
       1891 +3.2 SD;    1994 +3.0 SD
=====================================================================================================================================

 NDO015A   1872 to  2014     143 years                                                                                    Series  28

 [B] Entire series, effect on correlation (  .688) is:
       Lower   1896> -.013   1924< -.011   1881< -.009   1965< -.009   1914> -.009   1967< -.007  Higher   2007  .027   1984  .016

 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
       1972 +3.2 SD;    1983 +3.3 SD
=====================================================================================================================================

 NDO016B   1860 to  2014     155 years                                                                                    Series  29
```

```
 [B] Entire series, effect on correlation (  .544) is:
       Lower   1982> -.015   1896< -.013   1894> -.012   1872> -.009   1861< -.009   1936> -.008  Higher   2007  .025   1984  .024

 [E] Outliers     3   3.0 SD above or -4.5 SD below mean for year
       1896 -5.7 SD;    1907 +3.0 SD;    1982 +4.6 SD
====================================================================================================================================

 NDO017A   1839 to  2014     176 years                                                                                    Series  30

 [B] Entire series, effect on correlation (  .599) is:
       Lower   1980< -.011   2003< -.010   2004< -.009   1984> -.008   1894> -.008   1961< -.008  Higher   1936  .024   2007  .013

 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
       1893 +4.4 SD;    1919 +3.7 SD
====================================================================================================================================

 NDO017B   1820 to  2014     195 years                                                                                    Series  31

 [B] Entire series, effect on correlation (  .551) is:
       Lower   1984> -.014   1911> -.009   1847> -.008   1828> -.008   1851> -.007   1885> -.006  Higher   1826  .013   1936  .013

 [E] Outliers     5   3.0 SD above or -4.5 SD below mean for year
       1826 -6.1 SD;    1847 +4.1 SD;    1885 +4.0 SD;    1886 +3.5 SD;    1984 +3.5 SD
====================================================================================================================================

 NDO018A   1895 to  2014     120 years                                                                                    Series  32

 [A] Segment   High   -10    -9    -8    -7    -6    -5    -4    -3    -2    -1    +0    +1    +2    +3    +4    +5    +6    +7    +8    +9   +10
    ---------  ----   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---
    1895 1934    0    .03   .03 -.14 -.14 -.10   .09 -.01   .19 -.29 -.28   .36*  .15 -.11 -.06   .18 -.07   .18   .01 -.22 -.01 -.33
    - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1975 2014   -3    .07 -.14   .13 -.02 -.11 -.05 -.06   .38*  .11 -.03   .35|    -     -     -     -     -     -     -     -     -     -

 [B] Entire series, effect on correlation (  .412) is:
       Lower   2007> -.020   1910< -.016   1997> -.013   1911> -.013   1982< -.010   1955< -.010  Higher   1964  .017   1998  .016
     1895 to 1934 segment:
       Lower   1910< -.054   1911> -.039   1896> -.028   1899< -.027   1917< -.020   1902> -.015  Higher   1932  .055   1930  .049
     1975 to 2014 segment:
       Lower   2007> -.054   1997> -.031   1984> -.020   1989< -.018   2012> -.016   1986> -.014  Higher   1998  .049   1975  .025

 [E] Outliers     3   3.0 SD above or -4.5 SD below mean for year
       1904 +3.1 SD;    1997 +3.7 SD;    2007 +3.5 SD
====================================================================================================================================

 NDO018B   1880 to  2014     135 years                                                                                    Series  33

 [B] Entire series, effect on correlation (  .581) is:
       Lower   1981< -.032   1903< -.010   1936> -.010   1966> -.009   1958< -.009   1988> -.008  Higher   1998  .016   1911  .014

 [E] Outliers     6   3.0 SD above or -4.5 SD below mean for year
       1880 +3.5 SD;    1893 +3.6 SD;    1899 +3.9 SD;    1967 +3.3 SD;    1981 -4.5 SD;    1993 +3.2 SD
====================================================================================================================================

 NDO019A   1886 to  2014     129 years                                                                                    Series  34

 [B] Entire series, effect on correlation (  .609) is:
       Lower   1958< -.017   1886> -.013   2000> -.012   1921> -.011   1900> -.010   1989< -.009  Higher   1984  .036   1894  .019
```

```
 [E] Outliers     6   3.0 SD above or -4.5 SD below mean for year
       1886 +3.7 SD;    1900 +3.1 SD;    1901 +3.5 SD;    1921 +3.2 SD;    1958 -5.1 SD;    2000 +3.2 SD
====================================================================================================================================

 NDO019B   1896 to  2014     119 years                                                                                    Series  35

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1940 1979    0    .19  .02  .16 -.15 -.01  .03 -.22 -.01  .20 -.22  .29*-.36  .13 -.07 -.15 -.14  .11  .23  .05  .08 -.07

 [B] Entire series, effect on correlation (  .551) is:
       Lower   1959> -.022   2000> -.015   1950< -.015   1946< -.010   1949< -.010   1964> -.009  Higher   1998  .019   1911  .019
     1940 to 1979 segment:
       Lower   1959> -.069   1963> -.028   1969> -.026   1946< -.026   1964> -.022   1949< -.020  Higher   1944  .067   1966  .028

 [E] Outliers     3   3.0 SD above or -4.5 SD below mean for year
       1959 +3.9 SD;    1960 +4.0 SD;    2000 +4.0 SD
====================================================================================================================================

 NDO021A   1864 to  2014     151 years                                                                                    Series  36

 [B] Entire series, effect on correlation (  .618) is:
       Lower   2007> -.020   1989< -.009   1964> -.009   1973< -.009   2011< -.009   1872> -.008  Higher   1984  .031   1952  .009

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1910 +3.6 SD
====================================================================================================================================

 NDO021B   1851 to  2014     164 years                                                                                    Series  37

 [B] Entire series, effect on correlation (  .491) is:
       Lower   1865< -.013   1997< -.011   1888< -.008   1962< -.008   1893< -.006   1866< -.006  Higher   1984  .017   1952  .009

 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
       1870 +4.3 SD;    1950 +3.6 SD
====================================================================================================================================

 NDO022A   1815 to  2014     200 years                                                                                    Series  38

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1815 1854   -3   -.06 -.26 -.21 -.18 -.12  .20 -.03  .34* .09 -.03  .29| .00 -.11 -.03 -.09 -.18 -.12  .12 -.06  .18 -.03
    1820 1859    0   -.08 -.20 -.08 -.18 -.10  .23 -.06  .31  .05 -.03  .33*-.03 -.13 -.02 -.13 -.16 -.09  .17 -.06  .15 -.14

 [B] Entire series, effect on correlation (  .485) is:
       Lower   1911> -.022   1935< -.019   1826> -.017   1979< -.015   1844< -.011   1887> -.008  Higher   1936  .021   1894  .019
     1815 to 1854 segment:
       Lower   1826> -.060   1844< -.030   1817< -.028   1847< -.018   1839> -.015   1827< -.015  Higher   1851  .081   1846  .032
     1820 to 1859 segment:
       Lower   1826> -.075   1844< -.036   1839> -.021   1847< -.021   1827< -.017   1848> -.016  Higher   1851  .071   1846  .033

 [E] Outliers     6   3.0 SD above or -4.5 SD below mean for year
       1822 +4.9 SD;    1826 +3.2 SD;    1887 +3.8 SD;    1902 +3.5 SD;    1911 +4.1 SD;    1953 +3.6 SD
====================================================================================================================================

 NDO022B   1796 to  2014     219 years                                                                                    Series  39

 [B] Entire series, effect on correlation (  .523) is:
       Lower   1796< -.019   1961< -.018   1911> -.012   1973< -.008   1906< -.007   1966> -.006  Higher   2007  .018   1804  .017
```

```
 [E] Outliers     4   3.0 SD above or -4.5 SD below mean for year
       1796 -4.8 SD;    1808 +3.1 SD;    1860 +3.2 SD;    1961 -5.4 SD
===================================================================================================================================

 NDO023A    1816 to  2014     199 years                                                                                Series  40

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1900 1939   -6    .28 -.18 -.11 -.06  .41*-.29 -.18 -.03  .04 -.11  .32| .10 -.18  .16  .04 -.04  .05  .01  .02 -.13 -.13

 [B] Entire series, effect on correlation (  .528) is:
       Lower   1911> -.015   1917< -.015   1828> -.014   1849< -.012   1946< -.010   1874> -.009  Higher   1894  .023   1984  .023
     1900 to 1939 segment:
       Lower   1917< -.079   1911> -.039   1902> -.022   1907> -.020   1928< -.018   1904< -.016  Higher   1936  .073   1921  .033

 [E] Outliers     9   3.0 SD above or -4.5 SD below mean for year
       1825 +3.8 SD;    1828 +3.6 SD;    1849 -5.3 SD;    1874 +3.7 SD;    1903 +3.3 SD;    1907 +3.0 SD;    1911 +3.1 SD;
       1934 +4.4 SD;    2009 -4.6 SD
===================================================================================================================================

 NDO023B    1852 to  2014     163 years                                                                                Series  41

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1852 1891    8   -.20 -.14 -.02  .41  .15  .16 -.06 -.21 -.29 -.20  .38| .26 -.13 -.01  .05 -.11  .19 -.09  .43* .04 -.12

 [B] Entire series, effect on correlation (  .564) is:
       Lower   2007> -.013   1955< -.012   1995< -.012   2009< -.009   1938< -.008   1864> -.008  Higher   1911  .033   1894  .026
     1852 to 1891 segment:
       Lower   1864> -.050   1857< -.026   1871< -.022   1887> -.022   1855< -.019   1869< -.017  Higher   1879  .106   1883  .025

 [E] Outliers     7   3.0 SD above or -4.5 SD below mean for year
       1864 +3.3 SD;    1903 +3.1 SD;    1934 +3.0 SD;    1943 +4.4 SD;    1987 +3.8 SD;    2006 +3.9 SD;    2007 +3.7 SD
===================================================================================================================================

 NDO024A    1895 to  2014     120 years                                                                                Series  42

 [B] Entire series, effect on correlation (  .626) is:
       Lower   1895< -.038   1968< -.016   1984> -.015   1896> -.010   1904< -.008   2007> -.006  Higher   1911  .035   1936  .028

===================================================================================================================================

 NDO024B    1913 to  2014     102 years                                                                                Series  43

 [B] Entire series, effect on correlation (  .664) is:
       Lower   1984> -.043   1968< -.015   1940< -.014   1967< -.007   1923< -.007   2011< -.005  Higher   1964  .016   1951  .012

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1984 +4.0 SD
===================================================================================================================================

 NDO025A    1897 to  2014     118 years                                                                                Series  44

 [B] Entire series, effect on correlation (  .750) is:
       Lower   1989< -.016   1955> -.013   1950< -.012   1951< -.010   1990< -.008   1959> -.007  Higher   1911  .023   2007  .018

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1955 +4.3 SD
```

```
===================================================================================================================================

 NDO025B   1894 to  2014     121 years                                                                                    Series  45

 [B] Entire series, effect on correlation (  .640) is:
       Lower   1894> -.035   1908< -.013   1982> -.010   1929> -.009   1994< -.008   2000> -.008  Higher   1936  .026   1964  .015

 [E] Outliers     3   3.0 SD above or -4.5 SD below mean for year
       1894 +3.8 SD;    1901 +3.0 SD;    1910 +3.2 SD
===================================================================================================================================

 NDO026A   1895 to  2014     120 years                                                                                    Series  46

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1895 1934   -5   -.21 -.02 -.11 -.08 -.11  .39*-.17 -.03  .18 -.16  .29|-.30  .05  .02  .07  .11  .07 -.17 -.23  .24  .08
    1900 1939   -5   -.23  .01 -.18 -.04 -.07  .36*-.18  .09  .06 -.16  .35|-.35  .03  .03  .04  .17 -.06 -.12 -.14  .16  .13

 [B] Entire series, effect on correlation (  .567) is:
       Lower   1916< -.134   1958< -.014   1929> -.010   1998> -.009   1901< -.008   1911> -.006  Higher   2007  .042   1984  .027
     1895 to 1934 segment:
       Lower   1916< -.324   1929> -.025   1901< -.015   1907> -.004   1899< -.004   1919< -.002  Higher   1896  .023   1909  .023
     1900 to 1939 segment:
       Lower   1916< -.321   1929> -.022   1901< -.015   1907> -.003   1919< -.003   1934< -.003  Higher   1935  .022   1936  .020

 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
       1916 -9.0 SD;    1929 +3.1 SD
===================================================================================================================================

 NDO026B   1858 to  2014     157 years                                                                                    Series  47

 [B] Entire series, effect on correlation (  .723) is:
       Lower   1907> -.009   1871< -.008   2011< -.008   1962< -.007   1933< -.006   1858> -.006  Higher   1911  .020   1936  .015

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1907 +3.4 SD
===================================================================================================================================

 NDO027A   1858 to  2014     157 years                                                                                    Series  48

 [B] Entire series, effect on correlation (  .593) is:
       Lower   1874< -.021   1894> -.015   1985< -.014   1865> -.010   1889< -.010   1953< -.008  Higher   1964  .015   1936  .014

 [E] Outliers     3   3.0 SD above or -4.5 SD below mean for year
       1865 +3.3 SD;    1874 -4.9 SD;    1977 +3.2 SD
===================================================================================================================================

 NDO027B   1832 to  2014     183 years                                                                                    Series  49

 [B] Entire series, effect on correlation (  .606) is:
       Lower   1879> -.015   1845< -.014   1953< -.010   1844> -.009   1985< -.009   1893< -.008  Higher   1984  .025   1894  .014

 [E] Outliers     5   3.0 SD above or -4.5 SD below mean for year
       1844 +3.4 SD;    1876 +3.4 SD;    1879 +3.8 SD;    1899 +3.3 SD;    1946 +3.5 SD
===================================================================================================================================

 NDO028A   1835 to  2014     180 years                                                                                    Series  50

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
```

```
   ---------  ----    ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1835 1874    1     .15  .02 -.04  .16 -.13 -.30 -.29 -.20  .16  .11  .42| .52*-.11 -.25 -.25 -.18  .05 -.18 -.16 -.07 -.11
   1840 1879    1     .10  .08  .08  .32 -.14 -.31 -.23 -.14  .23  .05  .45| .47*-.13 -.29 -.24 -.17  .05  .02 -.01 -.15 -.35

[B] Entire series, effect on correlation (  .615) is:
      Lower   1984> -.020   1838< -.015   1888> -.011   1968< -.008   1858< -.008   1974> -.007  Higher   1911  .021   1894  .017
    1835 to 1874 segment:
      Lower   1838< -.064   1848> -.027   1860< -.027   1864> -.026   1858< -.025   1844> -.023  Higher   1839  .059   1869  .057
    1840 to 1879 segment:
      Lower   1858< -.039   1860< -.034   1848> -.029   1864> -.028   1862< -.026   1844> -.024  Higher   1879  .070   1869  .062

[E] Outliers     5   3.0 SD above or -4.5 SD below mean for year
      1856 +3.0 SD;    1869 +4.8 SD;    1888 +5.4 SD;    1958 +4.1 SD;    1974 +3.4 SD
==================================================================================================================================

NDO028B   1820 to  2014     195 years                                                                                  Series  51

[A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------  ----    ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1960 1999   -5     .04  .14 -.08  .10 -.10  .38* .02  .24  .11 -.08  .34|-.17  .08 -.28 -.14 -.08 -.20 -.31 -.19 -.10  .02

[B] Entire series, effect on correlation (  .605) is:
      Lower   1984> -.030   1968< -.012   1879> -.011   1821> -.009   1981> -.009   1987< -.006  Higher   2007  .026   1894  .014
    1960 to 1999 segment:
      Lower   1984> -.138   1968< -.056   1981> -.042   1967< -.025   1963> -.024   1987< -.021  Higher   1964  .089   1975  .032

[E] Outliers     5   3.0 SD above or -4.5 SD below mean for year
      1870 +4.2 SD;    1879 +3.0 SD;    1894 -4.6 SD;    1981 +3.7 SD;    1984 +4.5 SD
==================================================================================================================================

NDO029A   1894 to  2014     121 years                                                                                  Series  52

[B] Entire series, effect on correlation (  .636) is:
      Lower   2008< -.022   1998> -.021   1984> -.020   1997> -.013   1978< -.012   1919< -.010  Higher   1911  .028   1936  .024

[E] Outliers     3   3.0 SD above or -4.5 SD below mean for year
      1929 +3.2 SD;    1997 +4.1 SD;    1998 +3.9 SD
==================================================================================================================================

NDO029B   1941 to  2014      74 years                                                                                  Series  53

[B] Entire series, effect on correlation (  .520) is:
      Lower   1984> -.028   1966< -.019   1981> -.013   2007> -.011   1998> -.011   2005< -.010  Higher   1944  .031   1951  .021

==================================================================================================================================

NDO029C   1909 to  2014     106 years                                                                                  Series  54

[A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
   ---------  ----    ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
   1975 2014    0     .02  .25 -.05  .06  .08  .07  .27  .10  .30  .08  .36*   -    -    -    -    -    -    -    -    -    -

[B] Entire series, effect on correlation (  .553) is:
      Lower   1998> -.016   2008< -.016   1997> -.014   1993< -.012   2002< -.009   1984> -.009  Higher   1911  .027   1936  .023
    1975 to 2014 segment:
      Lower   2008< -.035   1998> -.034   1997> -.030   1993< -.020   2014> -.019   2002< -.016  Higher   1988  .043   1975  .028

[E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
      1997 +3.6 SD;    2014 +3.1 SD
```

```
=================================================================================================================================

 NDO030A   1860 to  2014     155 years                                                                                 Series  55

 [B] Entire series, effect on correlation (  .667) is:
       Lower   1922< -.016   1914> -.009   1946< -.008   1860< -.008   1918> -.008   2009< -.007  Higher   2007  .028   1911  .024

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1904 +3.2 SD
=================================================================================================================================

 NDO030B   1830 to  2014     185 years                                                                                 Series  56

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1830 1869    0   -.10  .12 -.20 -.13 -.02  .09  .04  .00  .05 -.08  .25*-.06 -.01 -.05 -.26  .21  .04  .22  .21  .02 -.19

 [B] Entire series, effect on correlation (  .665) is:
       Lower   1839> -.013   1981> -.012   1896> -.011   1843< -.008   1838> -.007   1901< -.007  Higher   1984  .021   1911  .020
     1830 to 1869 segment:
       Lower   1843< -.048   1839> -.045   1838> -.038   1831< -.038   1847> -.030   1846< -.022  Higher   1851  .067   1869  .039

 [E] Outliers     5   3.0 SD above or -4.5 SD below mean for year
       1838 +3.9 SD;    1839 +3.4 SD;    1855 +3.2 SD;    1896 +3.2 SD;    1981 +4.2 SD
=================================================================================================================================

PART 7:  DESCRIPTIVE STATISTICS:                                                                   17:37  Mon 27 Jul 2015  Page   8
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                                                       Corr   //-------- Unfiltered --------\\  //---- Filtered -----\\
                                No.    No.    No.      with   Mean   Max     Std   Auto   Mean   Max    Std   Auto  AR
 Seq Series   Interval        Years  Segmt  Flags    Master   msmt   msmt    dev   corr   sens  value    dev   corr  ()
 --- -------- ---------       -----  -----  -----    ------ -----  -----  -----  -----  -----  -----  -----  -----  --
   1 NDO001B  1887 2014        128      6      0      .513   1.76   4.05   .611   .793   .158   2.86   .448  -.026   2
   2 NDO002A  1840 2014        175      8      1      .558   1.51   3.03   .428   .720   .161   2.64   .362  -.011   1
   3 NDO002B  1674 2014        341     11      3      .465   1.12   3.00   .451   .808   .177   2.61   .348  -.050   1
   4 NDO003A  1888 2014        127      6      0      .664   1.14   2.02   .288   .535   .193   2.55   .420  -.040   1
   5 NDO003B  1806 2014        209     10      3      .554   1.59   5.36   .554   .620   .165   3.18   .508  -.043   1
   6 NDO003C  1862 2014        153      7      2      .534   1.37   3.05   .419   .693   .167   2.53   .315  -.029   1
   7 NDO004A  1781 2014        234     11      1      .522   1.61   2.94   .394   .519   .182   2.61   .337   .004   1
   8 NDO004B  1893 2014        122      6      0      .577   1.21   2.20   .279   .562   .165   2.77   .516  -.004   1
   9 NDO005A  1853 2014        162      8      0      .712   2.24   3.93   .451   .427   .174   2.53   .371  -.022   1
  10 NDO005B  1927 2014         88      4      0      .721   2.54   4.73   .611   .460   .192   2.55   .338   .013   1
  11 NDO006A  1908 2014        107      5      0      .641   2.93   7.41  1.114   .717   .178   2.53   .370  -.050   1
  12 NDO006B  1913 2013        101      5      0      .787   2.86   6.45   .996   .784   .180   2.61   .447  -.018   1
  13 NDO007A  1875 2014        140      7      0      .537   1.94   3.80   .655   .694   .203   2.47   .361  -.025   1
  14 NDO007B  1928 2014         87      4      0      .512   2.61   6.98   .893   .638   .202   2.70   .545   .011   1
  15 NDO009A  1835 2014        180      9      0      .482   1.01   2.03   .291   .772   .153   2.63   .476  -.006   2
  16 NDO009B  1946 2014         69      3      0      .528   1.25   2.33   .408   .584   .254   2.59   .556   .045   1
  17 NDO010A  1880 2014        135      6      0      .578   1.45   2.34   .277   .299   .179   2.72   .421   .009   1
  18 NDO010B  1870 2014        145      7      2      .526   1.45   2.76   .429   .629   .211   2.56   .378  -.059   3
  19 NDO011A  1805 2014        210     10      2      .620   1.81   5.71   .997   .719   .212   3.25   .454  -.070   1
  20 NDO011B  1888 2014        127      6      0      .763   2.56   6.11   .913   .539   .260   2.67   .439  -.044   1
  21 NDO012A  1939 2014         76      4      0      .709   2.43   4.96   .811   .572   .219   2.77   .503   .012   1
  22 NDO012B  1898 2014        117      6      0      .650   2.55   4.08   .556   .415   .191   2.60   .431  -.025   1
  23 NDO013A  1843 2014        172      8      0      .532   1.56   4.05   .563   .790   .169   2.61   .360  -.012   1
  24 NDO013B  1920 2014         95      4      0      .673   1.59   2.52   .367   .725   .134   2.47   .452  -.092   1
  25 NDO013C  1847 2014        168      8      0      .664   1.62  12.46  1.085   .657   .163   2.73   .337  -.040   1
  26 NDO014A  1860 2014        155      7      0      .586   2.31   5.30   .842   .716   .174   2.93   .367  -.031   1
```

```
  27 NDO014B  1867 2014    148      7      0    .655   2.57   5.53  1.016   .819   .178   2.58   .353  -.020   1
  28 NDO015A  1872 2014    143      7      0    .688   2.40   4.14   .615   .500   .200   2.59   .394   .023   1
  29 NDO016B  1860 2014    155      7      0    .544   2.17   3.88   .508   .399   .201   2.61   .376  -.007   1
  30 NDO017A  1839 2014    176      9      0    .599   1.66   3.34   .558   .526   .250   2.82   .431   .010   1
  31 NDO017B  1820 2014    195      9      0    .551   1.45   3.80   .555   .639   .237   2.54   .324  -.025   1
  32 NDO018A  1895 2014    120      6      2    .412   1.29   2.98   .458   .802   .163   2.62   .429  -.021   3
  33 NDO018B  1880 2014    135      6      0    .581   1.51   2.88   .337   .531   .162   2.65   .389  -.028   1
  34 NDO019A  1886 2014    129      6      0    .609   2.61   5.98  1.045   .699   .201   2.59   .419   .024   4
  35 NDO019B  1896 2014    119      6      1    .551   2.59   5.61   .843   .449   .247   2.75   .480  -.005   1
  36 NDO021A  1864 2014    151      7      0    .618   1.93   3.59   .545   .666   .180   2.69   .402  -.032   1
  37 NDO021B  1851 2014    164      8      0    .491   1.76   3.00   .411   .533   .170   2.83   .488   .022   1
  38 NDO022A  1815 2014    200     10      2    .485   1.67   3.61   .436   .676   .152   2.83   .442  -.033   2
  39 NDO022B  1796 2014    219     11      0    .523   1.49   2.68   .333   .708   .132   2.70   .452   .009   2
  40 NDO023A  1816 2014    199     10      1    .528   1.74   6.20   .716   .779   .182   2.68   .364  -.032   1
  41 NDO023B  1852 2014    163      8      1    .564   2.22   6.17   .841   .754   .200   2.71   .476  -.049   3
  42 NDO024A  1895 2014    120      6      0    .626   2.29   4.03   .551   .469   .201   2.63   .524  -.085   2
  43 NDO024B  1913 2014    102      5      0    .664   3.09   6.11   .843   .485   .214   2.82   .481  -.022   1
  44 NDO025A  1897 2014    118      6      0    .750   2.67   4.74   .603   .373   .209   2.63   .430  -.057   1
  45 NDO025B  1894 2014    121      6      0    .640   2.68   4.57   .599   .422   .192   2.79   .538  -.062   1
  46 NDO026A  1895 2014    120      6      2    .567   2.10   4.12   .673   .625   .211   2.51   .340  -.020   1
  47 NDO026B  1858 2014    157      8      0    .723   1.90   2.87   .377   .610   .146   2.40   .390  -.031   1
  48 NDO027A  1858 2014    157      8      0    .593   1.41   3.22   .583   .717   .207   2.60   .421  -.010   1

PART 7:  DESCRIPTIVE STATISTICS:                                                                   17:37  Mon 27 Jul 2015  Page   9
------------------------------------------------------------------------------------------------------------------------------------

                                                Corr   //-------- Unfiltered --------\\  //---- Filtered -----\\
                           No.    No.    No.    with   Mean   Max     Std   Auto   Mean   Max     Std   Auto  AR
 Seq Series   Interval  Years  Segmt  Flags   Master msmt   msmt    dev   corr   sens  value    dev   corr  ()
 --- -------- ---------  -----  -----  -----   ------ -----  -----  -----  ----- ----- -----  ----- -----  --
  49 NDO027B  1832 2014    183      9      0    .606   1.37   2.76   .439   .782   .164   2.81   .515   .039   1
  50 NDO028A  1835 2014    180      9      2    .615   1.22   2.34   .320   .608   .167   3.12   .545  -.021   1
  51 NDO028B  1820 2014    195      9      1    .605   1.15   2.34   .311   .701   .165   2.66   .348   .000   1
  52 NDO029A  1894 2014    121      6      0    .636   2.23   3.76   .653   .698   .180   2.82   .611  -.036   1
  53 NDO029B  1941 2014     74      3      0    .520   1.79   3.32   .548   .692   .165   2.80   .513  -.056   1
  54 NDO029C  1909 2014    106      5      1    .553   2.17   3.74   .588   .616   .173   2.65   .499  -.004   2
  55 NDO030A  1860 2014    155      7      0    .667   1.52   2.54   .360   .653   .162   2.55   .394  -.072   1
  56 NDO030B  1830 2014    185      9      1    .665   1.98   3.90   .737   .772   .190   2.65   .415  -.079   1
 --- -------- ---------  -----  -----  -----   ------ -----  -----  -----  ----- ----- -----  ----- -----  --
 Total or mean:           8333    395     28    .590   1.82  12.46   .575   .639   .184   3.25   .422  -.024

                                              - = [  COFECHA NDOAICOF  ] = -
```

Appendix 2. Pine COFECHA Output Summary Statistics

```
[]  Dendrochronology Program Library                                        Run NDPAI  Program COF  18:48  Sun 20 Mar 2011  Page   1
[]
[]  P R O G R A M      C O F E C H A                                                                          Version 6.06P    27839
------------------------------------------------------------------------------------------------------------------------------------

 QUALITY CONTROL AND DATING CHECK OF TREE-RING MEASUREMENTS

 File of DATED series:   NDPAI.txt

 CONTENTS:

    Part 1:  Title page, options selected, summary, absent rings by series
    Part 2:  Histogram of time spans
    Part 3:  Master series with sample depth and absent rings by year
    Part 4:  Bar plot of Master Dating Series
    Part 5:  Correlation by segment of each series with Master
    Part 6:  Potential problems: low correlation, divergent year-to-year changes, absent rings, outliers
    Part 7:  Descriptive statistics

 RUN CONTROL OPTIONS SELECTED                             VALUE

         1  Cubic smoothing spline 50% wavelength cutoff for filtering
                                                            32 years
         2  Segments examined are                           40 years lagged successively by  20 years
         3  Autoregressive model applied                     A  Residuals are used in master dating series and testing
         4  Series transformed to logarithms                 Y  Each series log-transformed for master dating series and testing
         5  CORRELATION is Pearson (parametric, quantitative)
            Critical correlation, 99% confidence level   .3665
         6  Master dating series saved                       N
         7  Ring measurements listed                         N
         8  Parts printed                              1234567
         9  Absent rings are omitted from master series and segment correlations  (Y)

 Time span of Master dating series is  1781 to  2014   234 years
 Continuous time span is               1781 to  2014   234 years
 Portion with two or more series is    1781 to  2014   234 years


                                       ****************************************
                                       *C* Number of dated series        40 *C*
                                       *O* Master series 1781 2014  234 yrs *O*
                                       *F* Total rings in all series   5863 *F*
                                       *E* Total dated rings checked   5863 *E*
                                       *C* Series intercorrelation     .597 *C*
                                       *H* Average mean sensitivity    .272 *H*
                                       *A* Segments, possible problems   12 *A*
                                       *** Mean length of series      146.6 ***
                                       ****************************************

 ABSENT RINGS listed by SERIES:            (See Master Dating Series for absent rings listed by year)

              No ring measurements of zero value
```

```
PART 2:  TIME PLOT OF TREE-RING SERIES:                                                            18:48  Sun 20 Mar 2011  Page   2
------------------------------------------------------------------------------------------------------------------------------------
 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000 2050 Ident   Seq Time-span  Yrs
   :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    : -------- --- ---- ---- ----
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   <===========>   . NDP001A    1 1895 2014  120
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   <================>   . NDP002A    2 1846 2014  169
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    <==========>   . NDP002B    3 1908 2014  107
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   <================>   . NDP003A    4 1846 2014  169
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .<==============>   . NDP003B    5 1862 2014  153
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .<==============>   . NDP004A    6 1860 2014  155
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   <================>   . NDP004B    7 1840 2014  175
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .<==============>   . NDP005A    8 1867 2014  148
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .<==============>   . NDP005B    9 1867 2014  148
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   <===========>   .    . NDP006A   10 1847 1969  123
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    <===============>   . NDP006B   11 1858 2014  157
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   <================>   . NDP007A   12 1844 2014  171
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    <===============>   . NDP007B   13 1855 2014  160
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   <================>   . NDP008A   14 1848 2014  167
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   <================>   . NDP008B   15 1848 2014  167
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <=====================>    . NDP011A   16 1781 2005  225
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <======================>   . NDP011B   17 1781 2014  234
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <===>   . NDP012B   18 1970 2014   45
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <===>   . NDP013A   19 1970 2014   45
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .<==============>   . NDP014A   20 1860 2014  155
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   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <==================>   . NDP015A   22 1820 2014  195
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   <================>   . NDP015B   23 1840 2014  175
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <========>  .    . NDP016A   24 1880 1979  100
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <==================>   . NDP016B   25 1820 2014  195
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    <==========>   . NDP017A   26 1902 2014  113
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <=============>   . NDP017B   27 1870 2014  145
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <=============>   . NDP019A   28 1875 2014  140
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   <================>   . NDP022B   29 1840 2014  175
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    <===============>   . NDP023A   30 1851 2014  164
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .<==============>   . NDP023B   31 1869 2014  146
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    <===============>   . NDP024A   32 1852 2014  163
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .   <================>   . NDP024B   33 1848 2014  167
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <=========>  .    . NDP29A1   34 1873 1973  101
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <===>   . NDP29A2   35 1976 2014   39
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <============>   . NDP029B   36 1882 2014  133
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <============>   . NDP031A   37 1881 2014  134
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    . <=============>   . NDP031B   38 1875 2014  140
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .<==============>   . NDP032A   39 1862 2014  153
   .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .    .  <============>   . NDP032B   40 1882 2014  133
   :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :    :
 1050 1100 1150 1200 1250 1300 1350 1400 1450 1500 1550 1600 1650 1700 1750 1800 1850 1900 1950 2000 2050
```

```
PART 3:  Master Dating Series:                                                                      18:48  Sun 20 Mar 2011  Page   3
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  Year  Value  No Ab    Year  Value  No Ab    Year  Value  No Ab    Year  Value  No Ab    Year  Value  No Ab    Year  Value  No Ab
  ------------------    ------------------    ------------------    ------------------    ------------------    ------------------
                        1800  1.237   2       1850 -1.104  15       1900 -1.237  35       1950   .830  37       2000   .575  36
                        1801   .347   2       1851  -.113  16       1901   .344  35       1951  1.556  37       2001  -.903  36
                        1802  1.642   2       1852 -1.696  17       1902  -.822  36       1952   .688  37       2002  -.952  36
                        1803  -.192   2       1853 -1.472  17       1903   .016  36       1953   .126  37       2003   .714  36
                        1804  -.337   2       1854   .556  17       1904   .408  36       1954   .337  37       2004  1.078  36
                        1805  -.726   2       1855  1.151  18       1905  1.167  36       1955  1.578  37       2005 -1.067  36
                        1806  1.637   2       1856   .032  18       1906  1.072  36       1956   .995  37       2006  -.826  35
                        1807   .931   2       1857   .099  18       1907  1.548  36       1957  -.040  37       2007  -.617  35
                        1808  -.880   2       1858  -.458  19       1908   .131  37       1958  -.471  37       2008  -.663  35
                        1809  1.160   2       1859  1.133  19       1909  1.017  37       1959  -.881  37       2009   .618  35

                        1810  -.376   2       1860   .125  21       1910   .203  37       1960  -.891  37       2010   .419  35
                        1811 -1.240   2       1861  1.037  21       1911 -1.272  37       1961  -.450  37       2011   .159  35
                        1812 -1.481   2       1862   .358  23       1912  -.402  37       1962   .450  37       2012  -.239  35
                        1813  -.877   2       1863   .858  23       1913 -1.040  37       1963  -.154  37       2013  -.011  35
                        1814   .404   2       1864   .824  23       1914  -.573  37       1964 -1.765  37       2014   .342  35
                        1815  -.748   2       1865  -.861  23       1915   .731  37       1965  -.583  37
                        1816  1.233   2       1866  -.846  23       1916   .968  37       1966 -1.779  37
                        1817  1.678   2       1867  -.525  25       1917  -.212  37       1967  -.076  37
                        1818  1.746   2       1868   .649  25       1918  -.863  37       1968   .487  37
                        1819  1.462   2       1869  -.968  26       1919  -.942  37       1969  1.127  37

                        1820  1.244   4       1870  -.019  27       1920  -.994  37       1970  1.473  38
                        1821   .081   4       1871 -1.366  27       1921 -1.239  37       1971   .325  38
                        1822  -.137   4       1872  -.594  27       1922  -.146  37       1972  -.750  38
                        1823  -.852   4       1873  -.975  28       1923   .971  37       1973   .049  38
                        1824  -.997   4       1874  -.069  28       1924   .983  37       1974   .806  37
                        1825 -2.302   4       1875   .464  30       1925  -.595  37       1975  1.108  37
                        1826 -1.322   4       1876   .094  30       1926  -.494  37       1976   .817  38
                        1827  -.112   4       1877  1.037  30       1927  -.597  37       1977   .090  38
                        1828  -.024   4       1878  1.354  30       1928  1.122  37       1978  -.069  38
                        1829   .865   4       1879 -1.009  30       1929  1.471  37       1979 -1.299  38

                        1830  1.232   4       1880   .189  31       1930  -.671  37       1980  -.773  37
  1781  1.604   2       1831   .877   4       1881 -1.504  32       1931  -.887  37       1981  -.161  37
  1782  -.677   2       1832 -1.715   4       1882  1.624  34       1932  -.431  37       1982   .146  37
  1783  1.390   2       1833 -2.071   4       1883   .181  34       1933  1.848  37       1983   .303  37
  1784 -1.823   2       1834  -.666   4       1884  -.178  34       1934   .483  37       1984  1.056  37
  1785   .515   2       1835   .027   4       1885   .121  34       1935  1.126  37       1985  -.116  37
  1786  -.806   2       1836  -.057   4       1886   .569  34       1936 -2.415  37       1986 -2.823  37
  1787   .893   2       1837  -.316   4       1887  -.751  34       1937   .157  37       1987  -.539  37
  1788   .151   2       1838  -.487   4       1888   .425  34       1938   .282  37       1988  -.913  37
  1789 -5.103   2       1839  -.628   4       1889  1.673  34       1939  -.138  37       1989   .791  37

  1790  -.712   2       1840  -.319   8       1890   .733  34       1940   .083  37       1990   .191  37
  1791  -.663   2       1841   .461   8       1891  -.331  34       1941 -1.286  37       1991   .583  37
  1792  -.679   2       1842  1.379   8       1892  -.329  34       1942  1.063  37       1992  -.525  37
  1793  -.324   2       1843  1.232   8       1893 -1.096  34       1943   .776  37       1993  -.180  37
  1794  1.212   2       1844   .916   9       1894 -1.107  34       1944   .122  37       1994  -.481  37
  1795  1.721   2       1845   .923   9       1895 -1.242  35       1945  -.097  37       1995  -.456  37
  1796   .301   2       1846   .449  11       1896   .332  35       1946  -.637  37       1996   .985  37
  1797  1.703   2       1847   .148  12       1897  1.319  35       1947  -.329  37       1997  1.552  37
  1798   .055   2       1848   .143  15       1898  1.006  35       1948 -1.345  37       1998  1.185  37
  1799   .392   2       1849  -.103  15       1899 -1.965  35       1949 -1.433  37       1999  -.090  36
------------------------------------------------------------------------------------------------------------------------------------
```

```
PART 4:  Master Bar Plot:                                                                          18:48  Sun 20 Mar 2011  Page   4
-----------------------------------------------------------------------------------------------------------------------------------
   Year Rel value  Year Rel value  Year Rel value  Year Rel value  Year Rel value  Year Rel value  Year Rel value  Year Rel value
                   1800---------E  1850-d          1900-e          1950--------C   2000-------B
                   1801-------A    1851----@       1901-------A    1951----------F 2001-d
                   1802----------G 1852g           1902--c         1952-------C    2002-d
                   1803----a       1853f           1903-----@      1953------A     2003--------C
                   1804---a        1854-------B    1904-------B    1954------A     2004---------D
                   1805--c         1855---------E  1905---------E  1955----------F 2005-d
                   1806----------G 1856-----@      1906---------D  1956--------D   2006--c
                   1807--------D   1857-----@      1907----------F 1957-----@      2007---b
                   1808-d          1858---b        1908------A     1958---b        2008--c
                   1809---------E  1859---------E  1909---------D  1959-d          2009-------B
                   1810---b        1860------A     1910------A     1960-d          2010-------B
                   1811-e          1861---------D  1911e           1961---b        2011------A
                   1812f           1862-------A    1912---b        1962-------B    2012----a
                   1813-d          1863--------C   1913-d          1963----a       2013-----@
                   1814-------B    1864--------C   1914---b        1964g           2014-------A
                   1815--c         1865--c         1915--------C   1965---b
                   1816---------E  1866--c         1916--------D   1966g
                   1817----------G 1867---b        1917----a       1967----@
                   1818----------G 1868-------C    1918--c         1968-------B
                   1819----------F 1869-d          1919-d          1969---------E
                   1820---------E  1870-----@      1920-d          1970----------F
                   1821-----@      1871e           1921-e          1971------A
                   1822----a       1872---b        1922----a       1972--c
                   1823--c         1873-d          1923--------D   1973-----@
                   1824-d          1874----@       1924--------D   1974--------C
                   1825i           1875-------B    1925---b        1975---------D
                   1826e           1876-----@      1926---b        1976--------C
                   1827----@       1877---------D  1927---b        1977-----@
                   1828-----@      1878---------E  1928---------D  1978----@
                   1829--------C   1879-d          1929----------F 1979e
                   1830---------E  1880------A     1930--c         1980--c
   1781----------F 1831--------D   1881f           1931-d          1981----a
   1782--c         1832g           1882----------F 1932---b        1982------A
   1783----------F 1833h           1883------A     1933----------G 1983------A
   1784g           1834--c         1884----a       1934-------B    1984---------D
   1785-------B    1835-----@      1885------@     1935---------E  1985----@
   1786--c         1836-----@      1886-------B    1936j           1986k
   1787--------D   1837----a       1887--c         1937------A     1987---b
   1788------A     1838---b        1888-------B    1938------A     1988-d
   1789t           1839--c         1889----------G 1939----a       1989--------C
   1790--c         1840----a       1890--------C   1940-----@      1990------A
   1791--c         1841-------B    1891---a        1941e           1991-------B
   1792--c         1842----------F 1892---a        1942---------D  1992---b
   1793----a       1843---------E  1893-d          1943--------C   1993----a
   1794---------E  1844--------D   1894-d          1944------@     1994---b
   1795----------G 1845--------D   1895-e          1945----@       1995---b
   1796------A     1846-------B    1896------A     1946--c         1996--------D
   1797----------G 1847------A     1897---------E  1947---a        1997----------F
   1798-----@      1848------A     1898--------D   1948e           1998---------E
   1799-------B    1849----@       1899h           1949f           1999----@
```

```
PART 5:  CORRELATION OF SERIES BY SEGMENTS:                                                        18:48  Sun 20 Mar 2011  Page   5
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 Correlations of  40-year dated segments, lagged  20 years
 Flags:  A = correlation under   .3665 but highest as dated;  B = correlation higher at other than dated position

 Seq Series  Time_span   1780 1800 1820 1840 1860 1880 1900 1920 1940 1960 1980
                         1819 1839 1859 1879 1899 1919 1939 1959 1979 1999 2019
 --- -------- ---------  ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ---- ----
   1 NDP001A  1895 2014                            .39  .55  .76  .40  .58  .60
   2 NDP002A  1846 2014                  .37B .53  .75  .79  .68  .54  .72  .65
   3 NDP002B  1908 2014                                 .64  .67  .58  .71  .77
   4 NDP003A  1846 2014                  .52  .42  .44  .57  .64  .58  .54  .50
   5 NDP003B  1862 2014                       .48  .30A .40  .56  .61  .71  .72
   6 NDP004A  1860 2014                       .67  .61  .49  .49  .68  .68  .54
   7 NDP004B  1840 2014                  .61  .52  .51  .61  .59  .68  .73  .60
   8 NDP005A  1867 2014                       .52  .73  .72  .64  .45  .55  .52
   9 NDP005B  1867 2014                       .75  .76  .74  .64  .53  .61  .57
  10 NDP006A  1847 1969                  .64  .72  .78  .66  .64  .55
  11 NDP006B  1858 2014                  .62  .66  .73  .75  .75  .66  .49  .41
  12 NDP007A  1844 2014                  .59  .68  .72  .72  .74  .64  .63  .52
  13 NDP007B  1855 2014                  .67  .73  .64  .58  .73  .73  .68  .59
  14 NDP008A  1848 2014                  .71  .78  .75  .77  .49  .40  .61  .45
  15 NDP008B  1848 2014                  .71  .68  .57  .62  .68  .57  .62  .48
  16 NDP011A  1781 2005   .69  .51  .45B .20B .50  .77  .62  .48  .29B .44  .51
  17 NDP011B  1781 2014   .71  .58  .67  .64  .51  .49  .65  .59  .52  .76  .65
  18 NDP012B  1970 2014                                                .47  .48
  19 NDP013A  1970 2014                                                .61  .58
  20 NDP014A  1860 2014                       .67  .67  .68  .70  .57  .49  .57
  21 NDP014B  1840 1998                  .52  .64  .51  .33A .46  .59  .57
  22 NDP015A  1820 2014             .59  .53  .60  .67  .73  .77  .66  .70  .62
  23 NDP015B  1840 2014                  .61  .64  .58  .60  .72  .66  .68  .73
  24 NDP016A  1880 1979                            .70  .76  .71  .69
  25 NDP016B  1820 2014             .52  .62  .60  .67  .76  .62  .65  .81  .45B
  26 NDP017A  1902 2014                                 .38  .51  .73  .61  .42
  27 NDP017B  1870 2014                       .68  .56  .59  .55  .54  .61  .54
  28 NDP019A  1875 2014                       .60  .58  .58  .56  .44  .42  .45
  29 NDP022B  1840 2014                  .35A .57  .61  .65  .62  .46  .49  .53
  30 NDP023A  1851 2014                  .56  .67  .70  .48  .51  .55  .36A .32A
  31 NDP023B  1869 2014                       .84  .85  .86  .85  .57  .59  .60
  32 NDP024A  1852 2014                  .59  .73  .83  .83  .79  .63  .40  .35A
  33 NDP024B  1848 2014                  .64  .72  .68  .56  .63  .67  .61  .58
  34 NDP29A1  1873 1973                       .61  .69  .68  .67  .74
  35 NDP29A2  1976 2014                                                .54
  36 NDP029B  1882 2014                            .57  .72  .79  .59  .48  .50
  37 NDP031A  1881 2014                            .66  .58  .65  .58  .68  .68
  38 NDP031B  1875 2014                       .64  .63  .72  .79  .63  .64  .63
  39 NDP032A  1862 2014                       .65  .66  .80  .87  .72  .50  .18B
  40 NDP032B  1882 2014                            .63  .56  .62  .71  .70  .60
 Av segment correlation   .70  .54  .56  .56  .63  .64  .64  .65  .59  .59  .54
```

```
PART 6:  POTENTIAL PROBLEMS:                                                                          18:48  Sun 20 Mar 2011  Page    5
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 For each series with potential problems the following diagnostics may appear:

 [A] Correlations with master dating series of flagged  40-year segments of series filtered with  32-year spline,
     at every point from ten years earlier (-10) to ten years later (+10) than dated

 [B] Effect of those data values which most lower or raise correlation with master series
     Symbol following year indicates value in series is greater (>) or lesser (<) than master series value

 [C] Year-to-year changes very different from the mean change in other series

 [D] Absent rings (zero values)

 [E] Values which are statistical outliers from mean for the year
====================================================================================================================================

 NDP001A    1895 to  2014     120 years                                                                                    Series   1

 [B] Entire series, effect on correlation (  .544) is:
       Lower    1916< -.040   1977< -.024   1979> -.018   1962< -.017   1895> -.011   1901< -.010  Higher    1986  .055   1936  .041

====================================================================================================================================

 NDP002A    1846 to  2014     169 years                                                                                    Series   2

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    --------- ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1846 1885   -2   -.16 -.28  .07 -.17  .27  .14  .22 -.04  .39*-.05  .37| .02 -.08 -.29  .12 -.19 -.05 -.34  .16 -.15 -.12

 [B] Entire series, effect on correlation (  .597) is:
       Lower    1875< -.027   1955< -.011   1887> -.008   1865> -.007   2011> -.006   1858< -.006  Higher    1986  .023   1936  .022
     1846 to 1885 segment:
       Lower    1875< -.080   1865> -.028   1850> -.023   1856> -.018   1877< -.017   1873> -.014  Higher    1852  .123   1882  .045

====================================================================================================================================

 NDP002B    1908 to  2014     107 years                                                                                    Series   3

 [B] Entire series, effect on correlation (  .661) is:
       Lower    1966> -.019   1920> -.015   1969< -.011   1961< -.009   1933< -.009   1954< -.009  Higher    1986  .048   1964  .016

====================================================================================================================================

 NDP003A    1846 to  2014     169 years                                                                                    Series   4

 [B] Entire series, effect on correlation (  .520) is:
       Lower    1913> -.018   1868< -.017   2002< -.014   1893> -.012   1871> -.010   1938< -.010  Higher    1852  .015   1933  .011

 [E] Outliers     3   3.0 SD above or -4.5 SD below mean for year
       1851 +3.2 SD;    1880 +3.5 SD;    1913 +3.4 SD
====================================================================================================================================

 NDP003B    1862 to  2014     153 years                                                                                    Series   5

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    --------- ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1880 1919    0    .13 -.01  .02  .00 -.10 -.01  .26 -.28 -.07  .00  .30* .01  .05 -.06 -.06 -.05 -.18 -.01  .05  .28  .03
```

```
 [B] Entire series, effect on correlation (  .540) is:
       Lower   1912< -.021   1911> -.019   1879> -.016   1946< -.010   1913> -.010   1960> -.008  Higher   1966  .015   2005  .013
     1880 to 1919 segment:
       Lower   1911> -.072   1912< -.053   1913> -.038   1893> -.031   1919> -.020   1904< -.015  Higher   1881  .070   1907  .040

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1911 +3.4 SD
==================================================================================================================================

 NDP004A   1860 to  2014     155 years                                                                                    Series   6

 [B] Entire series, effect on correlation (  .579) is:
       Lower   1932< -.017   1899> -.009   1925< -.008   2007> -.008   1938< -.008   1918> -.007  Higher   1986  .018   1966  .016

==================================================================================================================================

 NDP004B   1840 to  2014     175 years                                                                                    Series   7

 [B] Entire series, effect on correlation (  .601) is:
       Lower   1892< -.014   1869> -.013   1938< -.011   1893> -.009   1948> -.007   1917> -.007  Higher   1852  .012   1966  .010

==================================================================================================================================

 NDP005A   1867 to  2014     148 years                                                                                    Series   8

 [B] Entire series, effect on correlation (  .562) is:
       Lower   2003< -.015   1876< -.013   1966> -.009   2014< -.009   1895> -.008   1979> -.007  Higher   1986  .028   2005  .012

==================================================================================================================================

 NDP005B   1867 to  2014     148 years                                                                                    Series   9

 [B] Entire series, effect on correlation (  .646) is:
       Lower   1943< -.026   1982< -.016   1992> -.014   2013< -.009   1876< -.008   2012> -.008  Higher   1986  .033   1936  .016

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1992 +3.4 SD
==================================================================================================================================

 NDP006A   1847 to  1969     123 years                                                                                    Series  10

 [B] Entire series, effect on correlation (  .643) is:
       Lower   1966> -.023   1964> -.011   1950< -.010   1920> -.009   1919> -.008   1941> -.007  Higher   1899  .029   1879  .009

==================================================================================================================================

 NDP006B   1858 to  2014     157 years                                                                                    Series  11

 [B] Entire series, effect on correlation (  .629) is:
       Lower   1980< -.022   1990< -.015   1873> -.008   1882< -.008   1988> -.007   2012> -.007  Higher   1936  .024   1899  .013

==================================================================================================================================

 NDP007A   1844 to  2014     171 years                                                                                    Series  12

 [B] Entire series, effect on correlation (  .639) is:
       Lower   1873> -.014   1856< -.011   2006> -.010   1871< -.009   1944< -.008   1964> -.007  Higher   1936  .027   1899  .015
```

```
=================================================================================================================================

 NDP007B   1855 to  2014     160 years                                                                                 Series  13

 [B] Entire series, effect on correlation (  .644) is:
       Lower   1915< -.026   1925> -.012   2012< -.012   1879> -.010   1856< -.007   1917> -.007  Higher   1936  .039   1899  .012

=================================================================================================================================

 NDP008A   1848 to  2014     167 years                                                                                 Series  14

 [B] Entire series, effect on correlation (  .598) is:
       Lower   1954< -.029   1979> -.013   1949> -.011   1946> -.011   2000< -.007   1935< -.006  Higher   1899  .021   1986  .015

=================================================================================================================================

 NDP008B   1848 to  2014     167 years                                                                                 Series  15

 [B] Entire series, effect on correlation (  .606) is:
       Lower   1907< -.025   1925> -.013   2013< -.013   1966> -.012   1899> -.012   1999> -.008  Higher   1936  .037   1964  .011

=================================================================================================================================

 NDP011A   1781 to  2005     225 years                                                                                 Series  16

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1820 1859   -1   -.25 -.27 -.20  .04 -.27 -.15  .05 -.02  .22  .60* .45| .14 -.18 -.22 -.27 -.07 -.01  .15  .02 -.01 -.16
    1840 1879   -1   -.21  .18  .20 -.07 -.15  .28 -.02  .17 -.12  .30* .20|-.04 -.10 -.23  .05  .21 -.04 -.09 -.04 -.23 -.19
    - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1940 1979    6   -.13 -.40  .04  .12 -.15 -.09 -.22  .00  .11 -.06  .29| .06 -.07 -.12 -.01  .06  .29* .10 -.02 -.16 -.11

 [B] Entire series, effect on correlation (  .523) is:
       Lower   1951< -.021   1861< -.019   1798> -.010   1871> -.009   1960< -.008   2002< -.008  Higher   1789  .034   1986  .015
     1820 to 1859 segment:
       Lower   1850> -.045   1839< -.043   1838> -.027   1821> -.026   1820< -.026   1849> -.015  Higher   1825  .107   1842  .037
     1840 to 1879 segment:
       Lower   1861< -.127   1871> -.060   1874< -.033   1850> -.032   1869> -.023   1860> -.015  Higher   1879  .077   1852  .055
     1940 to 1979 segment:
       Lower   1951< -.140   1966> -.056   1965> -.011   1943< -.011   1959> -.009   1973< -.008  Higher   1955  .053   1979  .028

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1789 +3.4 SD
=================================================================================================================================

 NDP011B   1781 to  2014     234 years                                                                                 Series  17

 [B] Entire series, effect on correlation (  .622) is:
       Lower   1944< -.017   1792> -.011   1798< -.010   1878< -.008   1802< -.007   1803> -.006  Higher   1789  .044   1986  .010

=================================================================================================================================

 NDP012B   1970 to  2014      45 years                                                                                 Series  18

 [B] Entire series, effect on correlation (  .457) is:
       Lower   2003< -.061   1979> -.037   1970< -.035   2002> -.012   1977< -.009   2007> -.009  Higher   2005  .089   1986  .023

=================================================================================================================================
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 NDP013A   1970 to  2014      45 years                                                                                    Series  19

 [B] Entire series, effect on correlation (  .575) is:
       Lower   2005> -.037   2008> -.031   2011< -.031   1988> -.025   1997< -.017   2001> -.016  Higher   1986  .207   1979  .023

====================================================================================================================================

 NDP014A   1860 to  2014     155 years                                                                                    Series  20

 [B] Entire series, effect on correlation (  .610) is:
       Lower   1982< -.049   1967< -.019   1956< -.009   1871> -.008   1864< -.007   1964> -.007  Higher   1986  .020   1899  .014

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1982 -4.7 SD
====================================================================================================================================

 NDP014B   1840 to  1998     159 years                                                                                    Series  21

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1900 1939    0   -.14  .06 -.06  .04  .09 -.19 -.14  .08  .12 -.02  .33*-.22 -.19 -.03  .17  .17 -.01 -.09 -.20  .12  .01

 [B] Entire series, effect on correlation (  .505) is:
       Lower   1936> -.032   1914< -.023   1873> -.020   1979> -.008   1919> -.006   1851< -.006  Higher   1881  .012   1986  .011
     1900 to 1939 segment:
       Lower   1936> -.109   1914< -.043   1919> -.020   1930> -.017   1911> -.010   1921> -.009  Higher   1933  .050   1902  .039

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1873 +4.0 SD
====================================================================================================================================

 NDP015A   1820 to  2014     195 years                                                                                    Series  22

 [B] Entire series, effect on correlation (  .635) is:
       Lower   1873< -.022   2004< -.011   1896< -.009   1823> -.008   1864< -.007   1869> -.007  Higher   1936  .028   1899  .016

 [E] Outliers     2   3.0 SD above or -4.5 SD below mean for year
       1823 +3.1 SD;    1873 -5.0 SD
====================================================================================================================================

 NDP015B   1840 to  2014     175 years                                                                                    Series  23

 [B] Entire series, effect on correlation (  .637) is:
       Lower   1895> -.012   1917> -.012   1896< -.010   1871> -.009   1856> -.008   1970< -.008  Higher   1899  .020   1936  .020

====================================================================================================================================

 NDP016A   1880 to  1979     100 years                                                                                    Series  24

 [B] Entire series, effect on correlation (  .713) is:
       Lower   1906< -.022   1921> -.016   1899> -.012   1880< -.010   1945< -.009   1941> -.007  Higher   1936  .016   1966  .013

====================================================================================================================================

 NDP016B   1820 to  2014     195 years                                                                                    Series  25

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1975 2014   -6   -.13  .09 -.03  .21  .49*-.02 -.14 -.05 -.16 -.07  .45|   -    -    -    -    -    -    -    -    -    -
```

```
 [B] Entire series, effect on correlation (  .585) is:
       Lower   2011< -.032   2005> -.021   1958< -.011   1825> -.011   1897< -.010   1873> -.008  Higher   1986  .025   1966  .011
     1975 to 2014 segment:
       Lower   2011< -.130   2005> -.103   1997< -.023   2006> -.017   2000< -.015   2004< -.010  Higher   1986  .196   1979  .023

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       2005 +3.1 SD
====================================================================================================================================

 NDP017A   1902 to  2014     113 years                                                                                  Series  26

 [B] Entire series, effect on correlation (  .484) is:
       Lower   2011< -.029   1936> -.018   1928< -.016   1932< -.014   1911> -.012   1923< -.011  Higher   1964  .018   1948  .015

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       2011 -5.8 SD
====================================================================================================================================

 NDP017B   1870 to  2014     145 years                                                                                  Series  27

 [B] Entire series, effect on correlation (  .571) is:
       Lower   1968< -.014   2001> -.012   1950< -.011   1948> -.009   1949> -.008   1925> -.007  Higher   1986  .017   1966  .014

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 NDP019A   1875 to  2014     140 years                                                                                  Series  28

 [B] Entire series, effect on correlation (  .537) is:
       Lower   1989< -.021   1986> -.017   1881> -.011   1946< -.009   1887> -.009   1920> -.008  Higher   1899  .019   1936  .019

====================================================================================================================================

 NDP022B   1840 to  2014     175 years                                                                                  Series  29

 [A] Segment   High   -10    -9    -8    -7    -6    -5    -4    -3    -2    -1    +0    +1    +2    +3    +4    +5    +6    +7    +8    +9   +10
    ---------  ----   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---
    1840 1879    0   -.27 -.13 -.24 -.22 -.15 -.14  .07 -.01  .17  .33  .35* .05  .07  .01 -.07  .13 -.11 -.09 -.20  .01  .04

 [B] Entire series, effect on correlation (  .530) is:
       Lower   1975< -.012   2012< -.011   1985> -.010   1888< -.009   1849> -.007   1841< -.007  Higher   1986  .041   1933  .012
     1840 to 1879 segment:
       Lower   1849> -.038   1841< -.034   1850> -.029   1854< -.028   1858> -.025   1873> -.020  Higher   1871  .061   1853  .035

 [C] Year-to-year changes diverging by over 4.0 std deviations:
       1986 1987  -4.5 SD

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       1987 -4.6 SD
====================================================================================================================================

 NDP023A   1851 to  2014     164 years                                                                                  Series  30

 [A] Segment   High   -10    -9    -8    -7    -6    -5    -4    -3    -2    -1    +0    +1    +2    +3    +4    +5    +6    +7    +8    +9   +10
    ---------  ----   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---   ---
    1960 1999    0   -.08 -.03  .19  .29  .11  .00 -.25 -.26  .03  .00  .36* .10 -.16 -.28 -.35  .04 -.05  .33  .07 -.09 -.26
    1975 2014    0   -.20 -.10  .26  .24  .18 -.05 -.08 -.12 -.02  .04  .32*   -     -     -     -     -     -     -     -     -     -

 [B] Entire series, effect on correlation (  .518) is:
```

```
       Lower   1867< -.017   1923< -.009   1952< -.009   1986> -.008   1988> -.008   1974< -.008  Higher   1899  .034   1966  .017
     1960 to 1999 segment:
       Lower   1974< -.034   1988> -.032   1980> -.025   1991< -.025   1973< -.020   1964> -.019  Higher   1966  .124   1970  .040
     1975 to 2014 segment:
       Lower   1988> -.034   1980> -.026   1991< -.026   2013< -.026   2005> -.025   2006> -.015  Higher   1979  .046   2003  .030

====================================================================================================================================

 NDP023B   1869 to  2014     146 years                                                                                    Series  31

 [B] Entire series, effect on correlation (  .721) is:
       Lower   2013< -.010   1978< -.008   1966> -.007   2006> -.007   1877< -.006   1992< -.006  Higher   1936  .030   1986  .024

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 NDP024A   1852 to  2014     163 years                                                                                    Series  32

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1975 2014    0   -.20 -.16  .01  .12 -.23  .19  .24 -.04  .11  .01  .35*    -    -    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .632) is:
       Lower   1986> -.029   1990< -.023   1852> -.016   1964> -.011   1991< -.010   1976< -.006  Higher   1936  .020   1899  .017
     1975 to 2014 segment:
       Lower   1986> -.109   1990< -.064   1991< -.037   1976< -.022   2012> -.013   1993< -.011  Higher   2005  .072   1979  .042

====================================================================================================================================

 NDP024B   1848 to  2014     167 years                                                                                    Series  33

 [B] Entire series, effect on correlation (  .632) is:
       Lower   1921< -.016   1976< -.009   1887> -.008   1973< -.007   1980> -.007   1888< -.006  Higher   1899  .017   1986  .013

====================================================================================================================================

 NDP29A1   1873 to  1973     101 years                                                                                    Series  34

 [B] Entire series, effect on correlation (  .613) is:
       Lower   1877< -.023   1929< -.020   1921> -.020   1879> -.010   1892< -.010   1884> -.008  Higher   1936  .065   1942  .009

====================================================================================================================================

 NDP29A2   1976 to  2014      39 years                                                                                    Series  35

 [B] Entire series, effect on correlation (  .536) is:
       Lower   1979> -.062   1977< -.035   2000< -.020   1982< -.016   1985> -.015   1992> -.009  Higher   2005  .071   1986  .045

====================================================================================================================================

 NDP029B   1882 to  2014     133 years                                                                                    Series  36

 [B] Entire series, effect on correlation (  .614) is:
       Lower   1917< -.023   1986> -.016   1966> -.011   2002> -.010   1899> -.010   1983< -.008  Higher   1936  .047   2005  .013

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 NDP031A   1881 to  2014     134 years                                                                                    Series  37

 [B] Entire series, effect on correlation (  .627) is:
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```
       Lower   1970< -.022   1905< -.008   1924< -.008   1914> -.008   2000< -.007   1923< -.007  Higher   1986  .040   1881  .010

====================================================================================================================================

 NDP031B   1875 to  2014     140 years                                                                                    Series  38

 [B] Entire series, effect on correlation (  .663) is:
       Lower   1966> -.013   1979> -.011   1896< -.010   1989< -.009   2012> -.009   2014< -.008  Higher   1986  .036   1936  .013

====================================================================================================================================

 NDP032A   1862 to  2014     153 years                                                                                    Series  39

 [A] Segment   High   -10   -9   -8   -7   -6   -5   -4   -3   -2   -1   +0   +1   +2   +3   +4   +5   +6   +7   +8   +9  +10
    ---------  ----   ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---  ---
    1975 2014   -7   -.15  .32  .15  .34* .26  .10 -.17 -.19 -.02 -.19  .18|    -    -    -    -    -    -    -    -    -    -

 [B] Entire series, effect on correlation (  .627) is:
       Lower   2005> -.023   2002> -.014   1997< -.011   1971< -.009   1867> -.007   2000< -.007  Higher   1936  .043   1933  .010
     1975 to 2014 segment:
       Lower   2005> -.079   2002> -.051   1997< -.036   2000< -.026   1976< -.025   2010< -.021  Higher   1986  .079   1979  .057

 [E] Outliers     1   3.0 SD above or -4.5 SD below mean for year
       2005 +3.0 SD
====================================================================================================================================

 NDP032B   1882 to  2014     133 years                                                                                    Series  40

 [B] Entire series, effect on correlation (  .628) is:
       Lower   1929< -.042   1939< -.011   1905< -.010   1921> -.009   1995< -.009   2005> -.008  Higher   1936  .038   1986  .031

====================================================================================================================================

PART 7:  DESCRIPTIVE STATISTICS:                                                                   18:48  Sun 20 Mar 2011  Page   6
------------------------------------------------------------------------------------------------------------------------------------

                                               Corr   //-------- Unfiltered --------\\  //---- Filtered -----\\
                           No.    No.    No.   with    Mean   Max     Std   Auto   Mean   Max     Std   Auto  AR
 Seq Series   Interval   Years  Segmt  Flags  Master   msmt   msmt    dev   corr   sens  value    dev   corr  ()
 --- -------- ---------   -----  -----  -----  ------  -----  -----  -----  -----  -----  -----  -----  -----  --
   1 NDP001A  1895 2014    120      6      0    .544    .92   2.68   .508   .696   .325   2.71   .471  -.050   2
   2 NDP002A  1846 2014    169      8      1    .597   1.42   2.94   .616   .727   .284   2.57   .378  -.016   1
   3 NDP002B  1908 2014    107      5      0    .661   2.21   4.57   .678   .629   .206   2.76   .477   .057   1
   4 NDP003A  1846 2014    169      8      0    .520    .50   1.20   .216   .651   .281   2.92   .448   .017   4
   5 NDP003B  1862 2014    153      7      1    .540    .61   2.16   .293   .681   .287   2.73   .533  -.036   1
   6 NDP004A  1860 2014    155      7      0    .579    .61   1.64   .223   .645   .259   2.85   .462  -.001   1
   7 NDP004B  1840 2014    175      8      0    .601    .88   2.28   .459   .785   .278   2.67   .449  -.028   1
   8 NDP005A  1867 2014    148      7      0    .562   1.21   3.64   .721   .843   .271   2.61   .500  -.044   4
   9 NDP005B  1867 2014    148      7      0    .646   1.14   3.28   .678   .808   .286   2.69   .493   .004   1
  10 NDP006A  1847 1969    123      6      0    .643   1.83   5.36  1.193   .846   .278   2.57   .444  -.013   1
  11 NDP006B  1858 2014    157      8      0    .629   1.38   4.80  1.080   .884   .269   2.89   .490  -.068   1
  12 NDP007A  1844 2014    171      8      0    .639   1.30   2.76   .660   .821   .240   2.59   .406   .033   1
  13 NDP007B  1855 2014    160      8      0    .644   1.29   2.92   .629   .805   .245   2.58   .390   .003   1
  14 NDP008A  1848 2014    167      8      0    .598   1.20   3.53   .786   .855   .284   2.65   .459  -.048   1
  15 NDP008B  1848 2014    167      8      0    .606   1.42   3.95   .931   .841   .316   2.58   .454  -.033   1
  16 NDP011A  1781 2005    225     11      3    .523    .81   3.24   .481   .699   .314   2.82   .503   .012   3
  17 NDP011B  1781 2014    234     11      0    .622    .87   2.72   .556   .785   .327   2.61   .352  -.018   3
  18 NDP012B  1970 2014     45      2      0    .457    .53   1.15   .202   .472   .332   2.57   .470  -.069   1
  19 NDP013A  1970 2014     45      2      0    .575    .22    .45   .084   .392   .353   2.44   .485  -.120   1
```

```
 20 NDP014A  1860 2014    155      7      0    .610    .66   1.62   .277   .753   .208   2.69   .429  -.024    2
 21 NDP014B  1840 1998    159      7      1    .505    .73   1.89   .443   .889   .230   2.74   .446  -.006    3
 22 NDP015A  1820 2014    195      9      0    .635    .68   1.82   .410   .893   .251   2.64   .385  -.032    1
 23 NDP015B  1840 2014    175      8      0    .637    .90   2.87   .494   .856   .241   2.56   .369  -.004    1
 24 NDP016A  1880 1979    100      4      0    .713    .99   2.42   .420   .666   .250   2.84   .543   .021    1
 25 NDP016B  1820 2014    195      9      1    .585   1.09   2.48   .523   .734   .274   2.83   .459   .003    3
 26 NDP017A  1902 2014    113      5      0    .484    .82   1.85   .265   .495   .249   2.80   .515   .013    4
 27 NDP017B  1870 2014    145      7      0    .571   1.24   3.03   .473   .650   .258   2.66   .436  -.075    1
 28 NDP019A  1875 2014    140      7      0    .537   1.15   3.13   .650   .857   .266   2.65   .520  -.032    1
 29 NDP022B  1840 2014    175      8      1    .530    .78   2.42   .372   .715   .267   2.87   .437  -.022    2
 30 NDP023A  1851 2014    164      8      2    .518   1.03   2.89   .650   .865   .211   2.55   .380  -.025    1
 31 NDP023B  1869 2014    146      7      0    .721   1.68   4.17   .593   .643   .229   2.72   .420  -.029    1
 32 NDP024A  1852 2014    163      8      1    .632   1.14   3.42   .658   .798   .254   2.67   .468   .001    3
 33 NDP024B  1848 2014    167      8      0    .632   1.27   3.35   .607   .743   .288   2.61   .397   .029    2
 34 NDP29A1  1873 1973    101      5      0    .613    .79   2.06   .454   .717   .338   2.64   .414  -.020    1
 35 NDP29A2  1976 2014     39      1      0    .536    .69   1.34   .293   .662   .309   2.58   .531   .006    1
 36 NDP029B  1882 2014    133      6      0    .614   1.15   2.90   .530   .555   .334   2.61   .452  -.120    2
 37 NDP031A  1881 2014    134      6      0    .627   1.32   2.69   .556   .625   .293   2.49   .374  -.021    4
 38 NDP031B  1875 2014    140      7      0    .663   1.05   2.38   .443   .678   .281   2.59   .430  -.042    3
 39 NDP032A  1862 2014    153      7      1    .627   1.25   4.21   .779   .829   .259   2.59   .370  -.062    2
 40 NDP032B  1882 2014    133      6      0    .628   1.52   3.53   .603   .672   .258   2.69   .525  -.044    3
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Total or mean:           5863    275     12    .597   1.07   5.36   .555   .749   .272   2.92   .443  -.020

                                                - = [  COFECHA NDPAICOF  ] = -
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Vita

Allison Elizabeth Ingram grew up in Somerset, NJ. She is the daughter of James and Rhonda Ingram and has an older sister, Jennifer. She graduated in 2009 from Franklin High School, after which she attended Rider University in Lawrenceville, NJ. She became interested in dendrochronology after taking an Introduction to Environmental Science class with her undergraduate advisor, Dr. Daniel Druckenbrod, as a Rider freshman. She worked in his dendrochronology lab as a research assistant for her four years at Rider and graduated with a Bachelor of Science in Environmental Sciences in May 2013. She worked as a summer research intern at Princeton University for the summer of 2013 in Dr. Kelly Caylor's Ecohydrology lab under Dr. Adam Wolf. She analyzed impacts of the 2012 drought on forest growth and mortality in sites across North America by measuring the ring widths of tree cores. This work was extended for the 2013/2014 school year and Allison stayed on at Princeton to complete the project. In the fall of 2014, Allison began working towards a Master of Science in Geography at the University of Tennessee (UT) with a concentration in dendrochronology, dendroclimatology, and physical geography with Dr. Henri Grissino-Mayer as her advisor. At UT, Allison worked as a Graduate Teaching Assistant in Fall 2014-Spring 2016.