

Spatio-temporal variability of *Pinus rigida* in a coastal pine barren

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Abstract

Pinus rigida Mill. (pitch pine) is a native species of the eastern United States that establishes in stressful environmental conditions and has medium to low annual growth. The purpose of this study was to examine climate-growth relationships using dendroclimatological applications at the Wonderland pine barren in Acadia National Park, Maine. This woodland type is globally rare and also at the extreme northern range for pitch pine, making it susceptible potentially to impending climate change. Our chronology extended from 1711 to 2014 CE and included 63 dated series from 43 trees. We found significant ($p < 0.05$) positive correlations between the pitch pine growth chronology and winter and April temperatures, as well as with August precipitation during the period 1895-2014. Previous year July precipitation and minimum temperature were correlated negatively with growth. Moving interval correlation analysis of these monthly correlations showed that some remained stable while others varied. The late summer mean precipitation regime shifts showed an early 21st century upward trend along with general warming occurring over the past century. To assess regional tree growth-climate relationships, we performed a Principal Components Analysis with all chronologies located in Maine ($n=24$) and investigated climate response in KNMI Climate Explorer. This analysis revealed a spatial correlation between the PC1 eigenvalues and January-May sea surface temperature and the Labrador current. The climate signal for the Wonderland chronology did not correlate well with other chronologies in Maine and could be related to the unique ecology of the Wonderland site as a pitch pine barren.

Keywords: Dendroclimatology, pitch pine barren, Acadia, Maine, climate variability

Introduction

Species surviving at their range limits are often controlled by environmental factors that are different compared to those living within the optimum tolerance range (Bhuta et al 2009). These populations provide opportunities to examine the biotic and abiotic mechanisms that control establishment, growth, and mortality. As an example, a species could be limited by cold tolerance at the northern end of its range, while competition might be the driving factor in the middle portion of its range. These limiting growth factors are the key to dendroclimatology, a science that seeks to describe and analyze climate trends using long-term proxy records of climate recorded in tree-rings (Fritts 1976).

Pinus rigida Mill. (pitch pine) is a small to medium sized tree native to eastern North America, distributed from central Tennessee to southeastern Maine (Figure 1). Acadia National Park, Maine is representative of the northern limit of the *P. rigida* distribution. *P. rigida* is most commonly found in pine barrens at the northern end of its range which are harsh environments characterized by acidic, infertile, and shallow soils. Frequent natural fires prior to human settlement also helped shape these communities. *P. rigida* is well-adapted to fire and nutrient-poor soils, making it the dominant species in this ecosystem. The ecology of *P. rigida* barrens on

rock outcrops is poorly understood; however, research suggests that in the absence of fire *P. rigida* may represent a physiographic climax (Abrams and Orwig 1995).

The primary goals of this study were to: 1) create a tree-ring chronology for the *P. rigida* barrens of Acadia National Park, 2) explore the climate-growth relationships for *P. rigida* growing at its northern range limit, and 3) assess the suitability of the developed and existing regional chronologies for reconstructing climate. This work will add to our understanding of the ecology in this rare community, aid in future conservation efforts, and help to characterize historical climate in Acadia National Park.



Figure 1. *Pinus rigida* range (Little 1971).

Methods

Site Description

Our study area is located in the Laurentian Plains and Hills ecoregion of central Maine in Acadia National Park. Forests cover accounts for approximately 75% the vegetation in this ecoregion. The dominant species are spruce and fir, with *Picea rubens* Sarg. (red spruce) covering most of Mount Desert Island. However, isolated ecosystems of *Pinus banksiana* Lamb. (jack pine) and *P. rigida* are found along the coast; the former reaching its southernmost limit at higher elevations and the latter at its northeasternmost limit below 500m in elevation. In this ecoregion, *P. rigida* is most commonly found in southern barrens or along the rocky coastline.

Our site was located <1 km south of Highway 102A accessible from the Wonderland trail, located 5.5 km south of Southwest Harbor on Mount Desert Island in Acadia National Park, Maine (Fig. 2). The study site (hereafter known as Wonderland) is a 2.81 ha *P. rigida*/*Corema conradii* Torr. (broom crowberry) barren and is identified as a globally rare vegetation community, classified as both a S3 and G2 site on state and global rarity rankings respectively (Noss et al. 1995; maine.gov).

Field sampling and sample preparation

Sampling was undertaken on June 3rd, 2015 by ten NADEF scientists. We removed two core samples at 0.3 m height from 55 living *P. rigida* individuals ($n=81$) using Haglof 5.15 mm increment tree-bores. We targeted individuals for sampling that displayed signs of stress and age including: smoother bark, open and flat crowns, and twisted and sinuous boles (Pederson 2010). Care was taken to sample evenly throughout the site. Several trees suffered from heartwood rot (22%), and therefore pith was not achieved for the majority of the samples. Through cores were taken for most trees to achieve an A and B core, however trees with rot or larger in diameter were sampled from multiple angles on opposite sides of the tree where possible. At each tree, we recorded diameter at coring height and geolocation.

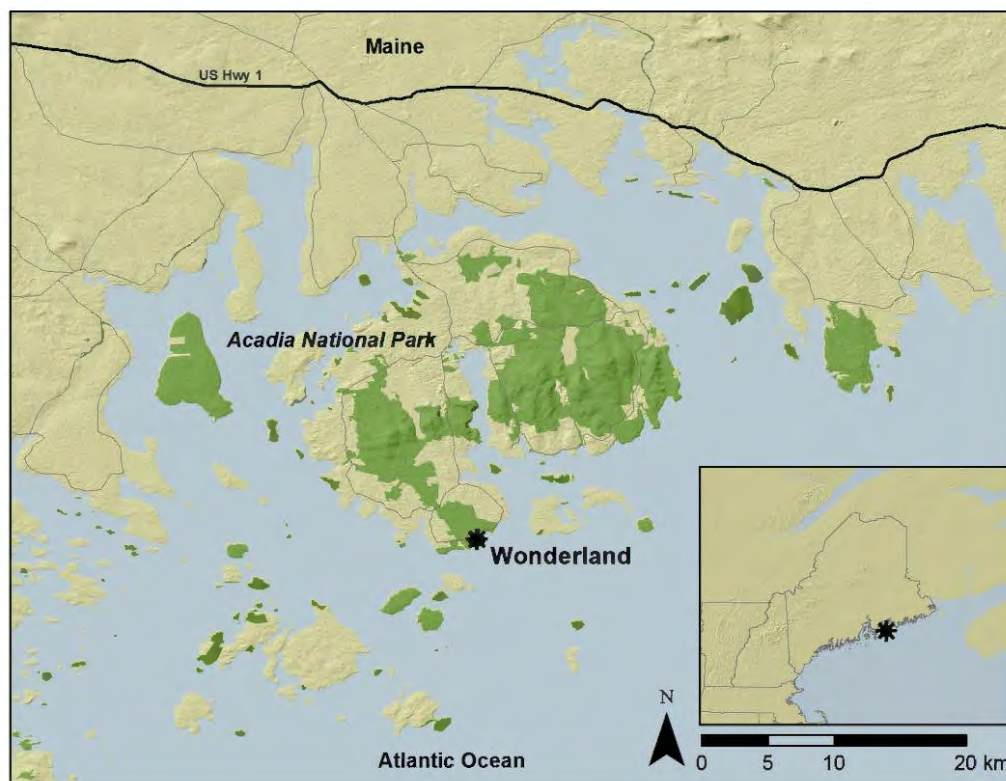


Figure 2. Map of Wonderland pitch pine barren.

Crossdating and Standardization

We prepared samples for analysis using standard dendroecological techniques (Stokes & Smiley 1968). All cores were dried in an oven at 60 degrees C or air dried in a fume hood, then sanded with progressively finer sandpaper (120, 220, 320 400, 600, 1800-grit) until cell structures were visible. All samples were ring counted, skeleton plotted, and then measured using either Velmex at a resolution of 0.001mm, WinDENDRO, or Coorecorder. Crossdating accuracy precision was verified using the program COFECHA (Holmes 1983, Grissino-Mayer 2001) and 63 of the samples from 43 trees (78% success rate) were retained in the chronology. ARSTAN was used to transform the raw ring-width measurements using the adaptive power transformation and standardized using a Friedman variable span smoother with a variable span

tweeter sensitivity of 7 (Cook and Holmes 1996) to remove the variability from stand dynamics while retaining the low frequency variability. The Keith Briffa rbar stabilization method smoothed the variability of the few older samples in the chronology.

Climate Data

Climatic data were collected from the National Climatic Data Center (NCDC) hosted by the National Oceanic and Atmospheric Administration (NOAA) (<http://www.ncdc.noaa.gov/>). Data collected represents the coastal portion of Maine (Climate Division 3; illustrated in Figure A1). Regional climate records were available from 1895 to 2014 including minimum/maximum/mean temperature, precipitation, and Palmer's drought severity index (PDSI). We also examined the relationship between standardized ring width chronologies with and additional climatic explanatory variables from the Royal Netherlands Meteorological Institute (KNMI) including radiation, sea surface temperature, and atmospheric pressure systems (i.e. North Atlantic Oscillations (NAO)).

Analysis

We investigated the relationship between standardized ring width and climate data using DendroClim2002 (Biondi, F. and K. Waikul 2004). Since there is often a lag between tree growth and climate drivers, an 18 month window was used to determine *P. rigida* response to temperature, precipitation, and PDSI. We investigated the relationship between the previous May through the current year's October precipitation, temperature, PSDI, and tree growth using the response and correlation, evolutionary moving response, and correlation functions (Figures A2 & A3).

To help interpret the results from DendroClim, we explored the climate data for regime shifts using the Regime Shift Detection Algorithm from Rodionov over 50-year periods tested at a 0.05 significance level. We also examined trends in Winter (December-February, DJF) and April minimum temperatures as they were found to be positively correlated with growth.

The chronology was entered into KNMI Climate Explorer and analyzed post-hoc for additional climate influences such as sea surface temperature. Finally, we used principal component analysis with all chronologies available on the International Tree-Ring Data Bank and the Wonderland chronology to 1) assemble a network chronology from the common pooled variance of all Maine chronologies and 2) elucidate our chronology's influence to other Maine chronologies common signal.

Results

We assembled a chronology based on sixty-four cores, spanning 1711–2014 with an interseries correlation of 0.553 and mean sensitivity of 0.255 (Figure 3).

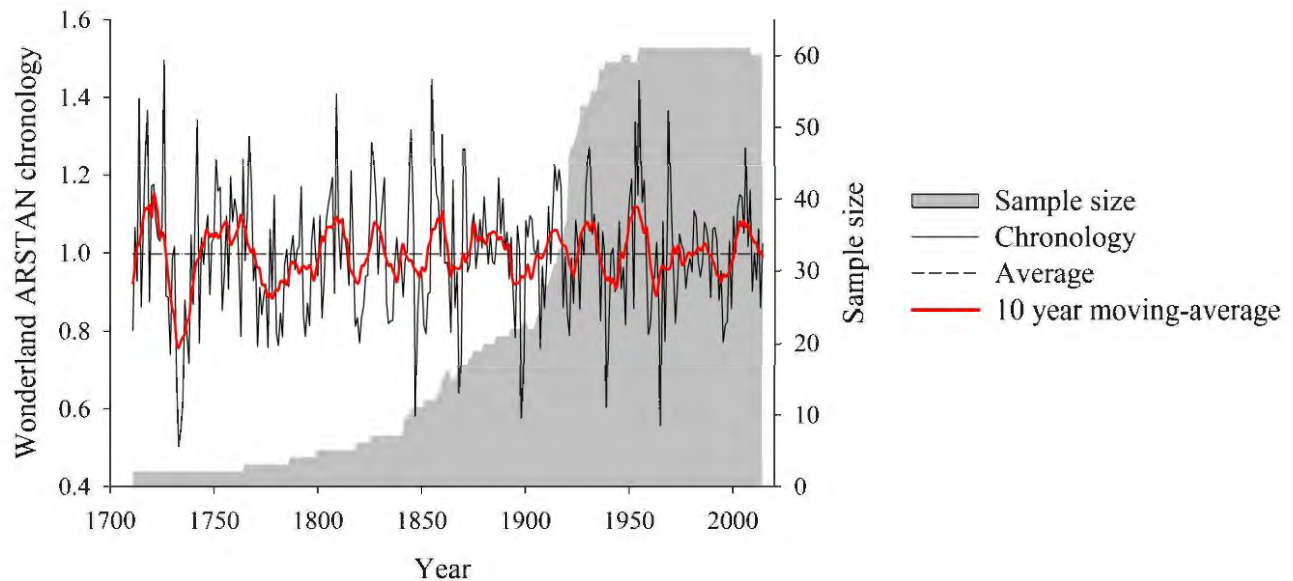


Figure 3: *P. rigida* ARSTAN chronology from Acadia National Park along the Wonderland Trail.

We found positive climate-growth response relationships between December–February and April minimum temperature and August precipitation, and a negative response to growth for previous July precipitation and temperature.

Moving correlation response analysis indicated a deteriorating August precipitation correlation to our chronology (Figure 4) from positive to negative correlation after 2003. Also, temporal instability was observed for winter minimum temperature throughout the 20th century. The spatiotemporal trend in mid summer precipitation was relatively stable for the majority of the record with a recent shift in the last decade to higher precipitation, which is part of a larger pluvial affecting New England (Figure 5). This is consistent with research in New England which indicates that the northeastern portion of the United States has been experiencing the strongest trends in precipitation intensity, frequency and extreme events (Pederson 2013). We identified significant shifts toward warmer regimes in the 1940s and 1990s. Temporal changes in climate-growth relationships or regime shifts such as these suggest caution should be used if interpreting climate reconstructions based on our Wonderland pitch pine chronology.

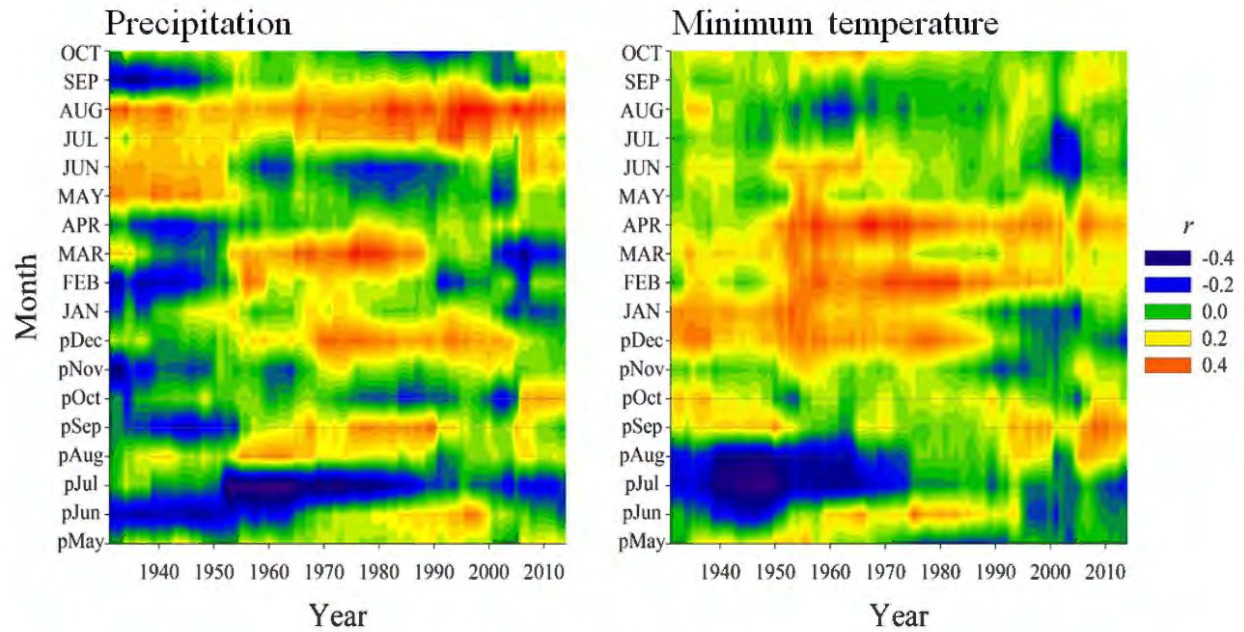


Figure 4. Correlations between standardized tree ring width and precipitation (left) and minimum temperature (right) using a 36-year moving interval correlation analysis. There were consistent positive correlations with late summer temperatures and winter/spring minimum temperatures.

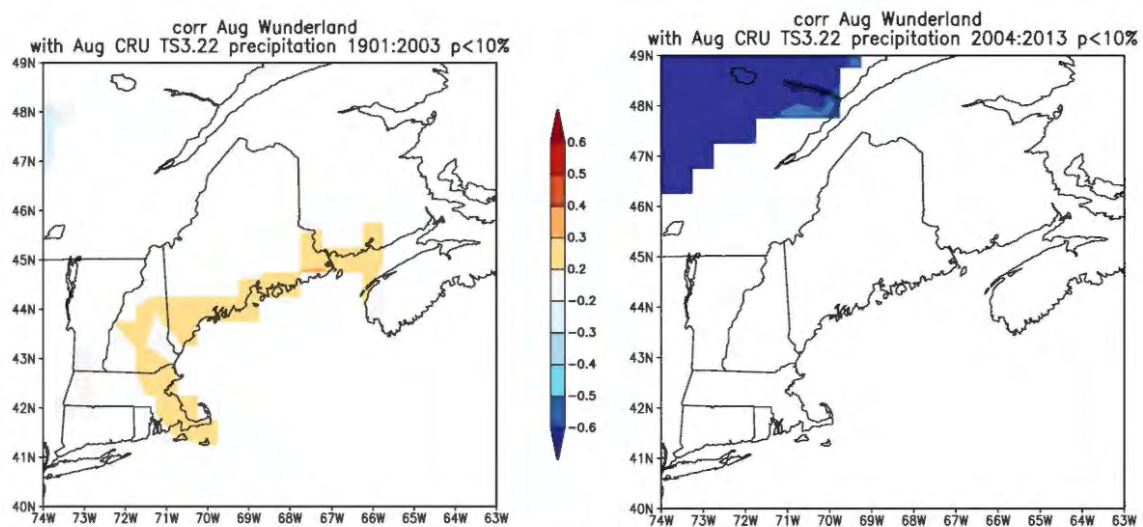


Figure 5: Pluvial shift from positive correlations with august precipitation to a negative for the northeast region.

A wavelet spectrum analysis was conducted to determine possible climatic drivers over the time series of the chronology (Figure 6). The y-axis portrays smaller waves or shorter periodicity that become larger wavelets that represent climatic factors with longer periodicity. We looked for statistical significance (blue to red) that fell within the cone of influence (area of plot where ability to detect patterns is greatest) and coincided with red noise. Within these three

parameters, we can detect two periodicities displaying statistical significance: smaller oscillatory waves at the 5–7 year period could represent a climatic influence, such as ENSO, though the smaller wavelet is not as strong as the longer wavelet found at 15–20 years. This longer oscillation coincides with the NAO, whose potential sphere of influence would be more dominant on our study site due to its proximity to the Northern Atlantic Ocean. This analysis helps determine the level of influence atmosphere-ocean interactions have on our study site and subsequently our chronology.

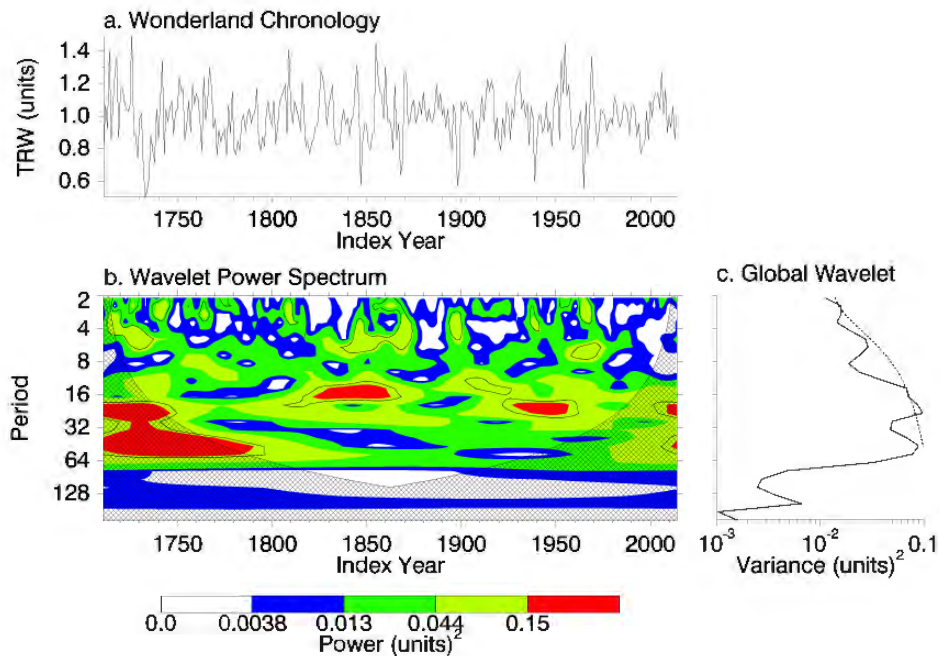


Figure 6. Wavelet spectrum analysis for the Wonderland chronology depicts climate drivers oscillating at 5–7 year periodicity and 15–20 year periodicity.

We found that from the twenty four chronologies we used in the principal component analysis wonderland contributed little to the first and second principal components (Figure A5). From the first principal component we assembled a common variance chronology from all Maine chronologies and found a strong, positive correlation with January–June sea-surface temperature in the North Atlantic (Figure A6). We attribute this positive correlation with warmer years of the Labrador current that positively influences tree growth at Wonderland. Additionally, this result may be coupled with winter and April temperature as maritime sea surface temperature modulate climate conditions at our site.

Conclusion

The results of the *P. rigida* chronology developed at Wonderland indicate the potential for further analysis of climatic sensitivity of trees at the limits of their distribution, particularly in harsh environments like the rock barren coast. Due to the spatio-temporal variability of climate-correlation response, the quality and reliability of climate reconstruction from Wonderland is limited. Additionally, the chronology does not correlate strongly with other tree-ring chronologies from Maine available on the ITRDB. Our contribution to the scientific community is that these old aged pitch pine barrens have a unique but unstable climate response.

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Appendix

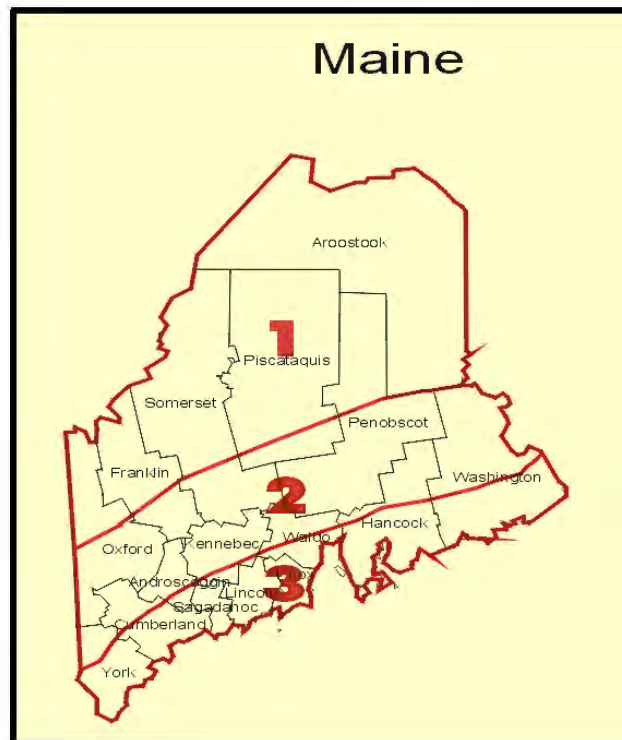


Figure A1. Maine climate divisions.

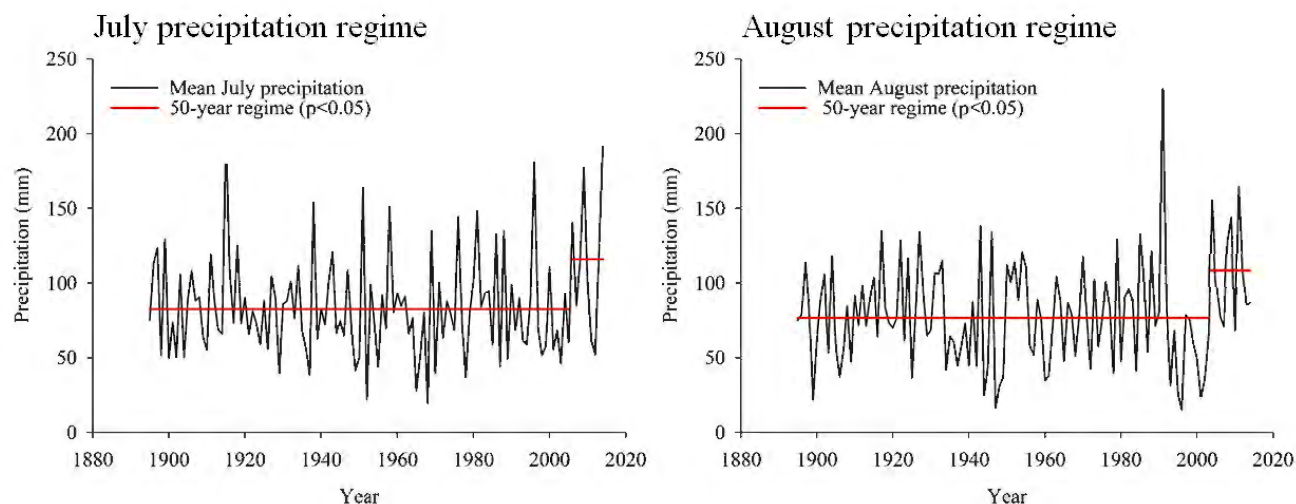


Figure A2. Precipitation regime shifts using the Regime Shift Detection Algorithm from Rodionov over 50 year periods tested at a 0.05 significance level.

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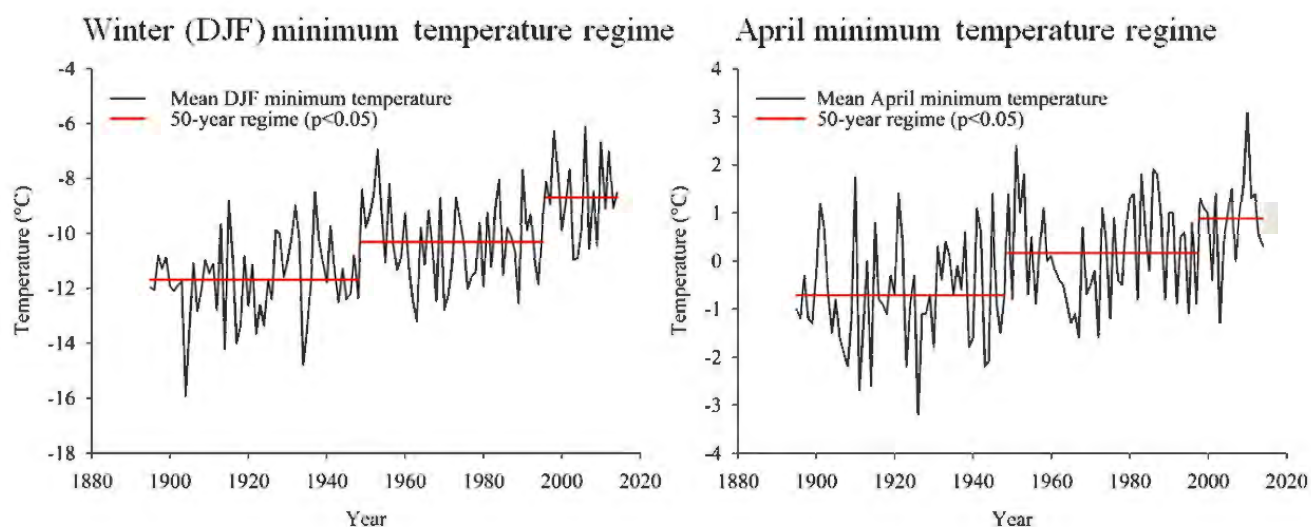


Figure A3. Minimum temperature regime shifts using the Regime Shift Detection Algorithm from Rodionov over 50 year periods tested at a 0.05 significance level.

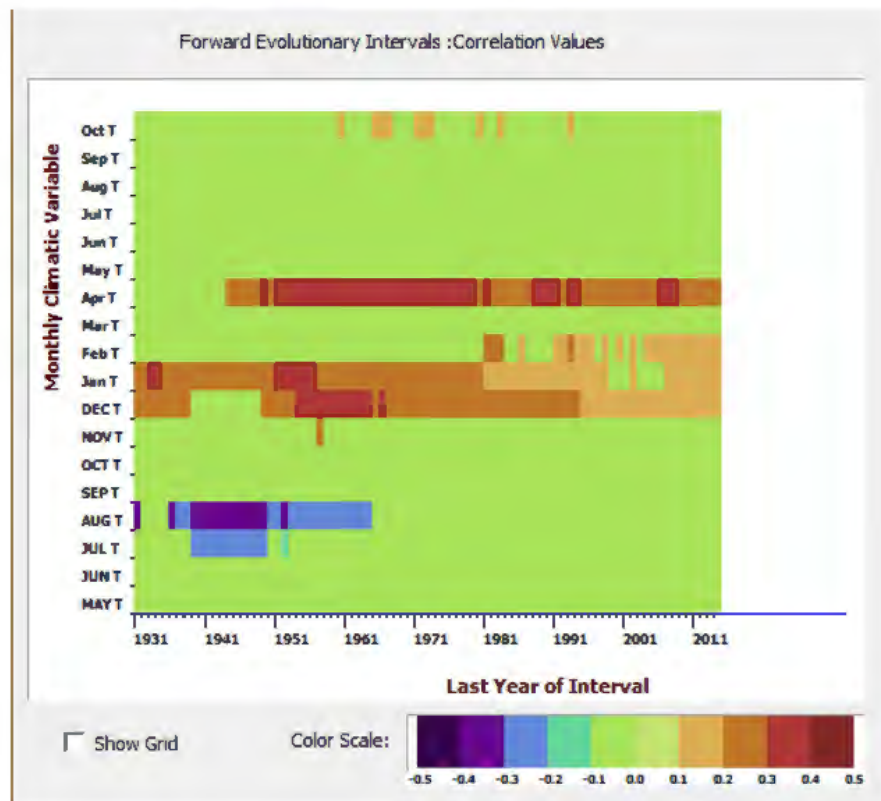


Figure A4. Aggregate of all Maine tree-ring chronologies average from Jan-May correlated with sea surface temperature.

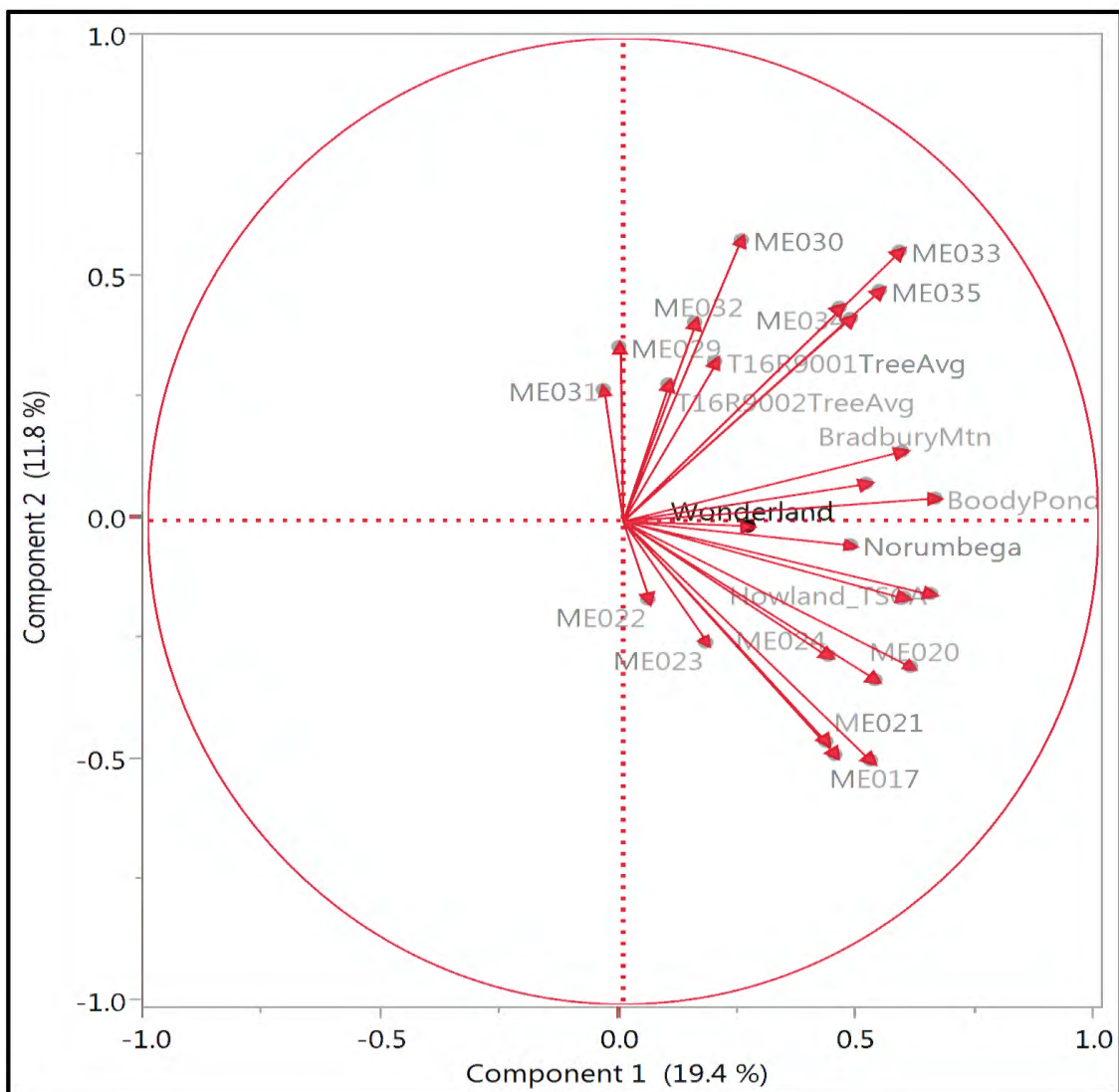
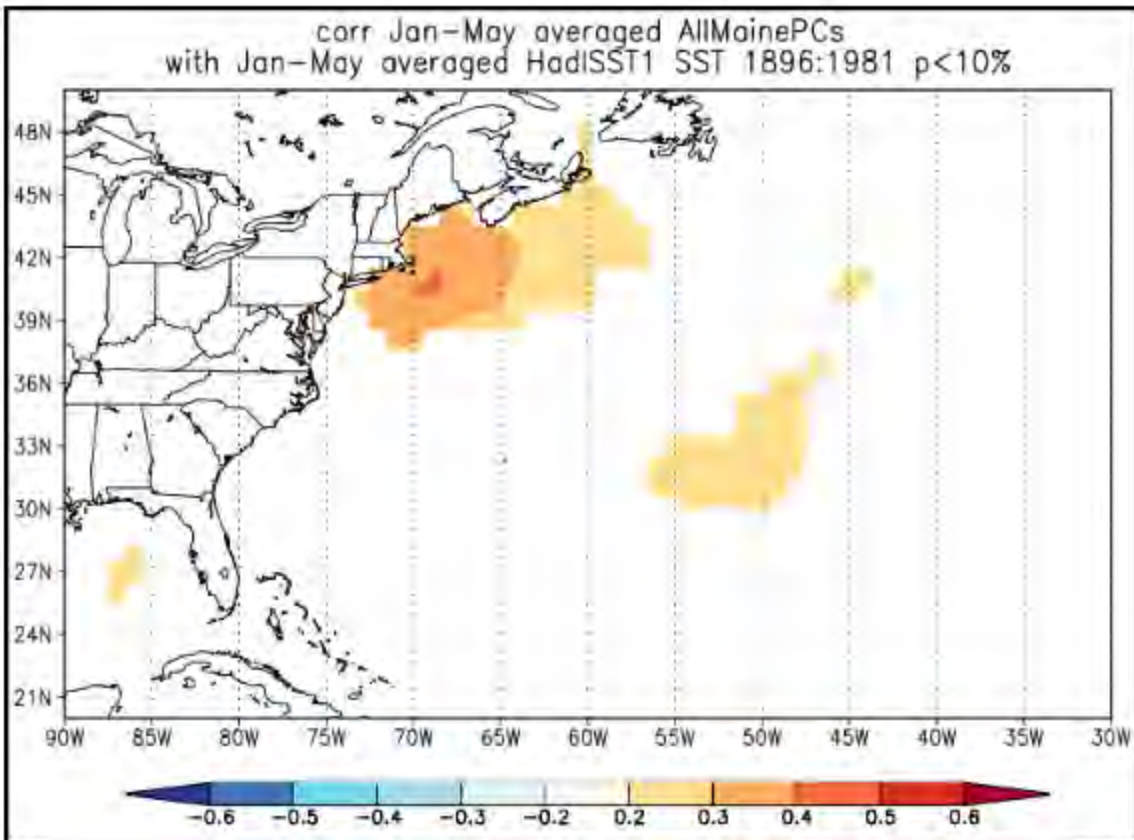


Figure A5: Principal component analysis for all Maine Chronologies with the wonderland chronology.



A6: Spatial correlations for the PC indexed chronology of all Maine chronologies with January–June sea surface temperatures.