

Report for Dendroclimatology II/ Fire History Group at NADEF 2015

GROWTH AND CLIMATE RESPONSES OF FOUR *PINUS* SPECIES ON NORUMBEGA MOUNTAIN, ACADIA NATIONAL PARK

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Introduction

Dendrochronology is the study of annual tree rings to make inferences about biotic or abiotic conditions that affected tree growth. The width of each annual ring produced by the tree can indicate whether growth conditions were favorable or not during any one year. Annual tree growth is a function of various intrinsic and environmental factors, including climate (precipitation, temperature, and drought); tree-level disturbances (such as canopy gaps, competition, or species-specific pathogens); stand-level disturbances (such as logging or fire); and random variability in annual growth not explained by the other variables (especially variation in genotype). In this study, we used dendrochronology as a tool to answer four research questions:

- (1) What are the species-specific growth patterns among four co-occurring pine species?
- (2) To which climate variables are these species responding?
- (3) How do climate-growth relationships vary over time?
- (4) What larger scale climatic drivers will affect spatial field correlation?

Methods

Data were collected from Norumbega Mountain in the Mount Desert Island section of Acadia National Park, located in the southwestern-most portion of the East Coastal biophysical region of Maine in Hancock and Knox Counties. The area was sculpted by glaciers which created a landscape of granite outcrops with acidic till and clay-rich sediments. While most of the park is less than 30 meters in elevation, seven mountains are over 270 meters tall (Mittelhauser et al., 2010) with Norumbega Mountain reaching an elevation of 260 meters. The mean annual temperature ranges from a high of 25°C in July to a low of 10°C in January. The average annual precipitation is 122cm, with the majority falling during the winter (Mittelhauser et al., 2010).

Acadia National Park contains strong environmental gradients which generate diverse habitats and rich biota within a short distance of the Atlantic ocean and maritime influence. Fifty percent of the plant communities of Maine can be found within the park boundary, with several of these species occurring in the northern and southern limits of their range (Mittelhauser et al., 2010). A mixed-conifer forest occurs on the summit of Norumbega Mountain consisting of white cedar (*Thuja occidentalis*), black spruce (*Picea mariana*), red spruce (*Picea rubens*), pitch pine (*Pinus rigida*), white pine (*Pinus strobus*), red pine (*Pinus resinosa*), jack pine (*Pinus banksiana*), eastern larch (*Larix laricina*), and a few deciduous species. The southern limit of jack pine overlaps with the northern limit of pitch pine on Norumbega Mountain, providing the opportunity to investigate climate impacts at the edges of the distribution of these species.

We sampled jack pine, red pine, pitch pine, and white pine for this study. Jack pine is a medium-sized tree that grows up to 20 meters tall and is found throughout Canada and into the northern United States, extending southward into Acadia National Park. Red pine, a medium-sized tree that can grow to a maximum height of 25 meters, is found in pure stands or in mixed stands with white pine and pitch

pine. Pitch pine ranges from Maine to southern Ohio, with spotty distribution further south. Pitch pine reaches a maximum height of 40 meters and is found from southeastern Canada southward into Tennessee in the southeastern U.S. All four pine species are found on poor to medium quality soil. White pine is somewhat shade tolerant while the other species sampled in this study are intolerant of shade and rely on fire to reduce competition and to aid in reproduction.

In June 2015, we collected 30 cores from 17 jack pines, 61 cores from 25 pitch pines, 15 cores from 11 red pines, and 18 cores from 9 white pines. Many of the trees sampled were growing on granitic outcrops near the summit ridgeline of Norumbega Mountain and exhibited stunted growth patterns, often with contorted trunks and branches. All cores were dried, mounted, sanded, and skeleton plotted for crossdating. Once crossdating had been achieved, ring widths were measured with a Velmex measuring system with a resolution 0.001 mm and checked using COFECHA for quality control of crossdating and measurement. Ring width series were detrended in ARSTAN using a 32-year cubic spline and the ARSTAN chronologies were used in all subsequent analyses.

To determine differences and similarities in species-specific radial growth patterns, correlation function analysis was conducted between all pairwise comparisons of species using Excel. The white pine chronology was also correlated with a white pine chronology from Acadia National Park published by Bartholomay (1997). Basal area increment (BAI; cm²) was computed from ring width (mm) by assuming a circular cross section for each tree. To calculate BAI we used the following formula from Biondi (1999):

$$a_t = \frac{\pi}{100} w_t \left(w_{t+2} \sum_{i=0}^{t-1} w_i \right) \quad (\text{Equation 1})$$

where W_0 is the first ring from pith. Five decadal BAI (cm²) means were calculated for each tree within the 1965-2014 period. A linear model compared these decadal means by species and by decade (Equation 2):

$$Y = \beta_0 + \beta_{\text{species}} + \beta_{\text{decade}} + \varepsilon \quad (\text{Equation 2})$$

where Y is the mean decadal BAI (cm²), β_{species} represents the four tree species measured, and β_{decade} represents five decades within 1965–2014. β_0 and ε represent the intercept and error terms, respectively. All BAI analyses were performed in R 3.2.0 (2014).

Growth-climate relationships were examined by performing Pearson correlation analyses in DendroClim 2002 (Biondi and Waikul, 2004) between tree ring indices (ARSTAN chronology) and monthly totals or averages of precipitation, Palmer Drought Severity Index (PDSI), Palmer Hydrological Index (PHDI), standardized precipitation, and minimum, mean, and maximum temperature. Correlations were considered significant at the 95% confidence level. To test the temporal stability between tree growth and climate over the 20th century, we used DendroClim2002 to perform forward evolutionary response functions using an initial 32-year base window.

Spatial analysis was run on the tree-ring indices using KNMI Climate Explorer (<http://climexp.knmi.nl/>). The explorer can be used to examine spatial field correlations at the 95% confidence level for the climatic signal found in tree-ring time series (Trouet and Van Oldenborgh, 2013). While an extensive range of climate variables can be selected in KNMI, we compared the four pine chronologies to mean, minimum, and maximum temperature, precipitation, and PDSI using data contributed by the Climate Research Unit of the University of East Anglia. The range of spatial coverage extended from 30°N to 50°N and from 60°W to 80°W covering the eastern seaboard of North America. Correlations were conducted for each individual month as well as for averaged seasonal groupings.

Finally, we conducted wavelet analysis using the online ION Wavelet software (<http://ion.exelisvis.com/>). Wavelets transform one-dimensional climate or tree-ring data into two-dimensional series based on frequency and amplitude. This permits us to identify dominant periodic signals in the data series.

Results and Discussion

Crossdating: All chronologies from the four pine species sampled on Norumbega Mountain showed interseries correlations between 0.432 and 0.526 (Table 1). This indicates that all species show a common signal related to an overarching climatic influence. Mean sensitivity values of all species ranged from 0.251–0.337 suggesting that growth is responsive to certain limiting factors, such as climate variations.

Table 1: Interseries correlation, mean sensitivity, and number of series for the four target species in this study.

Species	Interseries correlation	Mean sensitivity	Number of series dated
Jack pine	0.526	0.337	32
Pitch pine	0.579	0.297	61
Red pine	0.432	0.252	15
White pine	0.553	0.251	18

Species-specific growth patterns: Among the pairwise comparison of species-specific growth patterns for radial increments, pitch pine was significantly correlated with jack pine at the 99% confidence level with a correlation coefficient of 0.50, and with red pine with a correlation coefficient of 0.53. Jack pine also was significantly correlated with white pine at the 99% confidence level (correlation coefficient 0.36; Table 2). At the 95% confidence level, pitch pine growth was significantly correlated with white pine with a correlation coefficient of 0.21, and jack pine was correlated with red pine showing a correlation coefficient of 0.22. The only pairwise comparison that was not statistically significant was between red pine and white pine which had a correlation coefficient of 0.13 and a p-value of 0.24. The correlation between the white pine chronology produced in this study and that developed by Bartholomay (1997) was significant at the 99% confidence level, with a correlation coefficient of 0.30.

Table 2: Pairwise comparisons of species-specific growth pattern over common periods.

Pine chronologies	Range	<i>n</i>	Correlation coefficient (<i>r</i>)	P (2-tail)
Pitch vs. Jack	1934–2014	81	0.50	<0.001**
Pitch vs. Red	1903–2014	112	0.53	<0.001**
Pitch vs. White	1924–2014	91	0.21	0.048*
Jack vs. Red	1934–2014	81	0.22	0.046*
Jack vs. White	1934–2014	91	0.36	<0.001**
Red vs. White	1924–2014	81	0.13	0.24
Bartholomay vs. S & S	1924–1994	71	0.30	0.008**

Basal Increment Analysis: After running an additive model ($F_{7,337} = 20.79$, $p < 0.000$, $r^2 = 0.2871$) that compared mean decadal BAI between pine groups and the five decade groups, we found strong evidence of differences in the mean decadal BAI in the pine groups ($F_{3,337} = 44.3453$, $p < 0.000$). We also found moderate evidence of differences in the mean decadal BAI among the five decade groups ($F_{4,337} =$

3.1274, $p < 0.015$; Figure 1). Post-hoc analyses revealed significant differences in mean decadal BAI between jack pine and the other pine species. White pine also showed significant differences in mean decadal BAI with pitch and red pine. In terms of decadal differences, we found a significant difference in mean decadal BAI between the 1965–1974 and 2005–2014 decades. We also observed suggestive, but inconclusive evidence of differences in mean decadal BAI between the 1985–1994 and 1965–1974 decades.

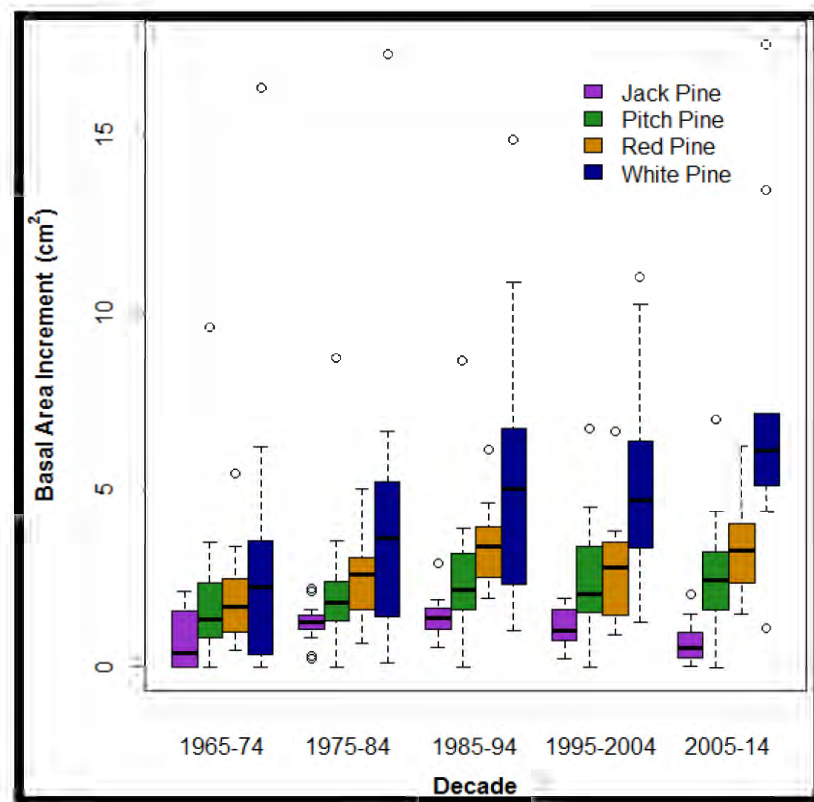


Figure 1: Results of Basal Area Increment analyses for the four pine species growing on Norumbega Mountain for the 1965-74, 1975-84, 1985-94, 1995-2004, and 2005-14 decadal groupings.

Response Function Analysis: Results of DendroClim2002 correlation analyses indicated that response to climate varied by species (Figure 2). White pine growth was negatively correlated with summer temperature while jack pine growth increased with warmer early season temperatures. Red pine was the species most influenced by climate. Growth in this species was positively correlated with warmer temperatures at the end of the previous growing season and early in the growing season. Additionally, red pine correlated with the PDSI and Palmer Hydrological Drought Index, indicating decreased growth during times of drought. This trend was also supported by a positive correlation with summer precipitation and a negative correlation with summer temperature. Pitch pine growth was also positively correlated with early season temperatures and variables associated with drought during the growing season.

Temporal stability: Results of the temporal stability analysis indicated that mean temperature was the most highly correlated climate variable over a temporal analysis for both pitch pine and jack pine. Jack pine exhibits a high correlation with mean temperature early in its chronology, but this relationship is not

longer evident after 1976. Pitch pine shows a correlation with high summer temperatures, exhibiting more growth in years with elevated temperatures. Red pine shows a negative correlation with the PDSI during the summer months until approximately 1955 indicating that red pine growth is maximized during drought conditions. Finally, white pine showed temporal stability in its negative correlation with maximum temperature, demonstrating that white pine grows better under higher maximum temperatures.

Species	Var.	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October
White	TMX	maximum temp															
	TMP	mean temp															
	TMN	minimum temp															
	PCP	precipitation															
	PHD	Palmer hydrological drought index															
	PDS	Palmer drought severity index															
Jack	TMX																
	TMP																
	TMN																
	PCP																
	PHD																
	PDS																
Red	TMX																
	TMP																
	TMN																
	PCP																
	PHD																
	PDS																
Pitch	TMX																
	TMP																
	TMN																
	PCP																
	PHD																
	PDS																

Figure 2: Results of Pearson correlation analyses between climate variables and tree ring indices from four pine species' growing on Norumbega Mountain. Red squares indicates significant negative correlations ($p < 0.05$) while black squares indicates significant positive correlations ($p < 0.05$).

Spatial analysis: Results from this analysis varied between species but largely supported the results from the response function analysis. The white pine index correlated negatively with June maximum temperatures. This indicates that the growth of this species is amplified when temperature conditions during the middle of the growth season are cooler. Pitch and jack pine growth were similarly correlated with spring (February to April) maximum temperatures. This indicates that warm conditions during the early portion of the growing season would optimize ring growth. The red pine index was more dynamic in its relationship to spatial climate data. All temperature variables (mean, maximum, and minimum) for the month of April were positively correlated with the red pine index. Additionally, the April values for PDSI were positively correlated in the northern part of the study range and negatively correlated over the southern portion. This is related to the jet stream and corresponding zonal flow storm tracks. When west to east zonal flow dominates during April the potential for wide ring growth is high.

Wavelet analysis: All four series demonstrated a similar condition with a dominant signal noted with a 16-20 year periodicity (Figure 3). This signal is significant in three of the four species. The amplitude of this signal increases around 1955 significantly within three indices and decreases 30 years later in two of the indices. We observed a similar amplitude pattern of 20-30 years back through time in these records. This indicates that a temporal pattern most likely related to an atmospheric oscillation affecting the growth of the targeted tree species. Further research directed at this potential relationship is recommended.

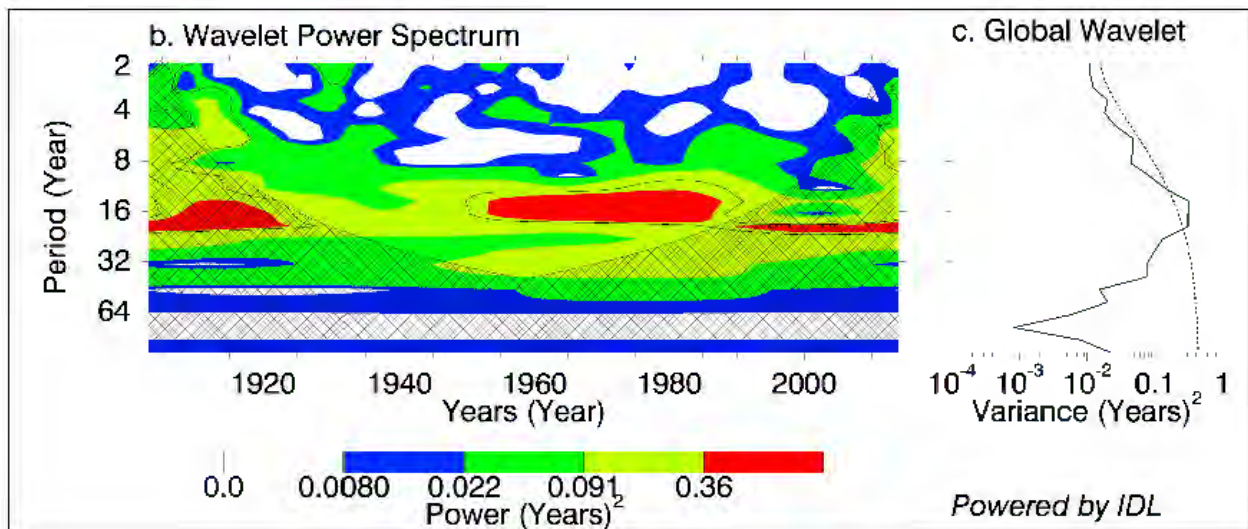


Figure 3: Results of the ION Wavelet analysis for the red pine index demonstrating the 16-22 year periodicity and 20-30 year amplitude.

Disturbance effect of Eastern Gall Rust on Jack Pine species: Our jack pine chronology indicates that a marked decline in growth rate in jack pine trees since the mid-1980s but especially in the last five years of tree growth, i.e. 2010–2014. This decline was not reflected in the comparisons to climate variables but rather appears to be more likely related to a disturbance factor at our study site. During our sampling, we noted that all the jack pine trees were either dead or dying and that eastern gall rust was present on some of the jack pine trees. This gall rust typically infects hard pine species such as jack pine and infection is most prevalent in moist environments where humidity prevails for over 24 hours (Anderson, 1970). Such an environment exists on Norumbega Mountain. Further research on Norumbega Mountain would be needed to confirm if eastern gall rust is contributing to tree mortality and decreasing growth.

Conclusions

We addressed the four research questions for our study:

Question 1: What are the species-specific growth patterns among jack, pitch, red, and white pine on Norumbega Mountain?

- Radial growth is similar among all species except between white and red pine.
- Under current modeled climate predictions, white pine is likely to dominate in the future as jack pine will likely disappear from its current southernmost margin.

- Jack pine is infected with eastern gall rust, indicating disturbance which might be causing mortality and declining growth rate in this species.

Question 2: To which climate variables are pine species on Norumbega Mountain responding?

- Temperature: As early growing season temperatures increase, pitch, jack, and red pines will be favored.
- Drought: Growth of red and pitch pines is negatively affected by drought during the growing season.
- Climate Change: If the temperature regime remains, white pine will dominate, but if summer temperatures increase as predicted by global climate models, the growth of white pine may be dampened.

Question 3: How do climate-growth relationships vary over time?

- Temporal relationships are fairly consistent for white, pitch, and jack pines.
- Red pines show a temporal shift in their relationship to PDSI.
- A 16-22 year significant periodicity exists that varies in amplitude over a 20 to 30 year period.

Question 4: What larger scale climatic drivers are identified in the spatial field correlations?

- Results of spatial analysis confirm the results of the climatic response function analysis.
- Consistent signals were found between the climate-growth relationships across the eastern seaboard.
- Temperature is the major driver of growth of all four pine species on Norumbega Mountain.

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APPENDIX: FIRE HISTORY ANALYSES

Field Methods

On the western side of Norumbega Mountain, our group explored the potential for extracting fire history information in the relatively moist conditions found in Acadia National Park. The sampling was done as a survey of fire history reconstruction potential in the area, but ultimately led to an extension of the red pine (*Pinus resinosa*) chronology when added to the core data for the northern portion of the mountain.

Fire scars were located by identifying “catfaces” at the base of red pine trees as they were found along the mountainside. A “catface” appears when one or more fire events kill the active cambium, and the tree grows over the wound. Sampling was done by taking partial cross-sections with a chainsaw (Figure A1).

Samples were surfaced with progressively finer grit sandpaper using a belt sander starting with ANSI 40 grit and advancing to 120, 220 and 320 grit paper. Where necessary, samples were hand-sanded with 1200 grit until the wood cells were visible under 10x magnification. Ring series on each section were first crossdated using skeleton plots and visual crossdating. Once dated, a line was drawn through the clearest rings extending perpendicular to the rings from the pith to the outer portion of the wood and then were measured. COFECHA was used to check crossdating.

Fire Analysis

We assigned fire scar dates based on position with annual rings. Seasonality of the scar within the ring also was assigned. Fire scars within the early portion of the earlywood occur after the tree breaks dormancy until late May, scars positioned in the middle of the earlywood indicate fire occurred between late May and early July, while earlywood scars suggest fire that occurred from late July to August (Baisan and Swetnam, 1995; Grissino-Mayer, 1995). Scars located directly in the latewood suggest fires that occurred in the later part of the growing season in late August to October.



Figure A1. A section of red pine sample NOW 07 that contains the fire scar observed on the catface while in the field.

Fire-scar Analysis

Fire-scar dates were entered into program FHx2 (Grissino-Mayer 2001) to analyze fire seasonality, fire frequency, and to create a fire history chart (Figure A2). All fire-scarred trees samples show recorded a fire in 1869. However, the data presented here should be considered preliminary and much further sampling and analysis will be required to develop a full data set from this site. It is hoped that further work may develop to increase the understanding of fire history in this region, based on our preliminary results gathered at the 2015 North American Dendroecological Fieldweek.

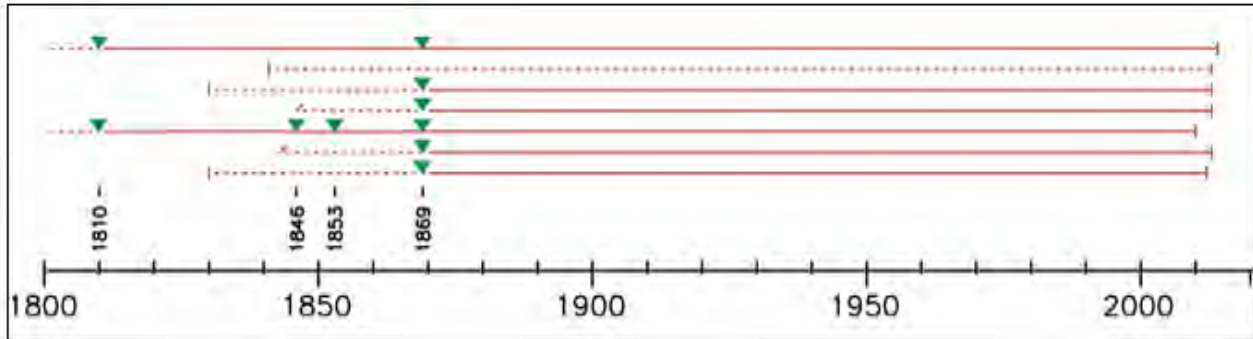


Figure A2: Fire history chart for the preliminary fire-scar data from the Norumbega Mountain site. Green triangles indicate a dated fire scar. A major fire is strongly suggested in the year 1869.

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