The association between growing season temperature and the growth of two conifers across a moisture regime gradient in the boreal forest of northeastern Ontario, Canada

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Introduction

- In recent years, a reduction in temperature sensitivity and decoupling of growth patterns from increasing temperature trends has been observed in various northern tree ring chronologies (Jacoby and D'Arrigo 1995, Briffa et al. 1998, Biondi 2000).
- This breakdown of the temperature signal in tree-ring series has been referred to as the divergence problem, and its extent and causes remain unclear. (D'Arrigo et al, 2007)
- Soil moisture can be a driver of growth responses in northern tree populations (Jacoby and D'Arrigo 1995) and the spatial pattern of divergence may be related to site-level moisture conditions (Lloyd and Fastie, 2002)

Objectives

- We examined populations of black spruce (*Picea mariana*) and jack pine (*Pinus banksiana*) in the boreal forest of northeastern Ontario to:
  - i. examine temporal change in the association between early growing season temperature and the growth of black spruce and jack pine, and
  - ii. determine if temporal variation differed across a moisture regime gradient
- We hypothesized that there would be evidence of divergence (a breakdown of positive association between higher temperature and greater growth) in combinations of species and moisture conditions that were prone to seasonal drought.

Methods

Study Area and Sampling Design

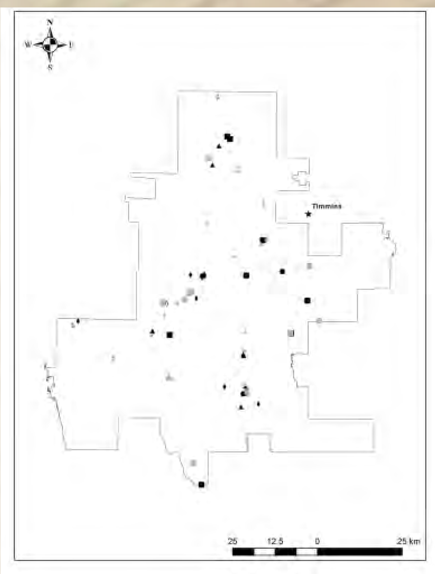

Figure 1: Plot locations within the Romeo Malette Forest. Different Shapes indicate different MR values.

- The study was conducted in the Romeo Mallette Forest (RMF), west of Timmins, Ontario (Figure 1).
- The subset of plots in this study were selected from different standardized moisture regimes ranging from a value of 0 (xeric site) to 9 (very wet site)
- Increment cores were collected in plots representing various MR values (Table 1) from dominant or co-dominant trees at a height of 1.30 m.

Table 1: Sample sizes for plots and individuals in each each moisture regime.

Moisture Regime	MR0	MR1	MR2	MR3	MR4	MR5	MR6	MR7	MR8	MR9
Black Spruce										
Plots	8	7	10	18	15	19	17	9	6	1
Individuals	33	29	46	95	82	98	97	50	30	6
Jack Pine										
Plots	4	8	6	10	5	8	1	1	-	-
Individuals	21	42	38	53	20	43	6	5	-	-

Processing and Analysis of Increment Cores

- Samples were mounted and sanded following standard dendrochronological procedures (Stokes and Smiley 1968)
- Samples from each species in each moisture regime were crossdated following the list method (Speer 2010).
- Cores were scanned and analyzed in WinDendro (version 2009b) to generate tree ring measurement series (Figure 2)
- Dating quality of each series was assessed using the program COFECHA
- Regional curve standardization (RCS) was used to develop a master chronology for each species in each moisture regime.

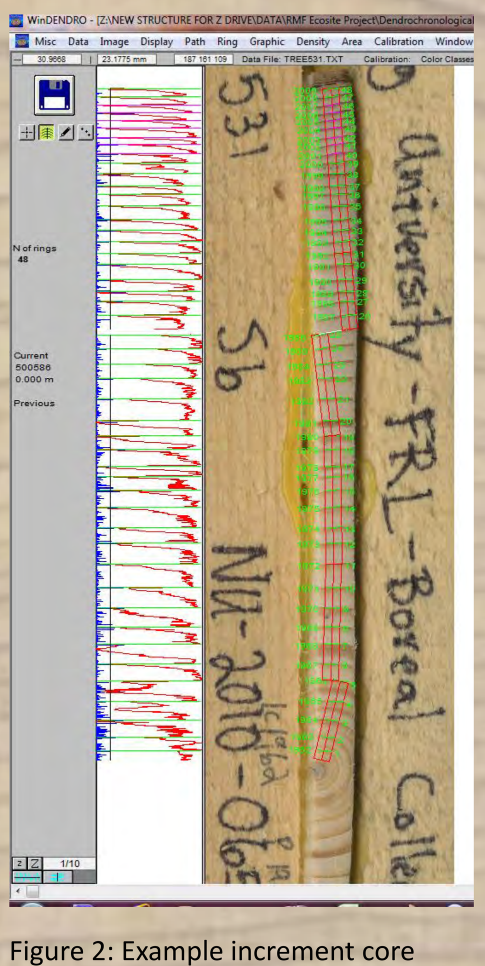

Figure 2: Example increment core measurement of black spruce core from the Romeo Malette Forest.

Climate Analysis

- Climate data (1922-2009) were obtained for Timmins weather stations from the Historical Climate Data Archive (Environment Canada, 2022).
- Temperature trends for the measurement period were examined by fitting moving average models to the historical data.
- The association between annual TRI values for each master chronology and climate variables was accessed based on the strength of Pearson correlation coefficients over the time period.
- A 30-year running correlation window was analyzed for each moisture regime chronology, tracing the changes in the TRI – climate variable association over the measurement period

Results

Climate

- April and May maximum daily temperatures have been steadily increasing during the study period of 1922-2009 (Figure 3)
- April maximum daily temperatures were found to have the strongest correlation to Jack pine growth while May maximum daily temperature was found to have the strongest correlation to Black spruce growth.

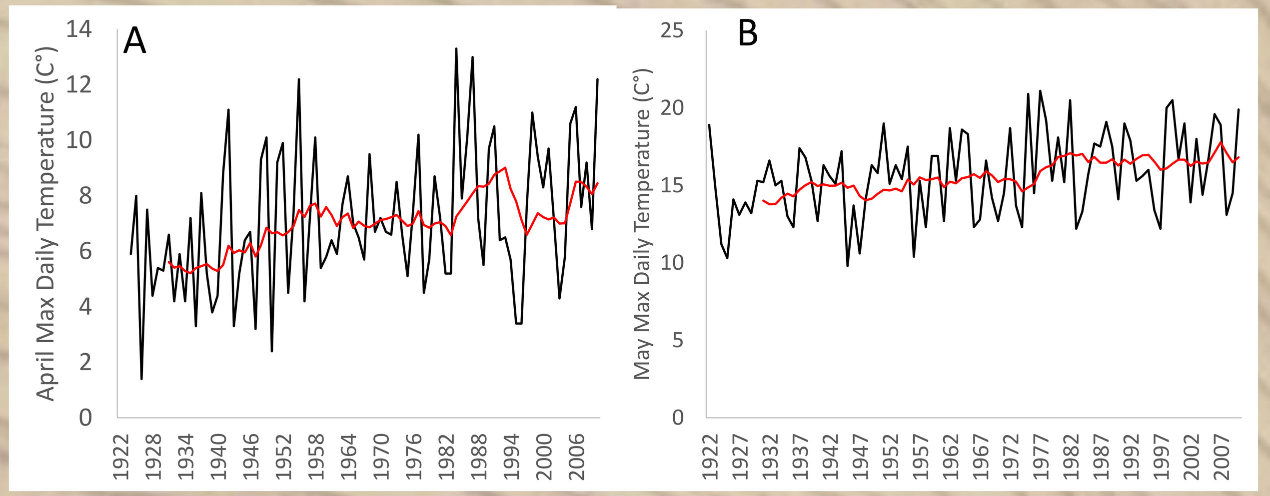

Figure 3: Maximum daily temperature over the time period of 1922-2010 with a 10-year moving average trendline (red). A = April Maximum Daily Temperature; B = May Maximum Daily Temperature.

Regional Growth Curves

- In black spruce, the RCS curves across all moisture regimes generally exhibit a similar pattern, peaking in growth at a cambial age of 5-6 years (1.5mm to 2.4 mm.yr^{-1}). There is an exponential decline reaching a rate of approximately 0.3 - 0.8 mm.yr^{-1} at a cambial age of 100 years (Figure 4)

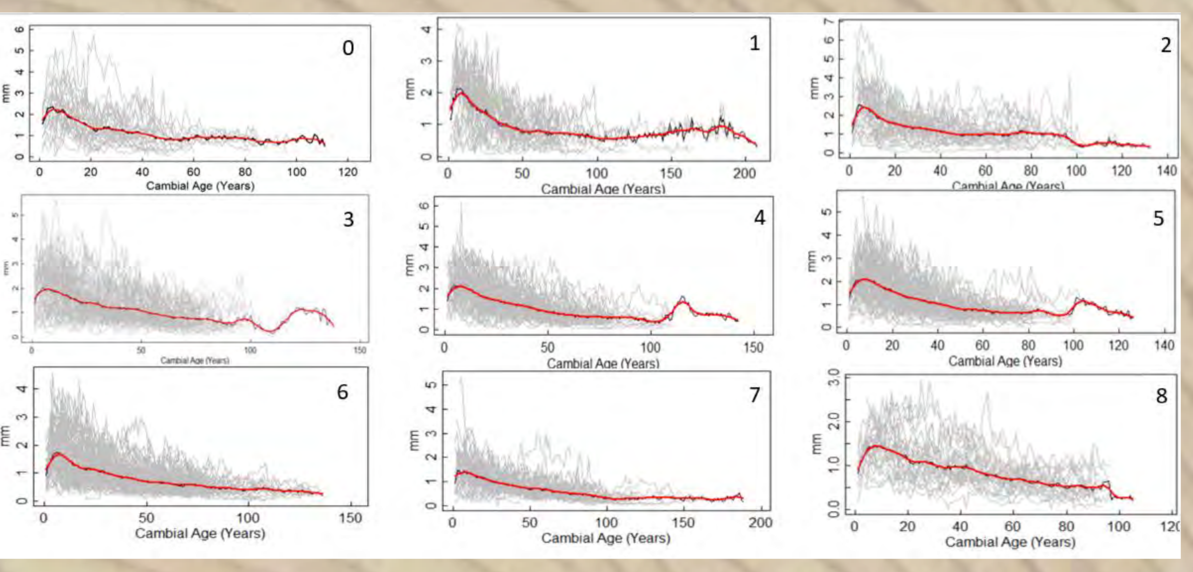

Figure 4: Regional growth curves for black spruce in nine moisture regimes (labelled 0-8) in the boreal forest of northeastern Ontario. The average radial growth over time is represented by the red trendline. Samples collected in the Romeo Malette Forest, near Timmins, Ontario, Canada.

- In jack pine, rapid growth in the early years peaks at 2.8 to 4.2 mm.yr^{-1} of radial growth. This occurs at the cambial age of approximately 5-6 years. After this peak the growth declines exponentially, reaching a value of 0.5 to 1 mm.yr^{-1} by the cambial age of 100 (Figure 5).

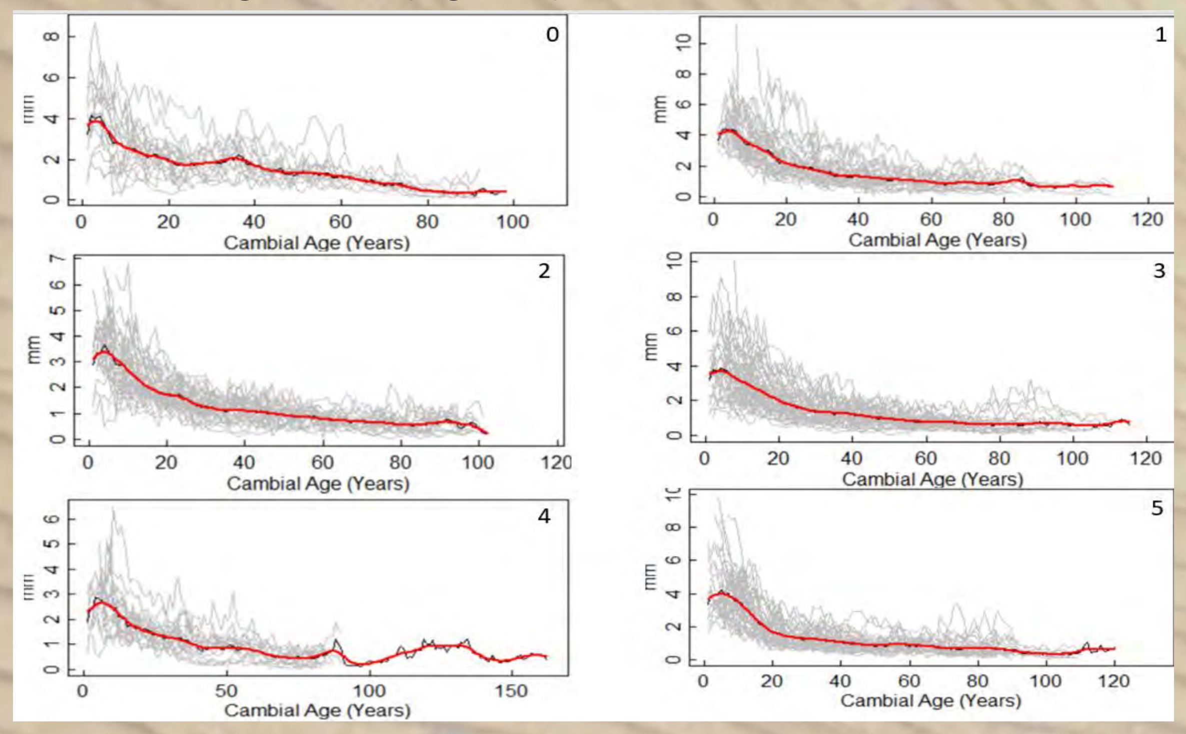

Figure 5: Regional growth curves for jack pine in six moisture regimes (labelled 0-5) in the boreal forest of northeastern Ontario. The average radial growth over time is represented by the red trendline. Samples collected in the Romeo Malette Forest, near Timmins, Ontario, Canada.

Running Correlation Analysis

- A 30-year running correlation of black spruce TRI and May maximum daily temperatures showed consistent trends across most moisture regime chronologies (Figure 6).
- In the years before 1955, there was a strong correlation between TRI and May mean daily maximum temperature (≥ 0.600 in some cases) and then a steady decrease to ~0.400 by 1975.
- In 1975, there was a sudden loss of the positive signal with correlations across the range of moisture regimes becoming slightly negative. After this loss of signal, the correlation slowly recovers to a slightly positive value in the different moisture regime chronologies by the end of the timeframe. However, it never reaches the peak that most moisture regime chronologies had before ~1950

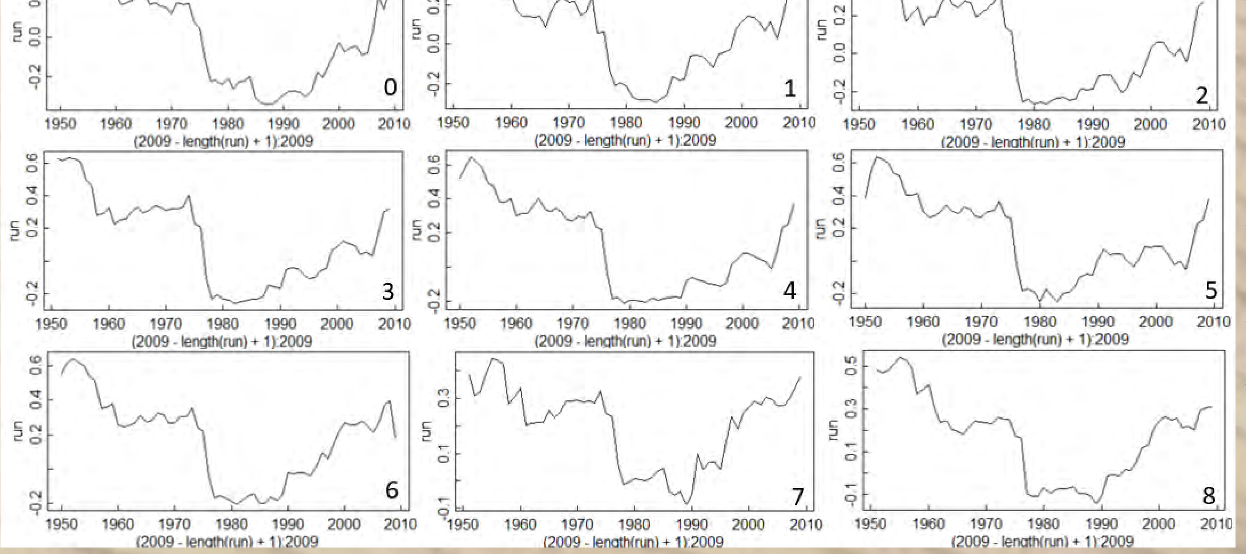

Figure 6: 30-year running correlation analysis of tree ring index values of black spruce with May maximum daily temperature

- A 30-year running correlation between April maximum daily temperatures and jack pine TRI values shows variability in trends over different moisture regimes (Figure 7).
- In moisture regimes 0, 2, and 5, there was a continuous increase in correlation with no major disruptions of the association over time.
- In moisture regimes 1 and 3, there were high correlations initially that steadily decreased over time until a major loss of correlation occurred. This loss of correlation occurred around 1980 in moisture regime 3 and around 1986 in moisture regime 1. These patterns were not evident in the other moisture regimes

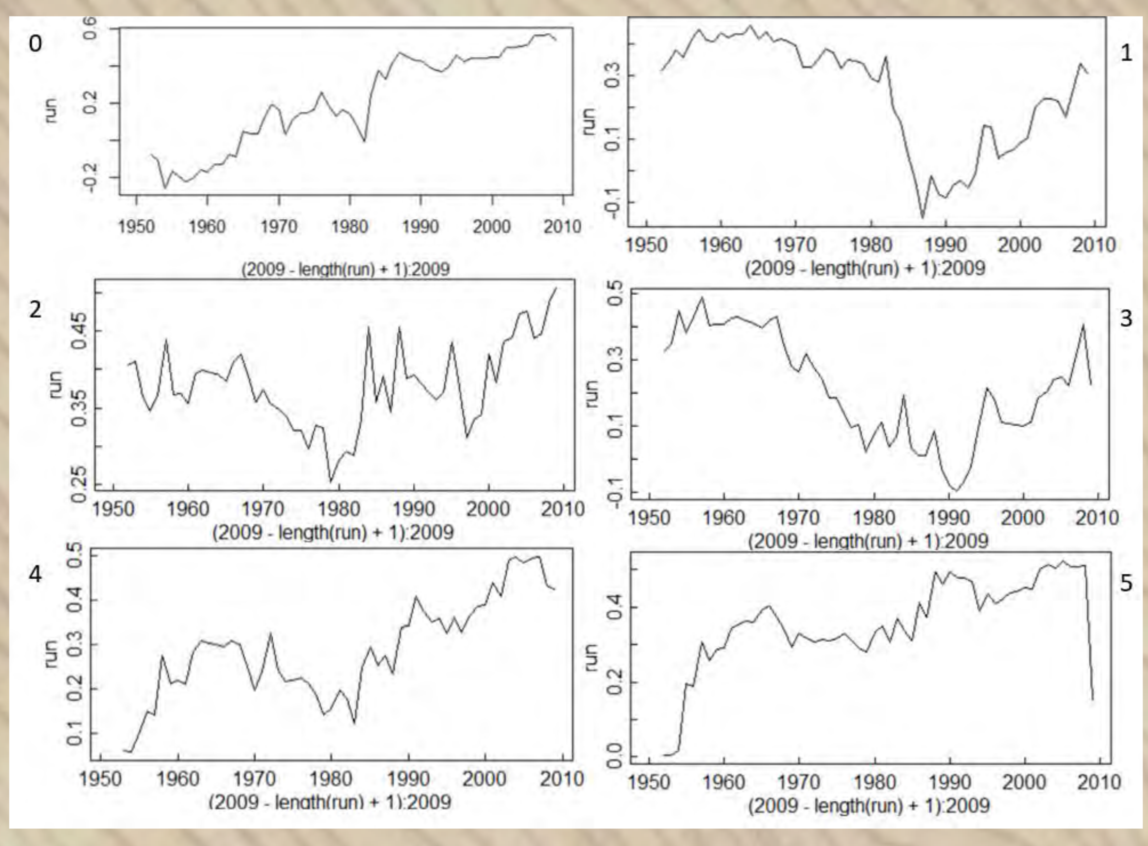

Figure 7: 30-year running correlation analysis of tree ring index values of jack pine with April maximum daily temperature

Discussion

- As a benchmark trend we observed a high correlation between April or May mean maximum daily temperatures to jack pine and black spruce TRI values, respectively.
- Divergence has previously been documented in Alaskan boreal forests where a noted shift in climate has occurred. This detected divergence began in the 1950s, becoming substantially noticeable after the 1970 (D'Arrigo et al., 2008).
- We observed a noticeable decrease in temperature sensitivity to May maximum temperatures in black spruce starting in the mid to late 1950s. However, there were known outbreaks of spruce budworm (*Choristoneura fumiferana*) in 1945-1955 and 1975-1987 (Lacey and Dech, 2012), and these clearly caused a loss of TRI-temperature association. The observed severe growth reduction event in Black spruce moisture regime chronologies in the years 1975-1987, and the related loss of climate signal in the 30-year running correlation can therefore be attributed to a spruce budworm outbreak.
- Spruce budworm causes the defoliation of black spruce and a decrease in radial growth. In the period following the most recent spruce budworm outbreak, a slow recovery of the TRI-temperature association was noted in the years post-1987. The TRI-temperature association does not recover to previously high levels after this outbreak, which could be interpreted as a continuation of the pre-outbreak decreasing trend.
- Jack pine chronologies show no evidence of divergence in the RMF as there is no consistent long-term loss of the TRI-temperature correlation. Some moisture regime chronologies show a temporary loss of temperature sensitivity; however, the correlation re-establishes afterwards. These temporary signal losses may be explained by other factors occurring during that time period such as fire, insect outbreaks, and wind events that have yet to been fully documented in the RMF.
- Despite the lack of a climate related divergence event in the RMF, both black spruce and jack pine still have the potential to be future predictors of divergence due to their temperature sensitivity.

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