Climatic Stress in the Acadian Forest:

History, Triggers and Evolution of Radial Growth Forecasting

-Compendium-

MAD LAB

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Preface

This compendium has been compiled from the full report of the same title. The limited information contained in this compendium includes mostly results and discussion and is meant as a brief overview of the 2009-10 dendroclimatological project (MAD Lab Report 2010-14). The following summary of the study is not referenced; it contains very limited visual examples and no statistical information. Please consult the full report if more information is required.

Introduction

To learn more about how forests may respond to changes in climate the Mount Allison Dendrochronology Laboratory, with support from the Fundy Model Forest, has been using tree-rings in New Brunswick for several years to build models of future radial tree growth. This report is the fifth in that series of radial tree growth forecasting studies and the second report to focus on a provincial scale. These studies have been important steps in re-conceiving the future of Acadian Forest tree growth, but it has been hard to evaluate how accurate the radial tree growth models may be. After completing forecasts of future radial tree growth for 12 tree species in southeastern New Brunswick, sugar maple was evaluated province wide and even into central Nova Scotia. That study concluded that long-term fluctuations in North Atlantic Ocean conditions were significant drivers of sugar maple radial growth and likely overall tree health. The oscillating conditions of the ocean, which heavily influence atmospheric weather events, seem to have created periods of non-optimal climatic states that have coincided with a reduction in radial tree growth of sugar maple. In other areas of the sugar maple range periods of dieback have affected tree health and have been caused by a number of stressors such as climate, pollution, insects and nutrient limitation, but in New Brunswick it appears climate, influenced by ocean conditions, has been the primary influence on sugar maple radial growth rates. Anomalous weather events have caused dieback of various tree species across many continents, and these events are often linked to fluctuating ocean conditions and climate change.

The objective of this study was to evaluate other important Acadian Forest tree species across New Brunswick for relationships to oscillating ocean conditions and attempt to forecast how those tree species would respond to future climate conditions. Sugar maple was re-evaluated, along with yellow birch, eastern hemlock, red spruce, eastern white cedar and white pine.

Tree-ring Chronologies

Thirty six tree-ring chronologies were used in this dendroclimatological analysis, constructed from samples collected near six New Brunswick climate stations across six tree species. Sugar maple samples were collected in 2007 and 2008, while yellow birch, eastern hemlock, red spruce, eastern white cedar and white pine samples were collected in 2009. Tree cores were extracted from trees as close as possible to long-term climate stations which included: Charlo, Edmundston, Miramichi, Aroostook, Fredericton and Moncton. Approximately 20 trees were core sampled twice at each site. The tree cores were glued into slotted mounting boards and sanded to a fine polish. Every tree-ring was then accurately measured to produce a ring-width radial growth history covering the entire life span of each sampled tree. Individual ring-width records of each tree, for each tree species, at each individual sampling site were cross-dated against one another to ensure no rings were missed. These ring-width records were then standardized to remove internal radial growth trends caused by age and competition. Finally they were averaged into master tree-ring chronologies representing the common growth signal for each tree species at each sample site.

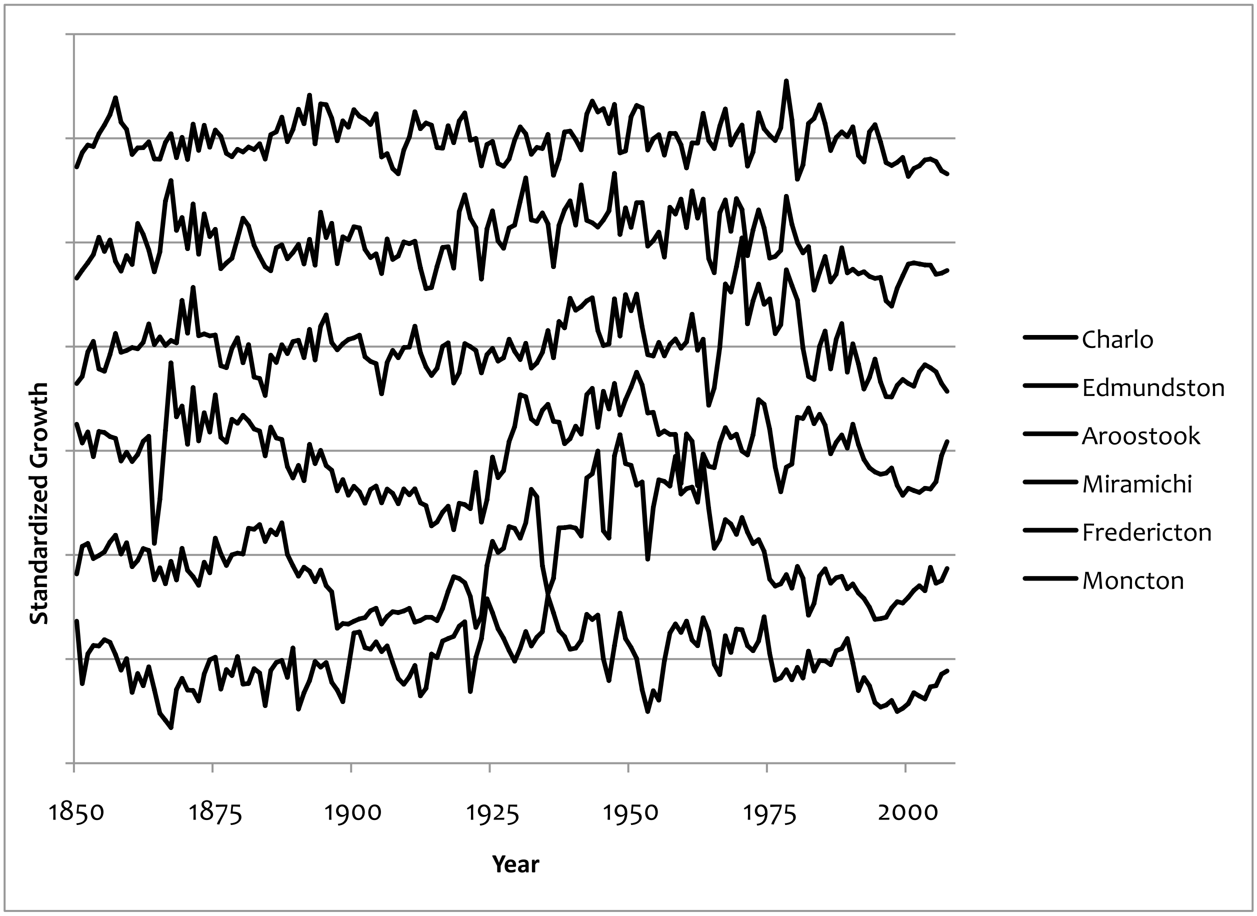

Figure 6.1. As an example, all six master **sugar maple** chronologies representing the six sample sites are illustrated over the common interval from 1850-2006. Each curve fluctuates around an average of one represented by the horizontal strike-through lines. Site names are presented adjacent to the radial growth curves and order of sites is from north to south with occasional shuffling of sites to preserve nearest neighbour associations.

Strong common growth signals were shared among the individual trees from within each sample site, producing 36 robust master tree-ring chronologies. Eastern hemlock master chronologies displayed the strongest common radial growth signals within each site, as that species most often grows in pure stands without competition from other tree species. Yellow birch master chronologies exhibited the weakest common radial growth signals within each site, as that species most often grows scattered throughout stands of other tree species and experiences much inter-species competition. Generally the most shade tolerant tree species (ie. sugar maple, eastern hemlock) were the most sensitive to climate. Some geographic patterns were obvious with the most sensitive yellow birch sites in the south of the province and the most sensitive eastern hemlock sites in the north.

When comparing same species master tree-ring chronologies between the six sample sites, yellow birch demonstrated the strongest common signal and displayed long-term, large magnitude fluctuation throughout the 20th century across all sites illustrating that its radial growth is influenced by widespread macro-climatic events. Eastern hemlock master chronologies produced a relatively weak common signal between sites due to short-term differences in radial growth during the last half of the 20th century providing evidence that it is influenced by more localized micro-climatic events confined to each site. Between sites, white pine master chronologies exhibited the weakest common signal of all studied species, through short-term, small magnitude, frequent anomalies, which also provided evidence that it was influenced by micro-climatic events confined to each site. Generally speaking, the results of the between site analysis indicated that large, widespread, radial growth disturbances, such as sweeping climate events, insect outbreaks, etc., act as radial tree growth synchronizers across the province.

Ocean Modulation of Radial Tree Growth

The long-term records of various oscillating ocean conditions were statistically compared to the records of the 36 tree-ring chronologies. It was found, in the North Atlantic Ocean, that the ocean surface temperature and the ocean surface pressure, had significant relationships with a majority of the tree-ring chronologies even reaching sample sites far inland. Oscillating ocean conditions of the Pacific Ocean were deemed to not have significant effects on New Brunswick tree growth however. The measure of North Atlantic sea surface temperature, called the Atlantic Multi-decadal Oscillation (AMO), displayed similar trends as those seen in the shade tolerant tree-ring chronologies of this study (sugar maple, eastern hemlock, red spruce, eastern white cedar) (Figure 6.2) .

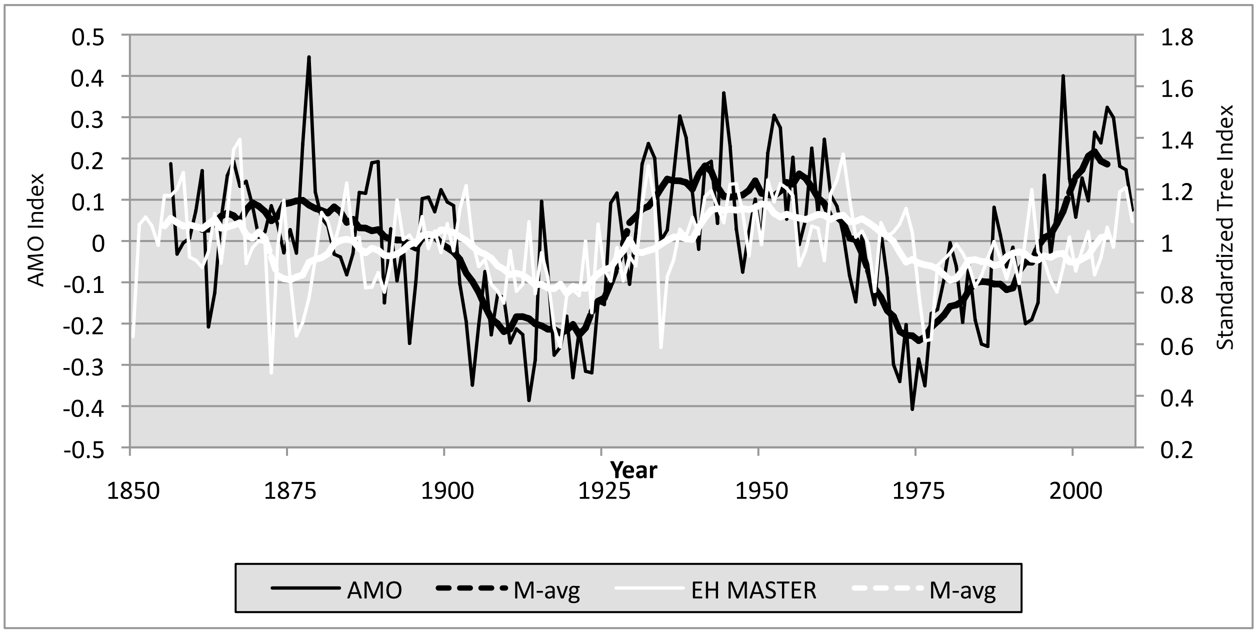

Figure 6.2. This is an example of the Atlantic Multi-decadal Oscillation (black lines) with a regional average of all six **eastern hemlock** master chronologies (white lines). Both the annual curves (thin lines) and 10 year moving averages (dotted lines) are illustrated.

It is therefore reasoned, that shade tolerant tree species in New Brunswick are significantly influenced by the temperature of the North Atlantic Ocean and this effect is slightly stronger in more continental areas of the province then coastal areas. Based on historical radial growth, it appears that shade tolerant tree species grow better when the North Atlantic Ocean conditions are warmer, even though New Brunswick normally experiences westerly air flow. Conversely, yellow birch, a moderately shade tolerant species, expresses a negative response to the AMO which was more extreme in coastal areas (Figure 6.3). Based on historical radial growth, it appears that yellow birch grows better when North Atlantic Ocean conditions are cooler.

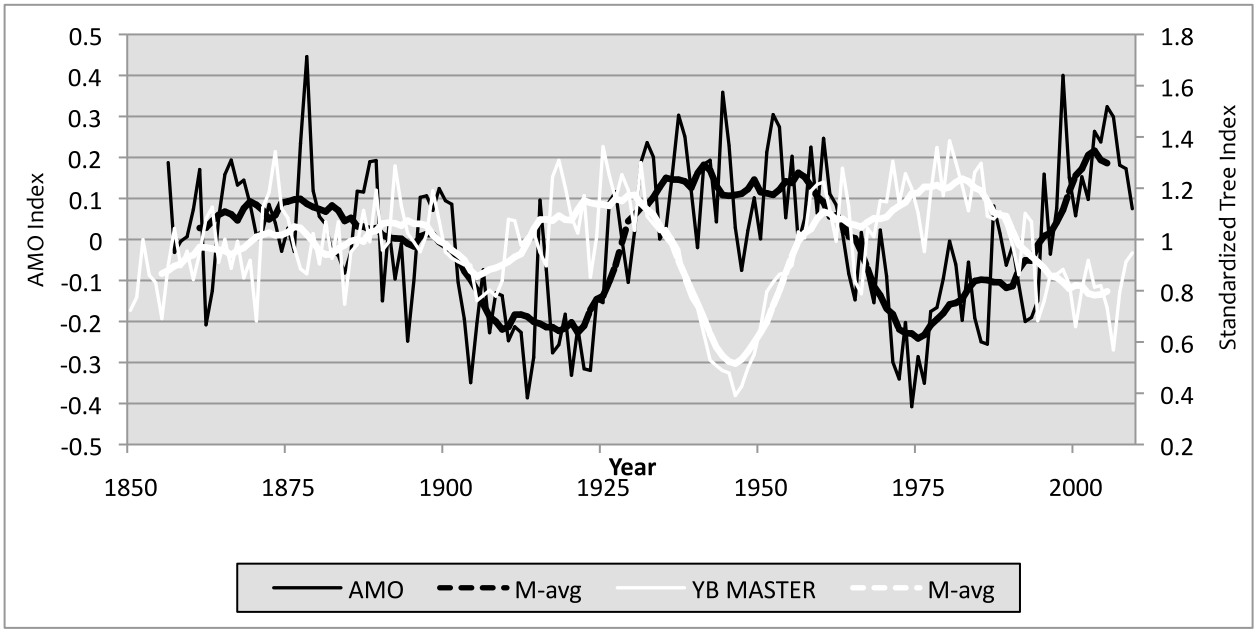

Figure 6.3. This is another example of the Atlantic Multi-decadal Oscillation (black lines) with a regional average of all six **yellow birch** master chronologies (white lines). Both the annual curves (thin lines) and 10 year moving averages (dotted lines) are illustrated.

The measure of sea level pressure that controls storm tracks over the North Atlantic, called the North Atlantic Oscillation (NAO), generally displays opposite trends as those seen in the shade tolerant tree species. It is therefore reasoned, that shade tolerant tree species in New Brunswick (sugar maple, eastern hemlock, red spruce, eastern white cedar) are influenced by the NAO, which controls air flow and storm tracks, and this effect is stronger in continental areas of the province (Figure 6.4). The NAO did not exhibit any significant relationships with the moderately shade tolerant species of this study (yellow birch and white pine).

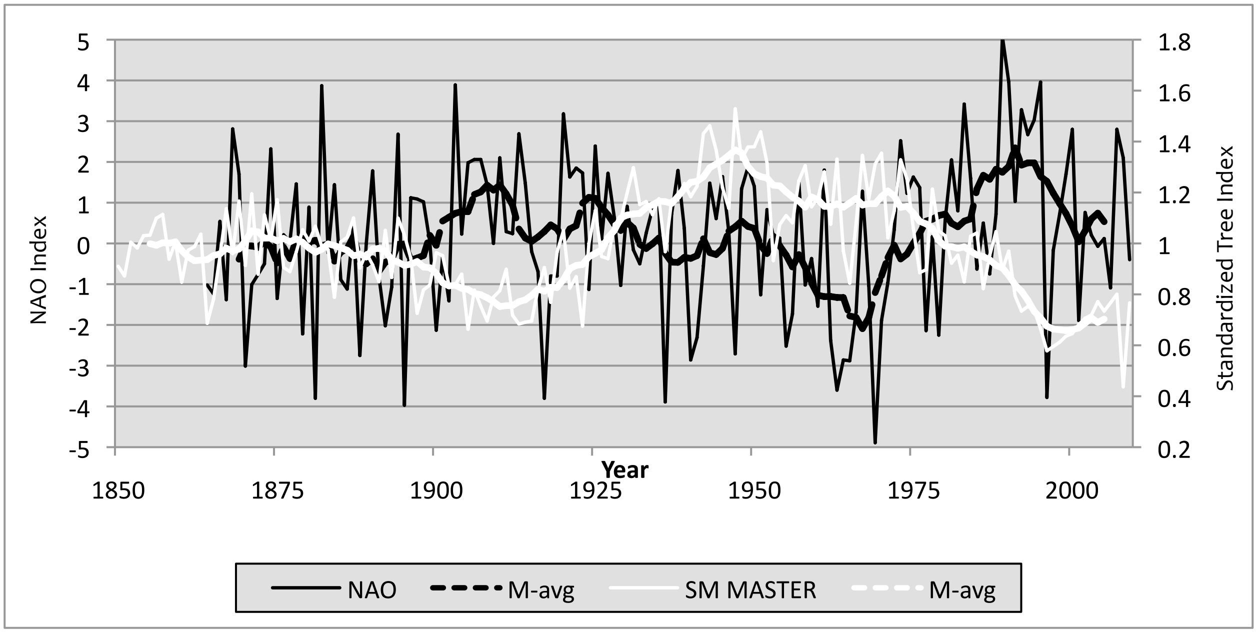

Figure 6.4. This is an example of the North Atlantic Oscillation (black lines) with a regional average of all six **sugar maple** master chronologies (white lines). Both the annual curves (thin lines) and 10 year moving averages (dotted lines) are illustrated.

Future Radial Growth Models

By studying many tree species over a relatively large area, this study has learned that ocean conditions are an important driver of tree growth. This result also has implications for radial growth models that forecast future tree growth. Although 56 radial growth models were produced in this study, many were weak and gave confusing results. As unreliable as the models were, important lessons were learned. Patterns and outcomes of the modeling procedure have led us to believe that radial tree growth does not simply have linear relationships with climatic elements. Rather, it is more likely that New Brunswick tree species will react to a climatic element, like summer temperature for example, in a linear fashion until a threshold is reached, beyond which the opposite reaction may occur. With oscillating ocean conditions, these thresholds may be passed in one period of time, then after the ocean condition switches phases, the tree response to the very same climatic element may reverse. For example, let’s imagine that spring precipitation is very important to a particular tree species when ocean conditions are warm and the summers are hotter and dryer. When the ocean cools, and a period of relatively cool damp summers become more common, wet spring weather may create poor growing conditions throughout the rest of the summer. As the conditions change the reaction of the tree species reverses and it instead prefers dry spring conditions. This type of situation makes it much more difficult to model radial tree growth. To produce better models, it is therefore necessary to identify these non-linear relationships and apply more complex modeling techniques in order to achieve reliable results. With that being said, it is still possible that a changing climate may alter the physiological response of trees when new extreme conditions, never before experienced, migrate over the region. If we reach a point in time where winter snow cover is an infrequent event, how will trees respond to this? The bottom line is that predicting a potential response of an organism to uncertain future conditions remains very difficult, however, without attempting to forecast we will learn nothing. Although our predictions seem unreliable at this point in time, our understanding of New Brunswick forests has evolved. Combining our evolution in understanding with improving certainty in future climate models, accurate forecasts could soon be achieved.

From the 56 models that were produced, several commonalities were observed across the models for each species. The radial growth models suggest that sugar maple prefers wet Junes, cold Aprils and cool Junes in the previous growing season. The yellow birch models preformed best with a wet summer, specifically lots of precipitation in July and August. The eastern hemlock models did not respond well to deep snow packs, suggesting a longer growing season is likely favorable for that species. The red spruce models indicated that wet falls in the previous growing season produced better results and that late summer precipitation is important in the northern sites while early summer precipitation is important in southern sites. The eastern white cedar models did not respond well to warm June temperatures or cold Februarys, nor did they fair well when the winters were cold and snow levels were low. The white pine models reacted positively to high amounts of summer precipitation.

Response of Trees to Future Climates

Perhaps the largest barrier to accurate future tree growth modeling is the ability of Coupled Global Climate Models (CGCMs) to model internal climate variability. This is what people often refer to as the cyclical nature of the climate. Some well known examples are El Nino and La Nina from the central Pacific Ocean, although that particular phase change of the ocean occurs relatively frequently compared to other more long-term ocean conditions like we experience in the North Atlantic. This internal climate variability, which occurs on comparatively long time spans, has up to now, tended to cause larger swings in regional climatic conditions then the more consistent global increase in temperature known as global warming. Where the phases of the oceans are thought of as internally forced by natural pulsing of ocean heat conveyers, global climate change is externally forced by inputs of greenhouse gases into the atmosphere. The gradual increase of global temperatures is currently well modeled by the various CGCMs considering the uncertainty of when greenhouse gas emissions will slow or stop. On the other hand, CGCMs do not model the internal variability of the ocean conditions well at all. This is an active area of research and we should soon have new climate models that can better predict changes in the oceans before they happen, perhaps even decades into the future. If and when these are created, in combination with more robust tree growth models, it is likely that the response of New Brunswick forests to climate could be well predicted years if not decades in advance. However, there is always an exception. How climate change may influence the magnitude and period of these macro-climatic ocean conditions is unknown at this point. There remains the possibility that the ocean conveyer may shut down if enough fresh water from melting ice enters the ocean, which could stop the transfer of equatorial heat to the North

Atlantic. Such an extreme situation would have obvious consequences for New Brunswick's forests. This is why both internally and externally forced climate changes need to be researched and modeled. However likely or unlikely an extreme circumstance is, the point remains that trees are dependent upon climate and the more we understand their potential responses to various conditions, the better we will be able to predict their future growth rates and subsequent health.

Direction and Trends of the North Atlantic Ocean

Despite all of the uncertainty surrounding the radial growth forecast models constructed for this report, we can make some informed speculation on the potential direction of ocean conditions and their expected impacts on New Brunswick forests over the shorter-term.

It is generally recognized that the last time the AMO shifted phases was in 1994-95. This shift was to a positive phase, which has generally resulted in increased radial growth of shade tolerant tree species in the past. We can use probabilistic projections of future AMO phase changes based on long-term tree-ring reconstructions to approximate when a shift of phase may occur. Based on a long-term, 424 year, AMO reconstruction from tree-rings, a study was produced that projected risk of future AMO phase shifting. The results suggest we should expect a 33% chance of a phase reversal in the next 5 years, a 59% chance of reversal in 10 years, a 78% chance of reversal in 15 years, a 92% chance of reversal in the next 20 years, and finally there is near certainty of a phase reversal of the AMO within 25 years based on past activity. Given these probabilities, it is likely that the AMO will undergo a phase reversal between 2020 and 2030. If that situation unfolds as envisioned, the radial growth of shade tolerant tree species should slow after this point, until the AMO finishes its negative phase. This probability of phase reversal of the AMO also has implications for yellow birch. If we do in fact experience another decade or more of positive phase AMO, the radial growth of yellow birch should continue to suffer as it has since the current positive phase of the AMO began. Once phase reversal occurs, yellow birch radial growth should again increase. However, until that situation unfolds, yellow birch may be more susceptible to dieback, insect outbreak, pathogen attack, or pollution.

Several studies have linked rising green house gas concentrations with more positive phase trends in the NAO. Two long-term NAO reconstructions shed light on the changing performance of the NAO. The first is a robust tree-ring reconstruction reaching back to 1400 A.D. and the second is a 218 year long NAO reconstruction from coral strontium-to-calcium ratios sampled near Bermuda. Both sets of data show that the NAO performance is linked to Northern Hemisphere mean temperature and the magnitude of the NAO waxes and wanes as the climate warms and cools. It is proposed green house gas emissions are forcing more extreme NAO phases that will make climate forecasting more difficult for the North Atlantic region and undermine the predictability of anthropogenic warming.

This could cause the radial growth of shade tolerant tree species in New Brunswick to experience periods of both rapid and slow growth. As we are currently ending an extended period of extreme positive phase of the NAO and transitioning toward a negative phase, shade tolerant tree species' radial growth should respond favorably, especially considering we are in a warm phase of the AMO. However, if future extended positive phases of the NAO occur simultaneously with negative phases of the AMO, shade tolerant tree species could experience suppressed radial growth and extended periods of stress leading to other disturbances such as insect or disease outbreaks and ultimately increased mortality.

Conclusion

The reaction of the relatively complacent forests of New Brunswick to climate has been little studied. Through the most geographically intensive and tree species inclusive dendroclimatology study ever in New Brunswick, we have introduced a new level of comprehension, regarding the past, present and potential future radial growth response of six New Brunswick tree species. Of the six tree species studied, the four most shade tolerant and one moderately shade tolerant, exhibited long-term fluctuations in their population level radial growth rates, which corresponded to long-term fluctuations in measurements of North Atlantic Ocean sea surface temperature and pressure. This ocean influenced, internal climate variability has likely been responsible for past widespread, population level, radial growth fluctuation. As such, the radial growth of some of New Brunswick's most important tree species appears to exhibit a much stronger internally forced climate signal, rather than an external anthropogenically forced global warming signal. These oscillating growth responses introduce difficulty into the future modeling of radial growth rates using Coupled Global Climate Models.

In light of unreliable 100 year forecasting models, radial growth rates of New Brunswick trees can still be predicted to a lesser extent using probabilistic projection of phase reversal in ocean surface temperature based on proxy records. This suggests with near certainty that phase reversal will occur on or before 2030, resulting in a cooler phase of the Atlantic Multidecadal Oscillation, and lowered overall radial growth after that time, of the shade tolerant tree species sugar maple, eastern hemlock, red spruce, and eastern white cedar, while increased radial growth of yellow birch should occur. Alternately the North Atlantic Oscillation, is currently diminishing into a negative phase, which in combination with the current positive phase of the AMO, should provide optimal climatic conditions for the four shade tolerant tree species of this study over the next several years. What is not yet well understood, is how exactly global warming will influence the oscillating conditions of the North Atlantic Ocean.

Increased certainty of the future climatic response of New Brunswick's forests requires two advances in knowledge. The first is the production of better Coupled Global Climate Models that have the ability to more accurately forecast fluctuating ocean conditions. The second is more complex radial growth models of New Brunswick tree species that can account for most climatic influences. Until these advances are completed, the future productivity of New Brunswick trees will have to be roughly approximated and uncertainty will remain.