Expanding on Radial Growth Forecasting: The Potential Future Response
of Three Southeastern New Brunswick Tree Species

Ben Phillips and Colin P. Laroque

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Abstract

Many people depend on forests to provide a wide range of necessities while believing forests are a static, non-mobile community. Future climates are now challenging that traditional perspective and are forcing us to reconsider our reliance on forested landscapes. The goal of this study is to expand on radial growth forecasts of the region's most important tree species over the 21st century in an attempt to mitigate economic and conservation problems before they occur. Three species of Acadian Forest trees from southeastern New Brunswick are investigated to produce future radial growth predictions for presently standing trees and their progeny. Examining the past relationships of the tree species and historical climates is achieved through regression analysis between archived weather data and past radial growth data sampled from living trees. The species specific relationships are then forecast over the period 2000 –2100 A.D. using multiple scenarios of coupled general circulation model outputs.   Results indicate a range of responses that indicate some species will flourish while others will decline. Red Pine will benefit the most from the forecasted future climates taking full advantage of a longer growing season while sugar maple will fail to produce the necessary radial growth to maintain a competitive edge. Beech is projected to maintain or slightly decrease their radial growth depending upon which climate change scenario is used.

1.0 Introduction

As a result of anthropogenic warming we are now facing eminent geographical shifts of forest ecosystems and tree species (IPCC, 2007). Our understanding of how tree specie migration takes place originates from fossil pollen records deposited during the Holocene period (Delcourt and Delcourt 1987). Historic geographical distributions and dispersal rates gleaned from these records are useful data to apply to the current situation. Beyond that knowledge, many scientists are relying on relatively short historical weather data, global climate models and current tree distribution data to estimate how and where tree species will migrate. Using this information researchers have constructed various sophisticated migration models based on a (bio)climate envelop approach (McKenney et al. 2007, Hamann and Wang 2006, Iverson et al. 2007). These models are now providing us with very convincing information on the potential range shifts of many species but much uncertainty remains regarding how processes such as growth response, disturbances, dispersal, and establishment will play out (Neil et al. 2005).

For various plants, such as trees, migration can only occur over the long-term and the individuals that are today rooted in the ground will be forced to tolerate sub-optimal conditions in the near future. A limitation of migration studies, based on presence only data, is the inability to assess how rooted trees will respond to changing climate normals. The strength of these studies, assessing the geographical shifting of various climatic envelops, is the identification of potential feeble or hardy species in the face of climate change. McKenney et al. (2007) have identified the Maritime Provinces as one area in Canada that should provide suitable climates for increasing numbers of tree species leading toward a higher level of tree species richness. This situation involves an exodus of the boreal associated species and an influx of temperate species but it remains unclear how this long-term process will affect forest composition in the short-term.

This study is using dendrochronological techniques to project future radial growth of three tree species in the Acadian Forest Region (AFR) of Atlantic Canada as a response of currently rooted trees to climate change. Biologically based forecasting models will be constructed by establishing a relationship between past radial tree growth and archived weather data, then the relationship is projected over the 21st century using two different scenarios of the Canadian Climate Center's third-generation coupled general circulation model (CGCM3).

2.0 Background

This analysis was designed to provide expeditious results for a small number of the most economically and ecologically important Acadian Forest tree species in the Fundy Model Forest (FMF) region, so as to provide important results on the past and potential future radial growth trends of our current forests. After the completion of five forecasts in 2006 this study was meant to build upon the pilot project and investigate three other species of the forest community including two of the first deciduous species.

2.1 Resource enhancement

Forestry is a very important industry in the Maritime Provinces to both industrial logging companies and local small woodlot owners. The future supply of available timber is paramount to a successful and profitable industry. Currently most forest industry sectors rely on traditional growth and yield models that are based on linear projections. These projections assume past radial growth is a dependable indicator of future forest productivity. Combined with this productivity assumption is the widely accepted idea that forest composition will remain in a stable state for perpetuity.

Previous studies conducted by the Mount Allison Dendrochronology (MAD) Laboratory have shown that all coniferous species in the Maritime Provinces produce annual radial growth rings with substantial year to year variability (Laroque 2005). Climatic conditions play the largest consistent role in this radial growth variability which means any changes in long-term climates should affect annual allowable cuts (AAC) substantially. If the forestry industry does not anticipate these changes, positive or negative, a great deal of economic opportunity could be lost. The prospect of knowing which tree species may grow better in the future would be very advantageous leading to, for example, an improved understanding of which stock to replant for maximal benefit. It is one of the goals of this study to begin the introduction of a variable model based on the best future climate predictions available. The estimates provided through AAC need to be corrected for climate variation and long term changes in order for the industry to maintain its profitability.

2.2 Conservation success

As temperatures increase in New Brunswick some tree species will become winners and some will become losers. Changes in tree species distributions and concentrations will lead to many ecosystem transformations. All other species living in forests, whether small plants or large animals, stand to be affected. Unanticipated tree species range migrations will create great difficulty for conservationists. Conserving an ecosystem that cannot continue to exist under changing conditions could be a futile effort. Protected area locations could be severely undermined and reforestation goals could be unproductive. The resulting forecast from this project is aiming to help forest managers working in conservation areas to anticipate and plan for future predicted forest reactions to a warming globe. By attempting to develop a future forecast this study hopes to deliver the knowledge to better use future resources in conservation efforts. In both cases those who work in the forest will gain the ability to plan ahead of climate change instead of reacting to it.

3.0 Main Objective

The main objective of this study is to collect representative growth data from three important species in the FMF region and based on past growth and climate relationships, forecast radial growth pattern in the region for the next 100 years.

4.0 Study Site

4.1 Site description

The centrally located area of southeastern New Brunswick (SNB) was chosen as a representative ecosystem within the Maritime region of eastern Canada for collection of past radial tree growth records and past weather data. Southeastern New Brunswick is located between 45° and 46°50' north latitude and 63°50' and 66° west longitude and the elevation ranges from sea level to a maximum of 450m asl. This area is covered by four of the seven distinct New Brunswick eco-regions as defined by the Ecological Land Classification, giving it a strong representation of tree species diversity occurring throughout the Maritimes region (Power & Matson 1995). The combination of lowlands, uplands, coast, and valley landforms has resulted in the four eco-region classifications. The climate varies over this region as the influence of coastal waters, elevation, and inland air masses contribute to relative differences. The number of growing degree days varies from 1500-1700 based on above 5°C rates and the May to September precipitation values vary from 400-500mm (Clayden 2000). Although this variability exists there is still a strong similarity between all four eco-regions as the latitudinal difference and elevation changes are not significant enough to bring about large climatic divergence.

4.2 Tree-ring sampling

Increment cores were collected from trees at 12 sites scattered over southeastern New Brunswick (Fig. 1). At least 20 trees were selected at each site, and cored twice for a total of 40 or more cores per site. Red pine (*Pinus resinosa*), sugar maple (*Acer saccharum*), and American beech (*Fagus grandifolia*) were the three species chosen. Each species was sampled at three locations or more within the study area. Beech was sampled at six sites over SNB due to potential unexpected consequences beech bark canker disease may have had on past radial growth.

Importance was given to finding sites that were geographically separated by at least 30 km within the study area, however, to locate stands of acceptably old trees this was not always possible. At least 100 years of radial tree growth was required for the analysis which was difficult to find for some species. All sample sites contained the particular species of investigation in a mature dominant or co-dominant role except for beech. To find trees of at least 100 years of age, site differences such as slope, aspect, elevation, substrate and marine proximity sometimes had to be ignored. These site to site differences, no doubt, contributed to variance in radial growth observed upon tree ring measurement but micro-site characteristics were of no concern to this study as the general climatic conditions and their relationship to radial growth was the focus of the study.
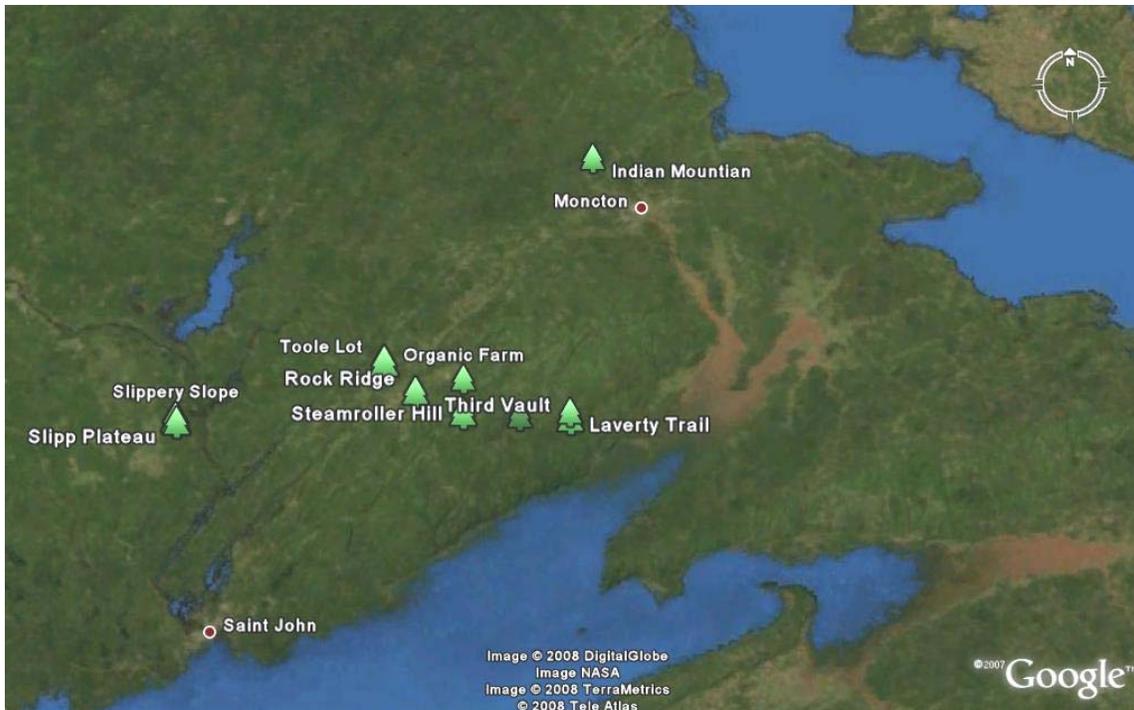
Figure 1 – Map of southeastern New Brunswick with locations of all tree species sampled in this study.

4.3 Climate data

Weather data used for the analysis was collected from Sussex for the period 1895-2005. Sussex is centrally located within southeastern New Brunswick, is far enough away from direct marine influences and is located within a river valley lowland area. When compared with historical weather data collected from the other largest SNB communities of Moncton and Saint John, Sussex showed nearly identical temperature and precipitation quantities through most months of the year. For this reason the Sussex data was taken to be representative of SNB.

The Third Generation Coupled Global Climate Model (CGCM3), produced by the Canadian Centre for Climate Modeling and Analysis, was used to derive the future weather data used in tree growth forecasts. The data was calculated for the grid square covering the latitudes from 44˚38'6.00"N to 47˚26'42.00"N and longitudes from 63˚17'6.00"W to 66˚5'42.00"W (Fig. 2).

Figure 2 – CGCM3 grid square covering southeastern New Brunswick.

5.0 Methodology

5.1 Future climate data calibration

The climate model grid square overlaying Sussex covers an area of 2.81˚ latitude by 2.81˚ longitude. This relatively large zone, compared to the much smaller region of SNB, incorporates many marine influences including a large portion of the Bay of Fundy, the Northumberland Strait and a section of the Gulf of St. Lawrence. The inclusion of these bodies of water influences the CGCM3 output significantly. An average result of temperature and precipitation is forced over the entire zone that does not necessarily represent all areas of the grid square to an accurate degree. The consequence of this generalization is a climate model data set which is approximately 2.5˚C cooler on an annual average than the Sussex data. The seasonal and monthly values of the CGCM3 deviate from the Sussex historic data in various ways. To correct for the problems encountered with the differences in geographical scale and season, a change factor conversion was carried out on the climate model data. The CGCM3 data was subtracted from the Sussex historical data on a monthly scale for each year during the period 1900 – 2000. The results were averaged for each month to create a mean monthly divergence value. These average monthly values were then applied back onto the annual CGCM3 figures at the same monthly resolution. The outcome of this correction was a modeled past climate data set that matched the past Sussex data in magnitude. The same correction was then applied to the future data set which adapted the zonal CGCM3 data to the land based point source conditions experienced in Sussex.

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5.2 Tree-ring data

Increment cores were measured, cross dated and individual master chronologies constructed for each site following standard dendrochronological methods. The individual masters were then entered into a 3 X 3 correlation matrix to determine how much divergence existed between sites. All sites were well above the critical correlation levels and significant to at least the 99% level. A visual examination of the degree of similarity was also conducted. Following the site to site testing, species master chronologies were constructed by averaging together the three individual site master chronologies for each species. This process differed slightly for beech as there were six sites and difficulties associated with diseased trees forced rejection of many cores from the site masters. Although many cores were rejected, the beech regional master chronology retained well over 60 cores. Sugar maple also encountered problems. It was believed that these were due to two of the sample site locations being on the periphery of the sample area. One site was too close to the Bay of Fundy and another site was near the Saint John River valley. These two sites seemed to introduce heterogeneous elements into the regional master and had to be eliminated in favor of the Moncton sugar maple site which represented the median signal between all sites.

5.3 Past climate data

Species masters were then entered into regression models with monthly resolution climate data, including both temperature and precipitation, collected in Sussex, New Brunswick from 1900 to 2000. In the regression models, temperature and precipitation data from Sussex consisting of the first ten months of the current year and the last eight months from the previous year were used amounting to 38 variables. An independent variable was also added for one year's previous tree growth in each species specific model. This was done due to expected high autocorrelation values between the current and previous year's growth as evidenced in most dendrochronological studies (Fritts 1976). These 39 variables were examined in a stepwise multiple regression analysis which established the most important factors contributing to annual radial growth in a sequential order for each species. The process identified months that most significantly contributed to radial grow and these variables were then entered into an equation which calculated the past annual radial growth, and then were used to calculate the future annual radial growth response of trees to forecasted climates.

5.4 Model Calibration and Verification

The model of tree growth response to climate was established using a 10% rule of thumb (plus or minus two) to the identified climatic factors contributing to annual radial growth in the regression analysis. For example, this meant that since the Sussex data had approximately 110 years of instrumental data, a maximum of 11 variables could be used in a regression equation to guard against over-fitting of the data. This value actually was lower, as we limited our models to 10% of the calibration time of each modeled data set. For all species of trees a 70/40 years of calibration to verification number was used,

meaning that a centre point of 7 variables could be used in any model with a minimum of 5 and a maximum of 9 variables possible based on the goodness of fit during the verification period. The resulting models based on past relationships, were then applied to the future corrected climate data to produce annual forecasted radial growth values.

5.5 Climate Model Scenarios

The International Panel on Climate Change (IPCC) has set out various social scenarios that indicate the projected amounts of CO_2 that will be in the Earth's atmosphere by the end of the 21st century in their Special Report on Emissions Standards (SRES). The CGCM3 calculates data based on these scenarios and two of them were used in this study. The first scenario used was the SRES B1 which is based on 550 ppm of atmospheric CO_2 by 2100 which is a conservative estimate (Fig. 3). The corrected data from this scenario shows a temperature increase of approximately 3°C between 2000 and 2100 for the Sussex area. Precipitation for this scenario shows significant variability but overall it only increases marginally by approximately 30mm annually by 2100.

The second scenario used was the SRES A1B which is based on 720 ppm of atmospheric CO_2 by 2100 which is a median estimate (Fig. 4). The corrected data from this scenario shows a temperature increase of approximately 4.5°C between 2000 and 2100. Precipitation for the 720 ppm scenario also shows significant variability but this time the mean trend of the data increases more rapidly by 100 mm in the first 80 years of the 21st century until it quickly declines back to 2000 levels at the 2100 mark.
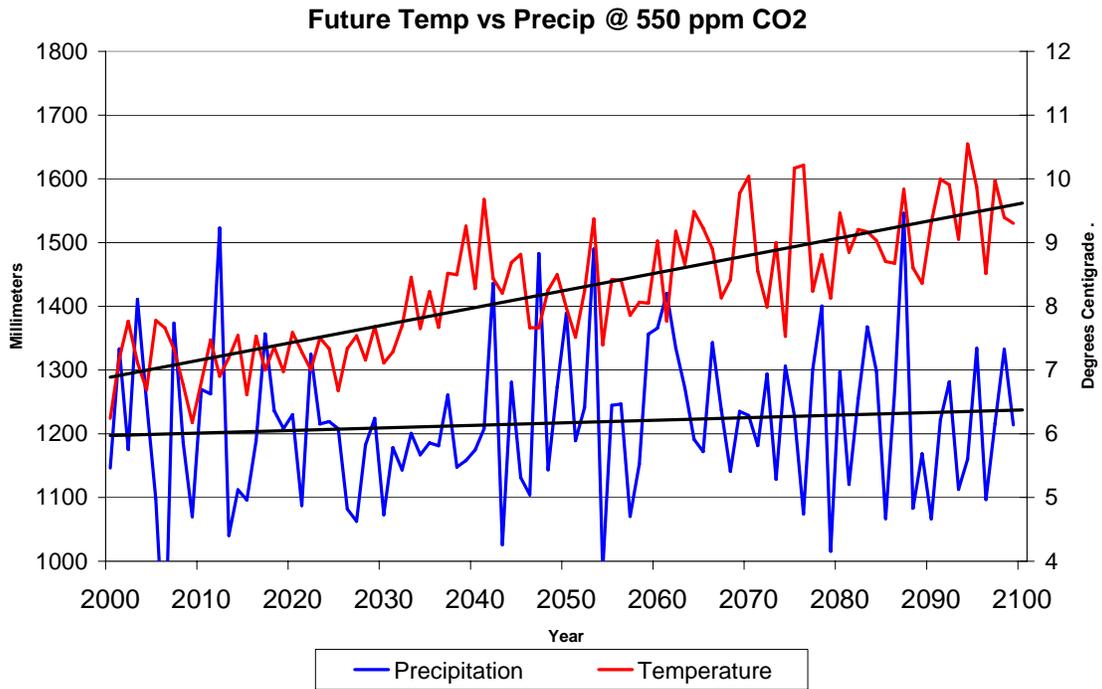
Figure 3 – Future temperature and precipitation values for the Sussex area based on the SRES B1 scenario.
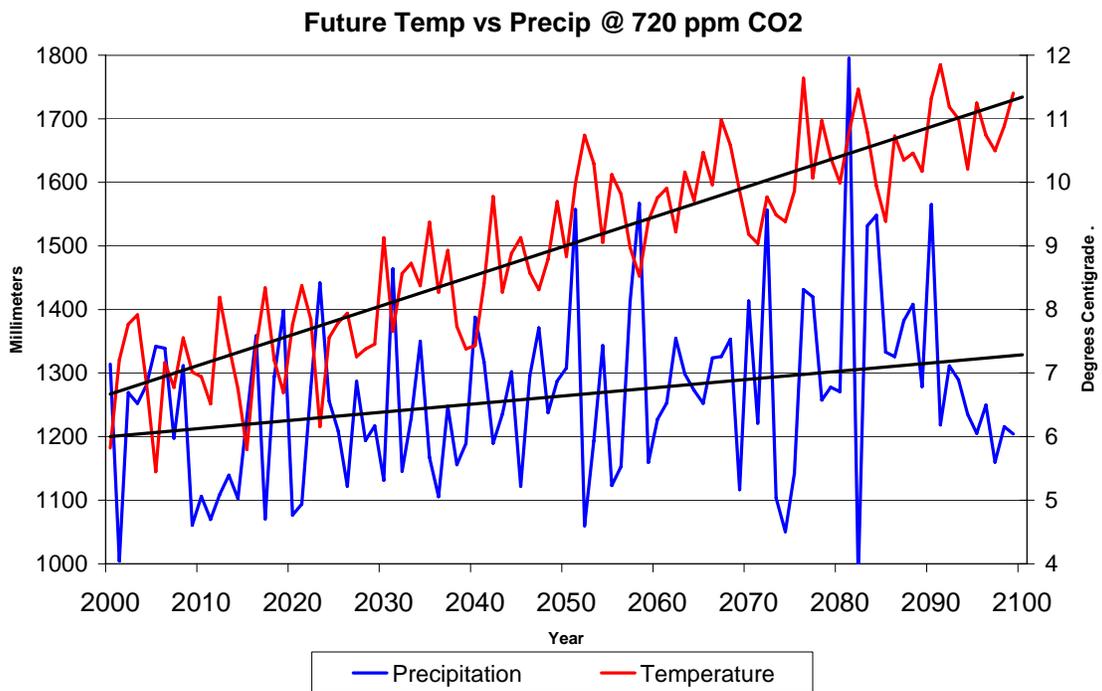

Figure 4 - Future temperature and precipitation values for the Sussex area based on the SRES A1B scenario.

6.0 Results

6.1 Tree Species Forecasts

The results of the modeled growth relationships are described below. Each of the selected tree species is dealt with on an individual basis.

6.1.1 Red Pine (Pinus resinosa)

The red pine model responded positively to high July and August precipitation. Also, warm temperatures in previous November, current January and current April, along with cool August and high values of previous year's radial growth were all identified as major drivers of growth. Together these factors explained the variance of actual past growth with only an 8.74% error in the calibration of the model (Table 1). The strength of the relationship between the calibration period in Figure 5 and actual past growth is further evidenced by a 0.918 Pearson's r-value (Table 2). The verification segment in Figure 5 illustrates the predictive capability of the model where the error explaining variance rose to 11.66% (Table 1). A Pearson's r-value of 0.694 (Table 2) in the verification segment further supports the models ability to predict independent past growth data.

Table 1 – Mean square error of prediction (MSEP) illustrating the error between variance in the model and actual past growth.

Tree Species	Red Pine	Sugar Maple	American Beech
MSEP for Calibration	8.74%	13.66%	7.90%
MSEP for Verification	11.66%	16.65%	14.40%

When the model was run using the SRES B1 CGCM3 data (550 ppm) it produced a forecast for red pine that shows a trend of about a 25% increase in growth over the 21st century compared to past radial growth (Fig. 5). Extreme values differ significantly between past and future curves.

Table 2 -Pearson correlation values confirming relationship between past radial growth and the specific calibration and verification periods that differ by species.

Tree Species Models	Red Pine	Sugar Maple	American Beech
Calibration Period	0.918	0.783	0.854
Calibration P-value	4.4E-29	1.2E-15	5.2E-21
Verification Period	0.694	0.626	0.449
Verification P-value	1.5E-6	1.6E-5	3.7E-3

The SRES A1B CGCM3 data (720 ppm) showed a much greater increase in radial growth trend toward the 2100 limit. Over the 100 year forecast, red pine radial growth increases by approximately 65% in the 720 ppm model (Fig. 6). This model also shows a decrease of extreme values observed in the past radial growth curve.
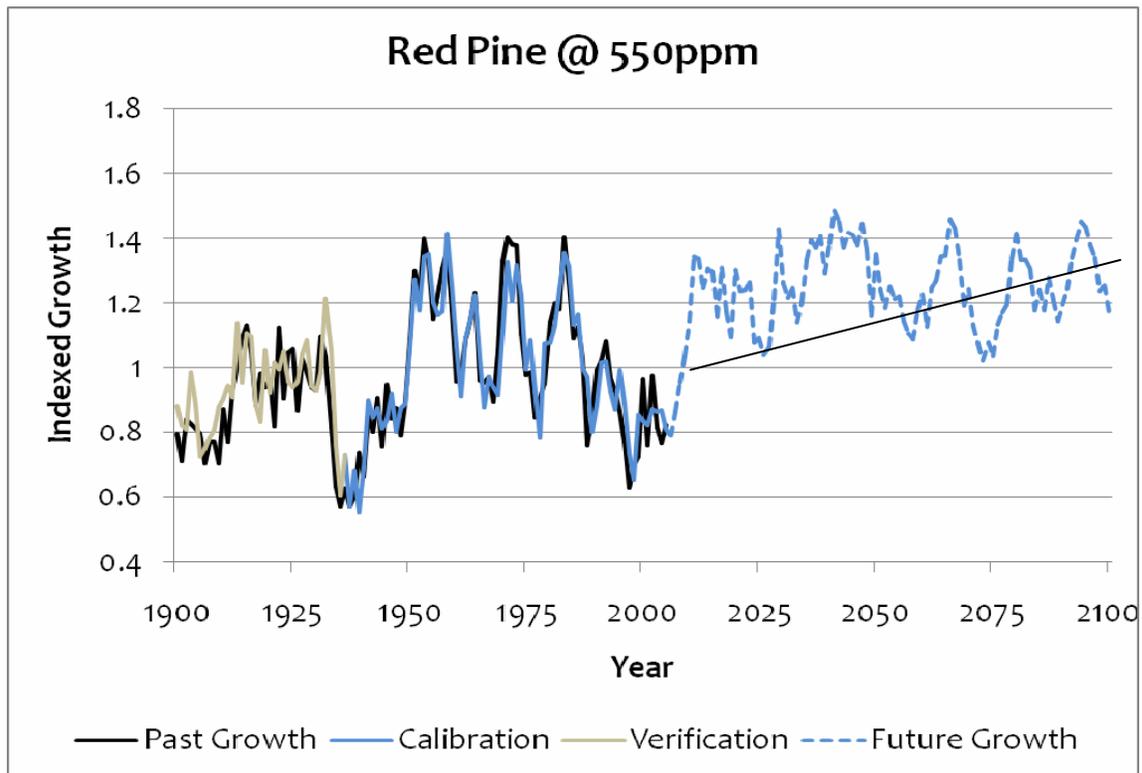

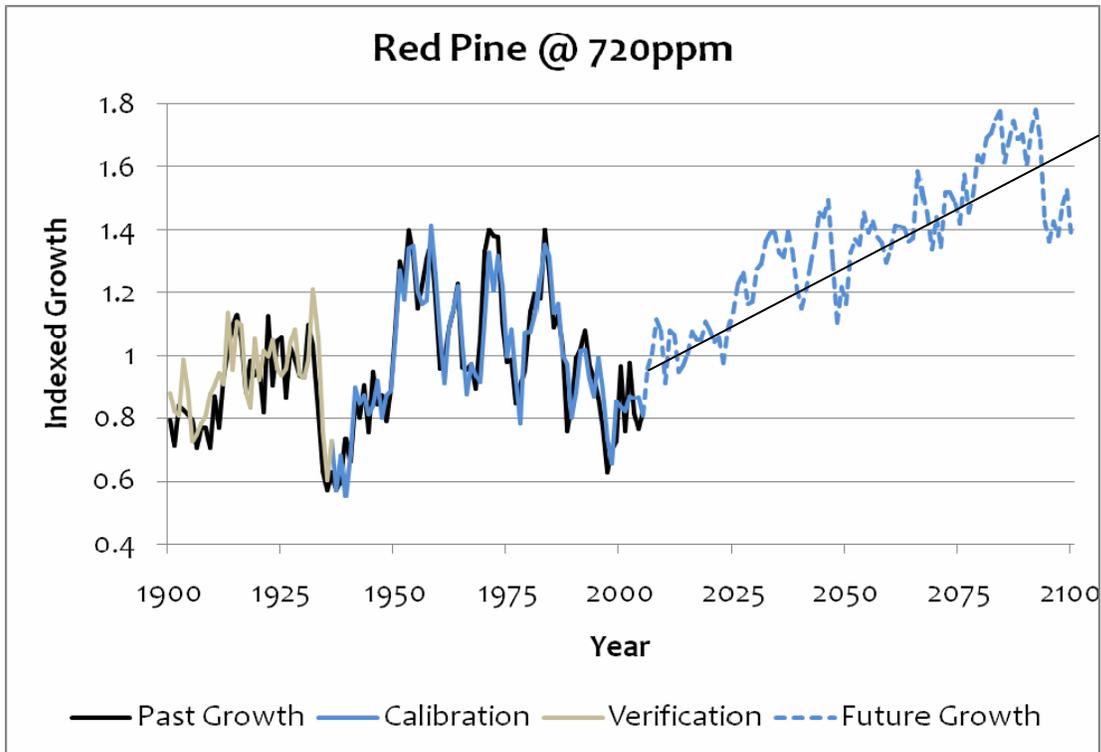Figure 5 – Red Pine forecast based on SRES B1 CGCM3 data.

Figure 6 – Red Pine forecast based on SRES A1B CGCM3 data.

6.1.2 Sugar Maple (Acer saccharum)

The sugar maple model showed a negative relationship to warm March temperatures and hot August temperatures. A positive relationship to high June and July precipitation and the previous year's growth were major growth drivers. Together these factors showed a 13.66% error (Table 1) in explaining past radial growth variance of the calibration segment in Figure 7. The relationship between past growth and the model calibration for sugar maple can be further evidenced by the Pearson's r-value of 0.783 (Table 2). The verification segment of the model in Figure 7 maintained a good fit with the past radial growth curve with a 16.66% error between actual past growth and modeled growth variances (Table 1). A Pearson's r-value of 0.626 (Table 2) also illustrates this strong relationship.

When the model was run using the SRES B1 CGCM3 data (550 ppm) the output revealed a rapidly decreasing growth rate trend over the 21st century resulting in a roughly 80% radial growth drop by the year 2100 (Fig. 7). Variance between past and future curves differed substantially.

The SRES A1B CGCM3 data (720 ppm) showed an even larger radial growth decrease of approximately 100% by the end of the 21st century (Fig. 8). Variance between past and future curves illustrates similar levels as compared with the SRES B1 scenario.
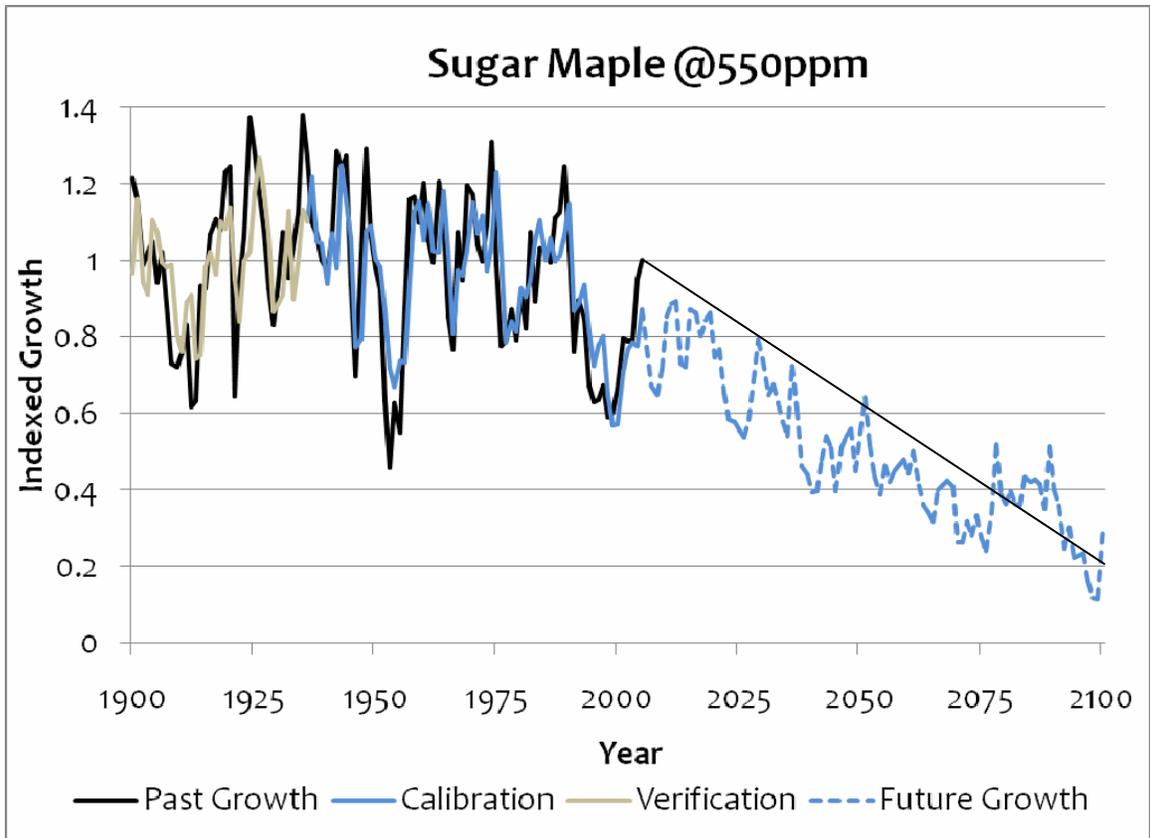
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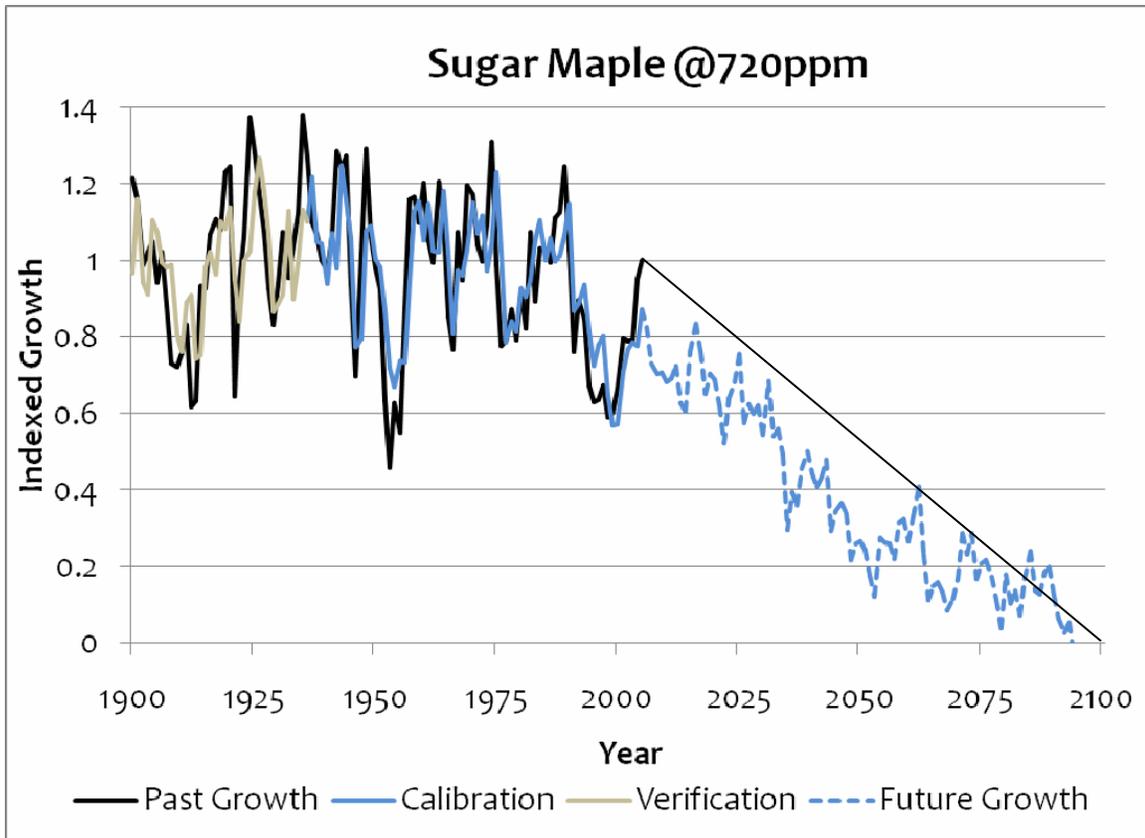Figure 7 – Sugar maple forecast based on SRES B1 CGCM3 data.

Figure 8 – Sugar maple forecast based on SRES A1B CGCM3 data

6.1.3 American Beech (Fagus grandifolia)

The beech model is driven by high precipitation from previous August and current June and July with a negative association to large March precipitation amounts. Cold September, warm previous April and the previous year's growth are also primary radial growth drivers. The model calibration segment (Fig. 9) when compared with actual past growth displayed a 7.9% error (Table 1) in explanation of variance and showed a Pearson's r-value of 0.854 (Table 2). The model verification segment in Figure 9 compared to actual past growth had a higher 14.40% error (Table 1) in explained variance and a lower Pearson's r-value of 0.449 (Table 2).

The SRES B1 CGCM3 data (550 ppm) used with the beech model show an approximately 10% decrease in radial growth by the end of the 21st century (Fig. 9). Variability between the past radial growth data and the forecasted radial growth illustrates lower future variability.

The output produced from the SRES A1B CGCM3 data (720 ppm) showed slightly less reduction of radial growth by the year 2100 (Fig. 10). Variability between the 720 ppm model output and past radial growth were again reduced in future years.
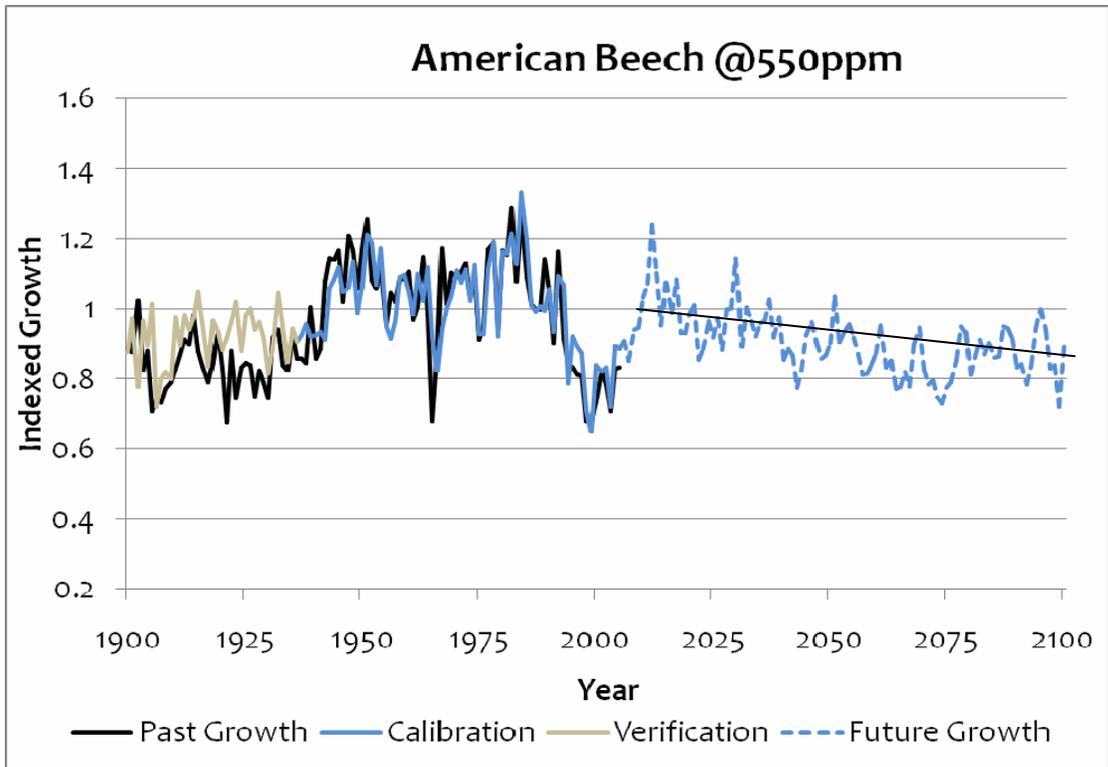
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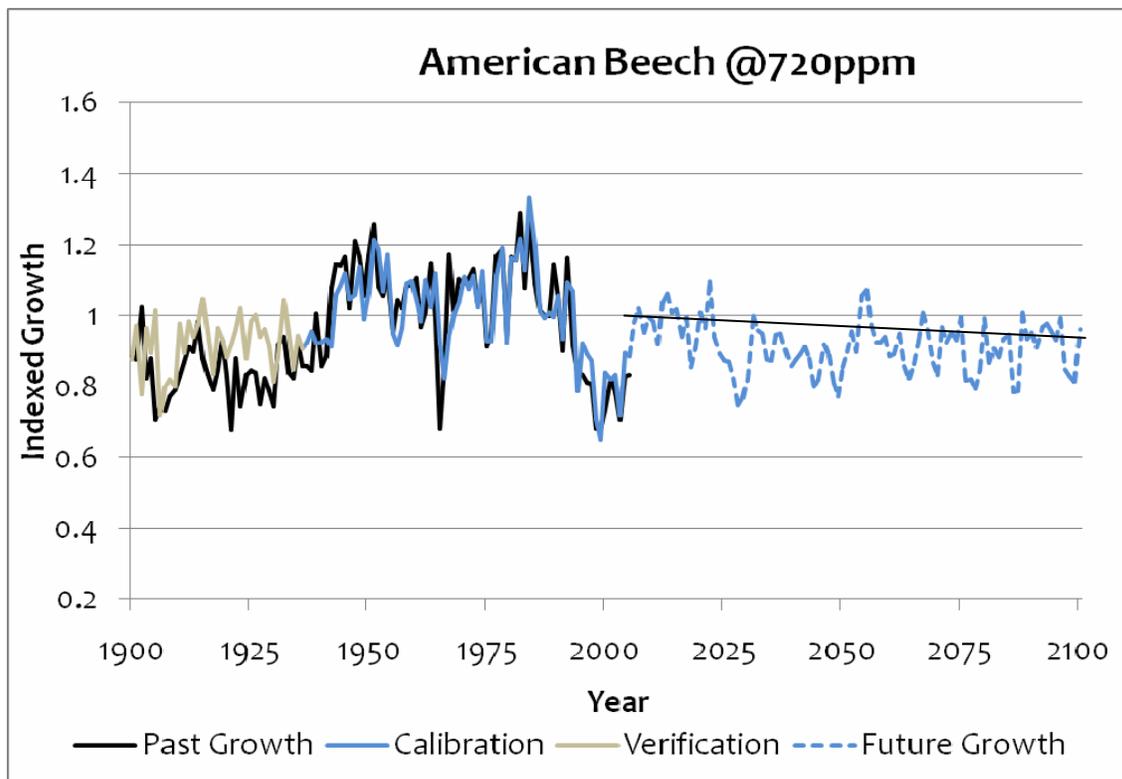Figure 9 – American beech forecast based on SRES B1 CGCM3 data.

Figure 10 – American beech forecast based on SRES A1B CGCM3 data.

7.0 Discussion

7.1 Individual Species Discussion

Results of the above analysis will be discussed species by species.

7.1.1 Red Pine (Pinus resinosa)

Red pine is similar to white pine in its dependence upon summer precipitation to develop large radial growth rings. It appears that red pine has a greater ability to take advantage of growing season length which results in greater future radial growth increases than for white pine. The large increases in future radial growth forecast by the models for red pine is related to future temperature increases in the early and late growing season, as the SRES B1 and A1B scenarios do not show large increases in future precipitation. The A1B scenario does show an increasing trend in precipitation over the 21st century that may be contributing to the much larger red pine growth increase forecast under the 720ppm model. It should be noted that increases in August temperatures and a lack of precipitation during the same time frame above those forecast in these CGCM models may be detrimental to future red pine growth. The CFS range relocation maps show the red pine range moving farther north but the Maritimes remains well within the extent of the range (McKenney 2007). This climate envelop model agrees well with our radial growth forecast.

A reduction in future red pine radial growth variance can be attributed to the inability of the future model to carry non-climatic factors forward. The calibration and verification segments of the past model have access to actual previous growth values and thus incorporate other potential growth drivers besides climate. This means the actual variance should be expected to be much more pronounced in future growth then in the model but the general trend will be as accurate as the input data currently allows.

7.1.2 Sugar Maple (Acer saccharum)

The potential for the continuing success of sugar maple in the SNB region is called into question with the two future radial growth models. Under the 720ppm forecast sugar maple could start to be eliminated from the landscape by the year 2100.

Like the red and white pines, sugar maple relies on summer precipitation for strong radial growth but other factors may play a more substantial role. Our models show a reliance on cold March temperatures and cool previous August temperatures to be very important in sugar maple's growth potential. It is assumed that hot August temperatures are associated with high evapo-transpiration leading to a smaller energy store for sugar maple to carry forward into the next growing season. Warm March temperatures are assumed to expose sugar maple to freeze/thaw cycles causing damage to tissues necessary for strong radial growth. Increasing temperatures in these two important months in both future climate change scenarios used in this study are expected to have serious implications for sugar maple in the SNB region. It could be theorized then, that

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more northerly locations of the Maritimes exposed to smaller increases in temperatures during future August and March may retain better sugar maple growth.

The sugar maple forecast of this study is in agreement with the CFS future range maps (McKenney 2007). In those climate envelop studies sugar maple is shown to be eliminated, first in Nova Scotia, and then later in southern New Brunswick. The southern edge of sugar maple's range in the Maritimes, shown in the CFS future range maps, may be associated with migrating winter temperature freeze/thaw boundaries which we believe plays a large factor in the radial growth of the species.

Like red pine, future sugar maple radial growth variability is much lower then actual past growth. The same reasons, as suggested in the red pine discussion, are responsible for this reduction in extreme radial growth situations and the forecast should also be regarded as accurate in growth trend only.

7.1.3 American Beech (Fagus granidifolia)

Beech radial growth seems to be reliant upon mostly precipitation. As with sugar maple, beech needs moisture in August to build up substantial energy stores for the next year. Early summer precipitation is also important and is forecasted in the climate models to undergo major changes over the next 100 years. Previous April warmth adds to growing season length and is a positive influence on beech growth but a negative association with September temperatures is interesting. Perhaps triggering mechanisms, normally associated with September, are important for the end of the beech growing season. Under both future climate change scenarios used in this study it appears some radial growth factors will favor beech and some will be a disadvantage. Since beech looks to be reliant mainly upon precipitation its future growth should not be substantially effected. It is also unknown how the beech bark canker disease will respond to a changing climate. If beech can somehow overcome the devastation of the disease its future viability in the Acadian Forest may be positive. The CFS range relocation maps show the climate envelop for beech remaining over the SNB region which is in agreement with the forecasts of this study (McKenney 2007).

Like red pine and sugar maple, future beech radial growth variability is much lower then actual past growth. The same reasons, as suggested in the red pine discussion, are responsible for this reduction in extreme radial growth situations and the forecast should also be regarded as accurate in growth trend only.

7.2 Predictive Limitations of Forecast Models

The forecast models created in this study are obviously limited by the predictive accuracy of the CGCM3 data. Global Climate Model data is an evolution in progress, constantly being updated, redefined, and constantly being fed better and more spatially continuous data. As such, the future predictions of this study need to be qualified by the ability of the modeled data to forecast scenarios set forth by the IPCC. As future scenarios change, and new generations of models are produce, the forecasts derived for future radial growth will also need to be updated.

Another limitation of the forecast models is the availability of past climatic situations that are analogous to future climatic scenarios. The forecast models in this

study are based on the past one hundred years of radial tree growth in comparison to the past one hundred years of historical weather data. During this one hundred year period there has been much climatic variability but there are certainly future forecasted climatic maximums of both temperature and precipitation that are outside of the range of the past climates. The models are completely based on the relationship of past radial tree growth to the experienced environmental variability. The models are therefore, somewhat limited in their capacity to provide a completely accurate prediction of radial growth under the forecasted climatic range that is outside of that experienced in the past. Ecological thresholds that relate to a tree's response to temperature or precipitation of a particular month or season may not have been reached in situations in the past 100 years and could therefore be missing from the forecast models. Therefore, as the models work their way into more extreme climate change scenarios it is expected their predictive capability will begin to fail. The potential for a particular species to modify which climatic factors it is dependant upon as it reaches potential climatic thresholds remains unknown.

It should also be kept in mind that these models are only predicting radial growth response to the future climatic inputs and do not at all account for radial growth reductions inflicted by insect outbreaks or other pathogens. As the climate warms trees will not be the only species to shift ranges in response to the new conditions. Other species will also have a migrational response that could differ substantially in geographical and temporal scales. Therefore, it should be anticipated that future radial growth of trees could be significantly affected by influences other then the changes of temperature and precipitation brought about by climate changes. This fact and the fact that the trees currently rooted in place versus the ability of insects to more readily disperse can not be taken into account in our models

8.0 Conclusion

Forecast models of potential future radial growth have been developed for three Acadian Forest tree species. Using the science of dendrochronology master chronologies were constructed for each species as a record of past average growth. Radial growth-climate relationships were produced using historical weather data in a regression analysis which explained a range of responses to a variety of averaged monthly influences. Forecasts based on two scenarios of coupled global climate model outputs were then produced covering the 21st century.

The red pine model projected the best forecasted growth realizing a 65% increase in radial growth by the year 2100 under the more extreme CGCM forecast. Red pine should take advantage of a lengthened growing season and may potentially expand its distribution on the landscape if it can find suitable habitat.

Sugar maple failed to prove its capacity to remain competitive under future Maritime climates. Sugar maple realized a 100% reduction in radial growth by the end of the 21st century under the more extreme CGCM forecast. Warming March and August temperatures appear to limit sugar maple's ability to build up energy stores and leave it vulnerable to freeze/thaw cycles.

Beech appears to be mostly limited by precipitation and should remain stable given current climate change forecasts.

Since this is the first dendrochronology study of deciduous species in the Maritimes, a naïveté regarding the regional variance of radial growth rates of the investigated species may have limited our ability to assess the vulnerability of these species to future climates. The effect of beech bark canker disease on beech radial growth rates and the theory of northern Maritime refuge for sugar maple both require further investigation. Sugar maple's current economic importance in non-timber forest products makes it a prime candidate for an expanded sampling range and analysis.

Even though the future radial growth of the sugar maple model is extreme, it is important to remember that these models represent the only look at the species future growth in the Maritimes. Limitations of the CGCMs introduce uncertainty along with ecological thresholds that may have escaped the model building process. Also, climate induced species migrations will be affected by widely varying temporal scales and trees may be at a large disadvantage leaving them vulnerable to insect attack or pathogen invasions. Although this investigation cannot provide full proof forecasts, the results provide the first meaningful, knowledge-based assessments for forest managers and conservation officials. Hopefully this allows them to plan ahead of climate changes instead of reacting to them in hindsight.

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