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Climate Change Impacts on Maple Syrup Yield in Nova Scotia

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Executive Summary

Average maple syrup yield/tap, while fluctuating, has constantly been declining, which is one of major concerns to maple syrup producers in Nova Scotia. Global warming and/or climate change is suspected to contribute to this decline in the syrup yield/tap. Nevertheless, no specific studies were conducted in Nova Scotia to ascertain this hypothesis. Moreover, the industry faces the challenge of identifying the optimal start date of the sap flow that would allow maximum sap yields and consequently high economic returns. Sap flow is a consequence of the interactions between the tree's physiology, environment and weather; and our knowledge on the influence of weather on maple syrup in Nova Scotia is very limited. Owing to this gap, no indicators are currently available to scientifically assist in projecting tap date or harvest decision processes. In order to address these issues, this project was initiated to: (i) assess the climate change scenario in Nova Scotia, (ii) understand the link(s), if any between the climatic factors and (iii) model the relationships, if any, to predict syrup yield and sap flow dates. Historical weather data from various weather stations was collected from Environment Canada and the Maple syrup production data was collected from growers across Nova Scotia. Changes in the weather parameters for mean temperature and effective growing degree days (EGDD) were assessed against the average maple syrup records from 1978-2013. We found that mean annual temperature has increased by $1^{o}C$ in the last 15 years. This increase has translated into an increased an average EGDD of 125 days. The implications on the maple tree growth were multi-faceted and negative in relation to syrup yield. When historical (1970-2013) syrup yields and EGDD were regressed, it was evident that the decline in syrup yields (0.65 to 0.33 L/tap/yr) coincided with the increase in the EGDD (~125 days) in Nova Scotia. Simultaneously, during this period, the start date for the sap flow has started earlier by approximately 5 days. These trends indicate a negative effect of climate change on the NS maple syrup production. However, the length of tapping season remains unchanged. Over 108 weather parameters were screened for their relationship with syrup yields, only six of the weather parameters strongly correlated with syrup yields and three weather parameters correlated with the start date of the sap flow. With these input parameters a neural network-based syrup yield model was constructed to predict syrup yields and start date of sap flow. The performance of the model varied from good fit to poor fit depending on the locations. The syrup yield model showed strong potential to predict the syrup yields and start date. However, its ability is limited owing to the small size of training data and lack of calibration data from multiple locations.

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Overview

This project was funded by the Nova Scotia Climate Change Adaptation Fund (CCAF) through the Nova Scotia Department of Environment to Dr. Lada. The Maple Research Program was established in 2012 at Dalhousie University, in partnership with the Maple Producers Association of Nova Scotia (MPANS) to provide Research, Development, Innovation, Education and Training. The Maple Research Program is led by Dr. R. Lada (Dalhousie University) and is supported by the Maple Research Program Steering Committee (MRPSC). The committee consists of Dr. Raj Lada and Robert Frame as co-chairs and Dale McIsaac (NS Maple Specialist) as the Secretary, William Allaway of Acadian Maple, and producers Kevin McCormick and Matthew Harrison. Ron Young (Department of Agriculture) represents the business development side of the MRPSC.

Introduction

In Canada, maple syrup is produced in the Eastern provinces of Nova Scotia, New Brunswick, Quebec, and Ontario with Quebec producing greater than 90% of the total supply (AgCan, 2012)(*Figure 1*). Though Nova Scotia (NS) produces less than 1% of the maple syrup produced in Canada, it provides more than $1,400,000 (Stats Canada, 2012) to the rural economy from various maple based products. The sugar maple tree (*Acer saccharum* Marsh.) is the principal source of maple sap. The trees are generally tapped early in the spring (February to March) for the first flow of sap. The sap is then collected in either tubing or buckets and concentrated through evaporated to produce maple syrup.

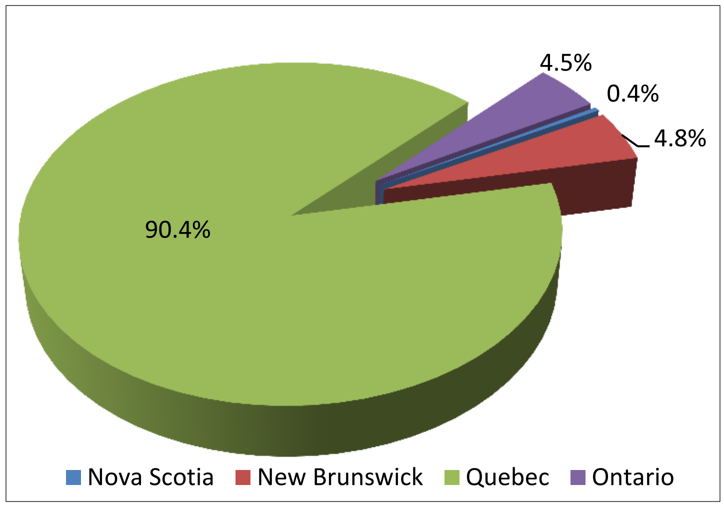

Figure 1. Canadian Maple Syrup Production (%) by Province

Since 1973, the number of taps has progressively increased from 75,000 to over 374,000 in 2012. The addition of infrastructure such as, vacuum pumps and reverse osmosis has been utilized to further increase the production of maple syrup. Nevertheless, the maple syrup yields (Liters of syrup/tap/year) have followed a declining trend over the years from 0.44 to 0.33 L/tap (**Figure 2**). Similar declines in maple production have also been reported in Quebec, Canada (Duchesne *et al.*, 2009). The recent declines in maple syrup production parallels the migration of the sugar maple range (Tang *et al.*, 2012) and an increase in winter temperatures (Betts, 2011). Overall, global air temperature have risen 0.8^{o}C since 1880, with two-thirds of the change reported since 1975 (Hansen *et al.,* 2010). These climate scenarios show a possible shift of two degrees north latitude (from 45°N to 47°N) in the sugar maple's current geographical range over the next 100 years with the replacement of maples with oak, hickory, and pine (Iverson and Prasad, 1998; Beckage *et al.,* 2008). A shift in the sugar maple's range has already occurred in the last century with areas in the United States previously tapping maples for sap (Iowa, Missouri, Tennessee, North Carolina and Virginia) in the 1860's no longer in production in 2002 (Iverson and Prasad, 2002). This migration of tree species is nothing new, and occurs as a natural response to the gradual changes in climate. However, Tang *et al*. (2012) reported that it is occurring at an alarming rate.

Climate change is suspected to affect the maple tree growth and physiology and potentially contribute to the fluctuations in maple syrup production (Duchesne *et al.*, 2009). The maple sap is collected during a six to eight week period each year from February through April. However, annual forecasts of maple syrup production are difficult to predict as the sap flow is dependent upon critical changes in temperature during this relatively short period of alternately freezing and thawing diurnal temperatures (Morrow, 1973). Optimal climatic conditions for sap production include a combination of night-time temperatures below ≤-5°C followed by temperatures above ≥5°C (MacIver *et al.,* 2006), and sub-freezing soil temperatures that delay budding onset as bud break produces a sour sap ending the sugaring season (Morrow, 1973). This once consistent spring weather pattern is becoming more inconsistent (MacIver *et al*. 2006). In maple trees, the sugar diffusion from the roots into the tree occurs as the air temperature drops causing the sap to freeze inside the branches creating a positive pressure in the stem, resulting in sap flow when thawing occurs. The exact mechanism of sap flow is not yet completely understood (Cortes and Sinclair, 1984). The shallow root system of the sugar maple also makes it particularly susceptible to these climatic changes, notably precipitation and temperature (Tyminski, 2011). By understanding the impact of climate change on the maple trees and their productivity is critical to understanding the influence on the Nova Scotia maple industry and how to mitigate its effects in order to enhance this rural economies ability to be competitive and sustainable. Therefore, this research focused on the following key objectives to:

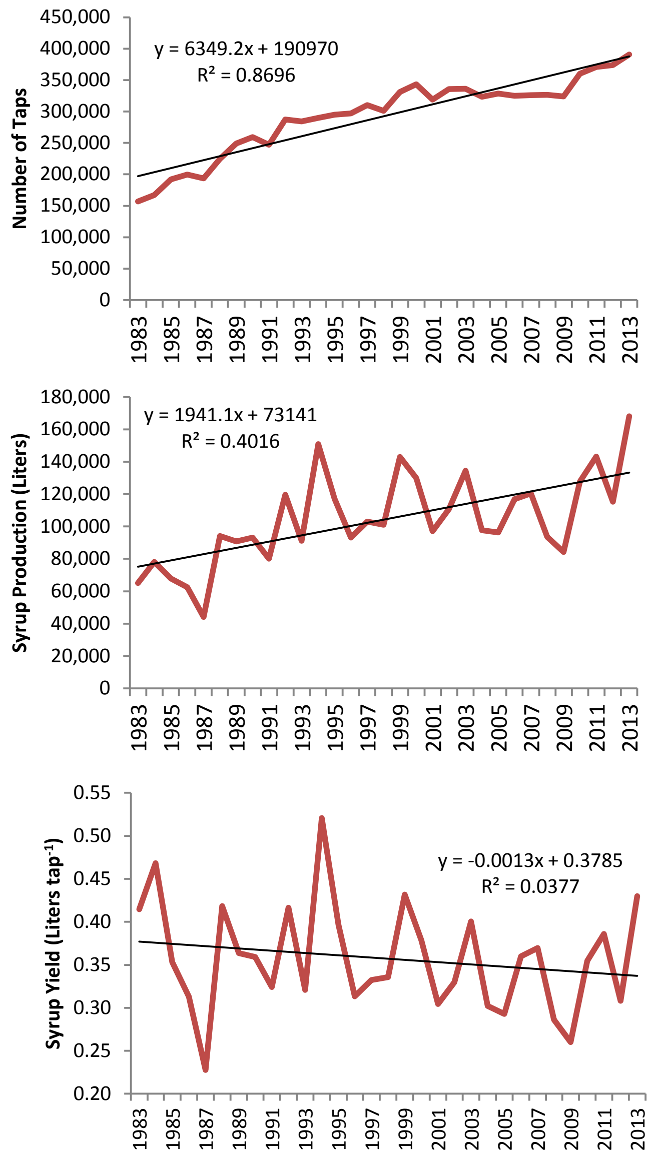

Figure 2. Maple syrup production, number of taps and yield in Nova Scotia from 1983-2013 (pers comm. Dale McIsaac)

1. determine the extent of climate change that occurred within the maple production areas of Nova Scotia and its influence on Maple syrup production;
2. investigate the linkages between weather parameters and syrup production yields and identify the nature of this relationship and to,

3. build a model to explain the relationship between key weather factors and predict the production and sap flow dates.

Methods

Climate Data

Comprehensive daily weather data consisting of minimum, maximum and mean temperature, precipitation and snow on ground (*Table 1*) was collected from six Environment Canada weather stations located in proximity to the key maple syrup sites (**Table 2**). We were limited in the proximity we could achieve to some weather stations as our syrup production sites were based on areas with available syrup data. Several of the weather stations had incomplete rows of data, which were excluded from our analysis. Based on this weather data, several weather indices were calculated: number of days that went below/above 5^{o}C, number of days below freezing, the number of freeze/thaw events (MacIver *et al.,* 2006), number of days with snow on ground and total monthly snow on ground, as well as the previous year's Effective Growing Degree Days (EGDD) (*Table 1*). These values were then transformed to their monthly means.

Table 1. Monthly climate parameters, times and their description investigated by preliminary regression analysis, for six weather stations (n=6) throughout the maple syrup regions in Nova Scotia

Climate Parameters	Time Periods	Description
Temperature	Annually, Monthly, Dec-Mar, Jan-Feb, Jan-Mar	Minimum, Maximum, Mean Temperature, and Temperature Differential
Temperature Above 5^{o}C	Annually, Monthly, Dec-Mar, Jan-Feb, Jan-Mar	Number of days with a minimum temperature above 5^{o}C
Temperature Below -5^{o}C	Annually, Monthly, Dec-Mar, Jan-Feb, Jan-Mar	Number of days with a minimum temperature below -5^{o}C
Temperature Below 0^{o}C	Annually, Monthly, Dec-Mar, Jan-Feb, Jan-Mar	Number of days with a minimum temperature below 0^{o}C
Freeze/Thaw Events	Annually, Monthly, Dec-Mar, Jan-Feb, Jan-Mar	Consecutive 3 days below -5^{o}C, followed by a day above 10^{o}C from December to March
Previous Years Effective Growing Degree Days	Annually	Number of degrees above >5^{o}C from April 1st after budburst to October 31st
Total Precipitation	Annually, Monthly, Dec-Mar, Jan-Feb, Jan-Mar	Amount of precipitation
Snow on Ground	Annually, Monthly, Dec-Mar, Jan-Feb, Jan-Mar	Amount of snow on ground from December to April, as well as the number of days from December to April with snow present on the ground.

Several of the weather sites encountered a change in their weather station equipment at least once in the last decade. This change potentially contributed to the fluctuations in the weather data. In order to successfully address this issue, initially, the Halifax International Airport weather station was chosen as a primary station for climate analysis. This particular site used the same weather station equipment and poses minimal influence of equipment on the data. The records from 1977 until 2011 were initially explored to determine if there were any climatic impacts. Once the nature of the trend was identified, other weather stations were analyzed/checked for a similar trend.

Table 2. Weather station name, climate identifier, stations position (latitude and longitude), elevation and years of daily records available.

Station Name	Climate Identifier	Latitude	Longitude	Elevation	Daily Data Records Available (years)
NAPPAN CDA	8203700	45.77	-64.25	19.8	1977-2005
NAPPAN AUTO	8203702	45.76	-64.24	19.8	2005-2013
TRACADIE	8205895	45.61	-61.68	66.7	2003-2013
HALIFAX INTL A	8202251	44.88	-63.51	145.4	1977-2011
HALIFAX STAN INT"L AIR	8202250	44.88	-63.5	145.4	2012-2013
CARIBOU POINT (AUT)	8200774	45.77	-62.68	2.4	1994-2013
CHETICAMP	8200825	46.65	-60.95	11	1977-1997
CHETICAMP CS	8200827	46.65	-60.95	43.9	1997-2013
DEBERT	8201380	45.42	-63.42	38.1	1982-2000
DEBERT	8201390	45.42	-63.47	37.5	2004-2013

In order to assess the climate changes, trend analysis for various temperature parameters were conducted. Some of these charts are provided in Appendix A. However, only the relevant findings are discussed in this report. The mean average temperature was calculated for two selected blocks of years. The first block comprised of 1978 to 1996 and the second block included years from 1997 to 2012. The year 1996 was chosen as a breaking point owing the observed changes in the weather patterns from multiple weather stations and knowledge gained from previous climate change reports. The other important parameters that significantly reflected climate change were EGDD and precipitation. A regression analysis was conducted to identify any potential changes in these parameters.

Syrup Data

Syrup production records were collected from ten (*n=10*) Nova Scotia maple producers. Data included information on annual syrup production and sap yield (Liters), number of taps, sap brix content, timing of tapping, date of first boil, and date of last boil, as well as any comments or notes regarding weather if available. Not all these parameters were available from of the producers due to the gaps in the records maintained. This incomplete nature of the data limited the analysis and scope of this study. To address this issue, selected portions of the data were used for specific analysis without compromising the quality of the results. The detail of this procedure is outline in respective sections.

The geographic location of sugar bushes, details of syrup data and distance from nearest weather station are presented in *Table 3*. Majority of the producers only recorded their maple syrup production (Litres) and not their sap production (Litres). Therefore, syrup yield was primarily used as a target productivity indicator in all of the analyses. From the data provided, we calculated the syrup yield (L/tap/yr) based on syrup production/number of taps to normalize the data. The length of the maple season (last boil-first boil) in days, and the number of days to the start and finish of the syrup season based on the Julian date were calculated from a January 1 start date for each year.

Table 3. Maple producer's site ID, syrup records collected, sites geographic location and distance from climate station.

Site ID	Syrup Records Collected (years)	Geographic Position*	Distance from Weather Station (km)*
1	2000-2013	45 32N, 62 5W	35.5
2	1991-2013	46 4N, 61 23W	45.7
6	2006-2013	45 6N, 63 9W	36.2
8	2004-2013	45 36N, 64 3W	24.12
7	1997-2013	45 25N 63 25W	28.2
9	1986-2013	45 35N, 64 11W	20.02
10	1978-2013	45 34N, 64 7W	25.15
11	2000-2013	45 34N, 64 10W	24.75
20	2010-2013	46 25N 63 25W	32.5
21	1994-2013	45 25N, 62 37 W	40.1

*Based on position and measurement designated by the Google Earth™.

Model Development Procedure

For screening the weather factors that influence syrup yield, data from the weather stations were processed to obtain the following weather parameters for each month. These parameters were chosen for two reasons: (i) based on the previous research reports and (ii) the physiological understanding of the sap flow suggest that critical weather factor(s) could reside in any month of the year.

1. Maximum temperature (^{o}C)
2. Minimum temperature (^{o}C)
3. Mean temperature (^{o}C)
4. Differential temperature (difference between maximum and minimum temperatures) (^{o}C)
5. Days below 5^{0}C (in days)
6. Freeze-thaw events (# of events)
7. Total precipitation (snow and rainfall) (in mm)
8. Snow on ground (in days)
9. EGDD of previous year (assuming this EGDD contributed to the current year's yield)- (in days)

In total, 108 input values were selected for screening. These values were matched with their respective annual syrup yields and dates of first sap flow.

Reliability of results from correlation analysis depends on the integrity of the data, completeness and size of the data. With limitations observed from the production records collected, selection of appropriate data became a critical factor. We chose the data from representative sites 10 and 9 that possessed quality records starting from 1978 until 2013. This dataset was devoid of gaps in syrup records and provided a range of values appropriate for correlation analyses. For identifying the input parameters, the correlation procedure as in SAS 9.3 was used (SAS, 2010). This procedure evaluated multiple statistical criteria such as, coefficient (R^2), *F* value and *P* values to evaluate the best multivariate combination of input parameters. Based on the results from the correlation analysis the highly correlated factors were identified.

Neural Network Model

Development of any model requires three different datasets: (i) one dataset to train and build a model (ii) second set to internally verify, calibrate the model and (iii) a third dataset to validate the built model. We segregated the data from our site 10into two sets. First set served to build the model and the second was used to calibrate the model. Independent data from Sites 9 and 6 were used to test the performance of the model. The model development was completed using the neural network application "Peltarion Synapse". This application provides an environment to select the suitable neural network architecture, selecting learning rate, converging algorithm and choose overall training strategy. Procedure followed in the step is similar to the model developed by Thiagarajan and Lada (2011). In short, aback-propagated feed-forward neural network architecture was used to build a syrup yield prediction model. Training and calibration of the model was completed with the Site 10 data and independent validation was carried out with data collected from Site 9. The training and validation efficiencies of the model were evaluated by the R^2 (forced through origin) values between the original and the predicated values.

Tree Core and Ring Analysis

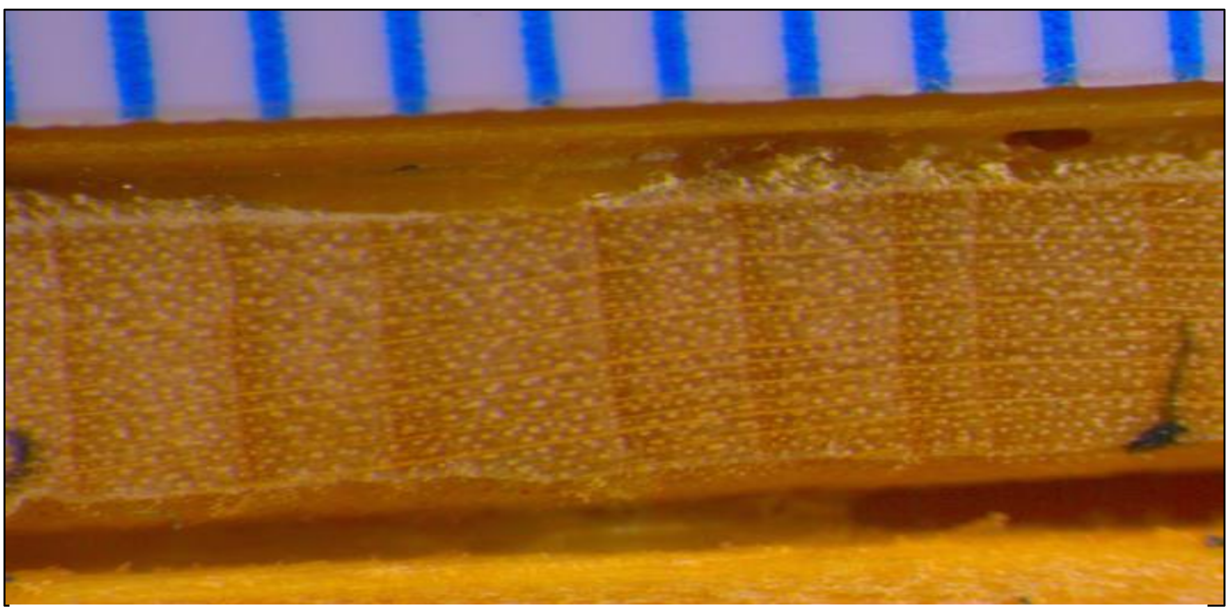

Figure 3. Tree ring analysis using Leica M80 boom microscope with camera and analyzed tree ring widths with LAS image analysis.

To analyze the effect of climate change on growth of the maple trees, a preliminary investigation on the tree rings was performed. Four increment cores were collected from four selected sites (*n=4*). These sites provided long-term maple syrup data. A 5.1 mm increment bore was used to extract the cores at breast height (1.3m from the ground) on the uphill side of the slope to avoid problems with reaction wood (Worbes, 2004; Tyminski, 2011). The cores were stored in plastic straws for transport and allowed to air dry. After collecting the cores site data was collected on average diameter breast height (DBH) of ten trees in the vicinity of the cored tree and stand density (number of trees/acre). To determine average DBH ten trees were randomly selected within the area of the cored tree. Measurements of the circumference of the tree were taken with a sewers measuring tape and converted to DBH (circumference/Π). To assess stand density a radius of 37.25 feet around the cored tree was sectioned off with flagging tape, and all trees >10.16cm in diameter were counted. Counts were multiplied by 10 to determine the number of trees per acre. Cores were allowed to air dry for one week in the straws. The cores were then mounted onto a wooden core mount with the cells aligned vertically so that the ring boundaries were visually apparent after sanding. The cores were sanded using progressively finer sandpaper, beginning with ANSI 120-grit and ending with ANSI 600-grit. The tree age and ring widths were determined using a Leica M80 boom microscope with a Leica DFC295 camera at 0.75x zoom (*Figure 3*). The images were imported into the Leica Application Suite (LAS) image analysis program to measure distance (mm) between rings.

Owing to the limitations in the small sample sizes (4 cores), only preliminary analysis on the tree rings were performed. It should be noted that multiple samples from every sample, replicated well in every site is required for corroborating the growth rings on the trees. As the resources and time planned on this analysis was limited, only a few samples were analyzed. Therefore, these results are presented with caution. As there were no corroborating rings available from each replication, only the outer 15 of the ring orders (1 being the youngest) were analyzed to avoid the variations in the age of the older rings. Tree-ring data from four sites were obtained and the mean and median values for the width of each ring from four cores from one site were obtained. The deviation from the median values was calculated and the trend plotted on a graph.

Statistical Analysis

Regression analysis was performed in MS Excel application to identify the trend line, strength and nature of the relationship. The polynomial functions and R^2 values were obtained from Excel. SAS 9.3 application was used to conduct the correlation analysis and to screen the various input parameters. An alpha value of 5% was used as the significance level. P values less than 0.05 were considered to be statistically significant for regression and correlation analyses.

Results and Discussion

Climate Data Analysis

A large pool of weather parameters from the six weather stations were initially investigated using regression analysis to determine trends in climate in the target maple producing regions of Nova Scotia. Review of the weather data indicated that many of the weather sites have seen a change in station location or a change in the station equipment (i.e. upgrade). Therefore, we initially used the Halifax International Airport’s weather data, which did not show any changes in station/placement from 1978-2011 for our investigations. From this station we determined that there have been changes in the temperature and precipitation. Changes in the climate parameters were found around the year 1996/97 to confirm this trend, the climate parameters were accessed for four (*n=4*) independent weather stations, confirming a change pre- and post-1996 time frame (data not shown).

Overall, the various temperature parameters indicated the greatest trends in climate change at our sites. Interestingly, Duchesne *et al.* (2009) also reported that temperature parameters explained 84% of the annual variation in maple syrup yields in Quebec, Canada.

A one-degree increase in temperature was determined to have occurred over the last 15 years in Nova Scotia (**Figure 4**). This increase in mean temperature is in agreement with Bonsal *et al.* (2001) who previously reported a 0.9 °C increase in the mean annual temperature across southern Canada. These findings are also in accordance with Betts (2011) and Beckage *et al.* (2008) who identified a one-degree upward shift in the mean annual temperature in Vermont, USA. An upward shift of even one-degree poses a significant impact on the climate. This increase could reduce the length of the cold season (tree dormant season) and increase the length of the warm season (growing season) and accumulated growing degree days. When we observed the mean annual summer and winter temperatures at these weather stations, the mean temperature during the winter months (December-February) were increasing more than the rate found during the summer periods (June-August). In particular, the mean temperature during the winter months recorded a 1.79°C increase, whereas the summer months recorded only a 0.61°C increase *(Figure 5)*. This specific trend between the winter and summer months are corroborated by Betts (2010) from his studies conducted in Vermont, USA. However, they reported a 2.5°C increase during the winter months (December-February) and a 1.1°C increase during the summer months (June-August). Our results are limited as they are only for 5 weather stations. Further investigation into the effects of climate on temperature revealed that the minimum annual temperature has shown an increasing trend from 1.4°C pre-1996 to 2.7°C post-1997, with a significant increase ($p \leq 0.001$, $R^2 = 0.3158$) during the summer months (Jun-Aug) and no change during the winter months (Appendix 1). The maximum annual temperature did not show any trends for its annual mean or during the summer or winter months (**Figure 5**).

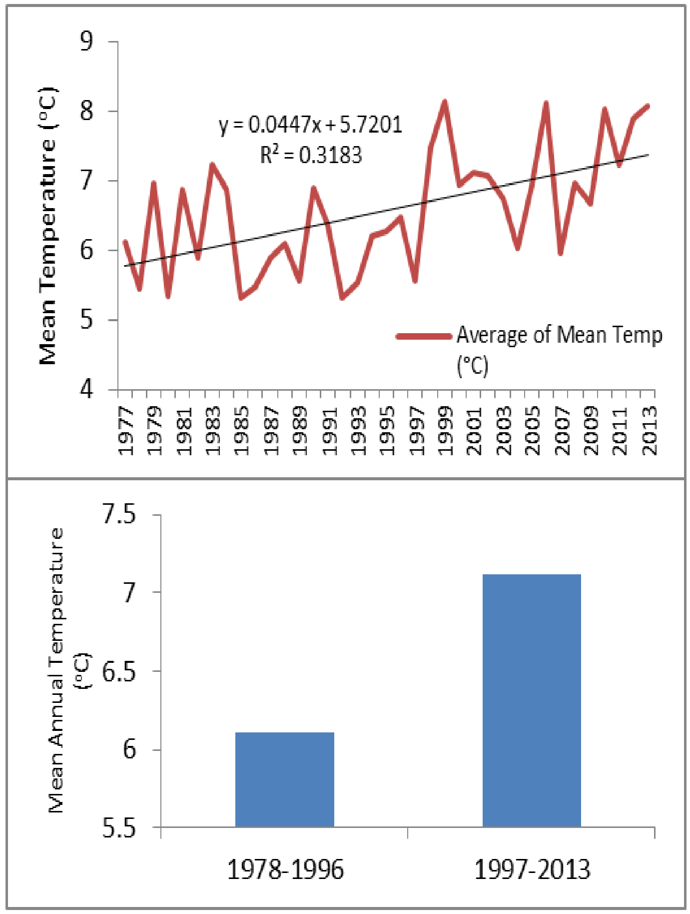

Figure 4. Annual mean temperature for five weather station sites (n=6) within Nova Scotia with linear regression (above) and the mean annual temperature increase pre and post 1997 (below).

> ***"Our initial investigations identified that the Nova Scotia climate has been changing. There is a one-degree increase in mean temperature in the last 15 years"***

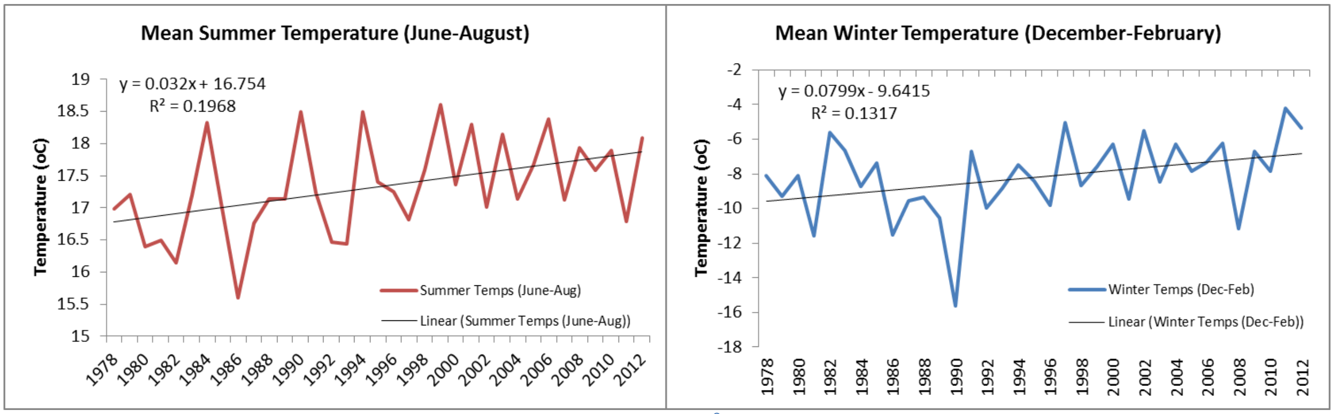

Figure 5. Mean annual summer (left) and winter temperatures (°C) (right) for six weather stations in Nova Scotia, Canada.

Exploration of the effect of these temperature changes on the number of days below freezing (0°C), and below -5°C and above 5°C were also investigated (*Table 4*). These parameters have an important impact on sap flow as air temperatures are required to go below freezing at night and above freezing during the day. If the number of days below freezing is reduced, sap production could be diminished; and if the days above 5°C increases it can cause the sugar maple trees to come out of dormancy ending the sugaring season (MacIver *et al.*, 2006). From the parameters we investigated we did not identify a change in the Days Below -5°C (*Table 4*). There was however an increase in the mean number of days above 5°C ($p=0.038, R^2=0.1556$). There was no such effect during the winter months. A slightly ($p=0.061, R^2= 0.1018$) decreasing trend in the number of days below freezing was observed (*Figure 6*), though again when we investigated the effect during the winter months, no further trends were identified (*Table 4*).

Generally, there is a trend towards warming temperature conditions with a one-degree increase in the mean annual temperature and a increase in the number of days above 5°C and decreasing number of days below zero. Interestingly, there was no effect on the number of days below -5°C.

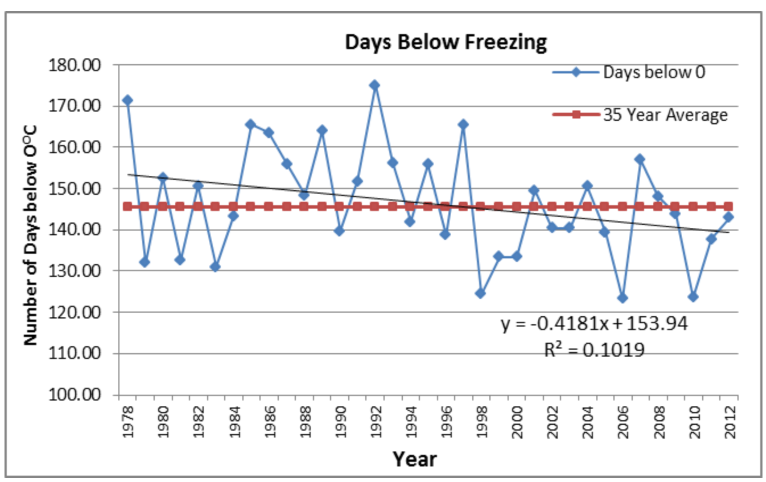

Figure 6. Mean number of days below freezing (<0°C) compared to the 35 year period from 1977-2012 for five weather station sites in Nova Scotia.

Table 4. List of climate parameters analyzed to assess changes in Nova Scotia's weather in the maple syrup prodyuction regions *p*-value significant at ≤0.05.

Climate Parameter	Time Period	*F*	*P-value*	R^2
Mean Temperature	Annual	16.33	0.000	0.3183
Mean Temperature	Dec-Feb	5.01	0.032	0.1317
Mean Temperature	Jun-Aug	8.08	0.008	0.1967
Mean Minimum Temperature	Annual	12.83	0.001	0.2800
Mean Minimum Temperature	Jan-March	2.51	0.122	0.0700
Mean Minimum Temperature	Jun-Aug	15.23	0.000	0.3158
Mean Maximum Temperature	Annual	0.68	0.416	0.0220
Mean Maximum Temperature	Jan-March	3.62	0.067	0.1075
Mean Maximum Temperature	Jun-Aug	0.44	0.512	0.0140
Temperature Differential	Annual	2.99	0.093	0.0831
Temperature Differential	Jan-March	1.29	0.265	0.0375
Temperature Differential	Jun-Aug	6.66	0.014	0.1680
Days Below -5°C	Annual	1.22	0.277	0.0357
Days Below -5°C	Jan-Mar	0.64	0.429	0.0190
Days Above 5°C	Annual	4.68	0.038	0.1556
Days Above 5°C	Jan-Mar	0.16	0.689	0.0049
Days Above 5°C	Mar	1.04	0.315	0.0305
Days Below 0°C	Annual	3.74	0.061	0.1018
Days Below 0°C	Dec-Mar	0.64	0.428	0.0191
Days Below 0°C	Jan-Mar	0.05	0.825	0.0014
Days Below 0°C	Jan-Feb	0.01	0.929	0.0002
Days Below 0°C	Feb	0.17	0.682	0.005
Days Below 0°C	Mar	0.08	0.775	0.0025
Effective Growing Degree Days	Annual	6.09	0.019	0.1482
Freeze/Thaw Events	Annual	0.01	0.932	0.0002
Freeze/Thaw Events	Dec	0.97	0.332	0.0002
Freeze/Thaw Events	Jan	0.97	0.331	0.0286
Freeze/Thaw Events	Feb	0.27	0.608	0.0078
Freeze/Thaw Events	Mar	1.14	0.292	0.0320
Freeze/Thaw Events	Jan-Mar	0.00	0.973	0.0000
Freeze/Thaw Events	Feb-Mar	0.35	0.560	0.0100
Total Precipitation	Annual	3.63	0.065	0.0989
Total Precipitation	Apr-Nov	0.71	0.150	0.0040
Total Precipitation	Jan-Feb	10.56	0.003	0.2420
Total Precipitation	Jan-Mar	15.24	0.008	0.1940
Total Precipitation	Mar	3.59	0.592	0.0090
Total Precipitation	Jun-Aug	0.11	0.067	0.0980
Total Precipitation	Aug	0.03	0.740	0.0030
Mean Snow on Ground	Annual	4.88	0.873	0.0010
Mean Snow on Ground	Jan-Mar	1.00	0.034	0.1290
Mean Snow on Ground	Jan-Feb	1.35	0.324	0.0290
Mean Snow on Ground	Feb	1.33	0.254	0.0390
Mean Snow on Ground	Mar	0.19	0.258	0.0386
Snow on ground (Days)	Annual	0.02	0.663	0.0058
Snow on ground (Days)	Jan	0.09	0.887	0.0001
Snow on ground (Days)	Feb	0.86	0.765	0.0027
Snow on ground (Days)	Mar	0.00	0.361	0.0253

As expected, the rise in temperature resulted in an increase in effective growing degree days (EGDD). The cumulative EGDD from April 1 to October 31 (MacIver *et al.* 2006) are presented in **Figure 7**. Regression analysis of the EGDD over the years since 1977 produced a positive linear regression ($p=0.019$, $R^2=0.1482$) (Appendix 1), indicating an increase in the EGDD in Nova Scotia. A 35-year average EGDD (1759) was calculated for the period 1977-2012 and is shown as a flat line on the graph (**Figure 7**). Values above this line indicate that there has been an increase in EGDD above the 35-year average. In general, since 1997 the EGDD has been increasing at our weather station sites across Nova Scotia by an average of 100-124. The implications of this rise in EGDD can be complex and multi-faceted. In maple trees, higher EGDD promotes tree growth and has a positive effect on the sap production in the following season as carbohydrates are stored in the form of starch, which is later converted to sucrose and dissolved in the sap (MacIver *et al*., 2006). On the other hand, an increase in EGDD means decreased snow cover on ground, disturbances in the freeze-thaw cycle durations and a potential shift in the sap flow dates.

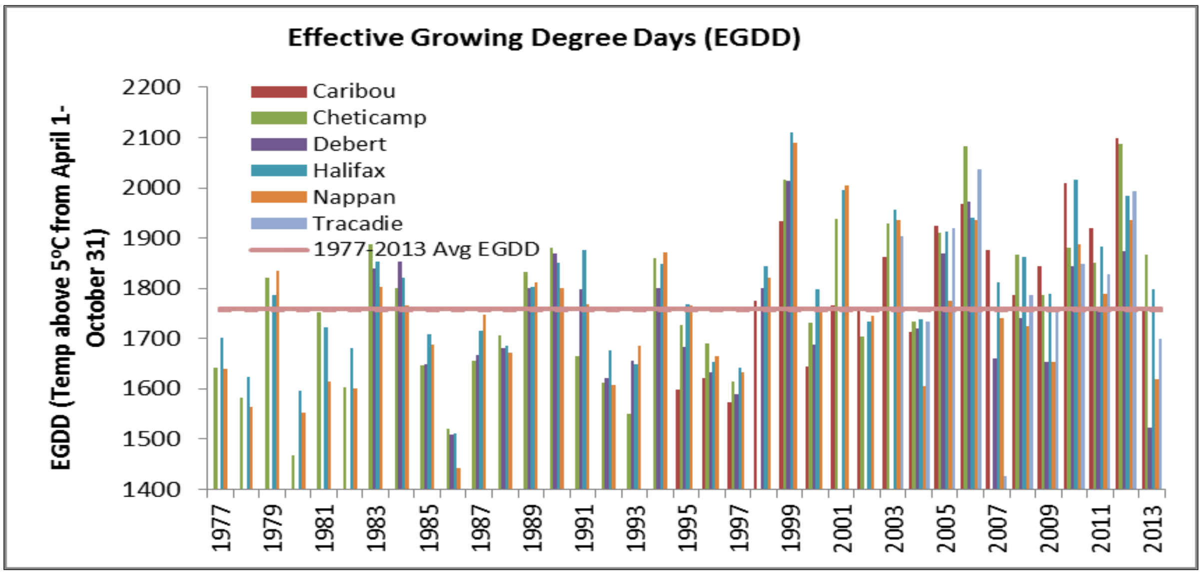

Figure 7. Previous year's effective growing degree days (EGDD) observed from 1977 to 2013 from six weather stations located in Nova Scotia, Canada.

No trends in the freeze/thaw events as noted by MacIver et al., (2006) were observed at our stations, however our parameter may have been too strict or the conversion of our data to monthly records may have concealed these effects.

However, annual precipitation data from five weather stations indicated a moderately negative linear trend since 1978 ($p=0.065$, $R^2=0.0989$). There was a significantly negative trend in the amount of precipitation occurring during the winter months

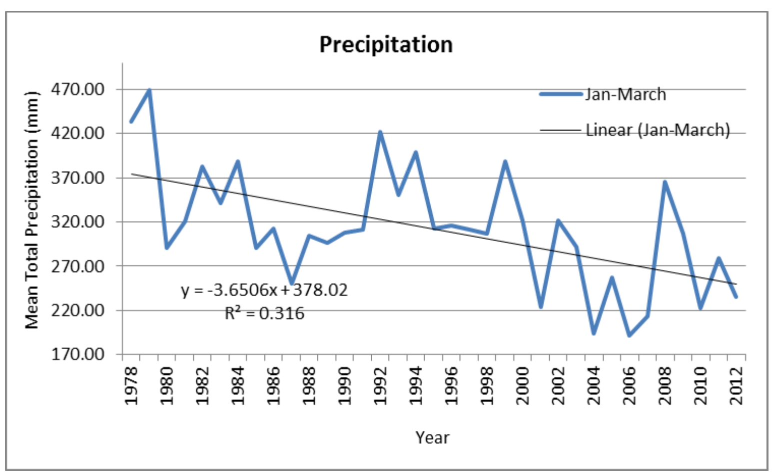

Figure 8. Regression analysis of the mean total precipitation (mm) between January and March from 1978-2012 for six weather station sites (n=6).

(Jan-Mar) (*p=0.000, R^2=0.3160*) (*Figure 8*). However, we were unable to discriminate between a snow or rain event, only as a precipitation event from the data. As the number of days below freezing (see above) has decreased, it could result in more rain events than snow events. There was no trend in the amount of precipitation during the summer months (*Table 4*). Previous studies indicate that precipitation during the summer months can be critical to growth and ability for the tree to accumulate starch for sap production (MacIver *et al*., 2006).

We investigated the trends in snow cover over the 35 year period (1977-2012) at four of the six weather stations to assess if there have been any significantly changes. Snow cover is an important aspect as it acts as an insulator preventing the sugar maples shallow roots from freezing, as well as providing moisture. Evaluation of the mean snow on ground indicated a significant increasing trend (*p=0.03, R^2=0.1290*) in the mean amount of snow present on the ground (*Figure 9*). However, further investigation revealed a polynomial trend, indicating that there was a period of decreased snow, which has now reversed since 1999. Longer data sets need to be analyzed to confirm these results. No other trends were observed in respect to the amount of snow on ground or the number of days with snow on ground (*Table 4*).

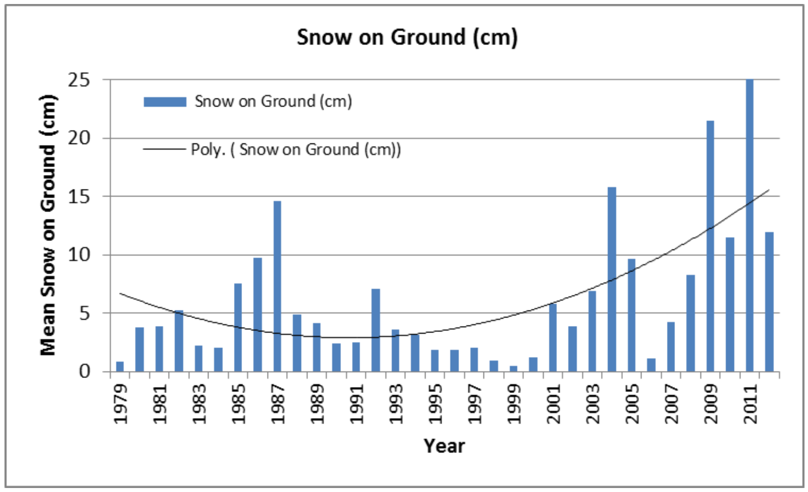

Figure 9. Mean annual snow on ground (cm) for four weather stations in Nova Scotia.

Impacts of Climate Change on Syrup Yields

Unfortunately, the increase in EGDD throughout Nova Scotia coincides with a progressive decline in syrup yields (**Figure 10**). The syrup yields ranged around 0.6 (L/tap) in 1980s and currently have dropped to around 0.35 L/tap in 2013. There has been a 40-50% drop in sap yield during this period. The EGDD was around 1800 in 1980s and now has escalated to around 2000 degree days. There is an average increase of at least 100-125 degree days during this period. Trend line analysis showed a significant correlation between both these observations. The increased EGDD seemed to have negatively affected the syrup yields across Nova Scotia. Apart from this, a shift in the entire tap season appears to have occurred in Nova Scotia. Due to only a few

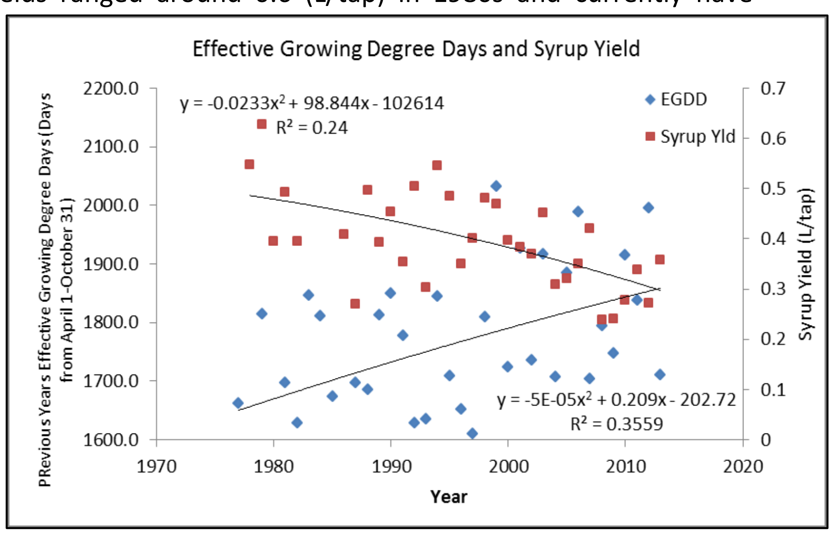

Figure 10. The previous year's effective growing degree days (EGDD) calculated from April 1 to October 31 plotted against the Nova Scotia maple syrup yield (L/tap) from 1977 to 2013.

data instances available prior to 1990, it is difficult to make any definitive conclusions. Therefore, the findings are presented with caution. The regression analysis fitted with a polynomial function (*P<0.05*) indicates that the season is starting earlier now compared to the 1980's. This trend is based on data obtained from six producers (n=6). The average start and end dates of the maple season from 1986-1990 were between 77.8 to 109 Julian days (Julian days are days counted from January 1) which ranged from March 16-23 to April 17-21. Whereas, the average start and end days to the maple season from 2009-2013 were reported as days 65.5 to day 101.6 from January 1, with a range of March 6-11 to April 3-22. A shift of 5 days was noticed in this period. Sajan (2005) reported that in Ontario, Canada the first boil date was March 24 in 1960s, but has advanced to March 7 in 2002 (MacIver *et al*. 2006). The maple season start and end dates in Vermont, USA are reported to have shifted 7 to 10 days earlier than 40 years ago, and that the season length (number of flow days) is decreasing (Perkins, 2007).

> ***"Syrup yields are declining in Nova Scotia along with increasing EGDD indicating a potenital negative effect of climate change"***

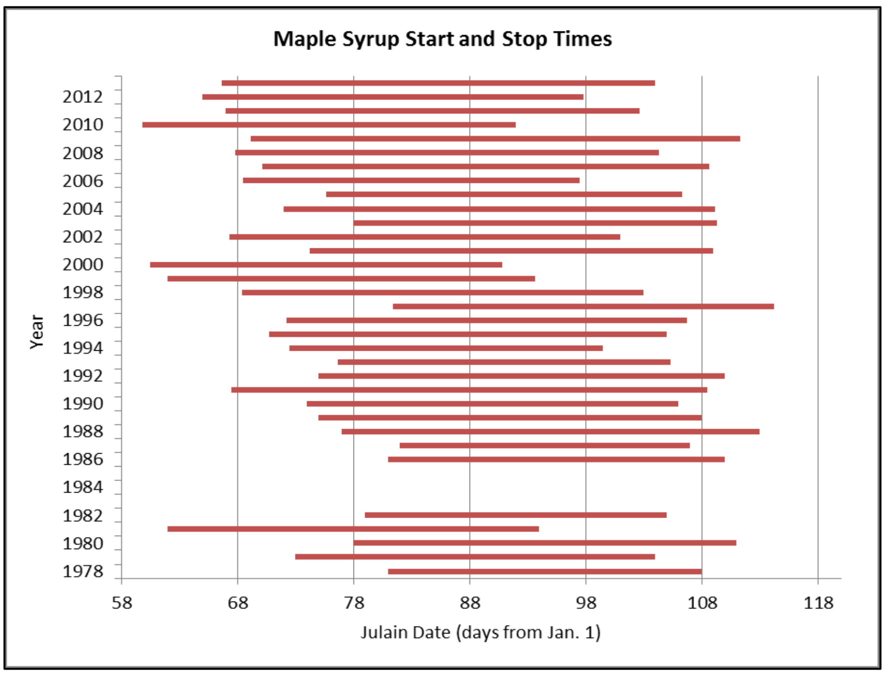

Figure 11. The change in the maple syrup season start and end date from 1978 until 2013, though the duration of the season has not changed.

Nevertheless, based on the records of the six *(n=6)* producer's, there does not appear to be a change in the duration of the maple season (p=0.906) (Figure 7) in Nova Scotia. The average season's length is approximately 34 days, with a standard deviation of 8.6 days due to the variations in seasons and sites. Again, caution must be exercised when regarding this data as the sample size *(n=6)* is relatively small and only one producer had long-term records back to 1978. The average season's length is lower than reported in the Maple Production Informatics and Maple Syrup Chemistry Report (Lada and Nelson, 2013) due to the smaller sample size.

Input Parameters

Stepwise regression (forward) analysis revealed that six of the 108 input parameters highly correlated with the syrup yields where R^2 value reached 0.80. The R^2 values of the analysis are depicted in Table 5. Even though original analyses involved multiple cycles, only the first 25 cycles are shown in this report (Table 5). Although, the R^2 values continued to climb as more factors were included in the model, the incremental value of the added factors did not justify the addition of the parameters. Accordingly, the first six factors were chosen as potential input parameters. The factors that strongly influenced the syrup yield are as follows:

1. Temperature difference in January (^oC)
2. Freeze-thaw events in April (# of events)
3. Freeze-thaw events in May (# of events)
4. Freeze-thaw events in October (# of events)
5. Total precipitation (mm) in January
6. Total precipitation (mm) in July

Although the exact mechanisms of how these parameters may influence syrup yield are not fully known, we hypothesize that these parameters possess significant physiological effects on syrup production. The temperature difference in January is likely linked to thawing and sap flow. It is interesting to note that the freeze thaw events play a major role in determining the syrup yields. The events in April could be directly linked to the sap flow dynamics. Nevertheless, the exact role of these events in May and October remains unknown. Total precipitation in January possibly relates to the amount of snow fall received and this must have a direct influence on the depth of snow, and snow cover affects root physiology and biophysical factors associated with sap flow. The precipitation received in July can be assumed to be rainfall that contributes to the foliage growth of the maple trees. Intensive research investigating the specific aspects of weather parameters and sap flow dynamics are required to understand the nature of these complex relationships.

A similar procedure was followed for predicting the start date of the sap flow using SAS and three input parameters were identified. The parameters identified are as follows:

1. Maximum temperature in March.
2. Mean temperature in February
3. Snow on ground in November

These parameters significantly correlated with the start date with a P value of <0.01 and an R^2 value of 0.85.

Table 5. Step wise regression analyses results for various weather parameters and syrup yields.

Step	Variable Entered	Number Vars In	Partial R-Square	Model R-Square	F	Pr > F
1	Total precipitation in January	1	0.3597	0.3597	16.29	0.0004
2	Freeze-thaw events in October	2	0.1051	0.4648	5.50	0.0263
3	Total precipitation in July	3	0.0877	0.5525	5.29	0.0294
4	Differential temperature in January	4	0.1205	0.6729	9.58	0.0047
5	Freeze-thaw events in May	5	0.0712	0.7441	6.95	0.0142
6	Freeze-thaw events in April	6	0.0612	0.8053	7.55	0.0112
7	Differential temperature in July	7	0.0528	0.8582	8.57	0.0076
8	Mean temperature in August	8	0.0280	0.8861	5.41	0.0297
9	Snow on ground in October	9	0.0253	0.9114	5.99	0.0232
10	Days more than 5°C in December	10	0.0184	0.9298	5.24	0.0330
11	Differential temperature in March	11	0.0227	0.9525	9.07	0.0072
12	Total precipitation in February	12	0.0140	0.9665	7.52	0.0134
13	Previous year EGDD-October	13	0.0152	0.9817	14.18	0.0015
14	Days below 0°C in May	14	0.0062	0.9879	8.21	0.0112
15	Days below 5°C in April	15	0.0027	0.9907	4.41	0.0531
16	Freeze-thaw events in February	16	0.0026	0.9932	5.28	0.0375
17	Snow on ground in November	17	0.0026	0.9958	7.91	0.0147
18	Total precipitation in April	18	0.0011	0.9969	4.25	0.0617
19	Total precipitation in September	19	0.0011	0.9979	5.66	0.0366
20	Differential temperature in April	20	0.0007	0.9987	5.74	0.0376
21	Total precipitation in April	19	0.0002	0.9985	1.21	0.2963
22	Snow on ground in March	20	0.0008	0.9993	11.36	0.0071
23	Maximum temperature in June	21	0.0004	0.9997	15.15	0.0037
24	Previous year EGDD in August	22	0.0001	0.9999	10.69	0.0114
25	Days above 5°C in March	23	0.0001	1.0000	11.71	0.0111

Syrup Yield Model

The neural network followed a back-propagated, feed-forward, architecture with 6 input nodes representing the six chosen input parameters (*Figure 12*). There was one hidden layer yielding same number of output nodes. One output value, syrup yield (L/tap/year) was selected to be modeled. Therefore, the output layer received 6 input nodes and yielded one output node with absolute values. The approximation function used was "tanh sigmoid" as this choice offered a convergence of input and output parameters. A total of 1000 epochs (training cycles) was performed to reach the convergence. The (momentum) learning rate was set at 0.7 and 40% of the data from Site 10 was reserved for calibration purposes. The rest of the data was used to train the model with a batch size of 9 cases per cycle. The error was analyzed in terms of their absolute values and normal distribution behavior. Based on the fitness of the predicted and actual values from the internal validation set (calibration set) *(Figure 13*), the model was chosen. For developing the start date model, a similar architecture was use however, only three input parameters were used. The selected parameters were maximum temperature in March, mean temperature in February and snow on ground in November. This model required 5000 epochs to converge. All other parameters remained the same.

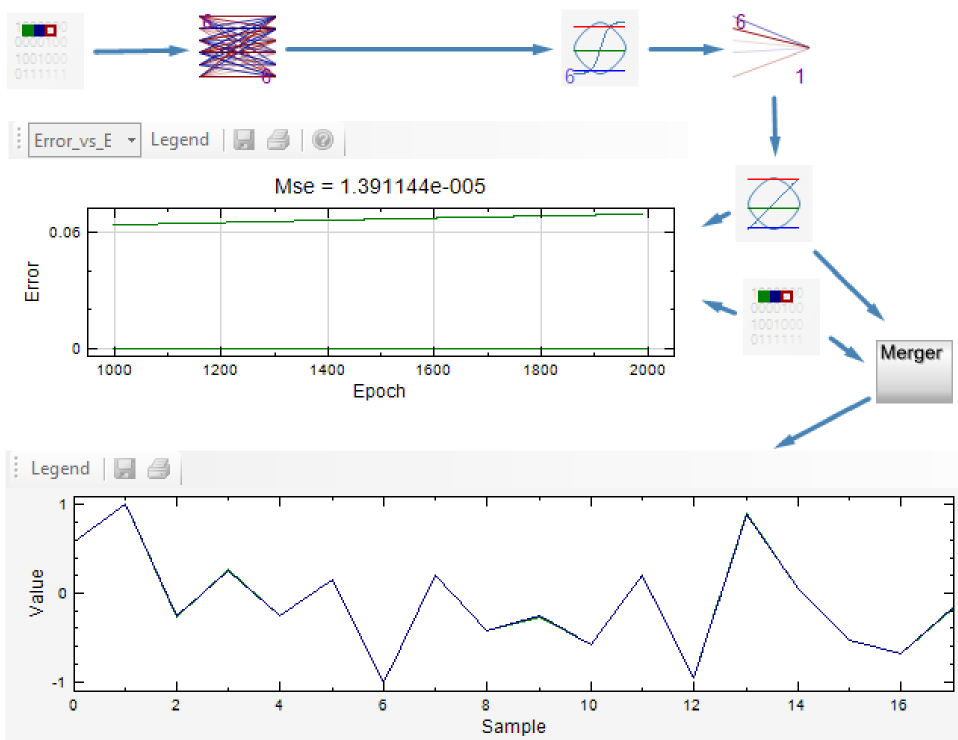

Figure 12. Illustration from Peltarion Synapse depicting the neural network architecture used for the syrup yield model. The top layer (from top left) shows the input dataset, input weight layer, function layer, hidden layer and output layer. The middle graph shows the mean square error of predictions. The bottom graph shows the convergence of observed data and the prediction data for each sample.

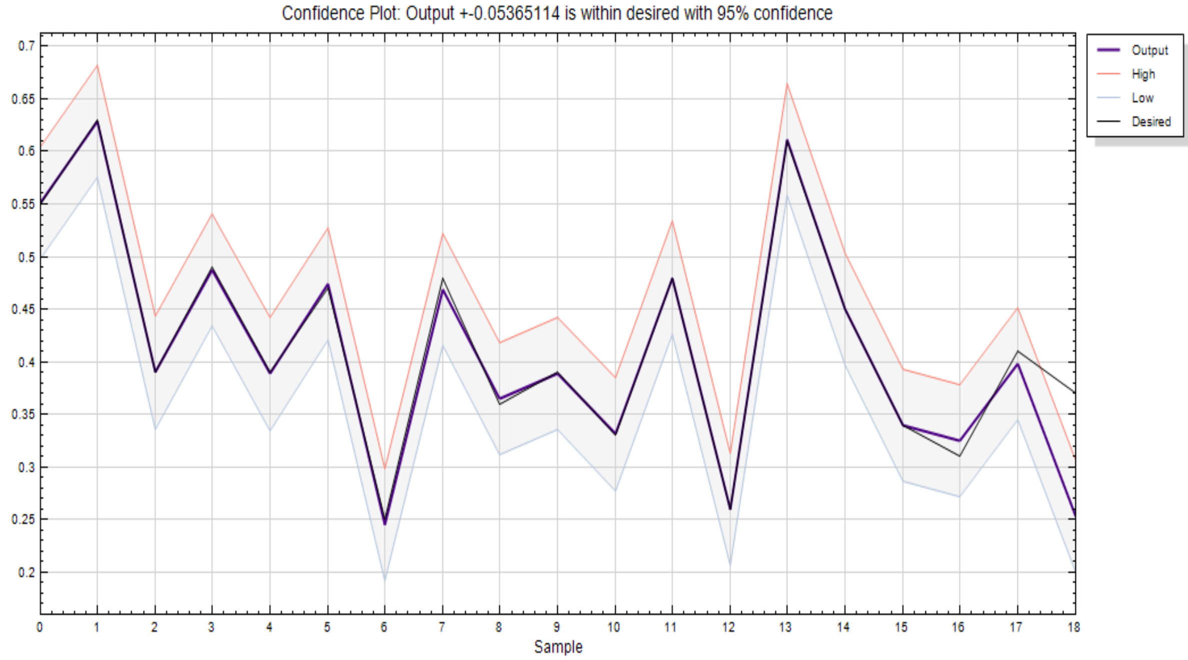

Figure 13. The fitness characteristics of the neural network based on the training set. The X-axis indicates the sample #, y axis represents the syrup yield values (L/tap/yr). The violet line is built on predicted values and the black lines are original values. The red and blue lines represent the upper and lower 95% confidence interval values.

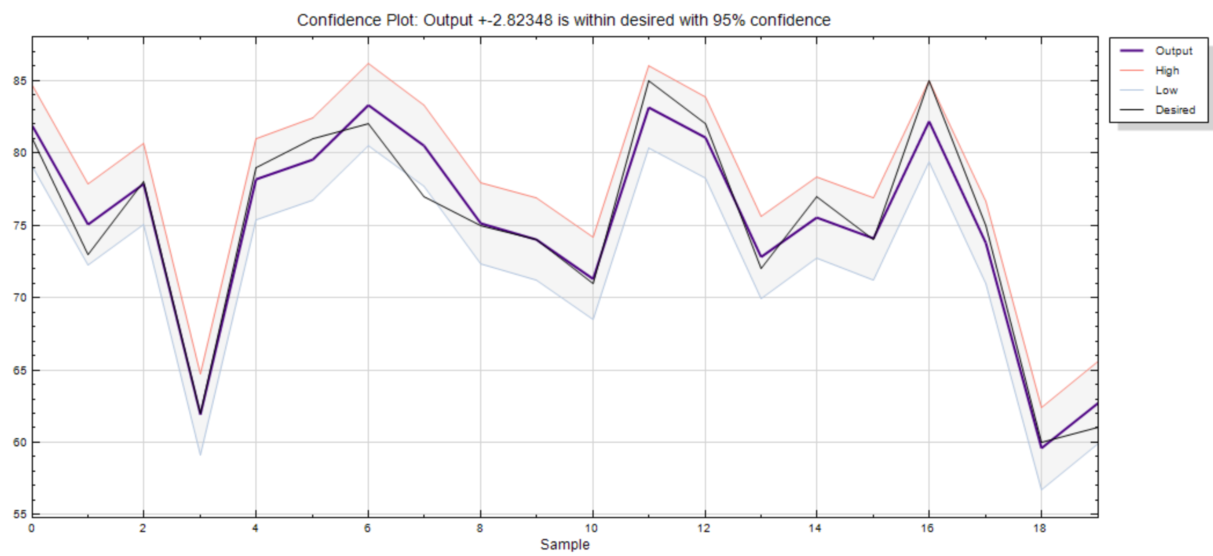

Figure 14. *The fitness characteristics of the neural network based on the training set for start date of the season. The X-axis indicates the sample #, y axis represents the Julian day values. The violet line is built on predicted values and the black lines are original values. The red and blue lines represent the upper and lower 95% confidence interval values.*

Performance of the Model

As illustrated in the *Figures 11 and 12* the training and internal validation data converged well after 5000 epochs. This behavior assures the potential that is lying with the selected weather parameters and the modeled factors.

Upon development of the syrup yield model, external validation was conducted with Site 9 and C. These two sites were chosen due to the data completeness and their integrity. Figure 13 represents the performance of the model in predicting the yields of Site 9. The model performed with an R^2 value of 0.45 and under-predicted the yields by ~23% (*Figure 15*). The Site 9 was geographically near to Site 10. The proximity in geography positively influenced the performance of the model.

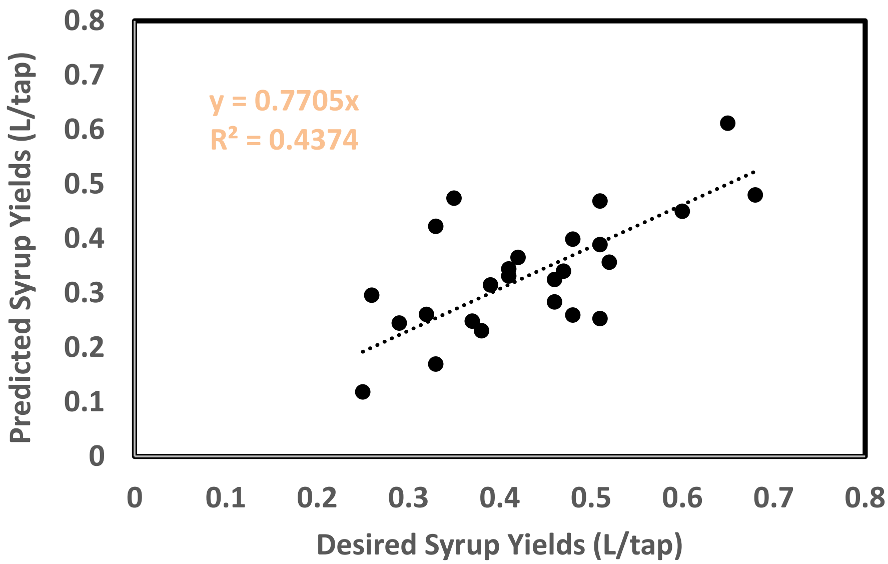

Figure 15. External validation of the syrup yield based on Neural network architecture. The R2 value of 0.43 indicates a moderate performance of the model in predicting the yield of an independent Site 9.

Nevertheless, when the validation was attempted for Site 6, the performance of the model suffered significantly and the R^2 was merely 0.23% (*Figure 16*). The slope value was close to 1, however the precision was poor. It should be noted that Site 6 was a distant location from Site 10. When these two validation results are taken together, the behavior of the model indicates that weather parameters hold a potential to predict the sap yields in Nova Scotia. Nevertheless, the inconsistent performance among different sites suggests two major limitations: (i) capability of the model is dictated by the small sample size of the input data, and (ii) a site-level calibration may be necessary to improve the model performance. Large data sets offers opportunity for the model to learn the width and breadth of the input parameters and adapt to various challenges. Site-level calibration allows a model to fine-tune their weight values to fit the changes that are unique to the micro climatic zones.

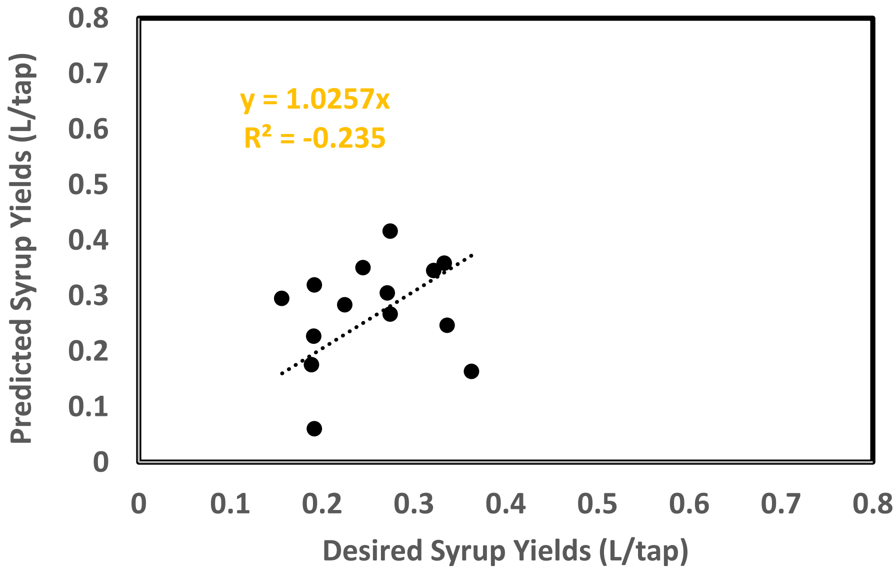

Figure 16. External validation of the syrup yield model based on Neural network architecture for independent site 6. The R^2 value of -0.23 indicates a relatively poor performance of the model.

For the season start date model, the external validation was performed with the data collected from Site 9. This site alone provided 19 years of season start date with no significant delay in flow or gaps in weather data. An x-y scatter plot was forced intercept of 0 was attempted to assess the performance of the model.

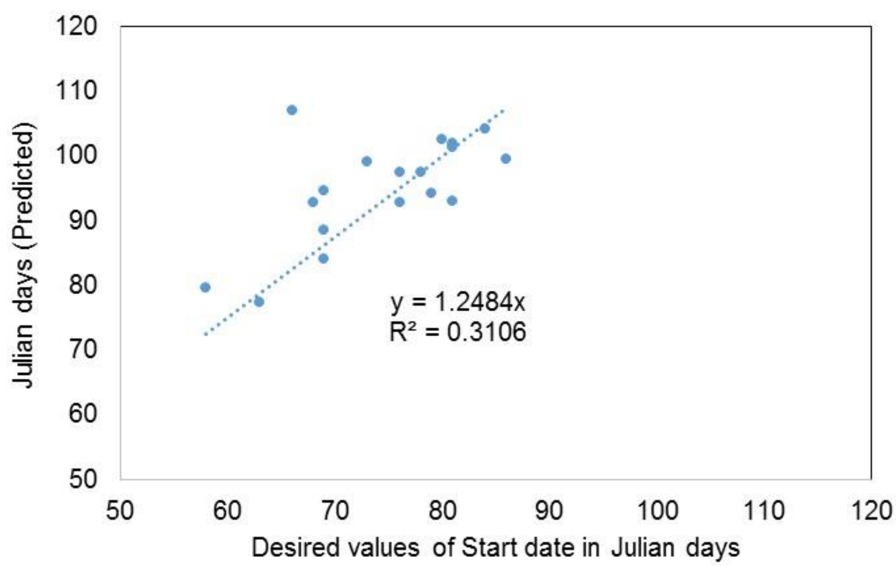

Figure 17. Scatterplot of season start date model for Site 9 for validation of the results.

The external validation curve indicated that the model performed moderately well (R^2=0.31) in predicting the values. The model over-predicted the season start date by around 25% and the strength was only moderate. Since the microclimatic influences can be strong in changing the sap flow date, calibration of the model to the local conditions may significantly improve the model's performance. Based on our results, these two models hold potential for future development with more robust data from multiple locations. In order to achieve this, proper on-site records should be collected and maintained in a database.

Tree Ring Analysis

Each group of bars in the charts represents the four cores in that year (*Figure 18*). The line 0 represents the mean or median value. The positive deviation (%) indicates ring growth above average and a negative value indicates a below average growth for the tree. Cores 1 and 2 appeared to have larger fluctuations in their growth when compared to cores 3 and 4. Core 4 showed a minimal growth deviation from the mean and median values (*Figure 18*). This phenomenon emphasizes the

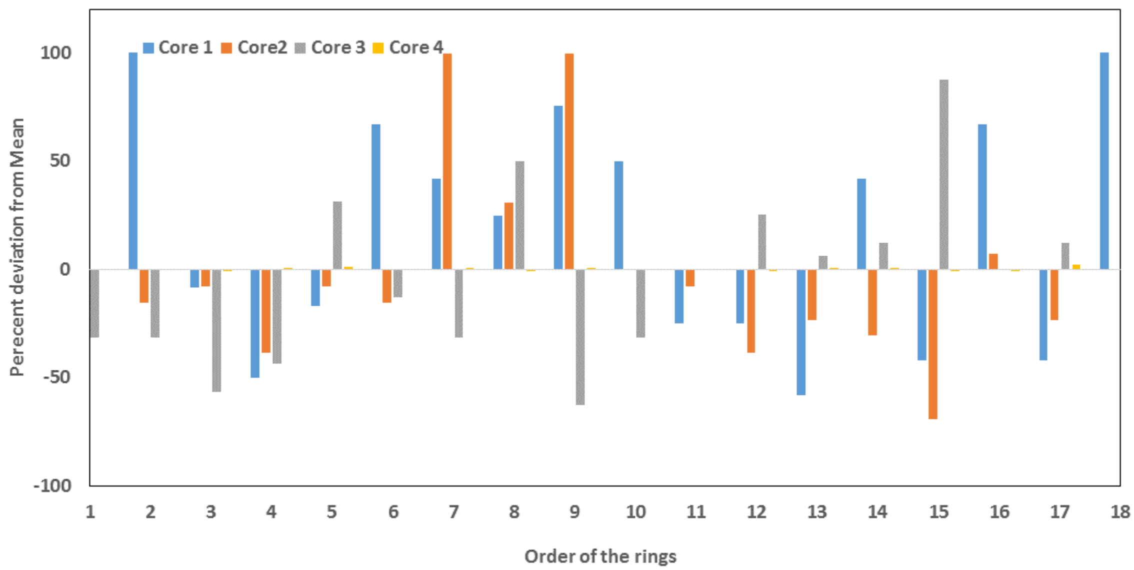

Figure 18. Percent deviation of the ring growth from the mean value observed in four cores for the last 18 years. Each bar represents value from a core from a separate site.

importance of multiple sampling. When the effect of each year on the growth where ascertained, it appears that the growth rings followed a similar pattern with certain exceptions. For example, in Year 1 all of the cores either showed a negative or 0 growth from the mean. Similarly, Year 11 and 12, all of the cores showed a negative or 0 deviation from the median growth (*Figure 19*). Nevertheless, this overall trend of positive and negative deviations is not completely intact across all years. To avoid these errors, large core sampling and an intensive study of growth patterns matched with weather parameters is required.

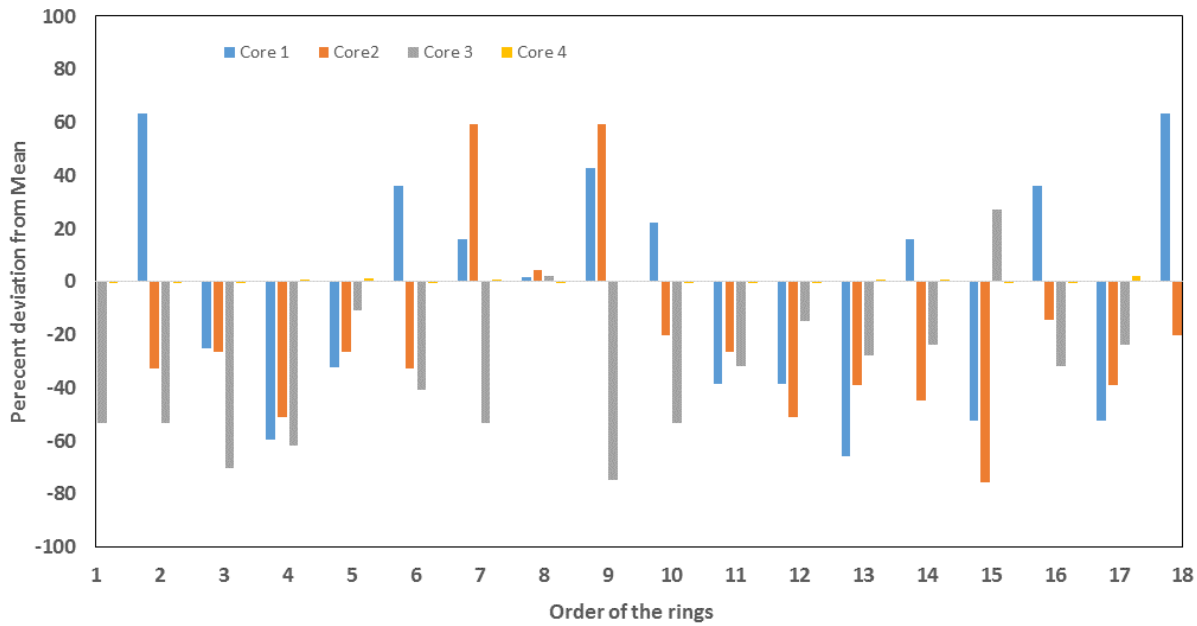

Figure 19. Percent deviation of the ring growth from the median value observed in four cores for the last 18 years. Each bar represents value from a core from a separate site.

Based on the tree core width analysis, the average age of the stands ranged from 50-80 years. This corresponded with the estimated age of the stands provided by the producers, except for one where the stand age was stated to be greater than 100 years. However, caution must be advised due to the limited number of cores collected. The mean diameter breast height (DBH) was 27.25cm with a standard deviation of 7.79 cm for all sites. The mean incremental growth of the tree core rings ranged from 1.5 to 2.5 mm.

When we compared the growth of our sample trees to other sugar maple areas we found conflicting information. Godman *et al*., (2009) stated that the average DBH (cm) for a medium and good site for sugar maples in the Lake States, USA fell between 14 and 29 cm for 40 and 80 year old stands, respectively. From our data, our trees diameter growth fell within the parameters of this (Table 3). However, Luzadis and Gossett (1996) stated that in the New York State area (USA) maple trees average approximately 5.24cm of diameter growth annually for the first 30 to 40 years, resulting in a 30 year old tree averaging 76.2 to 101.6 cm. However, upon investigation the diameter growth at our sites ranged from 12.4 to 54.8 cm, which is considerably lower than the above values.

Table 6. Mean diameter breast height (DBH) of well-stocked stands of northern hardwoods in the Lake States dominated by Sugar Maple.

Stand Age (yr)	Mean DBH (cm)
Good site	
40	19
80	29
120	38
Medium site	
40	14
80	24
120	31
Poor site	
40	10
80	19
180	25

Conclusions

1. Based on the available data, there is an increase of ~1°C in the mean annual temperature in Nova Scotia. The largest increase in temperature appears to occur during the winter months (Jan-Mar), compared to the summer months (Jun-Aug). The minimum temperature is increasing with the number of days below freezing (0°C) and the number of days above 5°C increasing at our sites. The effective growing degree days has been increasing steadily in the last 15 years and Nova Scotia is experiencing 100-125 more degree days than those typically recorded in 1980s.

2. There has been a decrease in the amount of precipitation, particularly in the winter months; however this cannot be fully attributed to less snow or rain without further investigation. Interestingly, the amount of snow remaining on the ground appears to be increasing, this appears to have only occurred since the mid-1990. Further understanding of these associations is needed.

3. These weather factors in combination negatively affected the sap yield and shifted the sap flow season earlier. In general, the increase in EGDD paralleled the progressive decline in sap yield. Sap yield was reduced by 40% and the season has advanced by 5 days in the last 15-20 years. Nevertheless, the season length remains largely unaffected.

4. Temperature difference in January, number of freeze-thaw events in the months of April, May and October, total precipitation received in January and July showed a strongly correlated with syrup yields ($P<0.001$, $R^2=0.8$) . Neural network model that used these input parameters predicted the syrup yield of an independent site with moderate accuracy (45%).

5. Start date was strongly correlated with February mean temperature; Maximum temperature in March and Snow on ground in November. The model performed moderately well with a R^2 value of 0.31. Limited availability of season start data from same location limited further exploration of the model. Calibration at each geographic location or climatic zones will greatly improve the performance of the model.

6. Preliminary tree-ring analysis showed a moderately consistent growth pattern among different sites across years. With preliminary analysis of the tree growth and diameter breast height, it appears that the maple trees in Nova Scotia are growing slowly, despite increases in EGGD. Intensive sampling of tree rings is needed to gain a solid understanding of the climate effects on tree growth.

Limitations/Issues

1. Stands in Nova Scotia are denser (220+ trees/acre) compared to other production areas (80-120 trees/acre) and this discrepancy can influence the findings to a certain extent.

2. Maple syrup data available from the producers were incomplete in several ways and the records for yesteryear are very limited. Our longest record went back to 1978; however, the majority of our records were after 2000. This limited the sample size for analysis and findings could be confounded by this effect.

3. Previous studies have also used raw maple syrup production as their variable of interest (Whitney and Upmeyer, 2004). However, maple syrup production is not only sensitive to climate, but to economic, social and political policies (Tyminski, 2011). To remove the variation in production caused by non-climatological factors sap yield production may be a more sensitive parameter. However, do to the limitation of records available from the maple syrup producers this was not possible.

4. The analysis of the start date and duration of the maple season was affected by the nature of data collected. In some instances, the flow date was very close to first tapping date; therefore, the actual date of first sap run may have been missed.

5. It has been recommended to sample trees older than 50 years in order to examine the potential changes in growth rates across the time span of human-caused climate change. However, we were limited in the age of trees available for the tree core analysis, as we needed to sample trees from sites with available syrup data. Approximately, 91% of the maple sugar stands in Nova Scotia are less than 100 years old (Lada and Nelson, 2013) and most of the sites used for the analysis were young (<70 years old) as they had been previously clear-cut.

6. Due to the limited expertise and time constraints involved in tree coring and analysis, only limited sample sizes were obtained to conduct this analysis. There is a need for an intensive sampling to conduct the cross-dating and further analysis of the growth of trees over time.

Acknowledgements

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We would also like to thank the Maple Producers Association of Nova Scotia (MPANS) and all the producers who participated and were willing to provide us with their maple syrup records. Thank you to the Maple Research Program Steering Committee (MRPSC): Robert Frame, William Allaway, Kevin McCormick and Matthew Harrison, as well Dale McIsaac (Perennia) and Ron Young (NS Department of Agriculture) for their contribution to this research.

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Appendix 1

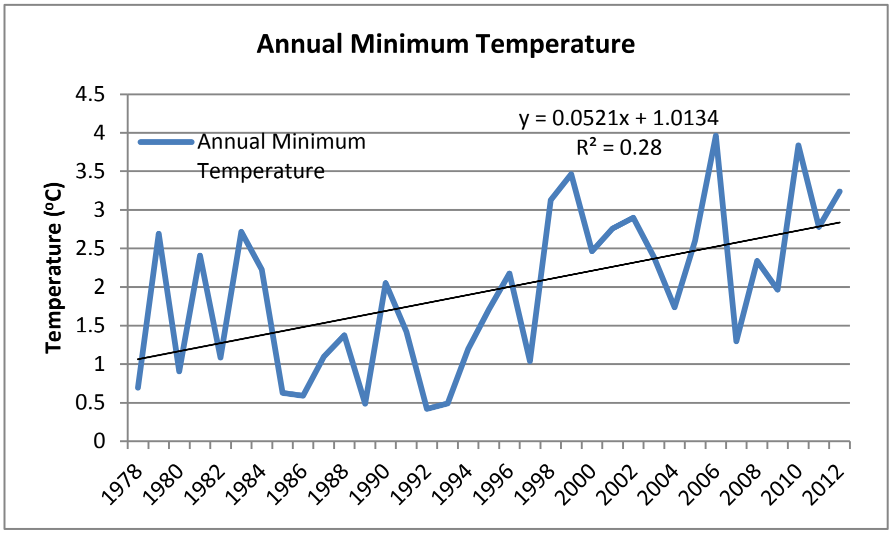

Figure 120 Annual minimum monthly temperature for five sites in Nova Scotia.

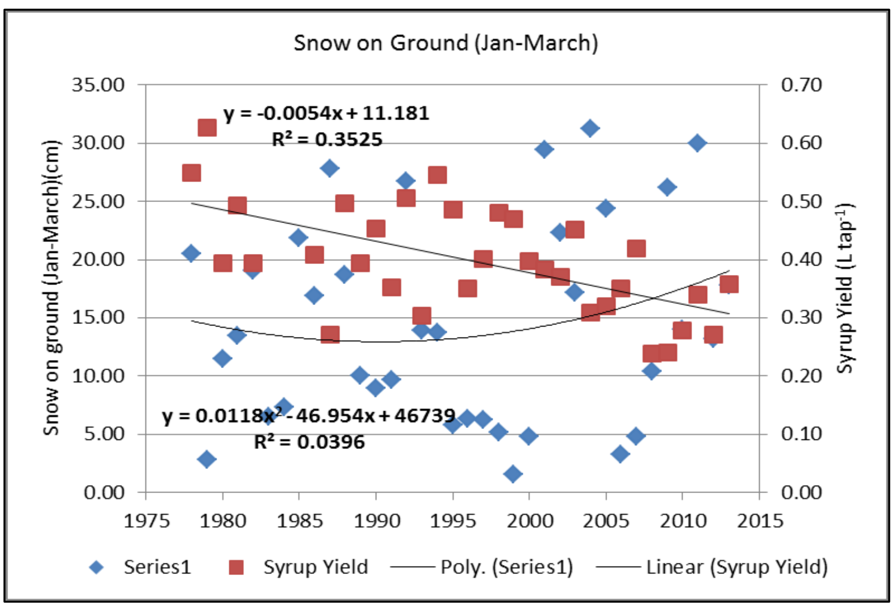

Figure 2 Regression analysis for snow on ground (cm) from January-March and Syrup yields (L/tap/yr).

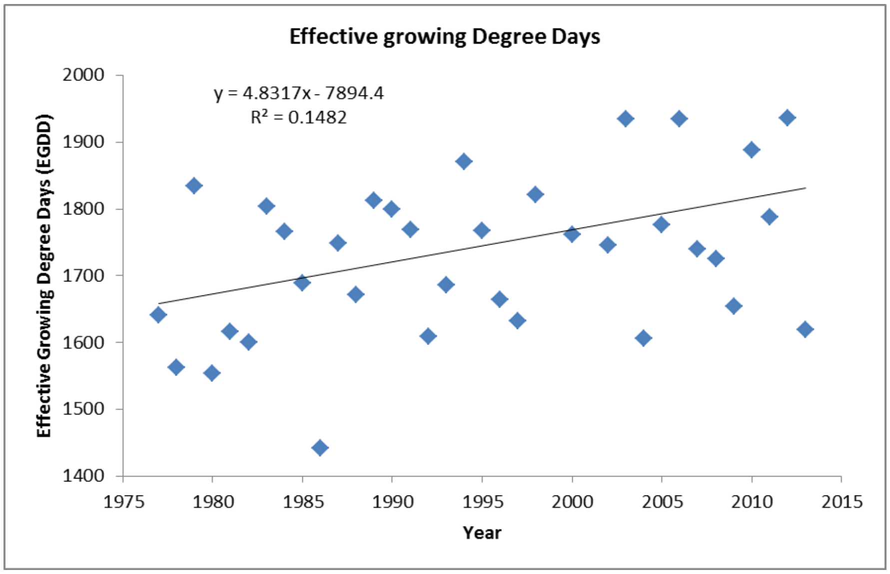

Figure 3 Effective growing degree days (EGDD) calculated as number of degrees above 5°C from April 1 to October 1 of the previous year.

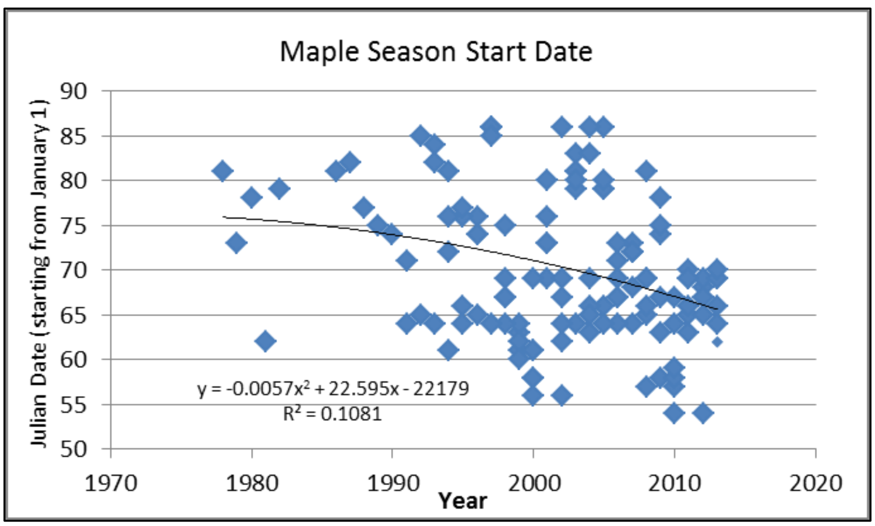

Figure 4 Maple syrup yearly start dates fitted with a polynomial regression line.

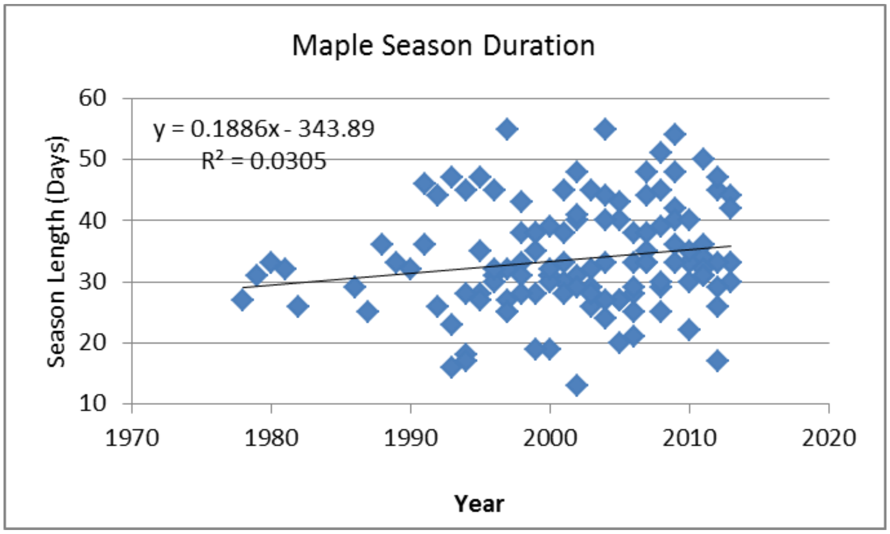

Figure 5 The duration of the maple season (days) from 1978 until 2013 has shown no change using linear regression analysis.