TREE-RING CHRONOLOGY DEVELOPMENT FOR WESTERN INSULAR NEWFOUNDLAND, COMPARED WITH DENDROCLIMATIC EVIDENCE

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Tree-Ring Chronology Development for Western insular Newfoundland, compared with Dendroclimatic Evidence

By

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Abstract

The development of the western Newfoundland tree-ring chronologies from cross-sections collected by the Newfoundland Forest Service is the basis for this study. Sampling undertaken by the Newfoundland Forest Service started in 1985 and continued through the summer of 1997 and beyond. The data obtained from the Newfoundland Forest Service were cross-dated, time-series evaluated and standardized to achieve five ring-width indices.

Abies balsamea is the dominant species used in the Western Newfoundland chronologies. Northern Peninsula ring widths are correlated with mean summer and winter temperatures. These ring widths are also correlated with sea-surface temperature and mean monthly surface-air temperature. The Northern Peninsula chronologies show evidence of 1820-1830s warming and subsequent cooling as well as the 1960-1970s North Atlantic anomalies.

Comparison between published data and developed tree-ring chronologies depicts much similarity in areas from the North Atlantic sector. Comparison between temperature correlation significance in Scandinavia and the Northern Peninsula chronologies shows a definite relationship between mean monthly surface temperature for winter months and ring-width indices.

Monthly climate data for western insular Newfoundland do not extend backward beyond the early 1930s. The development of tree-ring chronologies, extending as far back as 1760, will improve the understanding of environmental change in the Northwest Atlantic sector.

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List of Abbreviations and Symbols Used

ATPcpn	Average Total Precipitation
ATRain	Average Total Rain
ATSnow	Average Total Snow
FMD	Forest Management District
MmaxT	Mean Maximum Temperature
MeanTemp	Mean Temperature
MminT	Mean Minimum Temperature
MST	Mean Summer Temperature
MWT	Mean Winter Temperature
PSP	Permanent Sample Plot

Chapter I: Introduction

A dynamic relationship exists between trees and the climate within which they exist. The external climate is responsible for supplying trees with the energy, moisture and CO_2 necessary for photosynthesis and growth. Trees respire water vapor and oxygen; thermal convection of this water vapor into the atmosphere aids cloud formation.

Tree growth is a well-studied process, and the ability of trees to grow in different environmental conditions and tolerate stress is very important to tree health and vigor. Tree growth is dependent on the physical environment for its supply of nutrients and moisture. Different tree habitats exist, from highly productive well-sheltered sites to poor, very exposed, elevated sites.

Changes in climate can significantly alter the way of life of a human population and can affect ecosystems; this makes the monitoring of global climate crucial. Likewise, trees depend on the environment for all their physiological requirements; both biotic and abiotic factors are affected by climate. Due to this sensitivity, trees have been used as climatic biomonitors (Weisberg and Baker, 1995; Skre, 1993). The susceptibility of trees to environmental factors is the basis for the study of climate through its effects on tree vegetation (Skre, 1993).

1.1 Dendrochronology in Newfoundland

The Canadian boreal forest stretches from the west coast of British Columbia, on the Pacific Ocean, to the east coast of Newfoundland, on the Atlantic Ocean. Dendrochronological research is extensive in many different ecoregions of the Canadian boreal forest. This research has aided in the reconstruction of climatic records and has improved the understanding of environmental change.

Insular Newfoundland, in comparison, has experienced relatively little dendrochronology research. Potential exists for the application of dendrochronological and dendroclimatological research to monitor environmental change in Newfoundland. Dendroclimatological research undertaken in Labrador and in insular Newfoundland by D'Arrigo, Cook and Jacoby (1992, 1996), shows a relationship between mean surface air temperature, sea-surface temperature and tree rings. Tree rings have been related to indices of atmospheric and oceanic anomalies (D'Arrigo et al., 1991, 1992, 1996).

The dendrochronology of Newfoundland has largely been ignored in the Canadian boreal forest. Inclusion of Newfoundland dendrochronology and dendroclimatology in environmental-change research of the North Atlantic incorporates important paleoclimatic evidence, rendering Newfoundland tree rings valuable.

In order to interpret future climate, the limitations of long-term instrumental climatic records render important the reconstruction, by proxy indicators, of past climate in Newfoundland. Temperature fluctuations in the North Atlantic region are very important for the understanding of future fluctuations and possible change. Climatic fluctuations influence variations in terrestrial and oceanic resources, which should be properly monitored to evaluate and understand environmental change. The ability to evaluate long-term climatic variability and environmental change can be achieved with dendrochronological evidence.

One of the main principles of dendrochronology is the Uniformitarian Principle: "The present is the key to the past" (Hutton, 1785 from Fritts, 1976). This statement suggests that the same physical environmental vegetative links that exist in today's environment were present in the paleoenvironment (Fritts, 1976). This statement also suggests that the same climate-tree relationships in existence today also existed in the past. This does not mean the climate or growth of the past were the same as they are at present, only that the same physical processes were acting upon the growth in the same way (Fritts, 1976).

1.2 Western Newfoundland Environment

Western Newfoundland stretches 400 kilometers along a changing latitudinal and environmental gradient. Air temperature variations along western Newfoundland are evident, while sea-surface temperatures along the southern shore of the west coast show higher average yearly temperatures than along the tip of the Northern Peninsula. Significant differences in North Atlantic flow patterns along the northern and west coasts of Newfoundland are very important in influencing terrestrial climate. The Labrador Current carries cold, nutrient-rich Arctic water along the northern shore and down the west side of the Strait of Belle Isle. Further south, along the west coast, the Labrador Current becomes less important and the outflow from the Gulf of St. Lawrence dominates. The east side of the Strait of Belle Isle is a site of warm-water outflow from the Gulf of St. Lawrence, with periodic flow resulting from a small branch of the Gulf Stream (Huntsman, A.G. et al., 1954). As a result of these different flow regimes, the sea-surface temperatures along the southern region of the west coast are milder than along the Northern Peninsula or the northern sections of the west coast.

Variable climatic conditions are evident, locally and regionally, across insular Newfoundland. Collectively, they can best be described as a modified continental climate. However the high-average cloudiness and lack-of-precipitation seasonality indicate marine-climate influences.

Climatological records for western Newfoundland are relatively short, and only extend back to 1933 at Corner Brook and Deer Lake (Environment Canada, 1996). The Belle Isle temperature record, analysed by Banfield (1997), extends both summer and winter mean temperatures back to 1885. Despite certain broad similarities within climate over large spatial areas, considerable regional variability pertaining to the climatic parameters is evident (Banfield, 1981, 1993). Variability is caused by a number of factors affecting climate, with spatial variability dependent on geographic location, atmospheric constraints, oceanic influence, and seasonal variability (Banfield, 1993).

The climate of Newfoundland's Northern Peninsula is colder than that of the remainder of the island at all times of the year and becomes progressively colder northward. Winters on the Northern Peninsula are long and cold, with continuous snow cover averaging up to four months in the most northerly areas (Banfield, 1993). Summers on the Northern Peninsula are short and cool with high average cloudiness, especially over the Long Range Mountains. During the summer growing season, occasional warm days near the 25°C mark occur over coastal lowlands during offshore atmospheric flow (Banfield, 1981, 1983). Annual precipitation is high, near 1,500 mm, with less precipitation over the northeast coasts and more precipitation over the uplands (Banfield, 1981, 1993).

South of the Northern Peninsula, western Newfoundland has been divided into six climatic zones. The West coast (Bonne Bay and south), the South coast and the East coast and hinterlands are coastal climate zones, Figure 1.1 (Banfield, 1981, 1993). The Central lowlands, Central uplands and the Western hills and mountains are interior climate zones (Banfield, 1981, 1993). Milder winters are more frequent in the southern region of western Newfoundland. The Long Range Mountains have winters with average temperatures between –3 and –9 degrees Celsius and annual snowfall between 200 and 550 centimeters. Air temperature decreases with elevation gain (1 degree Celsius for every 100 meters of elevation gain). Snow cover at high elevations is continuous from December through April (Banfield, 1981, 1993). The remaining climatic zones experience similarly high snow accumulation and high-average annual precipitation (greater than 900 millimeters).

Temperature and precipitation increase toward the south and precipitation increases with elevation (Banfield, 1981). The temperature change in a southward direction along western Newfoundland is very evident. Spring arrives relatively early in the lower Humber Valley and summer temperatures can reach above 30 degrees Celsius, in comparison to the Northern Peninsula where growing-season temperatures rarely exceed 25 degrees Celsius (Banfield, 1981).

1.3 Objectives / Study Area Description

The objectives of this project are, (a) the creation of a dendrochronological record for western Newfoundland that can be verified with published North Atlantic and European chronologies, and (b) the investigation of the relationships between Western Newfoundland chronologies and climatic data from the North Atlantic Region.

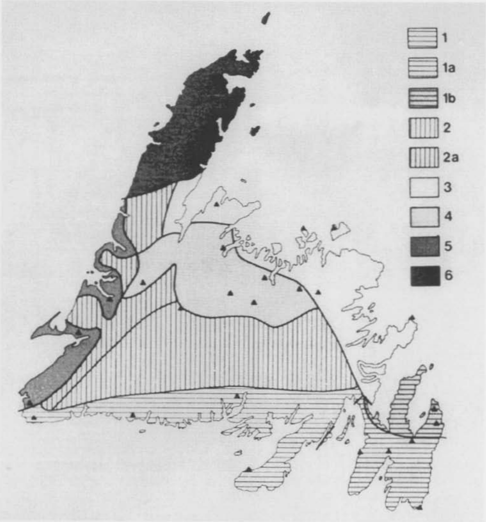


Figure 1.1 Climate Zones of Insular Newfoundland.

1 South and southeast coasts and immediate hinterlands.
1a Southeast coasts with even milder winters. Southeast Avalon, very cool in summer.
1b Southeast coasts have less mild winters with more frequent snowfalls
2 Central uplands.
2a Western hills and mountains.
3 East coast and hinterlands
4 Central lowlands
5 West coast (Bonne Bay and south)
6 Northern Peninsula

The study area consists of five forest management districts in western Newfoundland (Figure 1.2). The forest management districts are areas established by the Newfoundland Forest Service designated for forest management practices. Forest-product companies utilize the stands within a forest management district for harvesting and re-forestation. Forest management districts are designed to be small manageable units delineated on the basis of stand type and topography.

The five districts of western Newfoundland were chosen because of the north-south variation in climate and because these five forest management districts had the largest sample size. These districts encompass the majority of the Long Range Mountains, which run north-south, from south of Corner Brook up the Northern Peninsula. Gros Morne National Park, with a total area of 166,632 hectares, is excluded from the study area.

The boreal forest of western Newfoundland is comprised mainly of white spruce (*Picea glauca*), black spruce (*Picea mariana*), balsam fir (*Abies balsamea*), white birch (*Betula papyrifera*), *and* yellow birch (*Betula lutea*), with some sporadic occurrence at higher altitudes of mountain ash (Sorbus americana) (Anonymous, 1980; Bouchard et al., 1987; Damman, 1975). The main taxonomic groups that comprise the majority of stand types in western Newfoundland are *Picea* and *Abies*.

The spatial distribution of forest management districts and the distribution of sample plots led to the development of five tree-ring chronologies encompassing western Newfoundland from Channel-Port aux Basques to L'Anse aux Meadows. The five chronologies consist of mainly *Abies balsamea*, however some older *Picea glauca* were

Figure 1.2 Forest management districts of western insular Newfoundland. Each district represents a regional tree-ring chronology. Fmd 17 and Fmd 18 encompass the Northern Peninsula. Fmd 14, Fmd 15 and Fmd 16 are areas of the southern chronologies.

used. The development of these chronologies is for the further study of environmental change, through dendroclimatology.

1.4 Factors Influencing Growth

Tree growth in healthy stands can be directly related to climatic variables and events (Grace and James, 1993). Habitat chosen by tree species depends on abiotic factors present in the external environment (Kimmins, 1987). External factors governing tree growth are consistent around the globe. Differences arise between different geographical locations because different climatic factors become the major growth-limiting factor.

Temperature is widely considered the most important factor influencing growth in northern latitudes (Hughes et al., 1982). Tree growth in western Newfoundland is primarily limited by temperature, which influences the growing-season duration and overall productivity of vegetation. Temperature varies spatially in western Newfoundland due to topographical variations, elevation and relative distance from the ocean. Temperature affects many different growth-related factors, such as the range of the average frost-free period. From weather stations in western Newfoundland the average range of frost-free days is 103-135 days (Banfield, 1988).

Precipitation, although variable in western Newfoundland, is not an important growth-limiting factor. From Banfield's (1983, 1988, 1995) analysis it is evident that, during the growing season (June-Sept.), levels of precipitation are high compared to evapotranspiration rates and would rarely result in a water deficit.

Solar radiation exerts some influence on tree growth (Kimmins, 1987); however it is thought to have less of an influence on growth in western Newfoundland. The relevance of solar radiation takes effect when cloud cover over western Newfoundland is evaluated. Although cloud cover has an effect on the solar radiation influx, the overall reflectivity of solar radiation due to cloud cover would have to be relatively great to be a limiting factor (Perry, 1994).

The effects of wind flow are important during the growing season and the dormant winter season. Wind, although not usually recognized as a growth-limiting factor, is of great importance in western Newfoundland. Wind in Newfoundland is not a true growth-limiting factor during the growing season because precipitation rates in Newfoundland do not limit evapotranspiration rates (Banfield, 1983; 1988; 1995), which are highly dependent on wind. For this reason, wind is most important during the winter months.

The severity of the winter including its, snow depth, wind velocity, and temperature fluctuation patterns all attribute to winter desiccation and abrasion (Larsen, 1993). Snow depth is important because it provides insulation and protection to seedlings from abrasion and desiccation (Larsen, 1993). High wind velocities cause ice abrasion on tree vegetation above the snow. Damage from snow and ice abrasion has the potential to limit annual growth by causing the death of terminal buds, or a reduction in healthy foliage (Kimmins, 1987; Larsen, 1993). However, if a tree survives the winter undamaged, the severity of the winter should have no bearing on the summer growth of that tree.

Physiographic features influence tree growth through microclimatic features. Slope and aspect are the two most important physiographic features, resulting in the greatest effect on tree growth. North- and south-facing slopes will have dramatically different microclimates. Aspect affects the quantity of sunlight (solar radiation) trees receive, the rate of snow accumulation and the time period of the spring melt. Slope affects soil drainage quality in the area, this will have an affect on tree growth. Greater amounts of sunlight on south-facing slopes in the Northern Hemisphere affect transpiration and evapotranspiration rates resulting in increased water stress to trees. This difference in sunlight quantity will also affect snow accumulation-melt cycles, which cause winter desiccation on more exposed south-facing slopes.

Chapter II: Methodology

2.1 Data Acquisition and the Newfoundland Forest Service

The Newfoundland Forest Service completed data collection with the help of both Corner Brook Pulp and Paper and Abitibi Price Incorporated. The raw ring-width data were obtained from the Permanent Sample Plots (PSP) program, established in 1985 (Newfoundland Forest Service, 1993). The PSP program was undertaken to provide growth data that could be used to calibrate and validate growth and yield projection models, and establish a network of plots sufficient to sample the important stand conditions at an acceptable intensity (Newfoundland Forest Service, 1993).

The Newfoundland Forest Service maintained approximately 1,000 permanent sample plots (PSPs). These PSPs covered the entire island portion of the province, there were relatively few plots in Labrador. Primarily responsible for the set-up and collection of all data from the PSP program, the Newfoundland Forest Service, Inventory Division, sampled and measured all tree-ring data presented in this project. None of the ring-width data obtained from the PSP program was used previously for chronology development. The compilation of dendrochronological records was never the goal of the permanent sampling plot program. The ring-width measurements were taken as part of the age-collection procedure; they were used by the Newfoundland Forest Service as an accurate method of determining stand-age structure.

2.2 Sampling Methodology

The sampling procedure of the Inventory Division encompassed plot selection, plot establishment, and plot sampling. Prior to field operations, selection of probable permanent sampling plots was compiled from information available through aerial photographs, forest-cover type maps and existing information on the area.

The stand selection for plot establishment required the stand to meet certain criteria: (1) the stand possessed the characteristics of the stand type proposed; (2) the stands selected were widely distributed across the sampling region; (3) the stands were located in areas not scheduled for harvest or silviculture treatments in the near future. Selecting stands representative of different growing regimes equally represented plot-siting criteria such as slope and aspect.

The Newfoundland Forest Service within selected stands used the stem analysis sampling procedure. Three to six trees were sampled at each plot to determine age structure – the more age variation, the more trees that were sampled to fully determine the extent of the age structure, size structure and stand condition. All permanent-sample-plot sampling procedures are outlined in detail in the Permanent Sampling Plot Program Procedures and Specifications Manual, Newfoundland Forest Service, Inventory Division (1993).

Although age information can be taken from a tree using an increment borer, the sampling procedure employed by the Newfoundland Forest Service was to cut cross-sections of these sample trees. The most accurate method of measuring age and incremental growth are taken from ring-widths in these cross-sections. They were cut at both stump height and breast height, approximately one-inch thick. Cross-section rings were counted in the field to estimate age. Each disk was labelled with the district number, plot number, sample tree number, species, section and then returned to the

Corner Brook office for verification. Care was taken in the handling and storage of the disks to ensure quality.

The number of sampled cross-sections per plot increased with the number of plots and area required to achieve an adequate sample size. An adequate sample size was determined by the variance within and across the ring width data. A total of 1147 trees were used in the study; for ease of computation and management of such a large number of trees, regional chronologies were developed for this project.

Cross-sections sampled by the Newfoundland Forest Service, Inventory Division, prior to 1990 were measured visually with a Tree-ring Increment Measure (TRIM); accuracy was based on visual interpretation (Newfoundland Forest Service, 1997). Since 1990, the Inventory Division has used a Windendro Pro optical resolution scanner to digitize cross-sections. These incremental rings were measured to an accuracy of 0.02 millimeters x 0.01 millimeters (1200 dpi x 2400 dpi) (Regent Instruments, 1995). The software used in conjunction with the scanner was Windendro 6.1D (Regent Instruments, 1995). Two radii from each cross-section were measured from opposite sides of the tree. These measurements were cross-dated for purposes of visual comparison. Ring widths were then related to a specific calendar year.

2.3 Development of Ring-Width Chronologies

The sample size in the five western forest management districts was chosen to allow for a dendrochronological study with a minimum degree of unknown sample error. Each contained differing numbers of trees and sample plots.

The southernmost region, Forest Management District 14 (Fmd 14), located in the southwestern corner of western Newfoundland (Figure 1.2) is comprised of 29 sample plots with 134 total trees sampled (Table 4.1). North of Fmd 14 lies Fmd 15 (Figure 1.2), comprising of 15 sample plots and 122 trees sampled (Table 4.1). East of Gros Morne National Park lies Fmd 16 (Figure 1.2), comprising of 44 sample plots and 170 trees (Table 4.1). The Northern Peninsula contains the remaining two forest management districts. Fmd 17 borders Gros Morne National Park on the west side and Fmd 16 on the east side (Figure 1.2). Fmd 17 has the most sample plots of all the forest management districts. Fmd 17 comprises 160 sample plots and 494 trees (Table 4.1). At the tip of the Northern Peninsula lies Fmd 18 (Figure 1.2), comprised of 67 sample plots and 227 trees (Table 4.1).

Annual ring-width data acquired from the Newfoundland Forest Service were radially averaged, using Xlstem 1.2 (Fortin, R. 1996), in Microsoft Excel 7.0. All individually averaged ring widths for each plot were then compiled into five data sets, corresponding to the five forest management districts. To ensure the accuracy of visual cross-dating, ring-width time-series plots were compared (Fritts, 1976).

2.3.1 Standardization

Resulting tree-ring width sequences retained long-term growth fluctuations reflecting the trees' biological growth trend and other low-frequency trends (Earle, et al., 1994). These biological growth trends were removed to allow evaluation of external climatic parameters on tree growth, this is done through a process known as standardization (Fritts, 1976; Cook and Briffa, 1990; Cook et al., 1990). Standardization is achieved by fitting a smooth curve to the ring-width data for each tree and dividing each ring width by the corresponding fitted value, producing a ring-width index series with a stationary mean and variance (Earle et al., 1994).

Conservative, negative exponential and straight-line curve fits were used in the standardization process to remove the biological growth trend (Fritts, 1976; Hughes et al., 1982; Cook and Kairiukstis, 1990) and emphasize climatic-growth responses. All curve-fit methods were attempted for each tree-ring series. In many cases, only a straight line with a zero slope was used for the standardization process because a positive slope was associated with all other standardization procedures.

Standardization to remove biological growth trends can remove some climatic-growth signals within the chronology. Using a standardization procedure that results in a positive slope increases the likelihood of removing climatic-growth responses. Tree-ring series showing a positive slope may be exhibiting a climatic-growth release response, which would be removed, or its significance greatly decreased by both conservative and negative exponential curve fits. Straight-line standardization is justifiable in cases where the slope is positive, the least squares fitted line is rejected and a horizontal line is fitted through the mean ring width as the expected growth at all stages (Fritts, 1976).

Standardized indices for each tree within each forest management district were averaged to obtain a mean chronology for each district.

2.3.2 Dendroclimatic Evidence

Dendroclimatic evidence was used for verification of the northern tree-ring chronologies (Fmd 17 and Fmd 18). Comparison of western chronologies with published climatic data from the same area was limited. However, published data from other areas in the North Atlantic sector was available. The association between the two northern chronologies (Fmd 17 and Fmd 18) and chronologies from northern and southern Labrador, the North Peninsula and north central Newfoundland were examined (D'Arrigo et al., 1992). Other chronologies from the North Atlantic sector were correlated with mean monthly temperatures (D'Arrigo et al., 1993). Correlations between northern chronologies and mean summer temperatures and mean winter temperatures were obtained for comparison with monthly correlation values from other areas of the North Atlantic sector.

Climatic data from five different weather stations in western Newfoundland were obtained from Atmospheric Environment Services, Environment Canada, and through Dr. C. Banfield, Memorial University of Newfoundland (Banfield, 1997; Environment Canada, 1996). Climatic data for the northern weather stations, Daniel's Harbor and Belle Isle, were averaged to correlate with Fmd 17 and Fmd 18. Data from the southern weather stations (Deer Lake, Corner Brook and Stephenville) were averaged to correlate with Fmd 14, Fmd 15 and Fmd 16. Correlations between sea-surface temperatures and the five western chronologies were also determined. Sea-surface temperature data for the Northern Peninsula and the southern west coast sub-areas were averaged from three different sea-surface temperature regions, Table 2.1 (COADS, NOAA, 1997).

Table 2.1 Sea-surface Temperature Monitoring Locations from COADS, NOAA, 1997.

Newfoundland West Coast and North Coast Sea-surface Temperature Monitoring Locations	
Latitude	**Longitude**
46 26' N	053 23' W
46 30' N	053 24' W
46 44' N	048 48' W
47 17' N	057 21' W
49 16' N	053 37' W
51 40' N	052 33' W

Chapter III: Analysis of Data

3.1 Tree-ring Chronology Comparisons

All tree-ring chronologies for the period from 1842 through 1992 were taken for means of comparison and analysis of variance. The year 1842 is the starting year of the shortest chronology. The oldest chronology dates back to 1760; however the variance of all chronologies increases as the sample size decreases. Statistical methods can be used to correct a trend in variance due to a changing sample size. Shiyatov, S. et al., 1990, advises caution regarding these or similar methods because the resulting decrease in variance achieved by statistical correction will not necessarily improve the accuracy. Statistical correction will merely adjust the means as if they were based on the maximum sample size, resulting in decreased variance (Shiyatov, S. et al., 1990). Furthermore, the loss of accuracy may be masked by the variance correction (Shiyatov, S. et al., 1990).

Western Newfoundland chronologies were not corrected for changing sample size; the yearly variance was calculated and any large variance was examined to determine possible error. Analysis of variance was performed to compare the variation *among* tree-ring chronologies with the variation *within* tree-ring chronologies (Everitt, B.S. et al., 1991; Garlin, C.P. et al., 1988). Determination of the starting date of the constructed chronologies would be determined based on the between-tree variance within each year.

Very few trees represent the earliest years in each chronology. Due to the increase in variance caused by a smaller sample size, the accuracy and precision of the early years (eg. first 25 years) in each chronology should be viewed as only a general trend of tree-ring growth. Removing these earliest years and shortening the chronologies greatly decreases the variance. However, for the purposes of chronology evaluation, description and discussion, the chronologies remain their maximum length.

3.2 Climate-Growth Relationships

Examination of the association between the chronologies and monthly climatic variables was undertaken to determine any significant relationships. The Pearson correlation co-efficient was employed between ring-width indices and monthly climatic data (Earle, C.J., 1994). Mean temperatures for January of the year before ring formation through December of the year of ring formation were correlated with yearly ring-width indices. Climatic variables chosen for association were mean monthly temperature, mean minimum temperature, mean maximum temperature, total rainfall, total snowfall and total precipitation. Mean summer temperature (June through September) and mean winter temperature (December through March) were calculated and used in the correlation analysis.

Sea-surface temperatures averaged on a yearly basis were correlated with the ring-width chronologies. The lack of consistent monthly collection of sea-surface temperature data off the western and northern coasts of Newfoundland required the averaging of the sea-surface temperatures from three different locations along the west coast and the Northern Peninsula. Missing data has plagued the sea-surface temperature records for the west and northern coasts. For this reason, yearly sea-surface temperature averages were determined, minimizing the effect of missing data.

Monthly mean temperature data from the January of the previous year's growth to the December following the growing season were chosen for correlation because this period included two complete growing seasons. Many factors which can indirectly affect ring width, such as fine-root growth or the size of new foliar buds, are determined in the growing season previous to ring formation (Fritts, 1976; Kienast et al., 1987).

Data from two climate stations on the southern west coast (Corner Brook and Stephenville) and one climate station inland (Deer Lake) were averaged to form the climatic record (1933–1990) used in correlation analysis. Climatic data for the Northern Peninsula is more limited. Only mean summer temperatures and mean winter temperatures from Belle Isle climate station (1885–1990) and monthly data from Daniel's Harbour climate station (1946–1990) were available.

Monthly and yearly-averaged climatic data from the stations inland (Deer Lake), on the southern west coast (Corner Brook and Stephenville) and the Northern Peninsula (Belle Isle and Daniel's Harbour) were used in simple correlations between tree-ring indices and climatic data (Fig. 4.2.1-4.2.7).

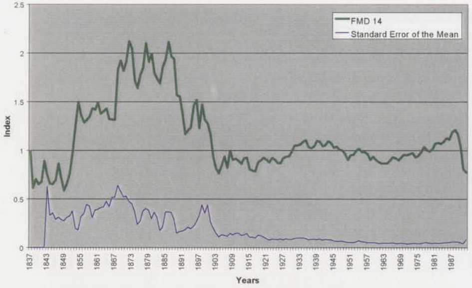
Chapter IV: Results and Discussion

Five tree-ring chronologies constructed for western Newfoundland are graphically represented in Figures 4.1- 4.5.

4.1 Tree-ring Chronology Comparisons

Table 4.1 contains the descriptive statistics and total variance for the five Western Newfoundland tree-ring width chronologies. Chronology variance decreases northward from Fmd 15 to Fmd 17, Table 4.1, which is directly related to an increase in the sample size of the chronologies. Fmd 18 shows a slight increase in variance; note that the maximum ring index is much larger for Fmd 18. The standard error of the mean decreases dramatically as the sample size increases, and is consistently low among all chronologies.

Table 4.2 contains the tree-ring chronology correlation matrix for forest management districts 14–18. The P-values are shown in parenthesis. Chronology correlations result in some statistically significant spatial relationships between chronologies. Fmd 14 and Fmd 15 form the most statistically significant positive correlation relationship and both show no significant positive correlations with the remaining chronologies. Fmd 16 is not significantly correlated with any of the other forest management district chronologies. Fmd 17 and Fmd 18 are positively correlated and show no significant positive correlation with the other forest management district chronologies. However, Fmd 17 does show a significant negative correlation with Fmd 14 and Fmd 15.



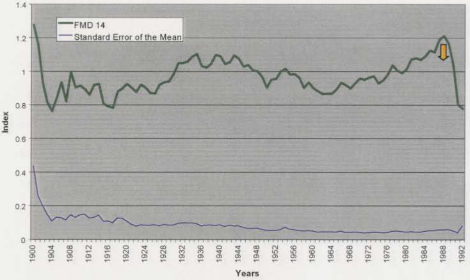


Figure 4.1 Forest Management District 14 chronology. The Fmd 14 chronology and standard error of the mean, 1837-1992 (top graph): Note a very small sample size and a single tree showing sharply increased growth causing the large SE early in the chronology. The Fmd 14 chronology, 1900-1992 (bottom graph): This enlarged portion of the chronology shows the lowest variance for the entire chronology and exhibits very similar growth to Fmd 15. The most recent significant drop in growth in the chronology is noted by the sharp ring-width decline after 1988.

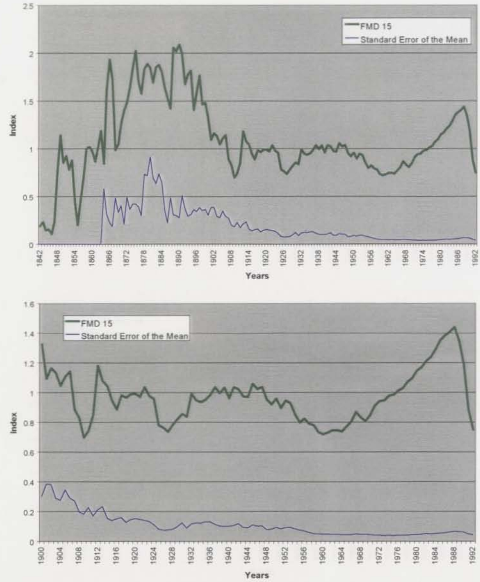
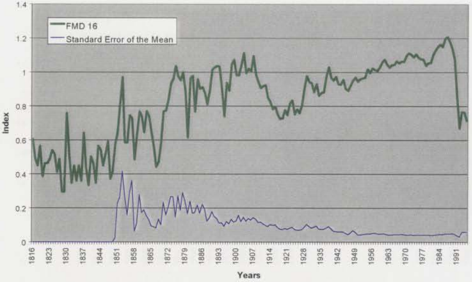


Figure 4.2 Forest Management District 15 chronology. The Fmd 15 chronology, 1842-1992 (top graph): Note a reduction in the sample size and a few trees showing above-average growth causing the increase in standard error of the mean early in the chronology. The Fmd 15 chronology 1900-1992 (bottom graph): This enlarged portion of the chronology shows the lowest variance and standard error of the mean for the entire chronology and exhibits very similar growth to Fmd 14. The most recent significant drop in growth in the chronology is noted by the sharp decline in ring width after 1988.



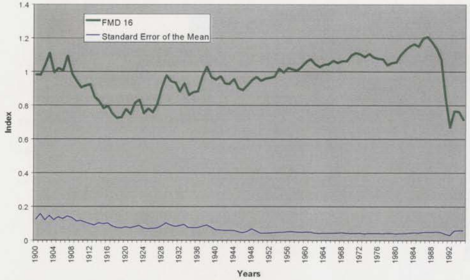
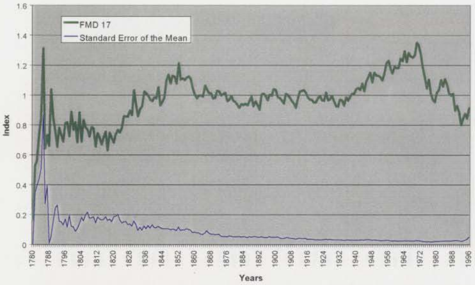


Figure 4.3 Forest Management District 16 chronology. The Fmd 16 chronology, 1816-1995 (top graph): Note an increase in standard error of the mean early in the chronology. This is cause by a reduction in the sample size. Fmd 16 chronology, 1900-1992 (bottom graph): This enlarged portion of the chronology shows the lowest standard error of the mean for the chronology. Fmd 16 exhibits very similar growth to Fmd 14 and Fmd 15 in the 1980's. The most recent significant drop in growth in the chronology is noted by the sharp decline in ring width after 1987.



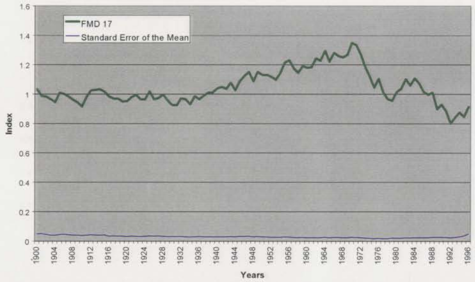


Figure 4.4 Forest Management District 17 chronology. The Fmd 17 chronology, 1760-1995 (top graph): This Northern Peninsula chronology is the longest of the five constructed. The dramatic increase in standard error of the mean early in the chronology is a result of a reduction in sample size to very few trees. Fmd 17 chronology, 1900-1992 (bottom graph): This enlarged portion of the chronology shows the low standard error of the mean for this period. Fmd 17 exhibits very similar growth to Fmd 18 in the most recent decades. The most recent significant decline in growth is noted by the sharp decrease in ring width beginning after 1970.

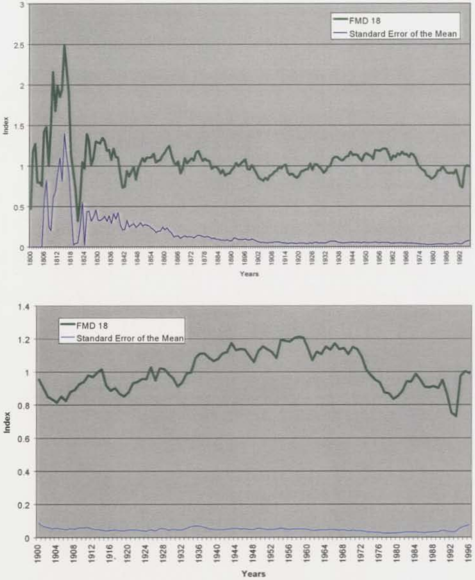


Figure 4.5 Forest Management District 18 chronology. The Fmd 18 chronology, 1800-1996 (top graph): This Northern Peninsula chronology notes an increase in standard error of the mean early in the chronology. This is due to a decrease in sample size. Fmd 18 chronology, 1900-1992 (bottom graph): This enlarged portion of the chronology shows the low standard error for this period. Fmd 18 exhibits very similar growth to Fmd 17 in the most recent decades. The most recent significant decline in growth is noted by the sharp decrease in ring width beginning after 1970.

High correlation values between Fmd 14 and 15, as well as between Fmd 17 and 18 reveal similar growth patterns occurring, presumably from similar climatic influences acting upon these correlated regions. The climatic influences in the Fmd 16 region differ from areas both north and south; however some similarities do exist between Fmd 16, Fmd 14 and Fmd 15 in the past decade, which are not shown by the low correlation co-efficient.

Fmd 17 shows a significant negative relationship with both Fmd 14 and Fmd 15. This is of interest, suggesting that climatic influences affecting growth on the Northern Peninsula are usually not applicable for the southern region of western Newfoundland. The pattern of growth for both Fmd 17 and Fmd 18 is very similar to published chronologies from D'Arrigo et al. (1993), which show growth influenced by the North Atlantic oscillation (D'Arrigo et al., 1993). A negative correlation between Fmd 17 and Fmd 14 and 15 shows the degree of influence maritime climate has on terrestrial ecoregions. This negative relationship reveals that the growth for the southern region of western Newfoundland does not receive the North Atlantic maritime influence to the same magnitude as the Northern Peninsula.

The North Atlantic maritime influence is the effect cold arctic water flowing around the Northern Peninsula has on terrestrial climate and vegetation. As the cold arctic water mixes with the warmer northerly flow through the Straits of Belle Isle, it cools the terrestrial climate, results in lower annual average temperatures, cooler sea-surface temperatures and greater fluctuations in sea-surface temperature. This mixing of the cold arctic water diminishes the North Atlantic maritime influence along the southern region of the west coast of Newfoundland. The diminishing of the North Atlantic

Table 4.1 DESCRIPTIVE STATISTICS FOR THE FIVE WESTERN NEWFOUNDLAND FOREST MANAGEMENT DISTRICT RING-WIDTH CHRONOLOGIES. (Ring measurements are indexed values, all times periods are in years).

	Chronology Time Period	Length of Chronology	Number of Sample Plots	Number of Trees Sampled	Mean	Median
Fmd 14	1837-1992	160	29	134	1.1298	1.0026
Fmd 15	1842-1992	155	15	122	1.0837	0.9912
Fmd 16	1816-1995	180	44	170	0.8293	0.8970
Fmd 17	1760-1996	217	160	494	0.9672	0.9821
Fmd 18	1800-1996	197	67	227	1.0928	1.0458
	Variance	**Standard Deviation**	**Standard Error of the Mean**		**Min**	**Max**
Fmd 14	0.1294	0.3597	0.0284		0.5872	2.1213
Fmd 15	0.1682	0.4101	0.0329		0.1068	2.0902
Fmd 16	0.0534	0.2310	0.0172		0.2961	1.2067
Fmd 17	0.0261	0.1615	0.0110		0.1669	1.3496
Fmd 18	0.0701	0.2647	0.0189		0.3247	2.4829

TABLE 4.2 FOREST MANAGEMENT DISTRICTS 14 - 18 TREE-RING CHRONOLOGY CORRELATION MATRIX. (P-values in parenthesis).

	Fmd 14	Fmd 15	Fmd 16	Fmd 17
Fmd 15	0.671 (0.000)			
Fmd 16	-0.044 (0.000)	0.253 (0.002)		
Fmd 17	-0.294 (0.000)	-0.354 (0.102)	0.192 (0.000)	
Fmd 18	0.158 (0.001)	-0.115 (0.163)	-0.036 (0.000)	0.442 (0.045)

influence gives rise to the marine influence on the southern west coast, which has a temperature-moderating effect, decreasing climatic temperature extremes. Fmd 16 is not significantly associated with any of the other chronologies; however, the most recent growth period in Fmd 16 (1980–1987) shows the same rapid growth reduction after 1987 as Fmd 14 and 15.

The largest range of growth appears to occur at the tip of the Northern Peninsula. However, examination of the raw ring-width measurements raises the possibility of error. A single tree in a single year is responsible for a dramatic increase in growth in the early 1800s and an increase in variance coincides with this dramatic growth increase. This particular tree would be considered an outlier and removed, or could be removed by shortening the chronology until the variance decreases with increased sample size. For the purposes of growth interpretation, this outlier in Fmd 18 will not be considered and Fmd 18 will be considered to have a similar growth range to Fmd 17. This particular tree growth appears to be anomalous in comparison to the remainder of the chronology.

The gradient of growth, which occurs in western Newfoundland, displays a decline in growth northward. As evident in Table 4.1, the minimum-growth index was variable for all chronologies. The maximum-growth index declines from Fmd 14 through Fmd 17. Fmd 18 has the highest maximum index, however it represents a single year prior to the beginning of Fmd 14 and Fmd 15 chronologies. Using the maximum index for the same period for all forest management districts results in a northward gradient of declining growth.

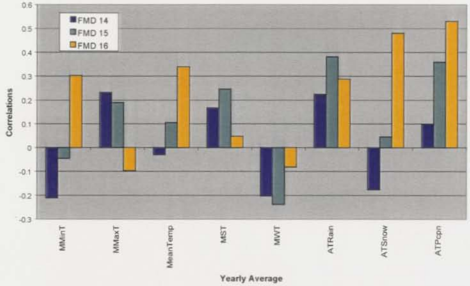
The maximum growth is expected in the southern region, as this area is not influenced by the arctic atmospheric flow to the degree that the Northern Peninsula is affected. A gradient of high, vigorous growth in the southern region, relative to the slow temperature-limited growth of the Northern Peninsula is evident. The minimum and maximum growth indices (Table 4.1) show Fmd 14 and Fmd 15 having the greatest growth potential with the widest annual rings; this declines dramatically in Fmd 16, Fmd 17 and Fmd 18.

4.2 Climate-Growth Relationships

Figure 4.2.1 displays the correlation co-efficients for mean minimum temperature (MMinT), mean maximum temperature (MMaxT), mean temperature (MeanTemp), mean summer temperature (MST), mean winter temperature (MWT), average total rain (ATRain), average total snow (ATSnow) and average total precipitation (ATPcpn).

Figure 4.2.2 and Figure 4.2.3 show correlations between annual ring-width chronologies and monthly mean temperatures for the year of ring formation and the year before ring formation, respectively. Figure 4.2.4 shows correlations between maximum monthly temperature and annual ring width. Figure 4.2.5 expresses the correlations between mean snowfall and annual ring widths. The summer months of June, July, August, and September were omitted from mean snowfall correlations.

Figure 4.2.6 defines correlations between annual ring widths for Fmd 17 and Fmd 18 and temperatures at the Belle Isle climate station. The Belle Isle climate record consists of only mean summer temperature and mean winter temperature. Both chronologies have been correlated with temperature records for the year of ring formation and the year previous to ring formation.



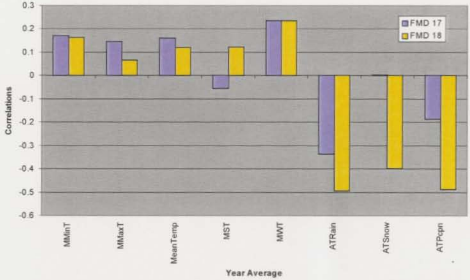
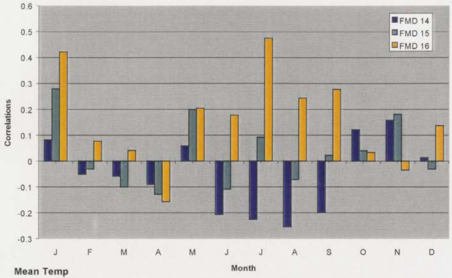


Figure 4.2.1 Correlations between annual averaged climatic variables and annual tree-rings for the Western Newfoundland chronologies. Correlations for Fmds 14-18 equal to or exceeding 0.12, 0.12, 0.14, 0.10 and 0.15 respectively, are significant at the 95 per cent confidence level. MminT = mean minimum temperature, MmaxT = mean maximum temperature, Mean Temp = mean temperature, MST = mean summer temperature, MWT = mean winter temperature, ATRain = average total rain, ATSnow = average total snow, ATPcpn = average total precipitation.



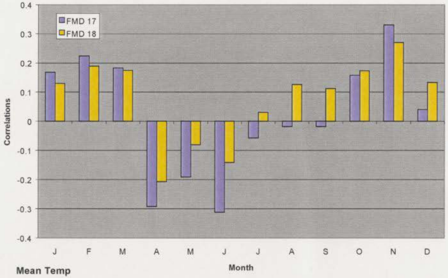
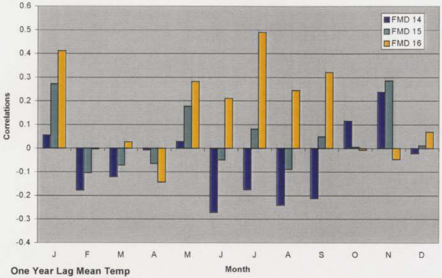


Figure 4.2.2 Correlations between monthly mean temperatures and Western Newfoundland chronologies. From January of the year of ring growth to December following ring formation, correlations for Fmds 14-18 equal to or exceeding 0.10, 0.09, 0.11, 0.11 and 0.10 respectively, are significant at the 95 per cent confidence level.



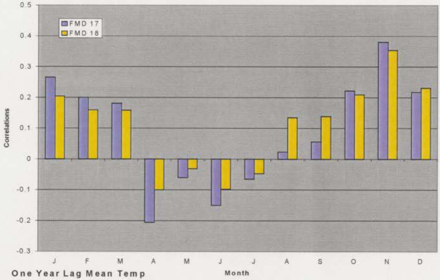


Figure 4.2.3 Correlations between monthly mean temperatures and Western Newfoundland chronologies. From January of the year prior to ring growth, to December before ring formation, correlations for Fmds 14-18 equal to or exceeding 0.10, 0.09, 0.12, 0.10 and 0.10 respectively, are significant at the 95 per cent confidence level.

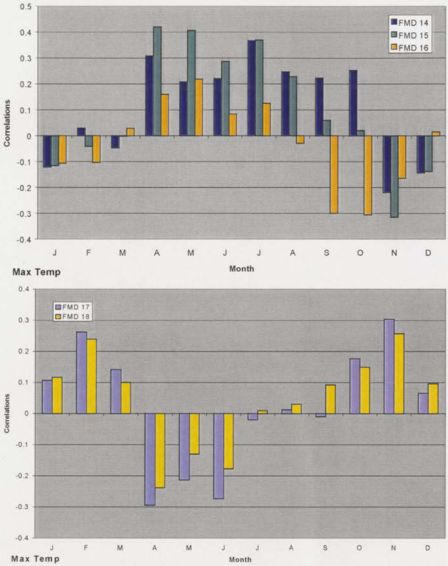


Figure 4.2.4 Correlations between monthly maximum temperatures and Western Newfoundland chronologies. From January of the year of ring growth to December following ring formation, correlations for Fmds 14-18 equal to or exceeding 0.12, 0.14, 0.10, 0.12 and 0.11 respectively, are significant at the 95 per cent confidence level.

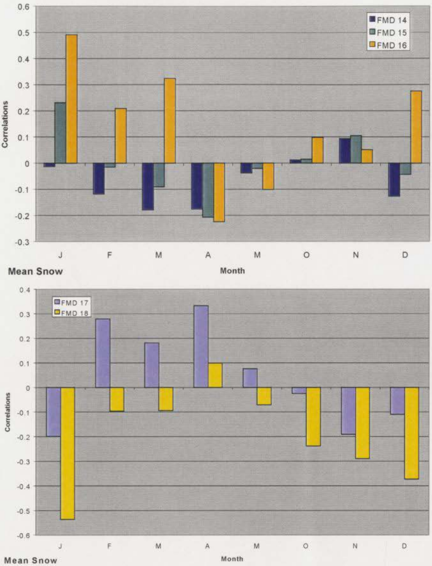


Figure 4.2.5 Correlations between monthly mean snowfall and Western Newfoundland chronologies. From January of the year of ring growth to December following ring formation, correlations for Fmds 14-18 equal to or exceeding 0.09, 0.10, 0.16, 0.15 and 0.14, respectively, are significant at the 95 per cent confidence level.

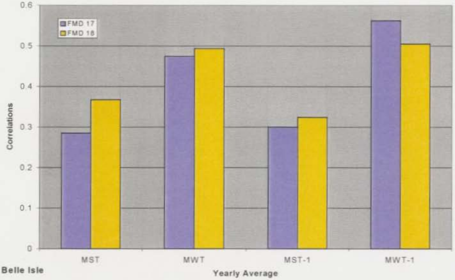


Figure 4.2.6 Correlations between ring-width and mean summer and mean winter temperatures for the year previous to the growing season and during the growing season. Correlations for Fmds 17-18 equal to or exceeding 0.13 and 0.10, respectively, are significant at the 95 per cent confidence level. Note the strong correlation between winter temperatures and ring growth.

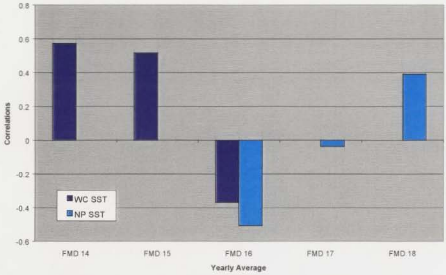


Figure 4.2.7 Correlations between sea-surface temperature and annual ring width for the Western Newfoundland chronologies. Correlations equal to or exceeding 0.17 are significant at the 95 per cent confidence level. Note significant correlations between Fmd 14, Fmd 15 and Fmd 18, and the strong negative correlation with Fmd 16. (WC - SST = West coast sea-surface temperature; NP SST = Northern Peninsula sea-surface temperature).

Figure 4.2.7 shows the relationship between annual ring width and sea-surface temperature. The west coast sea-surface temperature record was correlated with Fmd 14, Fmd 15 and Fmd 16. The Northern Peninsula sea-surface temperature was correlated with Fmd 16, Fmd 17 and Fmd 18.

The climatic relationships were evaluated for similarities between the climate relationships in Newfoundland and published findings of D'Arrigo et al (Fig. 4.2.1-4.2.7) (1992, 1993).

Figure 4.2.1 shows positive correlations between Fmd 18 tree-ring indices and all annual climatic data. Figure 4.2.1 shows positive correlations between Fmd 17 tree-ring indices and annual climatic data excluding mean summer temperature. These positive correlations with seasonal temperatures suggest summer temperatures are a limiting factor on the Northern Peninsula. The negative correlation between Fmd 17 and mean summer temperature is insignificant and could represent an error made during tree-ring width measurement. The southern region of western Newfoundland experiences much more erratic correlations with yearly climatic variables.

However, Fmd 14 and Fmd 15 chronologies show a significant negative correlation with mean winter temperature, indicating that relatively lower winter temperatures are correlated with above-average ring growth and relatively higher winter temperatures are correlated with below-average ring growth. Less tree stress results from winters with consistent cold temperatures than from winters with variable cold-warm cycles. Winter stress impacts are associated with desiccation, ice abrasion and frost cracking. Winter stress is evident in shoot growth the following spring. For the southern region, maximum temperature and mean summer temperature are positively correlated with Fmd 14 and Fmd 15, showing summer growing temperatures are affecting growth. Surprisingly, the southern chronologies all show a significantly positive relationship with ring width and precipitation. This indicates that precipitation has a degree of influence on tree-ring growth in addition to that of evapotranspiration.

Figure 4.2.2 and Figure 4.2.3 show significant positive correlations between mean temperatures and Fmd 18 growth for August-through-March for the year of ring formation and the year prior to ring formation. Fmd 17 growth is highly positively correlated with temperatures in October, November and January-through-March for the year of ring formation, and October-through-March for the year prior to ring formation. With the strong correlation between winter temperatures for the year of growth and the year prior to growth the Northern Peninsula shows that winter temperatures are important in determining growth. Survival of trees on the Northern Peninsula could be hypothesized as partially dependent on winter temperature regimes.

The southern chronologies do not show such a trend in correlation. The three southern chronologies show different growth influences associated with temperature. Fmd 16 shows significance with mean summer temperature from March through September for both years. Fmd 14 shows a negative relationship with mean summer temperature from June through September, which is unlikely, however this indicates other parameters are affecting growth. Fmd 15 is very erratic and shows no consistent pattern of influence due to temperature.

Figure 4.2.4 shows Fmd 14 and Fmd 15 have significant positive correlations with maximum temperature for the growing season of ring formation. April-through-August correlations are highly significant for both Fmd 14 and Fmd 15; however Fmd 14 is also highly correlated with September and October maximum temperatures. Fmd 16 shows significant correlations for only three months during the growing season, April, May and July. Minimal significance between Fmd 16 growth and maximum temperature can be inferred. Fmd 17 and Fmd 18 show only three months in which both chronologies are significantly negatively correlated with maximum temperature. No significant correlations exist between Fmd 17 and Fmd 18 annual ring widths and growing-season maximum temperature.

Fmd 16 shows the most significant trend in relation to snowfall, Figure 4.2.5. Fmd 16 correlations are highly significant from December through March for the winter before the growing season. The geographical location of Fmd 16, lying in the heart of the Long Range Mountains, makes it the likely region to be most greatly affected by snowfall and accumulation. Snowfall within this region is not as affected by frequent melt-accumulation cycles. Snow remains for extended periods of time in the winter months, giving long-term winter protection from desiccation. This geographical area differs from the northern region. Fmd 17 and Fmd 18 are affected by more frequent melt-accumulation cycles at lower altitudes. High winds are more frequent across the Northern Peninsula (Fmd 17 and 18), increasing the desiccation and winter stress.

Fmd 14 and Fmd 15 show no significant trend with snowfall; negative correlations from February through May express how a spring with heavy snow can greatly affect tree growth, resulting in a growth reduction the next growing season. April is negatively correlated with Fmd 14, Fmd 15 and Fmd 16. High April snowfall may therefore result in a decrease in annual ring width. Fmd 17 shows significant correlations for February, March and April. May shows a positive correlation and the remaining months show negative correlations. Fmd 18 only shows one positive correlation for the month of April, however this is not significant. The remaining months show negative relationships.

Figure 4.2.6 shows Fmd 17 and Fmd 18 are highly positively correlated with mean winter temperature. Mean summer temperature is negatively correlated with Fmd 17 and positively correlated with Fmd 18, however, this is not significant. Fmd 17 and Fmd 18 ring-width indices both show higher significance with Daniel's Harbor winter monthly mean temperatures than summer monthly mean temperatures. Figure 4.2.1 provides mean winter temperature from the Daniel's Harbor climate station and shows a highly significant relationship with Fmd 17 and Fmd 18. On the Northern Peninsula, mean winter temperature forms a strong relationship with annual ring growth.

The southern chronologies of western Newfoundland, Fmd 14 and Fmd 15 show strong positive correlations with the west coast sea-surface temperature, Figure 4.2.7. This influence by sea-surface temperature may be evidence of the marine climate influence on tree-ring formation. This marine influence is the temperature-moderating trait of the ocean, which decreases climatic temperature extremes. Both Fmd 16 and Fmd 17 show negative correlations with sea-surface temperature; less of a marine influence may be at work in these regions. These regions will be central to the area of mixing between the warmer water from the south and the colder arctic water from the north. The North Atlantic marine influence diminishes with the warming of the arctic water while it mixes and flows south. Fmd 18 has a strong positive relationship with sea-surface temperature. Fmd 18, dealing with the most northerly coastal exposed site, displays the effect of this North Atlantic marine influence in its annual ring widths. Sea-surface temperatures are also highly correlated with surface air temperature, therefore this marine influence effects continental climate.

This temperature-moderating trait of the ocean, the marine influence, affects continental climate in coastal regions, which affects growth. The marine influence plays a large roll in tree-ring formation. However, it is difficult to determine the percentage of the chronology variance resulting from marine influence.

Winter-season mean temperatures are significantly associated with Fmd 17 and Fmd 18 chronologies, which are affected by North Atlantic temperature and circulation anomalies. These findings are consistent with correlations found by D'Arrigo et al. (1993), for chronologies in Scandinavia. D'Arrigo et al. (1993) showed a relationship between Scandinavian tree-ring chronologies and monthly mean temperatures. Comparison between Fmd 17 and Fmd 18 chronologies and the findings of D'Arrigo et al. (1993), show correlations of similar magnitude in the North Atlantic sector. D'Arrigo found significant temperature correlations for the winter months prior to ring formation. Months of significant correlations were September-through-April (D'Arrigo et al., 1993).

From D'Arrigo et al. (1992), white spruce chronologies from two areas in Labrador (north central Labrador and southern Labrador near Goose Bay), a white spruce chronology from the Northern Peninsula and a white pine chronology from north central Newfoundland (Last Chance) all show evidence of North Atlantic temperature and circulation anomalies in the 1960's and 1970's. This same trend is seen in the developed chronologies from the Northern Peninsula. Fmd 17 and Fmd 18 both show this associated decline and low-growth indices starting with a rapid decline following 1971 and continuous into the late 1970's. D'Arrigo et al. (1992) determined that tree growth can continue to decline after temperatures begin to recover because severe conditions associated with a decline in temperature may result in large amounts of defoliation. This could have resulted in the continuous decline late into the 1970's, even after temperatures had recovered. Winters with increased desiccation result in decreased photosynthetic ability of the trees. Coniferous evergreens, which maintain their photosynthetic tissue from previous years, take longer to recover from extreme harsh conditions than deciduous trees which produce new foliage annually (D'Arrigo et al., 1992).

Chronologies Fmd 17 and Fmd 18 both show evidence of a 1820's and 1830's warm event and subsequent cooling and recovery in the North Atlantic (D'Arrigo et al., 1992) (Figure 4.4, 4.5). From D'Arrigo et al. (1992), a decadel-scale fluctuation in temperature appears to have occurred in the North Atlantic around the 1820's and 1830's. In Fmd 17, a growth increase is noted from 1820-1852 but it does not reach its above-average growth until 1830, then maintains above-average growth from 1846 to 1861. Fmd 18 reveals 1821 as the year of least growth in the chronology. From 1821 to 1825, growth increased rapidly and reached the maximum growth experienced since then. Growth reached its maximum in 1815. A word of caution is noted in Fmd 18 data before 1818 due to a large increase in variance caused by a single tree in a very small sample size.

The growth exhibited by Fmd 17 and Fmd 18 in the 1820's and 1830's approximated the same growth trend and significance as the northern and southern Labrador sites, the Northern Peninsula site and the north central Newfoundland site (Last Chance) described in D'Arrigo et al. (1992). However, Cook and Mayes (1987) state that the interval from 1827 to 1835 was an exceptional growth period, having the largest above-average growth until exceeded in 1970. Fmd 17 reached its maximum growth later than found by Cook and Mayes (1987), showing the effect of the exceptional growth period decreasing southward and inland. For Fmd 17, growth increased from 1935 to 1971. This time period appears to span the greatest period of growth in the past two centuries. Fmd 18 appeared to reach its maximum growth before the maximum found by Cook and Mayes (1987), however, it maintains a very high average growth from 1829 to 1835. This growth level has not been exceeded since.

Chapter V: Summary and Conclusions

The Western Newfoundland tree-ring chronologies (Fmd 14 through Fmd 18) have been compared to dendroclimatic evidence and other chronologies from the North Atlantic region. The Northern Peninsula chronologies (Fmd 17 and Fmd 18) show evidence of the late 1960's-1970's North Atlantic temperature and circulation anomalies and the 1820's-1830's warming and subsequent cooling. The correlations between the Northern Peninsula chronologies and monthly mean temperature show a similar relationship to correlations between Scandinavian tree-ring chronologies and monthly mean temperature. The Northern Peninsula chronologies have been verified with published chronologies to ensure chronology accuracy.

The northern peninsula chronologies are affected by similar North Atlantic anomalies as other published chronologies. Western Newfoundland shows the declining affect of the North Atlantic anomalies and the associated cold arctic water. The marine influence on climate is greater in areas with increased coastal exposure. Newfoundland is situated in an area of the North Atlantic affected by differing sea-surface temperature.

The southern chronologies of (Fmd 14, Fmd 15 and Fmd 16) do not correspond well to any published chronologies for the North Atlantic region. Fmd 14 and Fmd 15 chronologies do not extend back far enough to correspond to the 1820's-1830's warming and subsequent cooling. Fmd 16 does correspond to the 1820's-1830's warming and subsequent cooling, but not to the magnitude of either of the Northern Peninsula chronologies. Fmd 16 is a region showing poor association with the regions lying south and north. The Fmd 16 chronology does not correlate consistently with the same climatic variables as do the other chronologies; however, Fmd 14 and Fmd 15 form similar relationships with many of the climatic variables. Differences in magnitude exist but the signs of correlation are almost always consistent.

Analysis of comparisons between annual ring growth and climatic variables has found that climate-growth relationships differ between the Northern Peninsula chronologies and the southern chronologies. The southern chronologies were determined to be unlike the chronologies from the North Atlantic sector. The southern chronologies (Fmd 14, Fmd 15 and Fmd 16), were sampled, measured, cross-dated and standardized using the same methods as the Northern Peninsula chronologies (Fmd 17 and Fmd 18). From comparisons with published chronologies, confidence in the accuracy of the Northern Peninsula chronologies allows for confidence and accuracy in the southern chronologies.

The formation of five tree-ring chronologies allows for the further reconstruction of climatic variables. The ability to extend backward the temperature record 100 years beyond what is currently recorded will increase the ability of scientists to understand environmental change.

The ability of dendrochronology to help understand environmental anomalies in both the terrestrial and marine environments could be very beneficial to the Newfoundland resource-based economy. Although anthropogenic impacts have played a role in changing the North Atlantic environment, it is likely that environmental change and climatic anomalies have also played a role. The ability to understand, model and predict these environmental changes can only be fully understood through long-term monitoring, data collection and paleoclimatic reconstruction. Climate modelling is dependent on understanding long-term environmental change. Understanding long-term climate change will largely improve the manageability of the Newfoundland and North Atlantic environment.

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