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Multidisciplinary applications of tree-ring analysis in Newfoundland and Labrador

We describe the potential for using many types of tree-ring analyses, with particular reference to their application to Newfoundland and Labrador issues. Tree-ring analysis is an inexpensive, non-destructive method of studying a variety of living and dead trees and wooden objects. The adaptability of tree-ring analysis to many sub-disciplines renders this science useful for a number of different methodologies, with the results quickly applied to various interest groups throughout the province. Here, we discuss simple applications of tree-ring analysis to climate change scenarios, the power generation industry, forest ecology and management, parks and tourism, cultural heritage, and history across the province.

We also present an innovative tree-ring sampling strategy that has been established across Newfoundland and Labrador. The sampling grid consists of sampling tree species along lines of 1° latitude and 1° longitude across Newfoundland, and 1° latitude and 2° longitude across the majority of Labrador. This grid is the first of its kind in Canada and will provide the means of exploring spatial characteristics of issues that are particularly significant to Newfoundland and Labrador. We illustrate this through tree-ring analysis and the use of our established grid system. There are many potential benefits to Newfoundland and Labrador economic and cultural developments.

Tree-ring analysis is frequently used as an effective, inexpensive research tool that is non-destructive and has multidisciplinary capabilities. Most trees and shrubs growing in temperate regions produce annual rings that expand as a response to the local and regional environments in which they grew. Although many tree-ring studies in Canada focus on the relationship between tree rings and climate, we believe that much more information is contained in these annually-formed tree rings. The information derived from the science is therefore under utilised, specifically in Newfoundland and Labrador, where so many tree-ring applications are possible (Fig. 1). Newfoundland and Labrador has a long history, a rich culture, several natural-resource-based industries and a complex climate pattern; we believe that understanding of all of these aspects of the province can be greatly improved from tree-ring studies. The purpose of this paper is to introduce how the little-used subject of tree-ring analysis could be better applied to Newfoundland and Labrador.

Annual tree-ring formation

Tree radial growth commences in the spring, when environmental conditions permit and photosynthesis begins. At this time, the tree produces large cells with thin walls, called earlywood cells (Fritts) (Fig. 2). These cells grow in the tree sequentially from the bark-side inward. This radial growth continues until mid-summer when latewood cells, which are thicker, smaller and have a darker appearance, are produced as a response to deteriorating environmental conditions and as the tree begins to store resources for the next year's growth (Fritts). It is the contrast between the darker latewood cells produced at the end of a growing season and the paler earlywood cells produced at the beginning of the next season that identifies an annual growth ring (Fig. 2).

For most trees in Newfoundland and Labrador, the size of an annual ring is controlled by the environmental conditions that occur throughout the previous and current growing seasons, as within this timeframe the rate of uptake of nutrients and water by leaves and the roots is determined, and converted into radial growth (Fritts). As a result, there is usually a measurable relationship between tree rings and the environment; a favourable growth year results in more cell production and a wider growth ring than during a poor growing season. The exact determinant of "poor" and "favourable" conditions depends on each species of tree and its adaptation to its habitat. For some tree species, favourable conditions might mean a cool moist environment, while for others, the same environmental inputs could create a poor growth sequence.

Scarring

When cell-producing tissue is damaged, often production of woody tissue will cease and annual-ring formation becomes impossible at that location in the ring. However, the surrounding tissue can continue to grow and produce annual tree rings. The result is the formation of a scar that can sometimes be locked in time (Fig. 3). The exact date of the when the scarring event occurred can be deduced by counting the number of rings produced after the scarring event. Forest fire return intervals can be calculated using this method. For example, if a fire scar exists on a tree that is analysed in 2009, and the undamaged portion of that tree produced 20 additional rings beyond the scar, then one can infer that the fire occurred in 1989. Dating of scars is often useful to identify past fires (Bergeron and Archambault) and, in some cases, acquire information on animal population activities (Boudreau et al.).

Crossdating

Trees growing within the same regional climate experience similar environmental conditions and so have similar tree-ring patterns (Fritts). As a result, annual ring measurements from several tree samples can be averaged together to produce mean annual measurements, which essentially represent a tree-ring growth pattern that is representative of the species for that area. If this chronology is developed based on live samples, then it is called a "dated master chronology" because the year when each ring was formed is known. This overall growth pattern can serve as the basis for dating samples of the same species that have no known dates by matching the tree-ring patterns to those from a dated master chronology (Fig. 4). If a good pattern match is obtained between the two time series, then the time frame when the two chronologies overlap can be transferred from the dated to the undated series. In a scenario such as this, the last year when the patterns of the dated and undated samples overlap would represent the date when the unknown sample tree was felled and would provide insight into when the unknown sample lived. This process is referred to as crossdating and it can provide some highly accurate insights into historical events.

Previous tree-ring research in Newfoundland and Labrador

In Newfoundland and Labrador, the application of tree-ring analysis has been infrequent. Published studies have focused on the relationship between tree-rings and climate in northern Labrador (*c.f.* Duvick; D'Arrigo et al. 1992; 1996; Briffa, et al.; D'Arrigo and Jacoby). These studies have identified that some tree species in northern Labrador are climatically-sensitive and that terrestrial climate is an important driver for tree growth in Labrador, as is the proximity of the Labrador Sea (D'arrigo et al. 1993; 2003). However, the aforementioned studies have focused only on the relationship between tree-rings and climate—a small component of all the potential tree-ring research possible (Fig. 1).

Newfoundland and Labrador is also poorly represented in the International Tree-Ring Data Bank (ITRDB) (Contributors of the International Tree-Ring Data Bank 2009). Whereas other Canadian provinces have seen a recent exponential increase in the construction of tree-ring chronologies, Newfoundland and Labrador has seen no change since 2002. One third of the chronologies currently in existence from Newfoundland and Labrador were completed prior to 1988. The ITRDB currently holds 268 tree-ring chronologies for all of Canada, only 8 of those are from Newfoundland and Labrador, and all are from a single tree species, despite the existence of many species across the province (Contributors of the International Tree-Ring Data Bank 2009). Further, tree-ring analysis in Newfoundland and Labrador has been limited to single sites whereas the current trends in tree-ring analysis are for the creation of spatial networks (*c.f.,* Laroque and Smith; Watson and Luckman). As a result, the information derived from these single-site studies is often over-interpolated in order to try to represent regional conditions.

To alter this short-coming, we proposed to complete a systematic tree-ring sampling grid that contained more species and encompassed all of Newfoundland and Labrador. We believe that a systematic sampling grid will provide the base-level information necessary for further interdisciplinary studies, and that these studies will assist in providing information on various sub-disciplines that are of particular interest to Newfoundland and Labrador. Since the proposed grid encompasses the entire province, our sampling method will therefore also allow for studies to either focus on or near a single sampling site within our network, or on numerous sites if a study question has a spatial dimensionality to it. These results would thereby make it possible to yield results at various geographical scales.

Data collection—The grid (study sites, methods, results)

We have systematically sampled across all of Newfoundland and Labrador using a 1° latitude by 1° longitude grid pattern in Newfoundland, spanning from 47°N to 51°N and a 1° latitude by 2° longitude grid pattern from 52°N to 55°Nin Labrador (Fig. 5). This spatial grid is the first of its kind in Canada where most tree-ring sampling strategies, if they include several sites, are more opportunistic than systematic (e.g. Laroque and Smith; Watson and Luckman). Overall, 18 sites were sampled in Newfoundland and 28 sites in Labrador. At each site, samples from the two most dominant tree species were collected, except the six northern-most sites in Labrador where only white spruce was collected (*Picea glauca* (Moench) Voss). In all, four tree species have been sampled: white spruce, black spruce (*Picea mariana* (Mill.) B.S.P.), balsam fir (*Abies balsamea* (L.) Mill.), and eastern larch (*Larix laricina* (DuRoi) K. Koch).

In all, 86 tree-ring width chronologies were developed following standard methods, using 40 tree cores per chronology, taken from 20 dominant or co-dominant trees (2 core samples per tree, taken at right angles to each other) at each site (Stokes and Smiley 1968). The cores were collected at breast height (1.3 m) using a 5.1 mm increment borer and placed in plastic drinking straws for transportation to the laboratory at Mount Allison University. Once there, the core samples were glued onto mounting boards and sanded progressively, from 80 grit to 400 grit, to expose the tree rings (Stokes and Smiley 1968). The tree-ring widths were measured using specialised tree-ring software, WinDENDRO (version 2005), a semi-automated imaging software (Guay et al.), or a Velmex measuring stage coupled to J2X software and viewed under a 63X microscope. Both systems are capable of measurements of tree-ring widths with 0.001mm precision.

Sampling along this grid has resulted in the creation of 86 tree-ring width chronologies across Newfoundland and Labrador. Of these, 34 are from balsam fir tree species, 32 are black spruce, 12 are white spruce and 8 are eastern larch. The following is a description of the ways in which we hope to further utilise the tree-ring samples collected in the grid, and how we believe our grid can assist the many other fields that do not traditionally utilise tree-ring research in Newfoundland and Labrador.

Discussion

Our spatially-explicit sampling strategy for tree-ring analysis is the first of its kind in Canada. The following discussion points describe the possible application of the tree-ring grid for climate change studies, industry studies (with respect to both hydroelectricity and forest management), parks and tourism studies, historical and cultural studies.

Climate change

Previous tree-ring studies in Labrador have focused exclusively on the relationship between tree-rings and instrumental climate records (Duvick; D'Arrigo et al. 1992; 1993; 1996; 2003; Briffa, et al.; D'Arrigo and Jacoby). These relationships can be used to reconstruct approximations of past climates, a topic which is particularly relevant in today's society, where extended climatic records are providing a better context for current climatic variation. However, the information acquired through Labrador studies is limited by the number of species sampled (only one) and the site locations, which were opportunistic. The latter is significant because a stronger relationship can be established when using the closest and longest climate dataset, resulting in a better approximation of past climates. The grid we have completed can vastly improve on these studies through its systematic nature and sampling of multiple tree species.

Climate reconstructions are accomplished using trees that are growing at the edge of their habitat range. Here, tree growth is increasingly limited by a single climatic variable (for example, temperature), so a slight change in that variable produces a measurable change in the tree ring, which can easily be expressed as a relationship between tree growth and climate (Fritts). This relationship is subsequently applied to a chronology in order to reconstruct past climate for the length of that chronology. However, since such sensitive trees are usually found in remote northern areas where the instrumental climate data are scarce and short-term, this process often creates a weaker relationship than could be obtained using local and/or long-term data. To date, this has largely been the case for studies of the relationship between tree rings and climate in Labrador, where a relationship between white spruce tree rings from the Nain area and climate data from Goose Bay were used (D'Arrigo et al. 2003). One alternative is to use gridded climate data which applies interpolation methods to establish long-term climate data at fixed points in space. Our grid mimics the spatial pattern in such gridded climate data sets of sea surface temperature (SST) and terrestrial air temperature that span over 1 century (Mitchell et al.). Using these datasets overlapping with our grid would therefore result in high-quality reliable climate reconstructions for the province.

There are several regions and tree species in Newfoundland and Labrador which are ideal for studying the relationship between trees and climate and also to reconstruct past climates. For example, the growth of trees found in highland locations, including Gros Morne National Park and the mountainous regions of Labrador, is primarily limited by temperature (Fig. 5). Further to this, different tree species have different habitat ranges and different climate sensitivities. As such, using different species, such as those sampled with our grid, it might be possible to reconstruct different climate variables at different spatial and temporal scales, such as spring temperature, fall precipitation or even SSTs, the latter of which may introduce the possibility of understanding the long-term relationship between past fish populations in the Labrador Sea and the north Atlantic and SSTs.

Industry—electrical power generation

Hydroelectricity has played, and is forecasted to continue to play an important role in Newfoundland and Labrador. Since hydroelectric power generation relies on aquifer recharge and stream flow levels, knowledge of the variability in these processes can greatly improve the management of the industry. Using tree-ring analysis, it is possible to create a record of past moisture availability that spans several centuries. Annual and, in some cases, monthly precipitation levels have been determined using tree-ring widths (e.g., Case and MacDonald) or isotope ratios captured from annual rings (Jenkins et al.). New longer-term precipitation records would be readily used as a measure of aquifer recharge variation over the long term, which would directly assist better projections of the natural variations in electricity production.

Tree rings have also been used to reconstruct past stream flow (Cook and Jacoby; Beriault and Sauchyn), lake levels (Begin and Payette) and flood events (Harrison and Reid) across North America. Having access to such long-term records would help to complete the input and outputs of many of the water regimes that are so important to the hydroelectricity generation domain. Since our grid traverses several key hydroelectric projects in Newfoundland and Labrador, we have taken the first step in establishing a basis for further studies that would be able to derive valuable long-term data on moisture availability for this industry, and for existing and proposed sites (Fig. 5). This method could even be used to identify new locations for hydroelectric power generation.

Coastal locations of Newfoundland and Labrador are particularly windy, making them ideal locations for wind power generation. Although the majority of renewable energy production in Newfoundland and Labrador originates from hydroelectricity, wind power has proven to be an effective source of clean energy for all of Atlantic Canada. Coastal trees can incorporate the effects of the winds on their ring patterns. Studies have already illustrated that tree rings from coastal sites in Atlantic Canada might be able to provide a long-term record of wind activity at a site (Vanthournout and Laroque). As with other examples above, understanding longer-term processes would give a much better footing to a developer before they were to outlay funds towards the infrastructure in a large development project.

Forest ecology and management

Tree-ring analysis is a common practice in the forestry industry, and it is already being applied in the province as a means of obtaining information on forest population dynamics. Over half of the forests on the island are deemed productive (Heritage Newfoundland) and knowledge of forest processes can greatly improve forest management practices. Currently, the Province's mandate for forest management is to "…manage and conserve the Province's ecosystems, under the principles of sustainable development, using an ecologically based management philosophy, and sound environmental practices." (Government of Newfoundland and Labrador). Tree ring based studies can also assist in accomplishing this mandate by providing information on the frequency and intensity of forest disturbance events and on the population fluctuations of forest dwellers.

As part of the boreal forest continuum, the forests of Newfoundland and

Labrador are reliant on episodic disturbance events to maintain their biodiversity. Some of these disturbance events occur with regular frequency and knowledge of the variability in these patterns can assist with forest management practices. Current data on the frequency, intensity and spatial patterns associated with disturbance events is limited but could be greatly improved using data provided by a gridded tree-chronology system.

Forest fires and insect outbreak events are common disturbances in the province whose frequency could be better identified using tree rings, specifically the spatially dynamic aspects of these natural processes. Forest fires produce datable scars on trees and, if the tree survives and continues to produce annual rings, the fire event can be dated (Bergeron and Archambault) (Fig. 3). Defoliator insects, such as the spruce budworm (*Choristoneura fumiferana* (Clemens) and larch sawfly (*Pristiphora erichsonii Hartig*), both common in Newfoundland and Labrador, damage tree needles without killing the tree, resulting in identifiably-narrow tree rings for the duration of the outbreak (Girardin et al.). With our existing grid, we are in a unique position to be able to not only provide a long-term record of past forest fire and insect outbreak frequency, but also we can begin to describe the highly variable spatial extent of these disturbance events, both currently and in the past.

Animal population fluctuations can also be determined using tree-ring analysis. Trampling by large animals on tree roots produces scars similar to fire scars, which can be dated and used to reconstruct fluctuations in animal populations (e.g., Morneau and Payette). Using this method, a large spatial grid would also help to provide past information on the migration patterns for animal populations. This may be particularly significant in Labrador, where recently, the threatened woodland caribou (*Rangifer tarandus caribou*) populations have inexplicably changed their migratory patterns, but limited information is available on past population sizes (Schaefer et al.). In this case, using either the point source or multiple points in the sampling grid, we would be able to provide background information on past caribou activities for a period spanning the last century (e.g., Morneau and Payette).

Riparian trees can also be used to reconstruct past fish populations. In the Pacific Northwest, for example, relationships were established between pacific salmon abundance and tree rings as a result of the positive radial growth influence from additional nutrient availability from stream-spawning species (Drake and Naiman). As a result, Pacific salmon abundance for the last 350 years was reconstructed for several sites (Drake and Naiman). In Newfoundland and

Labrador, similar studies could be devised on species such as Atlantic salmon. These studies could provide information on the past fluctuations in fish populations, and give fishery managers a longer term perspective on past variation in stock numbers, and subsequently how they manage future harvest levels of the province's resource.

Tree-rings were also used in the Main River watershed in western Newfoundland to determine the time required for course woody debris to break down in a forest (Campbell and Laroque). Using living and dead samples, a visual wood decay classification scheme was established and used to put calendar-aged approximations on the length of time required for various woody debris to decompose in the forest. The study had the broader objective of better understanding the habitats of animals such as the endangered Newfoundland pine marten (*Martes americana atrata*), which occurs naturally in only a few regions of Newfoundland and Labrador and requires specific types of old growth forest habitat to live (Kyle and Strobeck). Tree-ring applications could further the knowledge of either a specific habitat, or a specific plant or animal within a given region of the province.

The relationship between tree rings and climate has also been used in conjunction with Global Climate Modelled (GCM) forecasts that are readily available from a number of sources worldwide. GCM data have been used to forecast the radial growth rates of trees to predict how our forests might respond to forecasted changes in climate. This methodology can be used to serve Newfoundland and Labrador's need for long-term sustainability for the province's forest resources, especially as it becomes increasingly important to plan for the future. For example, if it is determined that a common tree species will grow better under a forecasted wetter and warmer spring climate, then we can begin to approximate how tree species will grow in the future at a grid point. By then, using the wider grid, this process can be repeated across Newfoundland and Labrador, resulting in the knowledge of how these changes may then be represented spatially across the entire landscape.

Parks and Tourism

Newfoundland and Labrador has nine National Historic Sites, two National Parks (including Gros Morne National Park which is a UNSECO World Heritage site), and the extensive East Coast Trail. These locations are inherently significant to Newfoundlanders and Labradorians and generate significant economic benefits to the province through tourism activities. The information that can be derived from tree rings could greatly enhance the significance of these locations. Tree-ring analysis provides information on tree age and ecosystem characteristics in a manner that is inherently simple for the average person to understand. For example, tuckamore, a tree growth form that is of particular interest to people of the province, and its interesting characteristics could be better described to the public using tree-ring methods. Descriptions of ecological phenomena of interest to tourists could almost always be greatly enhanced by more information such as maximum tree ages, growth rates and a description of the effects of local stressors on trees such as moisture, wind, insects and fire.

History and Cultural Heritage

Using crossdating techniques, it is possible to provide absolute dates for the fabrication of past artefacts and structures using tree-ring analysis (Stokes and Smiley) (Fig. 4). Significant research on dating structures and artefacts using tree-rings has been conducted across Atlantic Canada. Recently, many objects such as a First Nation's canoe found partially buried in a beach in Val Comeau has been dated (Pickard et al. 2009). The canoe is presently undergoing restoration at the New Brunswick Provincial Museum, but it highlights the possibility of using tree-ring techniques to assign calendar dates to newly discovered artefacts and those that are known, but whose date of origin is only estimated.

Similarly, the cutting date of trees used for the construction of one of the oldest structures ever made in Canada, the Sinclair Inn in Nova Scotia, was determined using crossdating techniques. The construction of the building was determined to have evolved through time, as it was originally constructed from two buildings (the Soullard and Skene houses) and joined in 1769 (Robichaud et al.; Robichaud and Laroque). Prior to the tree ring analysis, the cultural history surrounding the building was speculated upon, but it was not until the exact dates of construction were determined that the cultural history was clarified from the various proposed provenances.

Similar studies have been conducted in New Brunswick (Selig et al.) and Prince Edward Island, but to date none have been conducted in Newfoundland and Labrador. This is despite an even longer timeframe of cultural richness in the province, and the existence of many datable artefacts and structures that would provide a greater understanding of Newfoundland and Labrador culture and history. In comparison to the Canadian mainland, Newfoundland and Labrador has an older and more vibrant history which should be better defined before many of the objects and structures are lost or degrade irretrievably with time. For example, several sites in Newfoundland and Labrador could be targeted. At the northern tip of the island, excavations by anthropologists have uncovered a rich history at L'Anse aux Meadows that includes settlements by aboriginal people approximately 6000 years BP (Parks Canada 2009). Since then, several groups, including more aboriginal groups, have populated the area and left further artefacts behind. Those made of wood, including tools and structural beams, could potentially be dated, thereby providing more accurate calendar-dated details on the history of this National Historic Site. In particular, during the 1500-1800 period, L'Anse aux Meadows and Red Bay, both national historic sites of Canada, were populated by French fisherman and Basque whalers, who would have left behind datable artefacts (Parks Canada). In addition, the Norse buildings identified as dating to the 11th century were made of sod, but this covering overlaid a wooden frame, likely made of material that might be datable to the exact year when the tree was felled. To date, over 2000 pieces of worked wood have been found at this site, spanning several soil layers (Parks Canada), but if calendar dating of these materials are not attempted soon, some of them could deteriorate beyond a point where dendrochronological analyses would be possible.

Conclusion

This paper has described possible applications of tree-ring analysis, with specific reference to Newfoundland and Labrador issues. Whereas previous tree-ring studies in the province focused exclusively on the relationship between tree rings and climate in northern Labrador, we have shown that the potential for many more applications exists. In particular, by using our newly created sampling grid we have developed a resource that should be the basis for many more studies in the province. Our sampling strategy can provide a base-level of tree-ring patterns that can be used to initiate many climatic change, industrial, tourism, historical and cultural questions across the breadth of the province, and do so for many multidisciplinary subjects. With these applications, we believe that there is potential to bring the province to the forefront of Canadian tree-ring analysis research.

Fig. 1: Descriptions and definitions of the various possible applications of tree-ring analysis. Different study-types can yield dating or environmental results, using tree scars or radial growth trends. The various applications discussed in the text are shown.

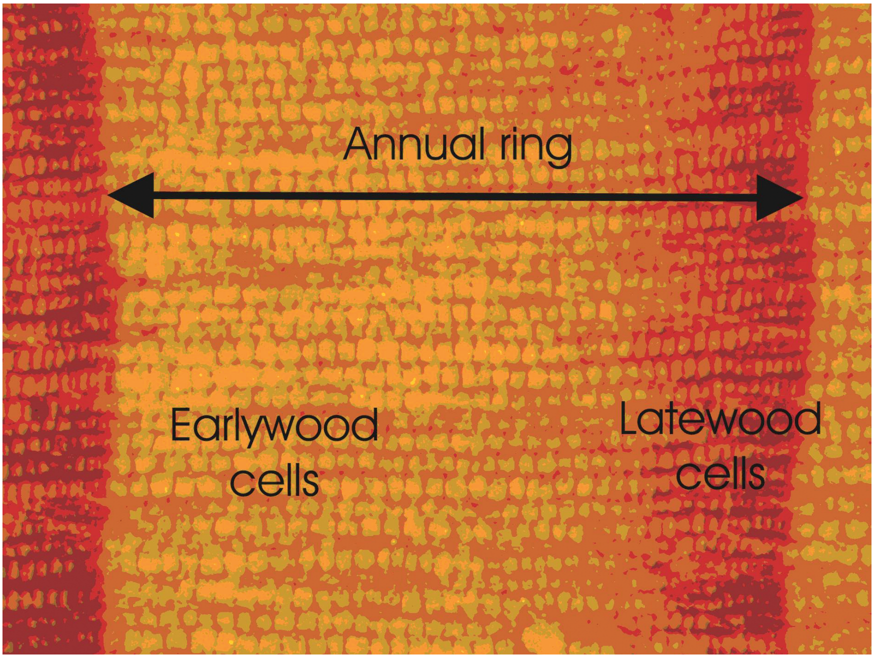

Fig. 2. An annual tree ring. Image illustrates the lighter appearance of the thin-walled earlywood cells, formed during the early part of the growing season. Latewood cells are formed by mid-summer, when environmental conditions begin to deteriorate. Latewood cells are smaller and have thicker walls than the earlywood cells.

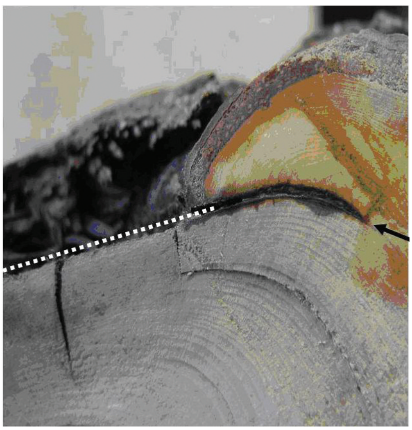

Fig. 3. Illustration of a fire scar found on a black spruce tuckamore tree collected in Labrador. The white dashed line represents where the tree was damaged by the fire. The black arrow shows where a scar exists, but the tree was able to continue to produce annual rings. By counting the number of rings produced after the scar was formed, we can accurately date a fire disturbance event. Annual tree-rings are visible above and below the scar.

Figure 4. Crossdating example between two tree-ring time series. The black line represents a dated master chronology that spans 1933-2006. The grey line represents an undated sample, whose tree-ring pattern match those of the dated master chronology from 1933-1964 (key matching patterns are shown by arrows). From this, it can be deduced that the undated sample died in 1964. Due to the tree ring standardisation process, the tree ring growth index is unitless (y-axis).

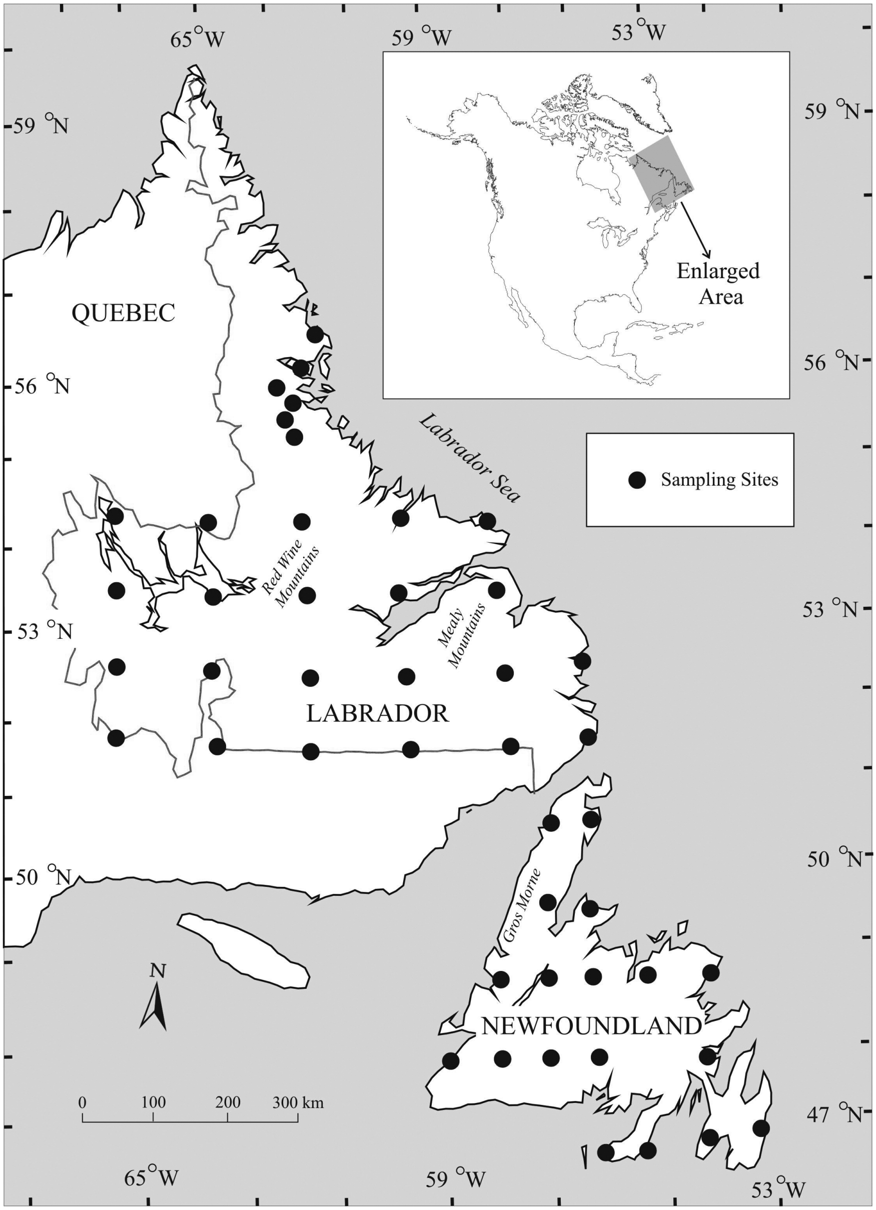

Figure 5. The sampling grid developed for this study. The grid consists of 18 locations in Newfoundland and 28 sites in Labrador. The grid is represented by 86 chronologies from four sampled species. Some locations discussed in text are shown.

Works Cited

Bégin, Y., and Payette, S. "Dendroecological evidence of lake-level changes during the last three centuries in subarctic Quebec." *Quaternary Research* 30. 2006, 210-220.

Bergeron, Y., and Archambault, S. "Decreasing frequency of forest fires in the southern boreal zone of Quebec and its relation to global warming since the end of the 'Little Ice Age'". *The Holocene* 3. 1993, 255-259.

Beriault, A. L., Sauchyn, D. J. "Tree-ring reconstructions of Streamflow in the Churchill River Basin, Northern Saskatchewan." Publication: *Canadian Water Resources Journal* 31. 2006, 249-262.

Boudreau, S., Payette, S., Morneau, C., Couturier, S. "Recent decline of the George River Caribou herd as revealed by tree-ring analysis". *Arctic, Antarctic, and Alpine Research* 35. 2003, 187-195.

Briffa, K.R., Jones, P.D., Schweingruber, F.H. "Summer temperatures across northern North America: Regional reconstructions from 1760 using tree-ring densities". *Journal of Geophysical Research* 99: 25 1994, 835-25; 844.

Campbell, L.J, and Laroque C.P. "Decay progression and classification in two old-growth forests in Atlantic Canada". *Forest Ecology and Management* 238. 2007, 293-301.

Case, R.A. and MacDonald G.M. "Tree-ring reconstructions of stream flow for three Canadian prairie rivers". *Journal of the American Water Resources Association.* 2003, 703-716.

Contributors of the International Tree-Ring Data Bank, *IGBP PAGES/World Data Center for Paleoclimatology,* NOAA/NCDC Paleoclimatology Program, Boulder, Colorado, USA. 2009.

Cook, E.R., and Jacoby, G.C. "Potomac River streamflow since 1730 as reconstructed by tree-rings." *Journal of Climate and Applied Meteorology* 22. 1983, 1659-1672.

D'Arrigo, R., Buckley, B., Kaplan, S., Woollett, J.. "Interannual to multidecadal modes of Labrador climate variability inferred from tree rings." *Climate Dynamics* 20. 2003, 219-228.

D'Arrigo, R.D., Cook, E.R., Jacoby, G.C.. "Annual to decadal-scale variations in northwest Atlantic sector temperatures inferred from Labrador tree rings". *Canadian Journal of Forest Research* 26. 1996, 143-14.

D'Arrigo, R.D., Cook, E.R., Jacoby, G.C., Briffa, K.R.. "NAO and sea surface temperature signals in tree-ring records from the North Atlantic sector". *Quaternary Science Reviews* 12. 1993, 431-440.

D'Arrigo, R.D., Jacoby, G.C. "Northern North American tree-ring evidence for regional temperature changes after major volcanic events". *Climatic Change* 41. 1999, 1-15.

D'Arrigo, R.D., Jacoby, G.C., Free, R.M. "Tree-ring width and maximum latewood density at the North American tree line: parameters of climatic change." *Canadian Journal of Forest Research* 22. 1992, 1290-1296.

Drake, D. C. and Naiman, R. J. "Reconstruction of Pacific Salmon abundance from riparian tree ring growth". *Ecological Applications* 17. 2007, 1523–1542.

Duvick, D.N. 1978. "The Border Beacon, Labrador, Picea glauca chronology". *Technical Note* (Laboratory of Tree-Ring Research, University of Arizona, Tucson) 12. 1978, 1-8.

Fritts, H.C. *Tree rings and climate.* Academic Press, London, 1976.

Girardin, M.P., Tardif, J., and Bergeron, Y. "Radial growth analysis of Larix laricina from the Lake Duparquet area, Québec, in relation to climate and larch sawfly outbreaks". *Écoscience* 8. 2001, 127–138.

Government of Newfoundland and Labrador. *What we do. Forestry services branch.* http://www.nr.gov.nl.ca/forestry. 2009, accessed March 2009.

Guay, R., Gagnon, R., and Morin, H.. "MacDendro, a new automatic and interactive tree-ring measurement system based on image processing". In T.S. Bartholin, B.E. Berglund, D. Eckstein, F.H. Schweingruber, and O. Eggertsson (eds.). *Tree-Rings and Environment: Proceedings of the International Symposium*, Ystad, South Sweden, 3-9 September, 1990, Lund University, Department of Quaternary Geology. Lundqua Report 34. 1992, 128-131.

Harrison, S.S., and Reid, J.R.. "A flood-frequency graph based on tree-scar data." *Proceedings of the North Dakota Academy of Science* 21. 1967, 23-33.

Heritage Newfoundland. *Forest industries.* http://www.heritage.nf.ca/society/forestry.html . 2000. accessed March 2009.

Jenkins, H.S., Baker, P.A., Evans, M.N. "Oxygen isotopes in tree rings: A 345 year record of precipitation in Amazonia". *American Geophysical Union, Fall Meeting 2008,* abstract #PP31B-1488.

Kyle, C.J., Strobeck, C.. "Genetic homogeneity of Canadian mainland marten populations underscores the distinctiveness of Newfoundland pine martens (Martes americana atrata)." *Canadian Journal of Zoology* 81. 2003, 57–66.

Laroque, C.P., and Smith, D.J.. "Predicted short-term radial-growth changes of trees based on past climate on Vancouver Island, British Columbia". *Dendrochronologia* 22. 2005, 163-168.

Mitchell, T.D., Carter, T.R., Jones, P.D., Hulme, M., New, M. "A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100)". *Journal of Climate:* submitted. 2003.

Morneau, C., and Payette, S.. "Long-term fluctuations of a caribou population revealed by tree-ring data." *Canadian Journal of Zoology* 78. 2000, 1784-1790.

Parks Canada. *L'Anse aux Meadows National Historic Site of Canada* – History. http://www.pc.gc.ca/lhn-nhs/nl/meadows/natcul/hist_e.asp. Accessed March 2009.

Pickard, F., Robichaud, A., and Laroque, C.P.. "THE VAL COMEAU CANOE: Tree-Ring Measurements". *Mount Allison Dendrochronology Laboratory Report* 2007-07.

Robichaud. A., and Laroque C.P. "Dendroarchaeology in Southwestern Nova Scotia and the construction of a regional spruce chronology". *Tree-ring Research* 64. 2008, 17-25.

Robichaud, A., Phillips, B.E., and Laroque, C.P.. "Le presbytère de Grande-Digue : une analyse dendroarchéologique". *Mount Allison Dendrochronology Report* 2007-05.

Schaefer, J. A., Veitch, A.M., Harrington, F.H., Brown, W.K., Theberge, J.B., and Luttich, S.N.. "Fuzzy structure and spatial dynamics of a declining woodland caribou population". *Oecologia* 126. 2001, 507–514.

Selig, N. E., Laroque, C. P. and Marsh, S.. "Dendroarchaeological investigations in the Maritimes: A case study of Dorchester House", New Brunswick. *Material Culture Review* 66. 2008, 42–49.

Stokes, M. A., and Smiley, T. L. *An Introduction to Tree-Ring Dating*. University of Chicago Press, Chicago. 1968, reprinted 1996 by University of Arizona Press, Tucson.

Watson, E. and Luckman, B. H. "Spatial Patterns of Pre-Instrumental moisture variability in the Southern Canadian Cordillera". *Journal of Climate* 18. 2005, 2847-2863.

Vanthournout, Z., and Laroque, C.P. *Wind Regimes in the Tantramar: An Analytic Dendrochronological Survey.* Mount Allison Dendrochronology Laboratory (MAD Lab) report 2005-08.