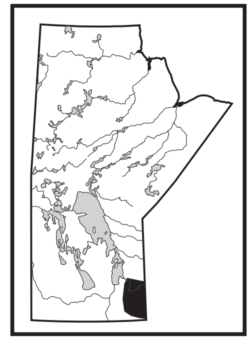
GS-14 Using tree-ring data to understand summer drought in a key watershed for Manitoba Hydro

by S. St. George[1] and D.M. Meko[2]



St. George, S. and Meko, D.M. 2007: Using tree-ring data to understand summer drought in a key watershed for Manitoba Hydro; *in* Report of Activities 2007, Manitoba Science, Technology, Energy and Mines, Manitoba Geological Survey, p. 155–160.

Summary

The Winnipeg River basin drains parts of northwestern Ontario, northern Minnesota and southeastern Manitoba, and is a key area for hydroelectric power production in Manitoba. This study uses a network of 54 tree-ring records to estimate changes in summer climate within the Winnipeg River basin, Canada since 1783 AD. Most records were developed from *Pinus resinosa* and *P. strobus*, with a limited number of collections made from *Thuja occidentalis*, *Picea glauca* and *Pinus banksiana*. Tree growth is significantly, but weakly, correlated with both temperature and precipitation during summer. High and low growth across the region is associated with cool/wet and warm/dry summers respectively; this relationship is supported by comparisons with archival records from early 19th century fur-trading posts. The tree-ring record indicates that summer droughts were more persistent in the 19th and late 18th century, but there is no evidence that drought was more extreme prior to the onset of direct monitoring.

Introduction

The Winnipeg River in south-central Canada is the largest single source of water used to generate hydroelectricity in the Canadian Prairies. Water managers have expressed an interest in understanding how the hydrology of this and other watersheds in the region has behaved during the last millennium, and have supported a number of independent research projects using several types of environmental proxies (Moos et al., 2005; Beriault and Sauchyn, 2006). This study uses a multispecies network of trees at sites within the Winnipeg River region to examine the nature of the environmental signals recorded in regional tree-ring data. A combination of empirical orthogonal function and response function analyses, and forward modelling are used to determine 1) if trees growing in this cool, moist environment retain a climate signal within their annual growth increment; 2) what factors might be responsible for creating that signal; and 3) if this information can be used to make inferences about climatic conditions prior to the onset of instrumental monitoring. This project is part of a larger study investigating the frequency and causes of hydrological drought in the Winnipeg River basin (St. George, 2007).

Study area

The Winnipeg River region is immediately west of Lake Superior and occupies the western edge of the Superior Province of the Canadian Shield. The region can be described generally as heavily forested, with little local relief, frequent bedrock outcrops and many large lakes. Where they are present, surficial deposits are mainly sandy tills derived from the surrounding Shield (Dredge and Cowan, 1989). Glaciolacustrine clay deposited in glacial Lake Agassiz is also present in the westernmost sector of the region, including the Lake of the Woods area. The Winnipeg River is a bedrock-channel river that begins at the northern end of Lake of the Woods and terminates in the south basin of Lake Winnipeg. The river is the single largest source of water to Lake Winnipeg and influences the production of over 4600 MW of hydroelectricity (St. George, 2007).

Tree-ring data

Tree-ring samples were collected at 24 sites in the Winnipeg River region between July and August in 2004 and 2005. At two sites (Moose Lake and Turtle Lake), samples were taken from both red and white pine, bringing the total number of new tree-ring collections to 26. Sampling concentrated on the three longest-lived tree species in this area: eastern white pine (*Pinus strobus*), red pine (*Pinus resinosa*) and eastern white cedar (*Thuga occidentalis)*. Stand-age maps provided by Abitibi Consolidated Inc. and the Ontario Ministry of Natural Resources were used as a guide to identify stands of older trees as targets for collection. This collection was supplemented by ringwidth data obtained from the International Tree-Ring Data Bank (National Oceanic and Atmospheric Administration, 2007) for sites located within the greater Winnipeg River region (47–52ºN, 90–96ºW). Data from an additional 15 sites was provided by Martin Girardin (pers. comm., 2006).

The combined network is made up of 54 ringwidth records from 44 sites in the Winnipeg River area (Figure GS-14-1). The dataset includes measurements of nearly 2000 radii from almost 1000 trees. Most collections are developed from red pine (24 records) and white pine (21), with a limited number made from eastern white cedar (3), jack pine (*Pinus banksiana*, 3), white spruce

[1] Geological Survey of Canada, 601 Booth Street, Ottawa, Ontario K1A 0E8
[2] Laboratory of Tree-Ring Research, University of Arizona, Tucson, Arizona 85721

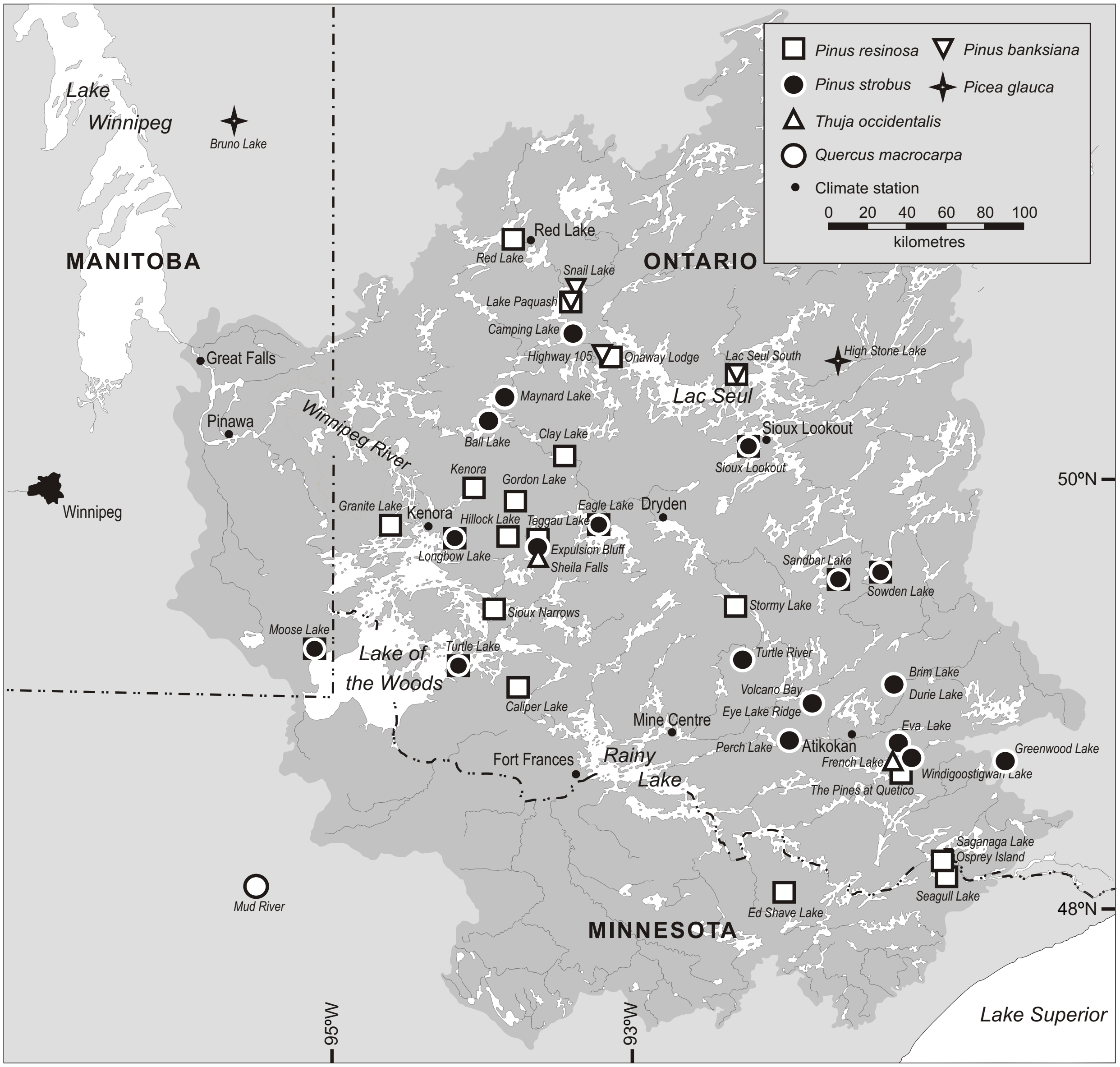


Figure GS-14-1: *Tree-ring sites and climate stations in the Winnipeg River region, Manitoba. Base map provided by the Lake of the Woods Control Board.*

(*Picea glauca*, 2) and bur oak (*Quercus macrocarpa*, 1). The majority of sites are located in the central part of the watershed in northwestern Ontario. There is only a single site in southeastern Manitoba and none in northwestern Minnesota, largely because of the increasing prevalence of grassland ecosystems in the western and southern part of the region.

Methods

Samples were prepared, cross-dated and measured following standard dendrochronological techniques (Stokes and Smiley, 1968). Empirical orthogonal function (EOF) analysis (North et al., 1982; Peixoto and Oort, 1992) was used to identify the dominant modes of variability present in the ringwidth network. The EOF analysis was repeated several times to determine the sensitivity of the final results to the choice of 1) detrending method, 2) the interval used for analysis (and associated spatial coverage of the tree-ring network), and 3) the application of the EOF technique. Potential relationships between annual tree growth and climate variables were assessed using correlation and response functions (Fritts, 1976) generated using DENDROCLIM2002 (Biondi and Waikul, 2004). In this program, bootstrapped confidence intervals are determined by shuffling the matrix of climate data 1000 times and calculating the 95th percentile range of the coefficients obtained from the randomized data.

Results

Chronology characteristics

Most ringwidth chronologies in the Winnipeg River region are between 100 and 170 years long. The median length of record recovered from a single tree is roughly 155 years. The oldest tree in the network is a 353 year old red pine, a sample of which was collected by H. Fritts at the Seagull Lake site in the Boundary Waters Canoe Area in 1971; if this tree is still alive, it is nearly 400 years old. The oldest tree in the Canadian portion of the Winnipeg River region is a 334 year old red pine, a sample of which was collected by M. Girardin at Sowden Lake in 2001. Only four sites have median tree ages greater than 200 years, and all are developed from red pines: Clay Lake and Sowden Lake in Ontario, and Seagull Lake and Saganaga Lake in Minnesota. The lesser ages of white pine stands are at least partially due to that species' tendency to exhibit heart-rot, as the innermost rings of white pines were often rotten and could not be sampled with an increment borer. Consequently, the ages shown here should be interpreted as minimum estimates of tree age only, especially for white pines.

Climate-ringwidth relationships

Regional tree growth is related to three independent climate signals (summer temperature, summer precipitation and growing-season length), but the correlations between tree growth and any single climate parameter are relatively modest. Significant correlation coefficients range between 0.2 and 0.4, and are not increased by aggregating monthly observations over longer intervals (2–4 month averages). There is some indication that regional tree growth responds differently to summer (June–July) temperature and precipitation conditions depending on the state of the other variable (Figure GS-14-2). Regional tree growth is more strongly influenced by summer precipitation when summer

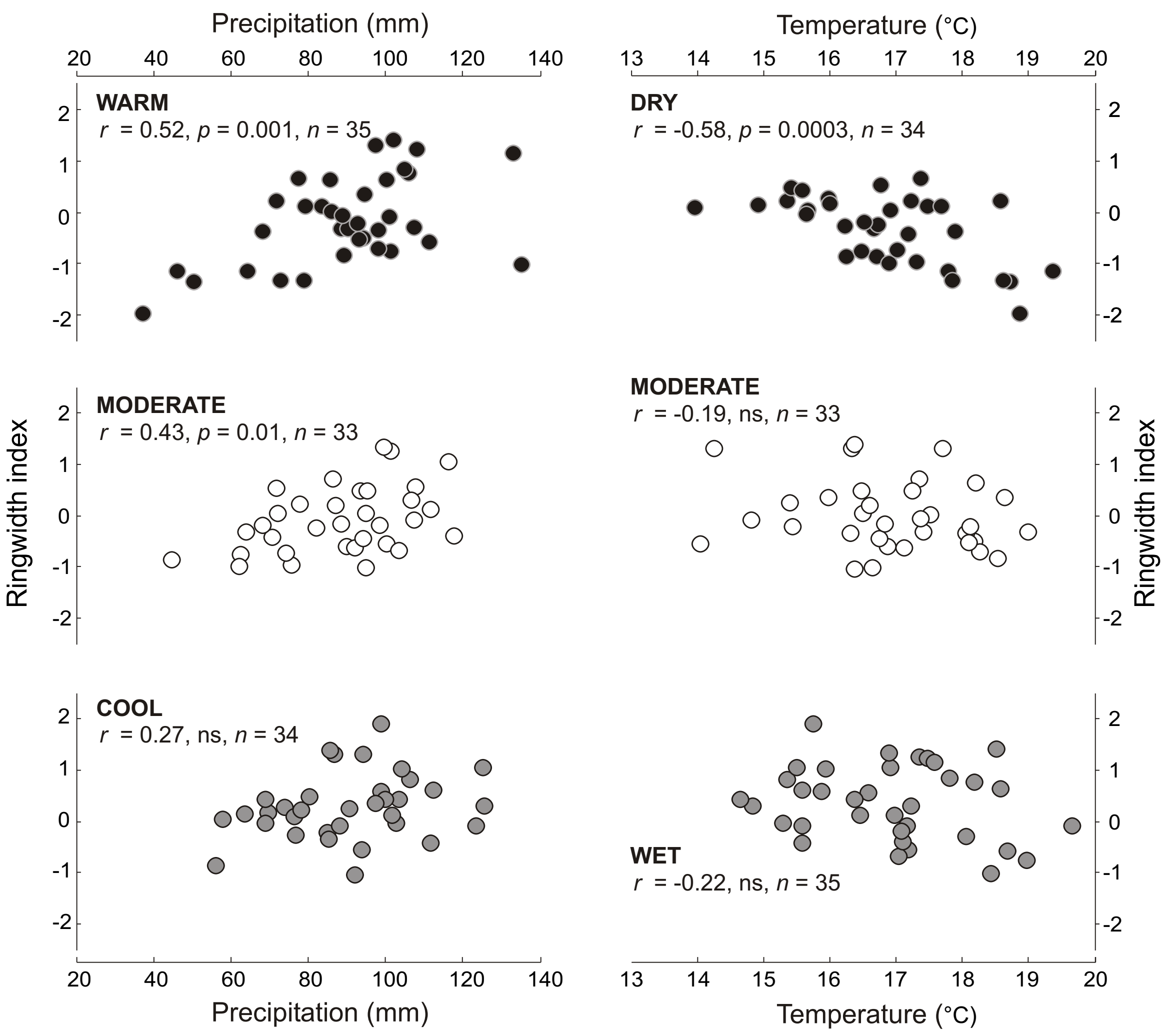


Figure GS-14-2: *Scatterplots comparing regional ringwidth with precipitation (left side) and temperature (right side) during summer. In each frame, the observations of ringwidth and the climate parameter are selected based on the state of the other climate variable. For example, in the WARM case, ringwidth is compared to precipitation using only those years where summer temperatures were in the top tercile of their distribution. The DRY case plots ringwidth and temperature data during years with low summer rainfall (precipitation in the bottom tercile). Note: r, correlation coefficient; p, significance level; ns, not significant; n, number of observations.*

temperatures are warm (in the upper tercile of its distribution). The correlation between precipitation and ringwidth is highest during warm summers, lower when summer temperatures are moderate and nonsignificant for cool summers. Similarly, ringwidth has a significant negative correlation with temperature only when summer precipitation is low (DRY) and is not significantly correlated when precipitation is either moderate or high. However, the correlation coefficients from the WARM and COOL cases are not significantly different from each other, and the coefficients for the DRY and WET cases are significantly different only at the 0.08 significance level.

Discussion

Although macro-scale climate variability is the most likely cause of the dominant regional growth pattern, the relationship between regional tree growth and any single climate variable is relatively weak. High growth is associated with long growth seasons and cool, wet summers, but the correlations between ringwidth and climate are not high enough to develop a traditional, regression-based dendroclimatic reconstruction (Fritts, 1976; Bradley, 1999). Because of these limitations, we focus our interpretation on the general relationship between summer climate conditions and the terciles of tree growth. As shown previously, high growth is commonly associated with cool temperatures and high rainfall, while low growth usually coincides with hot, dry summers. Therefore, we argue that regional ringwidth can be interpreted as a proxy record of past summer climate conditions in the Winnipeg River region, and classify years as either warm and dry (bottom tercile of ringwidth), cool and wet (upper tercile) or indeterminate (middle tercile).

This classification scheme provides some indication that summer drought may have been more persistent in the Winnipeg River region during the 19th century (Figure GS-14-3a). The 20th century has only one case (1946–48) where the region was in the warm/dry state for three consecutive years. This condition is more common in the earlier part of the record, as it happened four times in the 1800s (1829–31, 1839–41, 1862–64 and 1888–90) and once near the beginning of the record (1790–93). Persistent cool and wet conditions occur much less frequently, with only two cases in the entire record (1951–53 and 1999–2001). Applying the same classification after filtering to emphasize variations at decadal timescales indicates that the 1880s and 1890s had the longest run of warm, dry summers in the last 220 years (Figure GS-14-3b). This dry interval falls within an extended period of frequent forest fires from the 1870s to the 1920s identified by Suffling and Speller (1998) from the Hudson's Bay Company journal at Osnaburgh House (located immediately northeast of the Winnipeg River basin). The 1950s and 1960s had the longest-lasting period of cool and wet summers, with similarly persistent conditions observed in the 1850s. Determining the magnitude of climatic extremes in the pre-instrumental period is difficult because of the weakness of the relationship between tree growth and summer climate. However, because the years of both highest (1965) and lowest (1910) growth since 1783 AD occurred during the 20th century, we conclude that there is no evidence that summer climate was more extreme in the 19th or late 18th century.

In general, archival evidence from northwestern Ontario corroborates the tree-ring based classification of summer climate conditions during the early 19th century (Rannie, 2006). The Lac la Pluie post (near present-day Fort Frances, Ontario) was established by the North West Company in 1791, but its archives do not contain any entries that mention climate conditions until after the post was taken over by the Hudson's Bay Company in 1821. Although the post remained in operation until 1903, its

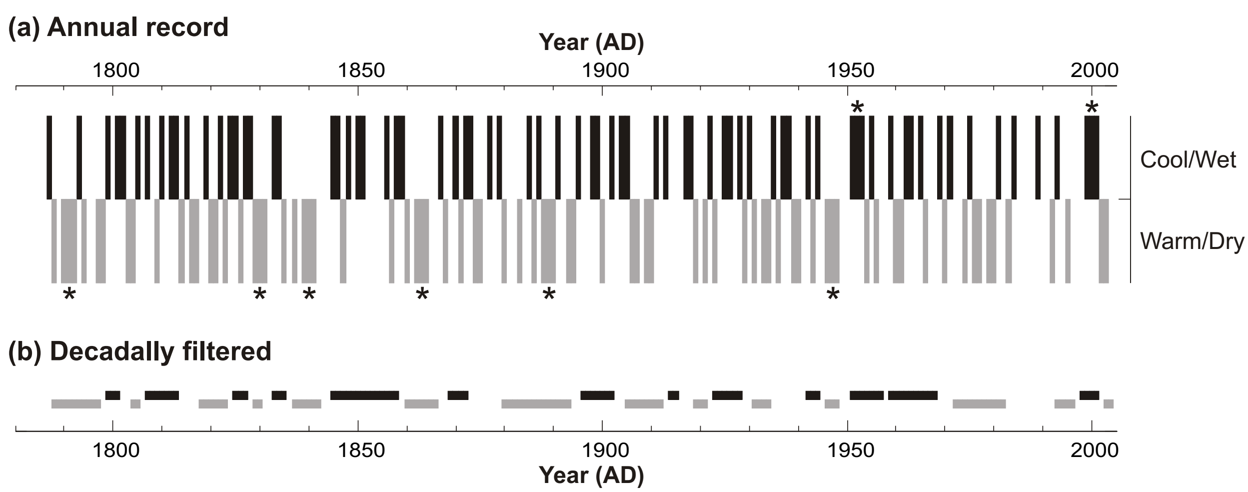


Figure GS-14-3: *Summer climate conditions in the Winnipeg River region, Manitoba, inferred from regional tree growth, 1783 to 2004 AD. Asterisks mark cases where climate is in the same state for three consecutive years. The lower plot is smoothed to highlight decadal variability, and is scaled to the proportion of variance in the tree-ring record at those timescales.*

archives were not maintained after 1841. Rannie (2006) identified seven "wet summers" within that 20-year period based on entries from the Lac la Pluie journal: 1824, 1825, 1827, 1828, 1830, 1832 and 1834. With one exception (1830), these years are classified as cool/wet based on the regional tree-ring record. The historical and tree-ring records also agree that there were no notably cool or wet summers between 1835 and 1841. However, there are no historical accounts that support the inference based on tree rings that the summers of 1822 or 1833 were cool and wet.

Conclusion

Although the cool, moist climate of the Winnipeg River area make it an important generating region for runoff, these same characteristics cause regional tree-ring records to contain a relatively weak, multivariate climate signal. Ringwidth data for this region contain a mixture of (sometimes competing) influences of temperature and precipitation during the growth season. However, the absence of a strong linear correlation with a single climate variable does not mean that tree growth in this region is not sensitive to climate. Instead, the climatic factors that limit growth are multivariate and likely change in importance from year to year. A common climatic influence remains the most likely factor responsible for the strong coherence in tree growth in multiple tree species across the region since the late 18th century. High and low growth across the region is associated with significantly different summer weather during the instrumental period, and this general relationship is supported by comparisons with archival records from early 19th century fur-trading posts. Therefore, even given the above limitations, this dataset still provides useful information about summer climate in this area since 1783 AD.

The tree-ring record suggests that summer droughts were more persistent in the 19th and late 18th century, with several instances of warm and dry conditions lasting for three consecutive years. Variability over longer timescales is also more prominent in the 19th century, with the longest interval of warm, dry summers in the last 220 years occurring in the 1880s and early 1890s. Estimating the magnitude of droughts inferred from the tree-ring record is more difficult, but because regional tree growth was at its lowest in 1910, we conclude that there is no evidence that drought was more extreme prior to the onset of direct monitoring.

Economic considerations

Since 2003, the Geological Survey of Canada, in co-operation with the Manitoba Geological Survey and the University of Arizona, has been working to understand changes in hydrology and climate in the watersheds used to generate hydroelectricity in Manitoba. In 2006/2007, hydroelectricity generated in Manitoba had a commercial value of roughly $1.8 billion (Manitoba Hydro, 2007). As with most hydropower operations, hydrological variability is the primary factor that influences year-to-year changes in the amount of energy produced at hydroelectric generation facilities and consequently, net income at Manitoba Hydro.

This research program has demonstrated that, unlike most regional rivers, river flow in the Winnipeg River system increased during the 20th century, with most of the gains occurring between 1920 and 1960 (St. George, 2007). This work has also shown that severe low flows are caused by a specific sequence of climatological 'events'; understanding this sequence may help improve forecasts of hydrological conditions several months in advance. For a longer perspective, tree-ring records from the Winnipeg River basin and the broader Prairie region have been used to estimate drought conditions in the Manitoba Hydro watershed during the last several hundred years. One of the principal goals of long-term planning at Manitoba Hydro is to ensure that their generating system can satisfy forecast energy demands under flow conditions equivalent to the lowest observed inflows. The period of lowest observed flows in the Manitoba Hydro system is described as the 'critical period', and is currently defined as the interval from 1939 to 1941. Drought records derived from tree rings provide a longer perspective that can be used to compare the 1939–41 event to other droughts from the recent past, and provide alternative worst-case scenarios for hydroelectric power production in Manitoba.

Acknowledgments

We thank J. Balmat, E. Nielsen and the staff at the Manitoba Geological Survey for field support, and J. Rowland and E. Margolis for laboratory assistance. Manitoba Conservation, the Ontario Ministry of Natural Resources and the Greenwood Lake Nature Reserve granted permission to collect samples within their respective jurisdictions. We thank M. Girardin for contributing his data from northwestern Ontario, and T. Ault for computing assistance. Financial support for this research was provided by Manitoba Hydro, the Manitoba Geological Survey, the Prairie Adaptation Research Collaborative and the Natural Sciences and Engineering Research Council of Canada.

References

Beriault, A.L. and Sauchyn, D.J. 2006: Tree-ring reconstructions of streamflow in the Churchill River basin, northern Saskatchewan; Canadian Water Resources Journal, v. 31, p. 249–262.

Biondi, F. and Waikul, K. 2004: DENDROCLIM2002: a C++ program for statistical calibration of climate signals in tree-ring chronologies; Computers and Geosciences, v. 30, p. 303–311.

Bradley, R.S. 1999: Paleoclimatology: Reconstructing Climates of the Quaternary; Academic Press, San Diego, 613 p.

Dredge, L.A. and Cowan, W.R. 1989: Quaternary geology of the southwestern Canadian Shield; *in* Quaternary Geology of Canada and Greenland, R.J. Fulton (ed.), Geological Survey of Canada, p. 214–235.

Fritts, H.C. 1976: Tree Rings and Climate; Academic Press, New York, 567 p.

Manitoba Hydro 2007: 2006/07 annual report; Manitoba Hydro, URL <http://www.hydro.mb.ca/corporate/ar/2006/annual_report_2006.shtml> [October 2, 2007].

Moos, M.T., Laird, K.R. and Cumming, B.F. 2005: Diatom assemblages and water depth in Lake 239 (Experimental Lakes Area, Ontario): implications for paleoclimatic studies; Journal of Paleolimnology, v. 34, p. 217–227.

National Oceanic and Atmospheric Administration 2007: The International Tree-Ring Data Bank; National Oceanic and Atmospheric Administration Paleoclimatology Program and World Data Center for Paleoclimatology, URL <http://www.ncdc.noaa.gov/paleo/treering.html> [October 2007].

North, G.R., Bell, T.L., Cahalan, R.F. and Moeng, F.J. 1982: Sampling errors in the estimation of empirical orthogonal functions; Monthly Weather Review, v. 110, p. 699–706.

Peixoto, J.P. and Oort, A.H. 1992: Physics of Climate; Springer-Verlag, New York, 564 p.

Rannie, W.F. 2006: Evidence for unusually wet 19th century summers in the eastern prairies and northwestern Ontario; Prairie Perspectives, v. 9, p. 85–105.

St. George, S. 2007: Streamflow in the Winnipeg River basin, Canada: trends, extremes and climate linkages; Journal of Hydrology, v. 332, p. 396–411.

Stokes, M.A. and Smiley, T.L. 1968: An Introduction to Tree-Ring Dating; University of Chicago Press, Chicago, 73 p.

Suffling, R. and Speller, D. 1998: The fire roller coaster in Canadian boreal forests; *in* Proceedings of the Workshop on Decoding Canada's Environmental Past: Climate Variations and Biodiversity Change during the Last Millennium, D.C. MacIver and R.A. Meyer (ed.), Environment Canada, Atmospheric Environment Service, Downsview, p. 19–26.