TREE RINGS INTO THE NEXT MILLENNIUM!

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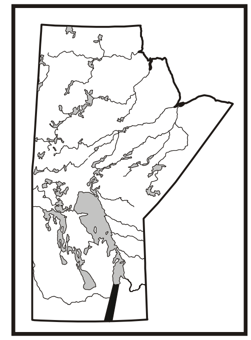

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SUMMARY

Instrumental hydrological data in Manitoba is limited both in length and spatial coverage. The Red River Research Project will use tree-ring records to reconstruct the pre-instrumental flood history of the Red River over the last 350-400 years. The current network of bur oak (*Quercus macrocarpa*) along the Red River includes 6 living tree sites, 5 historical buildings and logs recovered from Red River alluvium. The living oak record spans the period 1796 to 1997 and includes trees from Winnipeg, St. Jean Baptiste and Fort Dufferin. The addition of historical oak samples from mid-19th century buildings and alluvial logs generated a continuous record from 1648-1997. Red River oaks have common variance at high frequencies (> 32 years) and likely reflect the influence of a valley-wide environmental control. Preliminary analysis suggests that prairie level oaks respond significantly to variations in Red River water levels over a range of time scales.

INTRODUCTION

The present flood record of the Red River spans the entire 20th century, as well as a portion of the 19th. While this record has been supplemented by study of historical archives (e.g., Bumsted, 1997; Rannie, 1998), it is necessary to develop a better understanding of long-term hydrological fluctuations within the Red River Valley. Instrumental records of precipitation, runoff and discharge are of limited length in Manitoba and may not represent the true range of the hydrological record. Furthermore, the extremely limited availability of long records (greater than 60 years) may introduce severe spatial bias to hydrological studies.

Fortunately, proxy records allow the reconstruction of hydrological conditions that prevailed over past centuries (and, in some cases, over the last millennium or beyond), prior to the establishment of instrumental records. Reconstructions provide two major benefits to studies of environmental change, as they place the modern instrumental or human observed record into a longer term context of natural variation, and identify times or places of past changes which may provide analogues for future changes (Luckman, 1994). For example, evidence describing the recurrence of past extreme floods, such as those in 1826 and 1776(?), would aid strategies directed towards minimising flood damage in Manitoba communities.

As we enter the new millennium, even greater needs for proxy records with annual or even seasonal resolution for environmental reconstruction are anticipated. Tree-rings offer the greatest potential for yielding such records because of the wide geographical distribution of suitable sites, fine temporal resolution, and length of available records, as well as their identified environmental sensitivity (Luckman, 1990).

Certain species of trees growing in sensitive environments respond to hydrologic forcing during or prior to growing seasons. This consistent response provides crucial information relating to the frequency, distribution and persistence of hydrologic phenomena (Loaiciga et al., 1993). Proxy hydrological records other than tree rings, such as alluvial deposits along streambeds are valuable in the dating and magnitude assessment of past episodic hydrologic events, like floods. However, tree-rings are unique in that they document hydrologic fluctuations at annual (and, in some cases, seasonal) resolution and provide continuous records spanning hundreds of years.

This report describes the dendrochronological aspect of a large, multidisciplinary research program, initiated by the Geological Survey of Canada (GSC) and Manitoba Geological Services Branch (MGSB), that will reconstruct the pre-instrumental flood history of the Red River. Tree-ring analysis will provide annual reconstructions of important hydroclimatic variables within the Red River Valley over the last 350-400 years. Dendrohydrological techniques will also identify large Red River floods prior to instrumental and historical records and provide dating control for alluvial deposits.

DENDROHYDROLOGICAL MODELING TECHNIQUES

The Red River project will use three different approaches to dendrohydrological modelling of the Red River: (i) tree growth modelling of hydrological time series; (ii) tree damage (scarring or physiological anomalies) caused by extreme flood events; and (iii) dating of overbank sedimentation.

Reconstruction of hydrological time series from tree growth modelling

Dendrochronological studies mainly use three types of data derived from the annual growth ring: its width, density and chemical composition. Ringwidth is the easiest (and consequently, most common) data to collect; density and chemical series are more costly and more difficult to obtain. Each of these data are obtained from multiple samples (cores) for several trees in a stand; the data are then combined to produce a chronology. Tree-ring chronologies are series that represent average conditions exhibited by a stand of trees over time. It is these series, which represent common conditions across the entire stand of trees, that are related to environmental changes.

Dendrohydrologic studies use species of trees whose tree-ring growth is sensitive to hydroclimatic forcing (e.g., precipitation, temperature and water levels) to reconstruct the long-term behaviour of those controlling hydrologic variables. These techniques have been found to be particularly effective in temperate and subpolar regions, where certain species of long-living trees integrate hydroclimatic conditions well with other genetic and physiologic factors to leave an identifiable trace of past hydrology in the tree ring widths (Loaiciga et al., 1993). These trees are most commonly located close to the water body of interest where the association between hydrologically significant variables and tree growth should be strong. Several workers have identified significant relationships between tree ringwidth and hydrologically important variables such as precipitation and runoff. These relationships have been used throughout western North America to reconstruct precipitation (Case and MacDonald, 1995), Palmer Drought Severity Indices (PDSI; Cook et al., 1998) and lake water levels (Stockton and Fritts, 1973) over the last 350-400 years.

Tree damage caused by extreme flood events

As large flood events are characterised by high water velocities and commonly large quantities of floating ice and transported debris, their effects on floodplain trees may be considerable. Trees showing damage (scars) or physiological anomalies developed as a response to disturbance provide key information regarding the timing and areal extent of pre-instrumental floods.

"Flood scars" are formed when ice and debris in transport during peak flood stages lodge against or impact floodplain trees. If the external force is sufficiently strong, or if prolonged as during a flood, the bark is abraded and the wood becomes exposed, forming a scar. Upon the death of the cambium, a callus forms across the scar, or around its margin if the scar is large. In time, a new layer of wood will cross the scar and a complete annual ring will encircle the trunk. The length of time required for the scar to be completely covered with new wood is affected by the size of the initial scar, the recurrence interval of the impact event and by the time of year that the damage is inflicted.

Sigafoos (1964), Harrison and Reid (1967) and Gottesfeld and Johnson Gottesfeld (1990) demonstrated the applicability of scarring to

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flood frequency analysis by associating dated tree scars with recent flood events. Gottesfeld and Johnson Gottesfeld (1990) found good agreement between maximum scar height, normalised flood scar frequencies and measured peak discharges, suggesting that scar chronologies may accurately reflect local hydrological conditions.

While scars are external manifestations of the effects of floods on nearby trees, high water levels may also lead to internal changes in tree physiology. Working with ash (*Fraxinus americana* L. and F. *pennsylvanica* Marsh.) on the Potomac River (near Washington, D.C.), Yanosky (1983) observed changes in wood anatomy present in flood damaged trees. These changes were restricted to those rings formed during and shortly after high water events and were termed "flood rings". Flood rings were identified by a second earlywood layer within the annual ring, with the degree of abnormality being related to flood magnitude. Yanosky also described flood-damaged rings with jumbled vessels and discoloured tissues. When they are strongly developed in several trees, flood rings may be used as markers reflecting large-scale flood events.

Dating of overbank sediments

Red River alluvium contains an abundance of dead trees, killed either by high sedimentation rates around their trunks, ice damage to their bark, prolonged submergence or a combination of these factors. In situ tree stumps rooted within flood deposits may be cross-dated against living and historical trees, thereby providing minimum dates for their underlying growing surface. Additional prone allochthonous logs found in the Red River alluvium may similarly be used to date the enclosing sediment.

LABORATORY PROCEDURES

Sample collection

Tree-ring samples are collected in two forms: cores and cross-sectional disks. Core samples are obtained using a 16-inch Haglof Swedish increment borer, which is used to extract a thin cylinder of wood from the stem. As trees put on wood radially about the pith (centre), cores suitable for dendrochronological analysis ideally pass directly through the centre of the tree, coming close to, or hitting the pith. Normally, two cores at least 90º radially apart are taken from each tree. Trees with diameters less than sixteen inches may be cored completely through the tree. Disks are complete transverse sections of the tree and are collected exclusively from dead trees. Source material for disks included archaeological and alluvial samples, as well as trees removed for forest management. After collection, cores and disks are dried, mounted and sanded (surfaced) to prepare the sample for measurement.

For those samples taken from living trees, the outermost ring, next to the bark, was formed during the year of its collection. Therefore, it is possible to assign dates to each ring by simply counting backwards down the length of the core. The outermost ring acts as a temporal "anchor" by which other samples, whose outermost ring dates are unknown, may be dated.

Ringwidth measurement

Tree-ring measurements are time series representing each sample's ringwidth and are recorded using a microscope/shaft encoder combination. The main components of the system consist of a Nikon Stereoscopic Zoom microscope, a Acu-Rite linear encoder, a Quick-Chek single-axis digital readout and a desktop computer. The core or disk to be measured sits on a moveable platform directly below the microscope. Crosshairs within the microscope eyepiece act as reference points during measurement. Turning a crank advances the support platform, and, as it moves, the image of the core moves past the cross hairs. Samples are not to be held rigidly during the measurement stage as it is usually necessary to move the wood to keep the line of measurement parallel to the rays (see Pilcher, 1990). A manually triggered device signals the digital readout to record the position of the ring boundary in thousandths of millimetres (0.001 mm). The ringwidth is then obtained by taking the difference between the present position and the previous position.

RESULTS TO DATE

The Red River tree-ring network is currently composed of 6 living tree sites, 5 historical buildings and a number of samples collected from Red River alluvium (Table GS-31-1). Samples from only half of the living tree sites are presently available, as the remaining 3 sites are pending laboratory processing. The sampling sites extend along the Red River from Emerson to the North Kildonan area of Winnipeg (Fig. GS-31-1), a distance of 100 kilometres. Sites near the Red River have been chosen for sampling as these trees should respond most strongly to local hydrologic fluctuations.

While samples have been collected from a number of different Manitoba tree species, including spruce (*Picea* sp.), ash (*Fraxinus* sp.), elm (*Ulmus americana*), and tamarack (*Larix laricina*), ringwidth measurements are only available for bur oak (*Quercus macrocarpa*). Initial laboratory processing has concentrated on this species since oak is: (i) present in large numbers on the prairie level along the Red River flood zone; (ii) relatively long-lived (150-250 years typically), and (iii) available from historic buildings as well as alluvial deposits. Combining living oaks with historic and alluvial samples allows for the potential development of records spanning many centuries.

Table GS-31-1: Red River bur oak sites.

Type	Site	Span	No. of Trees
Living	Fort Dufferin	1866-1997	9
	St. Jean Baptiste Park	1883-1997	10
	Winnipeg	1796-1990	7
	Ste. Agathe	NA	10
	La Barriere Park	NA	10
	St. Vital Park	NA	10
Historic	Barber House	1648-1864	34
	Rat River House	1661-1859	6
	St. Boniface Museum	1664-1845	2
	Upper/Lower Fort Garry	1678-1838	2
Alluvial	Red River (near Fort Dufferin)	1662-1965	9

Living trees

Living tree sites have been developed at Fort Dufferin, St. Jean Baptiste Park and the City of Winnipeg. Fort Dufferin and St. Jean Baptiste Park are mature prairie-level stands of oaks with minor anthropogenic disturbances. The Winnipeg oaks consist of a number of old oaks collected from various locations within the city limits. While the growth of the Winnipeg trees may have been disturbed by human activity (particularly after 1950), their length of record (close to 200 years) make them useful for cross-dating historical material. Sampling was conducted during August 1999 at Ste. Agathe, La Barriere Park and St. Vital Park. However, these samples are still pending laboratory processing and are not available at this time.

The living oak record spans the period 1796 to 1997 and consists of 40 samples collected from 26 trees. The oldest tree was collected from Kildonan Park in north Winnipeg; this specimen is 194 years old and lived from 1796 to 1990.

Sampling in fall 1999 and spring 2000 will target old, relatively undisturbed stands of oak along the Red River between Winnipeg and Emerson. Development of chronologies near climatological and hydrological stations will be a priority. This collection will provide a better understanding of environment-tree relationships during the 20th century, which are critical to any paleoenvironmental reconstruction. Additional new living tree sites will be collected, generating a living oak tree-ring network of up to 20 sites.

Historical buildings

Dendrochronological samples from historical buildings allow tree-ring records to be extended backwards in time further than the natural life span of the species under investigation. While bur oak in the Red River Valley rarely exceed ages of 200 years, the collection of trees used in the construction of mid-19th century buildings will augment the record by 100 to 200 years.

Historical oak samples consisting of transverse sections of oak timbers were derived mainly from 19th century Red River buildings. Barber House located at 99 Euclid Avenue in Point Douglas, was constructed in the mid 1860s. Roughly 50 discs were prepared from logs taken from this house in a 1980s restoration project. The second main source of historic timbers was from the remains of a house (termed Rat River House) that floated in and came to rest at the mouth of the Rat River

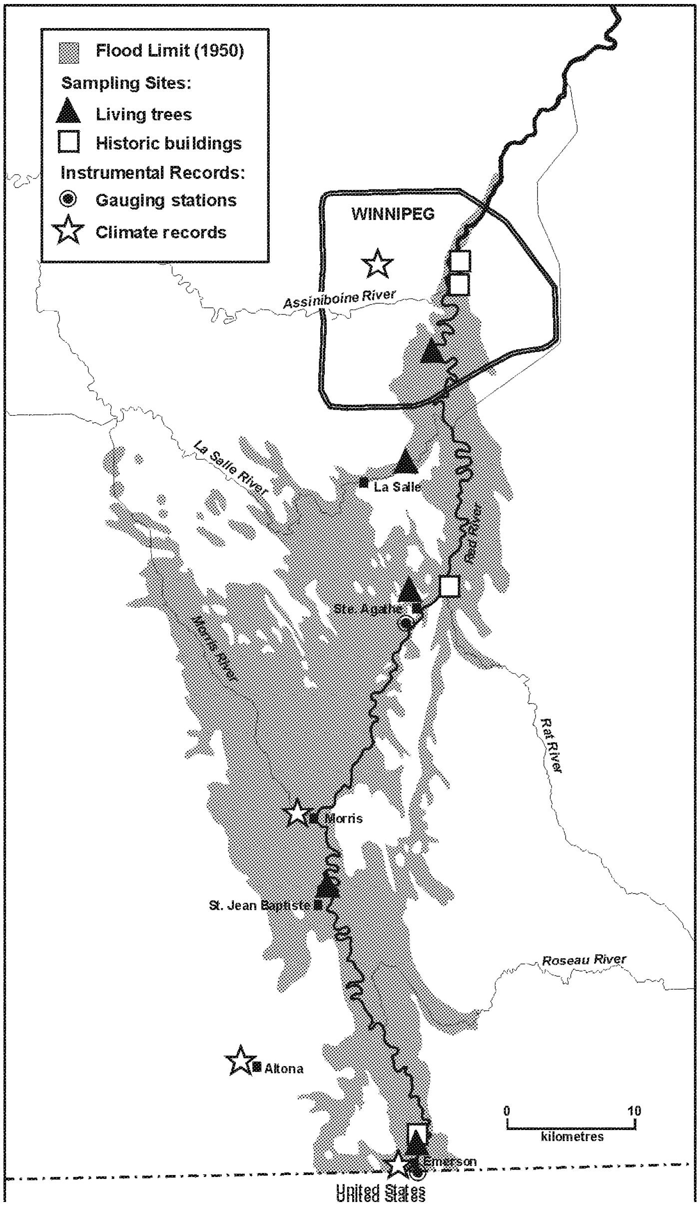

Figure GS-31-1: Bur oak tree-ring sites within the Red River Valley.

during the 1997 flood of the Red River. Nothing is known about the origin of this building but it was situated somewhere upstream of the confluence of the Red and Rat rivers and appears to have been built after the summer of 1859.

Samples have also been collected from several additional historical buildings, including the St. Boniface Museum and Upper and Lower Fort Garry. However, these structures have not contributed a sufficient number of specimens to warrant separate categorisation at this time. Additional collections during fall 1999 are planned at Fort Dufferin, Henderson House and Delorme House.

Alluvial logs

The final source of tree-ring material consists of logs recovered from Red and Assiniboine river alluvium. Trees are typically waterlogged but well preserved and once samples have been air-dried, they may be surfaced and sanded. Radiocarbon dates for selected samples up to 1500 BP indicate the high potential for developing a long (1000-2000 year) annual record for southern Manitoba.

Combined oak samples

Figure GS-31-2 illustrates the record for the Red River bur oak tree network. The entire database consists of 160 samples taken from 109 trees. The combined record extends from 1648 to 1997, providing an annually resolved record of tree growth. Over the next year, additional sampling of historical and alluvial material may extend the present chronology well into the 16th century.

The Red River oaks cross-date from seven sites over a distance of 100 kilometres. This relationship suggests that trees growing along the Red River Valley have observed similar high frequency (>32 years) trends over the past 350 years. This coherent ringwidth signal presumably reflects the influence of a large valley-wide control. As researchers in other North American environments have found either climatic (such as temperature or precipitation) or hydrologic (water levels and floods) factors to be causal to tree growth, it is likely that the oak is responding to a similar environmental influence.

Ringwidth-climate relationships

In order to represent the relationships between climate and tree growth, it is necessary to obtain quantitative estimates or models that represent these relationships. Empirical dendroclimatic models describe tree growth as a function of changing climate conditions over a range of time scales and simulate fundamental relationships as accurately as possible based on current knowledge of the growth controlling

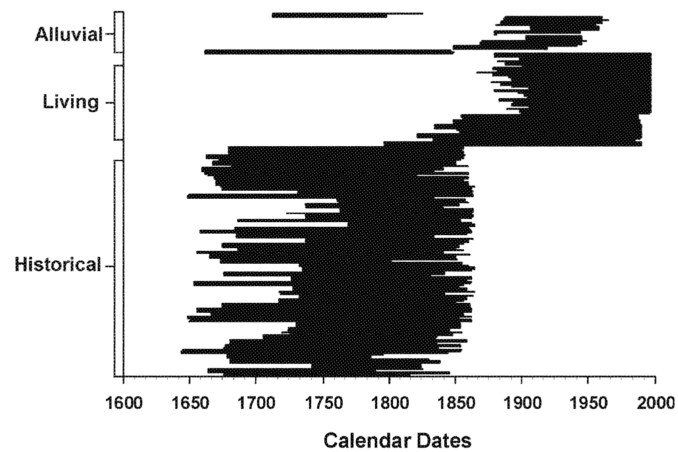

Figure GS-31-2: Length of record for bur oaks in the Red River Valley.

processes and dendrochronology. The models most commonly describe relationships between ring characteristics and monthly, seasonal, or annual conditions where the basic processes linking causal factors to growth are unknown or poorly defined (Fritts, 1991).

One of the main requirements of paleoclimatic modelling is the availability of suitable climate records, which are necessary in order to evaluate the ringwidth-climate relationship. Growth modelling for paleoclimatic studies typically uses monthly climate data, which has a suitable resolution to evaluate seasonal differences in tree response. Monthly data is also commonly available in sufficient length of record for statistical testing. Maximising the length of climate records allows the relationship(s) between ringwidth and environmental parameters to be established with suitable confidence.

The current climate database available to the Red River tree-ring project is outlined in Table GS-31-2. Environment Canada climate records of length greater than 50 years are available at four stations along the Red River: Winnipeg, Morris, Altona and Emerson. Climatic variables available include mean monthly temperature, total precipitation, total rain and total snow. Those stations with missing records will have values replaced using linear regression. The second source of available hydrological data is water levels recorded from two stations along the Red River; records at Ste. Agathe and Emerson cover 37 and 83 years respectively.

Ringwidth records for each oak site will be compared against the suite of available hydroclimatic data. Variables that are causal or related to tree growth will be identified and then reconstructed for the length of the tree-ring record.

Table GS-31-2: Available long hydroclimatic records from the Red River Valley. Data are from Environment Canada.

Parameter	Station	Period
Temperature	Winnipeg	1872-1999
	Morris	1915-1987
	Altona	1949-1998
	Emerson	1877-1997
Precipitation	Winnipeg	1872-1999
	Morris	1883-1998
	Altona	1948-1998
	Emerson	1877-1997
Water Levels	Ste. Agathe	1958-1995
	Emerson	1912-1995

CONCLUSIONS

Tree-ring research shows considerable potential to provide annually-resolved reconstructions of pre-instrumental hydrologic conditions along the Red River. The Red River Research Project has developed a bur oak network of living, historical and alluvial trees that covers a 100 kilometre transect along the Red River. The oak record spans 1648-1997 and contains considerable common variance at high frequencies (>32 years). This regional coherence must reflect an environmental forcing which covers the entire Red River Valley. Preliminary analysis showed significant correlations between living oaks at St. Jean Baptiste and monthly, seasonal and annual water level records at Ste. Agathe.

Over the next year, the living oak network will be expanded to evaluate the spatial consistency of tree-climate relationships. Also, the collection of more historical/alluvial material will lead to the extension of the chronology back in time. The network will form the basis of regional climatic and/or hydrologic reconstructions that will extend the current instrumental records by several centuries.

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