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RESEARCH REPORT

DENDROCHRONOLOGICAL POTENTIAL OF *SALIX ALAXENSIS* FROM THE KUUJJUA RIVER AREA, WESTERN CANADIAN ARCTIC

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ABSTRACT

This study presents the first annually-resolved chronology using *Salix alaxensis* (Anderss.) Cov from Victoria Island, Northwest Territories, Canada, an area well north of treeline. Forty-one samples were collected and examined for subsequent analysis. However, crossdating was difficult because of locally absent or missing rings and the narrowness of the rings, and ultimately thirteen stems were crossdated and used to evaluate their dendroclimatological potential. The chronology spans 74 years (1927–2000) and could potentially be extended further using subfossil wood. Precipitation data from December of the previous year to March of the current year were the most consistently and highly correlated with ring width. This suggests that the recharge of the soil moisture by early summer snowmelt is a key factor limiting growth of these shrubs.

Keywords: dendrochronology, Victoria Island, Northwest Territories, Middle Arctic vegetation, Canadian Arctic, *Salix alaxensis*.

INTRODUCTION

There are few climate data from the Canadian Arctic Archipelago. Those records that are available mostly date to post A.D. 1950 and are too short to study long-term climate variability (Maxwell 1980; Przybylak 2003). In addition, existing data provide a spatially restricted picture of the Arctic climate, as all meteorological stations are located on the coast. The presence of coastal effects, and the low altitude of the existing stations means that our understanding of the climate of the region is biased (Atkinson and Gajewski 2002). Paleoenvironmental records can provide information about past climates and in some cases may provide quantitative estimates of climatic conditions from interior as well as coastal regions (Gajewski and Atkinson 2003). However, few quantitative paleoclimatic reconstructions have been produced from the Canadian Arctic, and even fewer of these are annually resolved.

The resolution of proxy-climate records varies considerably, but few natural archives offer annually resolved records of past climates. Ice cores (*e.g.* Fisher and Koerner 1994; Bourgeois 2000)

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and some varve sequences (*e.g.* Lamoureux and Bradley 1996; Gajewski *et al.* 1997; Lamoureux *et al.* 2001; Moore *et al.* 2001) may provide annual or even seasonal records of past climatic conditions, however, the dating of these is associated with some error, because ice accumulation or varves may be missing in a particular year. In addition, there is little or no replication in these proxy records, which would help reduce the error associated with dating. North of treeline, *Cassiope tetragona* (Anderss.) Cov, an evergreen dwarf-shrub, has provided paleoclimate data for some regions of the Canadian High Arctic (Johnstone and Henry 1996; Rayback and Henry 2005a, 2005b; Welker *et al.* 2005). Dendrochronological analysis of shrubs, including the widely distributed willow *Salix arctica* Pall. s. lat. (Porsild and Cody 1980), could potentially provide records of past climates in Arctic regions (Warren Wilson 1964). However, Beschel and Webb (1993), and Woodcock and Bradley (1994) noted the difficulty of using willows for dendrochronological studies because of narrow and often missing rings. Woodcock and Bradley (1994) discussed various factors that made it difficult to crossdate willows, including slow growth rate, difficulty in delineating growth-ring boundaries and the presence of annual rings only one cell wide. Studies have suggested that *Salix* or *Betula* could be used for dendroclimatology, however no study has yet managed to produce a response function that relates the shrub growth to climate (Kuivinen and Lawson 1982; Woodcock and Bradley 1994).

Tree-sized willows have been reported as far north as the Minto Inlet–Kuujjua River area of Victoria Island (Edlund 1983; Edlund and Egginton 1984). In 2001, we collected some *Salix alaxensis* (Anderss.) Cov sections from the Kuujjua River area. Although these particular samples were not tree-sized, they offer the potential of providing a dendroclimatic record for the region. In this paper, we present the first dendrochronological series from a population of *S. alaxensis.* The goals of this study are to: (i) develop a tree-ring chronology using *S. alaxensis* from Victoria Island; and (ii) investigate the growth-climate relationship of this chronology.

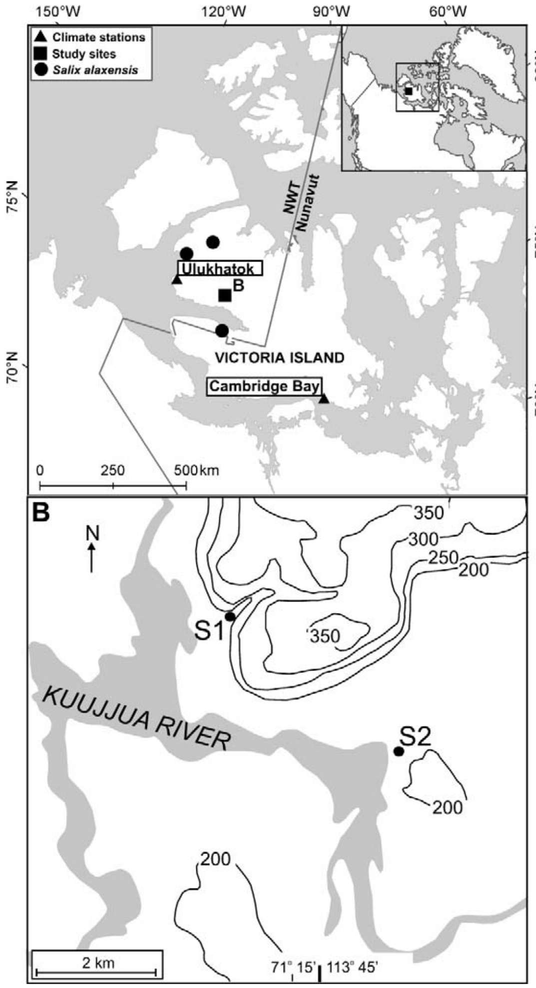

Figure 1. Location of the study sites in the Kuujjua River area, Victoria Island, Northwest Territories, Canada. The upper map includes an inset map of Canada, and a larger-scale view of Victoria Island with the location of the study sites, the location of *Salix alaxensis* on Victoria Island (Porsild and Cody 1980) and the two closest climate stations (Ulukhatok (Holman) and Cambridge Bay; Cambridge Bay (Ikaluktutiak) is *ca.* 435 km away from the study sites). The lower map (point B from the upper map) shows the study sites, with contour intervals in m a.s.l.

METHODS

Study Site

The study area is along the Kuujjua River on Victoria Island in the Northwest Territories (71°17′N, 113°49′W; 166 m a.s.l.; Figure 1). Western Victoria Island experiences cold winters and short cool summers, with mean January and July temperatures of −28.6°C and 9.2°C, respectively (Meteorological Service of Canada 1971–2000 climate normals from Ulukhatok (Holman) Airport, 70°46′N, 117°48′W; 35 m a.s.l.). Precipitation is low with an average total of 162 mm annually, consisting mostly of rain during the summer months. Thus, we would expect that plant growth might be limited by precipitation as well as temperature. The area is classified as Middle Arctic (Polunin 1951) or prostrate dwarf-shrub, herb tundra (CAVM Team 2003). The vegetation includes small prostrate shrubs (particularly *Dryas* and *Salix arctica*) and the typical assortment of herbaceous and lower plants found in the High and Middle Arctic, as well as the willows we discuss in this paper (Edlund 1983; CAVM Team 2003).

Field Methods

We collected *S. alaxensis* sections from 2 sites located *ca.* 5 km from each other along the Kuujjua River (Figure 1). Site 1 (71°18′N, 113°46′W) is located in a rock fall and Site 2 (71°16′N, 113°42′W) is situated on sand dunes bordering the river above the flood level. Stems were collected from several shrubs in a small area; only a minimum number of stems were sampled in order to minimally impact the population. Each willow was cut as low as possible on the base of the shrub to obtain the oldest chronology possible. Some dead stems were also collected in an attempt to extend the length of the chronology.

Chronology Development

Forty-one cross-sections were taken from different *S. alaxensis* shrubs at both sites. Many of the sections were very short and/or difficult to crossdate and thirteen stems were eventually used to develop the chronology; six from Site 1 and seven from Site 2. Sections were dried and sanded using progressively finer grades of sandpaper (180, 220, 320, 400 and 600 grit) until the cellular structure was visible under a microscope. All samples were visually crossdated using skeleton plots, as outlined by Stokes and Smiley (1996). The annual rings were then measured using a Quick Check QC-1000 connected to an AcuRite III digital encoder with a precision of 0.001 mm. The rings of the measured radii were clearly visible and crossdatable, but only one radius was measured per sample because the rings were too narrow to obtain two measurable radii that were separated by at least 90°. The accuracy of crossdating was verified using the computer program COFECHA, version 6.06, available in the Dendrochronology Program Library (http://web.utk.edu/~grissino/software.htm; Holmes 1983; Grissino-Mayer et al. 1992). Ring-width measurements were detrended using linear regression (program ARSTAN, version 6.04; Cook 1985; Grissino-Mayer *et al.* 1992; Fritts 2001) and the residual chronology retained for subsequent analysis.

Climate Data and Climate-Growth Relations

Two meteorological stations are located on Victoria Island: Cambridge Bay (Ikaluktutiak) and Ulukhatok (Holman). The meteorological records from Cambridge Bay, although farther from the site than Ulukhatok, were used for the analysis because they were longer and contained fewer gaps and missing data than those of Ulukhatok Airport (Figure 1; http://www.climate.weatheroffice.ec.gc.ca/prods_servs/cdcd_iso_e.html). The temperature record of Cambridge Bay had significant missing data in some of the earlier years, and the climate series were therefore truncated to include only the years with complete data (1949–2000). The precipitation data in the retained period (1949–2000) included missing numerical values. If less than 14 days had missing data, precipitation was the sum of all available data. Only one month had more than 14 days with missing values (October 1999 had 28 days with missing values), and was therefore omitted from the analysis. Months with a value of "trace" were replaced with 0.001 mm. Climate-growth relationships were investigated using Pearson's correlation coefficients between the ring width and the mean monthly temperature and total monthly precipitation of the current and previous year, using data from the 1949–2000 period.

RESULTS

Chronology Characteristics

Crossdating was difficult because of locally absent rings, missing rings and the narrowness of the

Table 1. Summary statistics from computer program COFECHA (version 6.06) for the 13 samples used in the residual chronology. Samples 1–6 are from Site 1 and samples 7–13 are from Site 2 (Figure 1).

		Annual increment (mm)					
Sample No.	Series Length	Mean	Max.	Std. Dev.	Auto Corr.	Mean Sens.	Correlation with Master
1	1972–2000	1.016	2.286	0.027	0.687	0.440	0.598
2	1972–1999	1.016	2.540	0.024	0.177	0.587	0.570
3	1960–1980	0.508	1.270	0.010	0.105	0.344	0.633
4	1983–1995	1.524	3.302	0.036	0.295	0.593	0.569
5	1957–1985	0.508	2.540	0.020	0.122	0.772	0.495
7	1958–1984	0.508	1.270	0.014	0.286	0.585	0.721
7	1957–1984	0.762	2.032	0.017	0.451	0.392	0.396
8	1942–1991	0.508	1.016	0.009	0.587	0.384	0.312
9	1940–1973	0.762	2.540	0.021	0.007	0.684	0.466
10	1926–1977	0.508	1.778	0.017	0.694	0.471	0.530
11	1947–1997	0.762	1.778	0.016	0.307	0.455	0.386
12	1939–1993	0.762	2.540	0.024	0.457	0.597	0.362
13	1960–1983	0.762	2.032	0.023	0.388	0.559	0.409
Mean		0.762	3.302	0.019	0.386	0.588	0.468

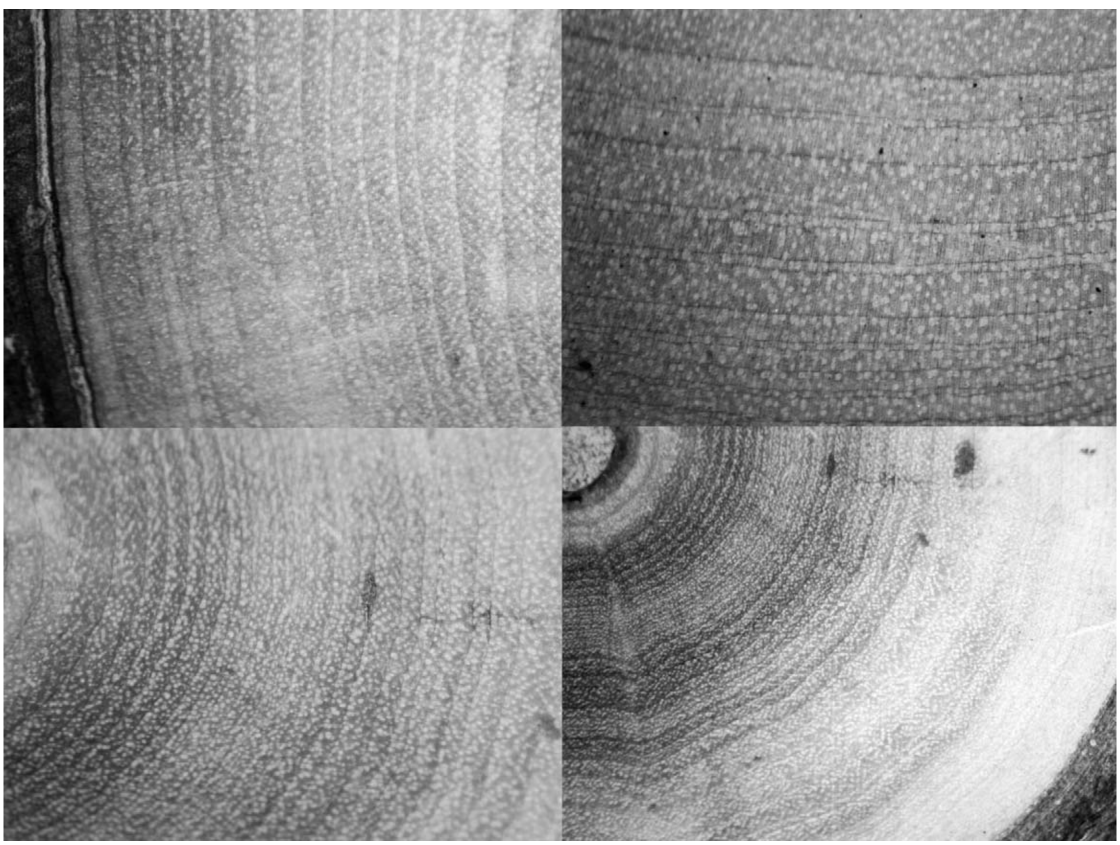

Figure 2. Partial cross-sections of four *Salix alaxensis* samples from the Kuujjua River area, Victoria Island, Northwest Territories. The radius of the lower-right figure is approximately 1.2 cm; the magnification of the other sections is 2× that of this photo.

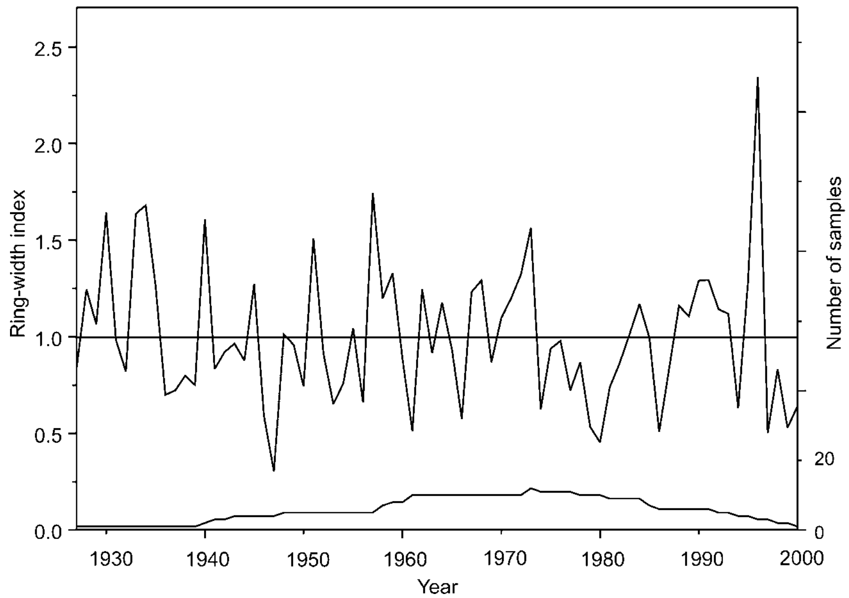

Figure 3. *Salix alaxensis* chronology from the Kuujjua River area, Victoria Island, Northwest Territories.

rings. None of the samples used in the final chronology had missing rings although locally absent rings were present in most samples. The mean ring width was 0.762mm, which is comparable to that of other Arctic species (Table 1; Figure 2; Warren Wilson 1964; Kuivinen and Lawson 1982; Woodcock and Bradley 1994). Nevertheless, it was possible to crossdate a sufficient number of stems to develop a chronology, because the individual series demonstrated common tendencies in growth pattern. Pointer years, those with narrow ring widths, could be distinguished on many sections. The most important pointer years that were used to crossdate the samples are 1995, 1993, 1988, 1982, 1979, 1977, 1968, 1959, and 1945.

The chronology spans 74 years (1927–2000) (Figure 3). Below-average growth occurred during the 1940s through the first half of the 1950s and in the late 1970s through the late 1980s. Fifty-four percent of the samples were established between 1950–1980, which corresponds to a period of above-average ring width, suggesting that more favorable climatic conditions may correspond to a higher rate of establishment (Woodcock and Bradley 1994).

The mean correlation coefficient between the individual raw ring-width series (*i.e.* before detrending) was 0.47 ($n = 13$, $p < 0.05$). A principal components analysis (PCA) extracts the dominant covariation in the ring-width series and was used to summarize the major tendencies in the growth of the trees in the plot. In this study, the PCA indicated that 47% of the variance of the 13 raw ring-width series was accounted for with the first three components (the first component accounted for 22% of the variance). This suggests that there was a tendency for the growth of the shrubs in this region to be correlated. The range of mean sensitivity for these series (0.34–0.77; Table 1) indicated a relatively high interannual variability.

Climate-Growth Analysis

The average monthly temperatures and total monthly precipitation for the years 1949–2000 were used to estimate the relation between ring-width growth and climate (Figure 4). Precipitation values from December of the previous year to March of the current year were the most consistently and highly correlated with ring width. There were no significant relationships between temperature and ring width.

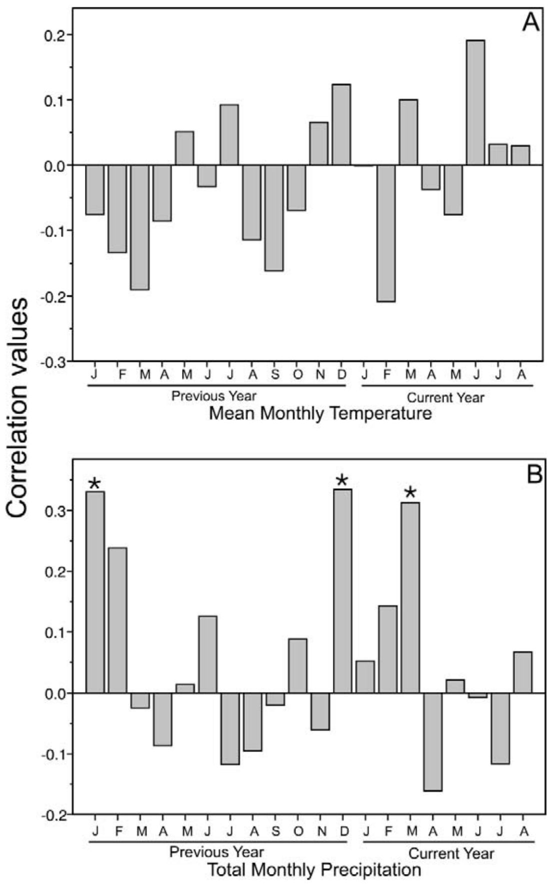

Figure 4. Correlations of mean monthly temperature (A) and total monthly precipitation (B) from Cambridge Bay with the ring-width chronology in the Kuujjua River area, Victoria Island, Northwest Territories. ⋆Significant at $p < 0.05$.

DISCUSSION

This study demonstrates that it is possible to crossdate *Salix alaxensis* and to develop a dendrochronological series from these data. The derived chronology is correlated with winter precipitation, which indicates that *S. alaxensis* has the potential to be used for a dendroclimatic analysis. This is all the more remarkable because the climate station correlated with the ring-width series is quite distant and the calibration period quite short. However, a large number of samples would be needed to derive a long paleoclimatic series because only a third of the samples investigated could be used in the final chronology.

The ring-width chronology is most consistently correlated with winter precipitation, which suggests that spring snowmelt is important for shrub growth. Winter precipitation (December to March) represents only 15% of the total annual precipitation, however it is probably important to plants because the spring snowmelt is an important source recharging soil moisture in the dry habitats where the shrubs are growing. It is therefore understandable that the shrubs are responding to changes in total monthly precipitation occurring in the months prior to the growth season. The period of high growth between 1950–1980 seems to correspond to a period of high shrub establishment.

The chronology is short by dendroclimatic standards, although this is the first precisely-dated tree-ring chronology from the western Arctic. One reason for the short length is that *S. alaxensis* is not as long-lived as other species used for dendrochronological analyses (Edlund and Egginton 1984). In addition, it was difficult to use subfossil wood to extend the chronology. The portion nearest to the bark was the most difficult to crossdate because the ring boundaries were often not clearly visible and therefore common patterns of thin and wide rings were often indistinguishable. In addition, sampling *S. alaxensis* too early in the growing season, before the leaves start to develop, may render it difficult to distinguish live from dead stems. Finally, we collected only few samples because of the exploratory nature of the study and the desire to minimize detrimental impacts on the population. Nevertheless, it may be possible to obtain longer chronologies by sampling larger shrubs or perhaps obtaining a more extensive collection of subfossil wood from the river valley (*cf.* Edlund and Egginton 1984). This offers the potential for developing a more extensive network of *S. alaxensis* sites from the Arctic and extending our knowledge of the spatial pattern of Arctic climate.

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