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SALIX ARCTICA (PALL.): ITS POTENTIAL FOR DENDROCLIMATOLOGICAL STUDIES IN THE HIGH ARCTIC

Key-Words: *Salix arctica*, dendroclimatology, high Arctic
Parole chiave: *Salix arctica*, dendroclimatologia, regione artica

Abstract

Salix arctica *(Pall.), is one of the most northerly occurring plants. A 40-year climate record is available for northern Ellesmere Island (82° 50'N, 78°W) and so 30 to 60 year-old samples of arctic willow from this area were evaluated for their potential for dendroclimatological reconstructions. Nine of the 11 samples could be partially cross-dated but growth was very slow (0.07 mm/yr). Missing rings in older wood were common. To minimize missing rings and facilitate ring width measurement chronologies must be developed using sections from the entire stem length. Frost rings and establishment years are also promising sources of weather information. Four specimens became established in the mid-1950s, a period of warm summers, and four in the mid-1930s, suggesting that similar conditions prevailed at that time.*

1. Introduction

To date, the majority of dendroclimatological studies have been based on data from coniferous and deciduous trees growing in temperate regions of the world. In regions where trees are rare or absent, other long-lived plant forms which lay down secondary growth in annual increments may be found, including long-lived species with tap roots and dwarf shrubs. Such species can be sources of material for dendroclimatological analyses, and studies based on the growth of these species can greatly increase the geographic area for which dendroclimatological reconstructions are possible.

Woody plants growing north of timberline at high latitudes are a potentially valuable resource. Growth rates of these species are, however, very slow, with reported annual increment values of less than a millimeter for birch (*Betula pubescens* Ehrh.) growing at high latitudes (ELKINGTON, JONES 1974; KUIVINEN, LAWSON 1982; ECKSTEIN ET AL. 1991), and less than 0.2 mm for the dwarf willow, *Salix arctica* (Pall.), growing at or north of 75°N (BESCHEL, WEBB 1963; WARREN-WILSON 1964).

S. arctica is one of the most northerly occurring plants. It has a wide geographic distribution, occurring in both Asia and North America. In the high Arctic it forms a prostrate shrub with individual plants reaching at least 87 years old (BESCHEL, WEBB 1963). Since very few instrumentally recorded meteorological records for these latitudes are greater than 45 years in length, dendroclimatic studies offer the prospect of extending our perspective on the climate of recent decades to the turn of the century or earlier.

S. arctica is semi ring-porous and has well-defined growth-rings whose boundaries are delimited by one or more rows of cells rectangular in cross-section (see SCHWEINGRUBER 1990). Nevertheless, material collected from this species growing at high latitudes presents a number of problems for obtaining reliably cross-dated ring-width series because of the eccentric pith, and missing, false, and discontinuous rings (BESCHEL, WEBB 1963).

This paper reports the results of a study to investigate the potential of *S. arctica* for future dendroclimatological reconstructions at a site close to the northern limit for all plants, northern Ellesmere Island in the high Arctic. Growth patterns and growth-ring characteristics of this dwarf willow are examined with the goal of determining appropriate methods for delineating growth rings and measuring ring widths. The feasibility of cross-dating this type of material to generate increment series suitable for future dendroclimatological analyses is evaluated.

2. **Methods**

2.1. *The sample site*

Samples of *S. arctica* were collected from flat, well-exposed deltas approximately 15 m above sea level, adjacent to Lake C-2, Taconite Inlet (82° 50'N, 78°W) on Ellesmere Island (Fig. 1). Weather records for the past 40 years are available from the Alert weather station on Ellesmere Island, approximately 200 km east of the collection site (Fig. 1). Mean temperatures at Alert range from -33°C in February to +3.5C in July. The length of the snow-free season is vari-

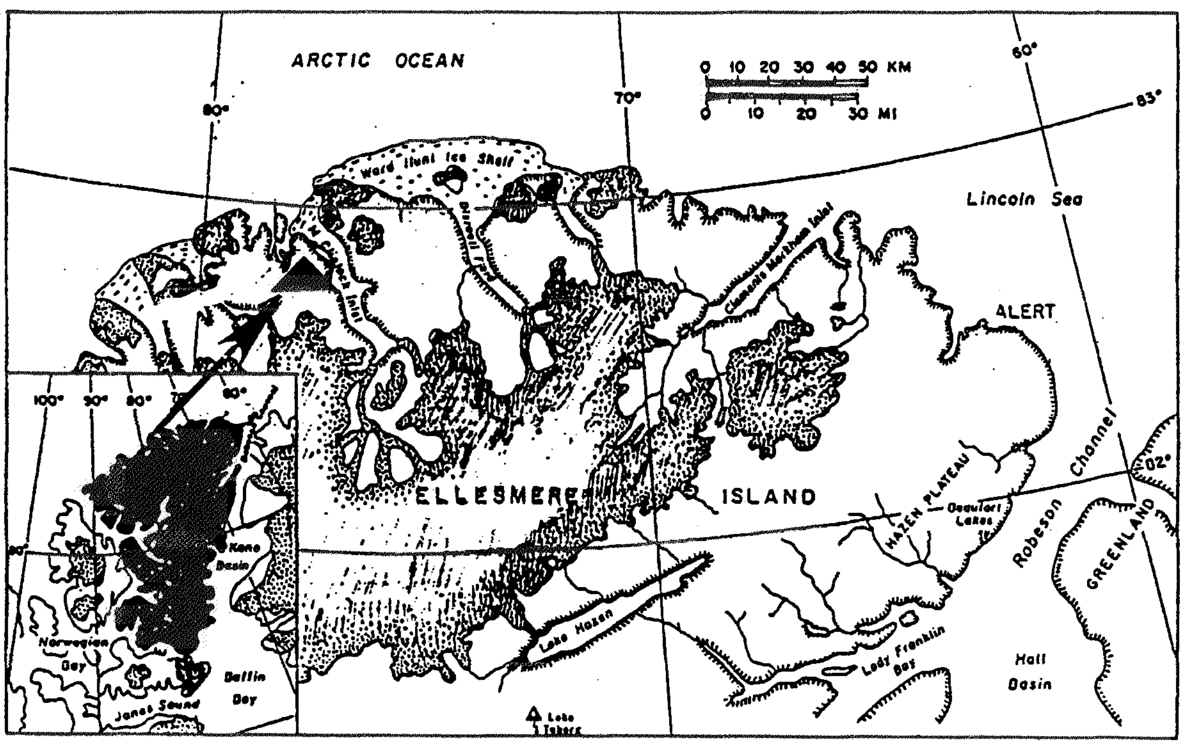


Fig. 1 - Map of the northern portion of Ellesmere Island (insert) showing the location of the study site (triangle) and the Alert weather station.

able, ranging from five to eight weeks beginning in July and lasting until about mid-August. Lowest values for melting degree days for the period 1960 to 1990 at Alert were recorded in 1968 and 1977.

2.2. *Sample collection and preparation*

Two-centimeter stem sections were collected just above the root collar from 11 living, relatively large diameter specimens at the end of the summer of 1992. Maximum stem diameters ranged from 0.8 cm (xylem 0.5 cm) in the smallest specimen to 1.5 cm (xylem 1.1 cm) in the largest. Preliminary hand lens examination of transverse surfaces indicated that the pith was eccentric, especially in older specimens.

The slow reported growth rates for this species growing at high latitudes (WARREN WILSON 1964) indicated that microscopic examination of the specimens would be necessary to delineate and measure the growth-rings. The samples were sectioned with a sliding microtome, taking 15 μm sections from four different locations along the length of the sample. Sections were stained with 1% safranin. Fig. 2 shows cross sections of one younger and one older specimen.

2.3. *Delineation of growth-ring boundaries*

Growth-ring boundaries in *S. arctica* have been variously reported as being delineated by either radially flattened fibers (BESCHEL, WEBB 1963) or terminal parenchyma (WARREN WILSON 1964). WARREN WILSON (1964) also reported that terminal parenchyma is laid down around the complete circumference of the stem in every year. Transverse sections were therefore carefully examined to characterize the structures of the wood, especially the cells of the growth-ring boundary. Growth-ring boundaries least likely to include a missing ring (those separating two wide rings in young wood) were compared with boundaries in areas of partial rings where a ring was known to be missing.

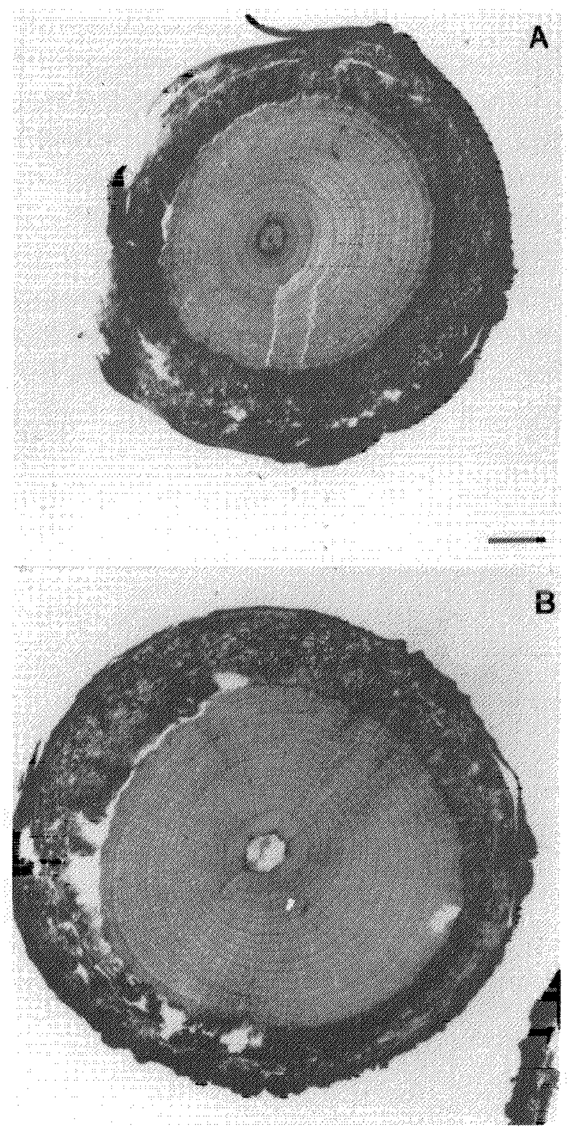


Fig. 2 - Cross sections of samples 5 (A), and 6 (B) (Table 1). Estimated ages of the samples are 37 and 55 years respectively. Bar=1 mm.

2.4. *Cross-dating and ring-width measurement*

The value of this material for dendroclimatological reconstruction is dependent upon successfully cross-dating the samples. A skeleton plot (Douglass 1939) using both wide and narrow rings was therefore constructed for each sample from tracings of a magnified portion of a section.

An approximately 15° segment of the circular section, in which a maximum number of the identifiable rings was represented, was projected onto paper using a Leitz projecting microscope (about x 100 final magnification), and all identifiable growth-ring boundaries were traced. A conservative approach to delineating rings was used, requiring that at least one vessel be identified in at least one of the four sections examined. Partial rings were very frequent in the areas of the shorter radii but could occur in all parts of a ring. It was therefore not possible to represent all the rings in the section and/or segment selected for tracing. The location of rings that were absent from the selected area but present elsewhere in the section were represented by a very narrow ring inserted into the drawing. Evidence of frost damage was recorded in the drawings as an aid to cross-dating.

A preliminary skeleton plot (Schweingruber et al. 1990) was prepared for each sample based on examination of the tracing. It became clear from comparisons of the preliminary plots that years were missing in some of the samples, particularly in recent years in the oldest specimens and in years immediately preceding years of very slow growth. The original sections were therefore re-examined, particularly in areas where it seemed likely that rings were missing and/or where rings were narrow. In practice, it was necessary to go back and forth repeatedly between the initial skeleton plots and the sections under

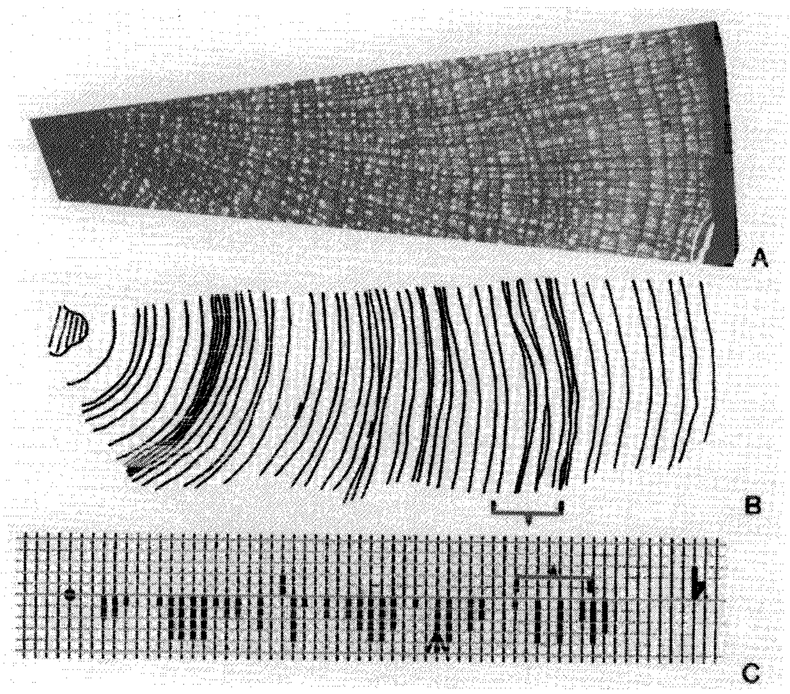


Fig. 3 - Portion of sample 7 (Table 1) to show an area (A) from which a tracing (B) was made. The selected area was projected to enlarge the image to about x 100. A skeleton plot (C) for the sample was prepared from inspection of the tracing and the original sections. Corresponding areas on the tracing and skeleton plot are indicated by the bracket. Rings detected in another area of the section are indicated by a short line on the tracing. A missing ring is indicated in the skeleton plot by an arrowed line. Bracketed area=0.4 mm.

the miscoscope to be certain that all the rings represented in the sections had been identified. A newly-identified ring was inserted into the tracing as a very narrow ring. A tracing was considered final only after this procedure failed to locate any more rings. An example of a portion of a cross section, the trace obtained from it, and the skeleton plot derived from the trace is shown in Fig. 3.

Cross-dating the skeleton plots indicated that after this procedure some of the samples still had missing rings. The postulation of missing rings to produce a match between plots was, however, used conservatively. To be 'missing', a ring had to be 1) clearly identified in at least two other samples and 2) be narrow in the samples in which it appeared i.e. indicate a year in which a ring would be likely to be missing. It was regarded as additional circumstantial evidence for a missing ring if its location in the series preceded a narrow ring (based on the argument that a narrow ring would be likely to follow a 'starvation' year).

Once missing rings had been inserted into the plots, a master skeleton plot was prepared using unweighted and weighted compilations of the individual plots (Schweingruber et al. 1990). Pointer years (Schweingruber et al. 1990) were defined for these samples as years in which a negative event year was present in at least 66% of the samples and represented a reduction in growth of more than 70%. Event years based on relative ring widths were identified and displayed as described by Schweingruber et al. (1990).

For future reference, ring widths of the nine cross-datable samples were measured. A 40 times enlargement of the original sample obtained by reducing the x 100 tracing proved to be an appropriate size for measuring ring widths.

Sample #	Age[a]	Mean annual increment (mm)				
		First 10 yrs	Last 10 yrs	Max	Min	Mean
1	31	0.14	0.11	0.13	0.10	0.12
2	37	0.14	0.05	0.10	0.04	0.9
3	37	0.28	0.05	0.16	0.08	0.12
4	37	0.18	0.05	0.08	0.04	0.06
5	37	0.13	0.05	0.08	0.05	0.07
6	55	0.16	0.08	0.11	0.05	0.08
7	58	0.10	0.09	0.07	0.04	0.06
8	58	0.15	0.13	0.10	0.04	0.07
9	59	0.11	0.06	0.09	0.05	0.07
10[b]	43	0.13	0.02	0.08	0.06	0.07
11[b]	59	0.31	0.04	0.18	0.09	0.14

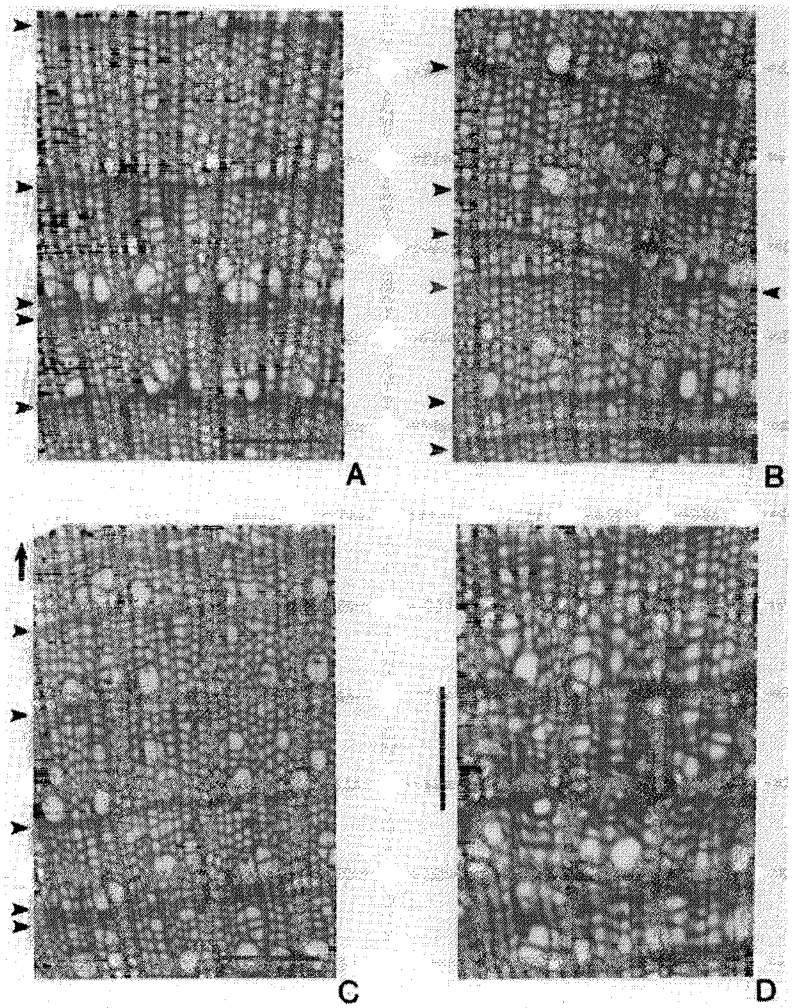
[a] Number of growth rings, including missing rings identified through cross-dating.
[b] Samples for which cross-dating was not possible because of very slow growth during the past 20 years. Ages shown are minimum.

Tab. 1 - Mean annual growth increments for eleven samples of *Salix arctica.* Values are shown for the first and last decades of growth for each sample, the maximum mean growth rate (measured over the longest radius), the minimum mean growth rate (measured over the shortest radius) and the mean growth rate (averaged over the longest and shortest radii for all years).

3. **Results**

Ages of the samples of *S. arctica* wood examined here ranged from approximately 31 to at least 59 years old (Table 1). Annual increment was highly variable from year to year (Fig. 2, Fig. 3A and B). In spite of slow growth rates and a prostrate growth habit this material thus provided potentially useful material for dendroclimatological reconstruction. Some of the older samples had,

Fig. 4 - Examples of growth rings and ring boundaries. Ring boundaries consist of one or more rows of rectangular cells and are indicated by arrows. (A) is a portion of a section from young wood. Annual increment is highly variable from year to year, but all the rings shown are entire. (B) is a portion of a section that includes a partial ring. The ring boundary in the portion of the stem where this ring is missing is indistinguishable from other growth ring boundaries. (C) shows several areas where defining ring boundaries is difficult, particularly in the upper portion of the field (vertical arrow). (D) shows damage interpreted as frost damage. Bar=0.1 mm.



however, been growing extremely slowly for the past 20 years (Fig. 2B); others were apparently still growing well (Table 1).

Fig. 4 shows examples of growth rings for good and bad growing years from young material (Fig. 4A), an area with a partial ring (Fig. 4B), and an older area (Fig. 4C) with a range of annual increments, including an area where ring boundaries are impossible to delineate (top of Fig. 4C). Damage interpreted as frost damage can be seen in Fig. 4D. Growth ring boundaries were clearly identified by the presence of one or more rows of rectangular cells. There was no evidence to support the hypothesis that terminal parenchyma is laid down around the complete circumference in every year. Growth-rings in the samples ranged from relatively wide, 'normal' looking rings almost 0.5 mm in width typical of this species (see SCHWEINGRUBER 1990), to extremely narrow rings less than 0.005 mm in width, represented for most of their circumference only by rectangular cells and thus undetectable in most of the ring (Fig. 4B). The complete range of ring type was generally represented within a single section from a single specimen except in the case of the youngest wood where very narrow rings were less common and partial rings were absent.

Age estimates and mean values for annual increment and annual increment along the longest and shortest radii for each sample are shown in Table 1. Mean growth rates for the first and last decades of growth for each sample are also shown. Mean annual increment for the eleven samples combined was 0.08 mm, very similar to the value of 0.07 mm reported for *S. arctica* growing on Cornwallis Island (WARREN WILSON 1964). Plant age was not a good predictor of mean growth rate (r^2=0.0152, $p > 0.05$). The lack of a relationship could be due to genetic variability among the samples and/ or to a high degree of sensitivity to microsite differences in specimens of *S. arctica* growing at this latitude.

Growth in recent years was very slow in several of the older specimens (Table 1, Fig. 2). Unambiguous identification of individual growth ring boundaries was not always possible in such areas (Fig. 4C). No attempt was

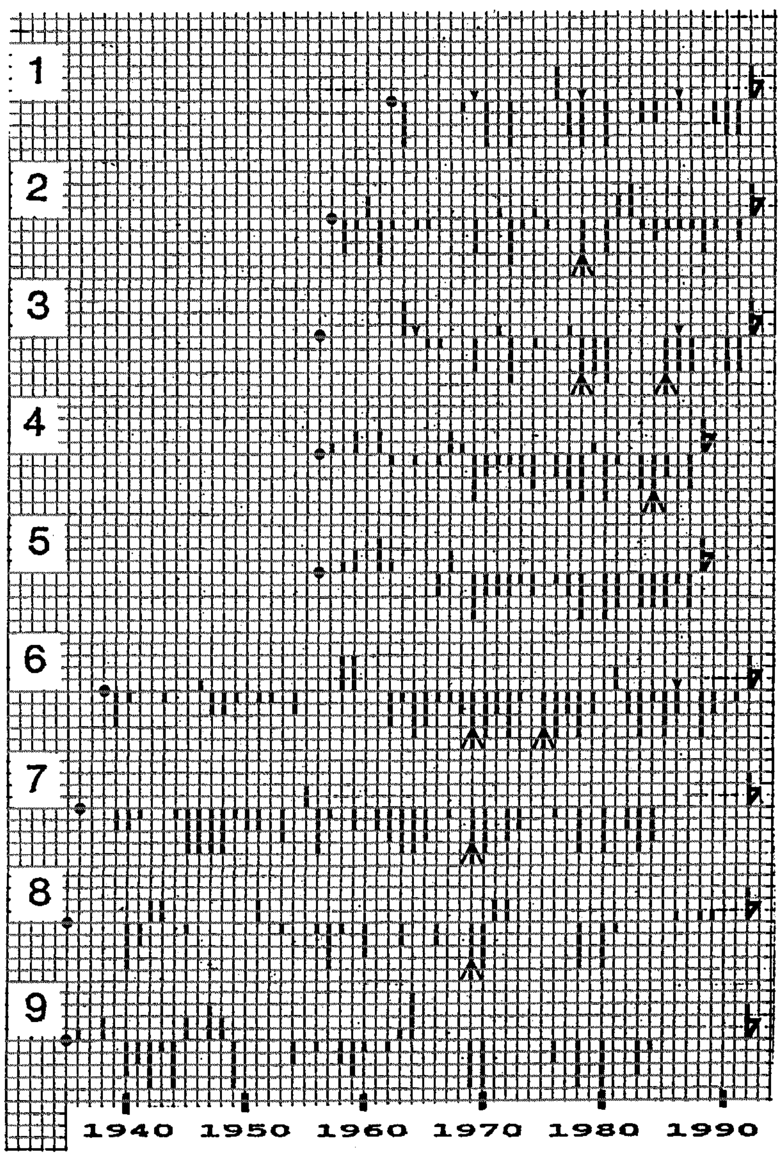
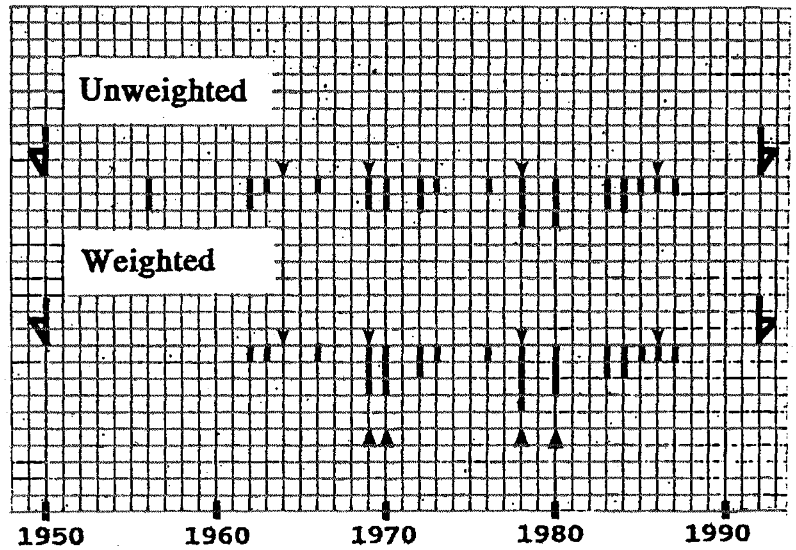


Fig. 5 - Skeleton plots for samples 1 to 9 (Table 1) following conventions of SCHWEINGRUBER ET AL. (1990). Damage interpreted as frost damage is indicated by small arrows above the center line. Missing rings are represented by arrowed lines.

Fig. 6 - Master skeleton plots (unweighted and weighted, SCHWEINGRUBER ET AL. 1990) prepared by summing event years (Fig. 5) for samples 1 to 9. Pointer years are arrowed below the plot on the weighted master plot. Pointer years, assuming no missing years, are 1969, 1970, 1978, 1980.



made to cross-date samples 10 and 11 (Table 1) in which this effect was pronounced.

Final skeleton plots for specimens one to nine are shown in Fig. 5. Rings postulated as missing on the basis of comparisons of skeleton plots are indicated on the plots. Narrow rings proved more useful for cross-dating than wide rings (Fig. 5). There was no evidence to suggest that false rings were present although the possibility that false rings are sometimes formed cannot be eliminated. Pointer years were identified for the period 1956 to 1990, a period in which at least seven samples were represented in any year (Fig. 5). Assuming no years missing from the series, pointer years in this period were 1969, 1970, 1978, and 1980 (Fig. 5). These years showed strongly negative growth in most samples (weighted master plots, Fig. 6). Two of these years (1969, 1978) followed years with unusually low values for melting degree days. There is also evidence of frost damage (Fig. 4D) in two of these years (1969 and 1978). Frost damage was also present in 1964 and 1986 (Fig. 6). Fig. 7 shows a portion of sections from samples 2 and 7 for the period 1976 to 1982 which includes the pointer years 1978 (missing in sample 2, Fig. 7A) and 1980, which was very narrow in sample 2 and represented by very few vessels in sample 7 (Fig. 7B).

4. Discussion

Our results indicate that *S. arctica* growing in the high Arctic has good potential for dendroclimatological studies. In spite of the slow growth and prostrate habit of this species at high latitudes, it was possible to cross-date at least a portion of the increment series of nine of the eleven samples. Some of the older specimens were growing well at the time of harvesting (trees 6, 7, 8 and 9, Table 1) suggesting that specimens older than 60 years will be found in northern Ellesmere Island. There is also the possibility that dead material preserved in these Arctic environments can be cross-dated to extend chronologies developed from living material.

Besides the climatic information contained in the ring-width series, these sam-

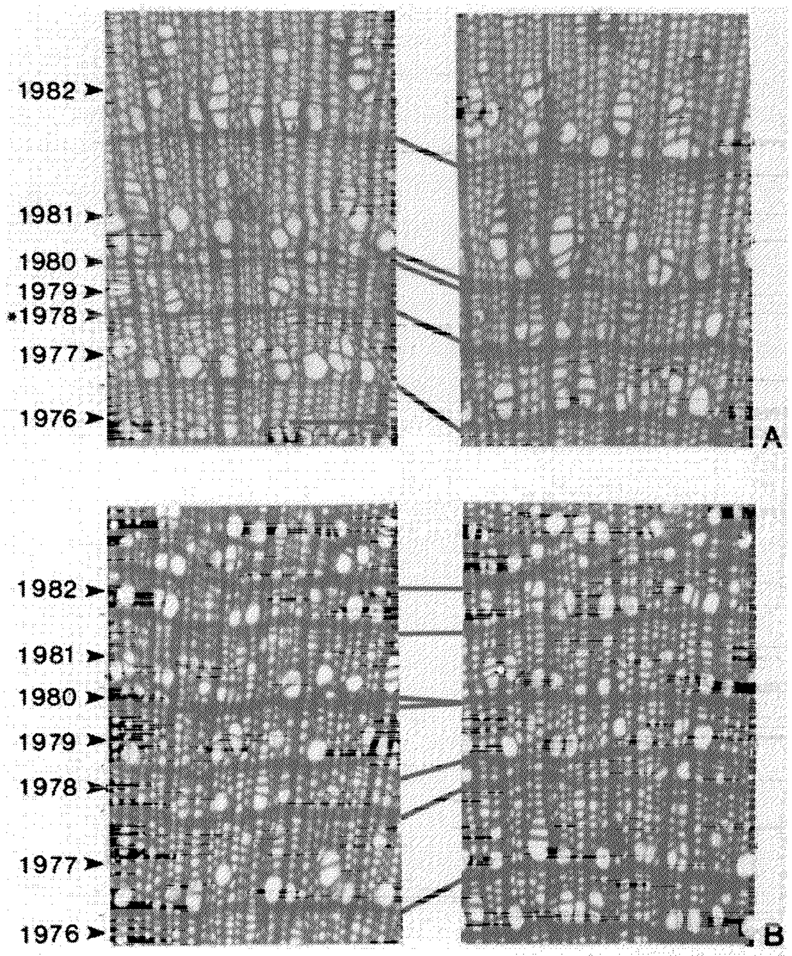


Fig. 7 - Area from two radii each from samples 2 (A) and 7 (B) for the period 1976 to 1982 (assuming no missing rings between 1982 and 1992). Growth in 1980 was very slow in both samples, and this ring was missing in much of the sample. The year 1978 (starred) was missing in (A), and laid down unevenly in (B). Bar=0.1 mm.

ples also offer other clues to past weather events. Frost damage in 1964 (sample 3), for example, is consistent with the fact that in this year the summer was extremely cold throughout the high Arctic, probably due to circulation changes associated with the eruption of Mt. Agung (BRADLEY, ENGLAND 1978). Damage presumed due to frost is evident in three of the eleven samples. These specimens appeared frost-susceptible since damage occurred in multiple years (Fig. 5). Damage detected in some, but not all, samples may be due to microsite differences.

A second potential source of weather information is through the characterization of 'establishhment' years for *S. arctica*. It is highly unlikely that at these latitudes, close to the species' northern range limits, every year will present suitable conditions for flowering, seed set and seedling establishment. In support of this hypothesis is the observation that four samples apparently became established in the early 1930s and four in the mid-1950s (Table 1) suggesting that a particularly favorable combination of conditions for *S. arctica* establishment prevailed at these times. The mid-1950s are known to have been unusually warm at Alert, with temperatures reaching 20°C. No weather records are available for the early 1930s for Ellesmere Island but a regional warming trend in surface air and sea temperatures is reflected in the growth time series for *Betula pubescens* at 60°N at Qinguadalen, Greenland (KUIVINEN, LAWSON 1982).

It was apparent, however, that working with this material will present a number of problems for dendroclimatological reconstruction. Comparable annual increment estimates are difficult to obtain from material with an eccentric pith and partial rings. KRAUSE and ECKSTEIN (1993) obtained increment measurements from root material with highly eccentric pith by measuring along a trace that followed the direction of eccentricity. For our specimens it would be difficult to include all rings with a single trace but the measurement of four radii evenly spaced in the long-radius portion of one selected section from each specimen would generally intercept all rings at least once. Averaging these measurements would provide comparable growth estimates.

There also remains the problem of unequivocal identification of growth-ring boundaries. Growth ring boundaries, as interpreted here, frequently consist of multiple rows of cells rectangular in cross-section (Fig. 4, Fig. 7). When growth is slow most of the ring is only represented by this cell type, and there remains the possibility that no vessels are formed in some years or are so small and infrequent that they will be missed. If no vessels are formed in a year, there is no way at present of positively determining how many years of growth are represented by multiple rows of rectangular cells. Our conservative approach to ring identification could mean that a preliminary chronology derived solely from this set of samples will have missing years. Missing years, if any, should eventually be identified with more extensive sampling.

Three approaches that in combination should minimize missed years and provide good growth estimates are the following:

1) Analyse material from the complete length of the stem. Cambial activity may have ceased near the base of older specimens and rings missing from this portion of the stem may be identified in younger wood (see KOLISHCHUK 1990). Better estimates of annual increment can be obtained from areas where wood is laid down around the complete circumference and growth is less eccentric.

2) Analyse material from as wide a range of age-classes as possible. In combination with the first approach, this would ensure that material of comparable age was available for all time periods included in the chronology and would also allow the identification and characterization of 'establishment' years.

3) Analyse material from a range of micro-environments. This will help to identify rings that may be entirely missing in some samples due to extreme weather events, and will provide additional clues concerning past weather events.

Examination of more specimens using the approaches outlined above will allow the development of a protocol to generate reliably cross-dated increment series.

Although slow-growing prostrate shrubs like *S. arctica* growing in high latitudes present problems in developing ring width series, our results indicate that these problems can be overcome. When good increment series are available, the 40 years of climate data available for Ellesmere Island will allow the identification of correlations between growth of *S. arctica* at high latitudes and climate variables. Long climate records are not available for validation of the models, but models based on analyses of this material could be evaluated indirectly by comparisons with climate reconstructions from other time-series data such as ice core melt records. *S. arctica* is an as yet untapped resource for climate reconstruction in the high Arctic but its wide geographic distribution and occurrence at very high latitudes make it a potentially useful source of dendroclimatological information that can complement climate data from other sources.

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SUMMARY

Salix arctica *(Pall.): its potential for dendroclimatological studies in the high Arctic*

Stem sections from 30 to 60-year old *Salix arctica* (Pall.) samples from northern Ellesmere Island in the high Arctic were evaluated for use in future dendroclimatological analyses. Four specimens established in the 1950s, a period of warm summers. Four others established in the 1930s, suggesting similar conditions prevailed at that time. Nine of the 11 samples could be partially cross-dated but to minimize missing rings and facilitate ring width measurement chronologies must be developed from sections from the entire stem length.

RIASSUNTO

Salix arctica *(Pall.), potenziale indicatore dendroclimatico per studi nella regione artica*

Salix arctica (Pall.) è una delle specie maggiormente diffuse nella zona artica e potrebbe verosimilmente fornire utili indicazioni di carattere dendroclimatico. Tuttavia l'eccentricità dei suoi fusti, gli incrementi anulari annui estremamente ridotti (approssimativamente fino a 0,07 mm annui) e l'omissione frequente di anelli rendono porblematica l'elaborazione di cronologie.

Ai fini di valutare la possibilità concreta di effettuare ricostruzioni dendroclimatiche sono stati raccolti in Islanda (82°50'N, 78°W) alcuni campioni di 30-60 anni. Nove sono stati sincronizzati fra loro e nelle cronologie relative sono stati identificati gli anelli corrispondenti ad annate fredde. Quattro campioni segnalano estati calde negli anni cinquanta e altri quattro situazioni analoghe per gli anni trenta. Tuttavia al fine di individuare perfettamente le successioni anulari, di ridurre i casi di omissione di anelli e di agevolare le misurazioni sarebbe opportuno esaminare sezioni trasversali complete prelevate a vari livelli dei fusti.

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