IMPACTS OF DROUGHT ON GROWTH AND REGENERATION OF CONIFERS ON THE CANADIAN PRAIRIES

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ABSTRACT

In the Canadian prairie provinces, the natural distribution of conifers is generally restricted to moist areas in the north and at high elevation, where annual precipitation exceeds potential evapotranspiration. Predictions of a warmer and drier future climate pose concerns for the productivity and regeneration of all trees in this region, especially on the prairies, where conifers are absent except in plantations and shelterbelts. We conducted tree-ring analysis at three plantations on the prairies of southern Saskatchewan to examine the impact of climatic variability on conifer growth in this drought-prone region. Radial growth of 30-80 year old white spruce (*Picea glauca* (Moench) Voss), jack pine (*Pinus banksiana* Lamb.) and other conifers was severely reduced during major drought years in 1980, 1984 and 1988, but growth had fully recovered during the first 1-3 years following each drought. These results indicate that conifers are capable of withstanding severe drought, at least once they have attained a certain size. However, previous studies suggest that climatic conditions on the prairies are too dry to permit natural regeneration of conifers from seed, and historic records indicate a low success rate in establishing conifer plantations in these drought-prone regions. Thus, although conifers represent an excellent opportunity for afforestation and agroforestry on the Canadian prairies, innovative approaches to plantation establishment would be necessary to avoid drought-induced mortality of seedlings during the first few years after planting.

***Keywords*:** plantation, dendrochronology, tree-ring, drought, conifer, spruce, pine

INTRODUCTION

In the western Canadian interior, several species of coniferous trees share a similar southern limit of natural distribution that is governed, either directly or indirectly, by moisture (Zoltai 1975; Hogg 1994; see also Figure 1). In this region, boreal and cordilleran forests are generally restricted to climatically moist areas where mean annual precipitation is more than sufficient to satisfy plant water use on a well-vegetated landscape, leading to significant water runoff into streams and rivers during most years. However, in the drier, southern portions of the Canadian prairie provinces, natural forests are either absent (prairies) or restricted to stunted patches of deciduous trees (aspen parkland). In these areas, drought poses challenges to the artificial establishment and maintenance of plantations and shelterbelts. The natural range of trembling aspen (*Populus tremuloides* Michx.) and other poplars extends further south into dry areas where conifers are naturally absent; however, poplar forests on the Canadian prairies and parklands are prone to severe crown dieback following periods of drought (Zoltai et al. 1991; Hogg and Hurdle 1995; Hogg et al. 2002) or after lowering of water levels along rivers (Tyree et al. 1994).

Conifers have been extensively planted as shelterbelts and plantations for various purposes across the Canadian prairies (Johnson 1953; Jameson 1956; Johnson and Lesko 1977). These conifers include native species such as white spruce (*Picea glauca* (Moench) Voss) and jack pine (*Pinus banksiana* Lamb.) that have been transplanted far outside their natural range, as well as introduced conifers such as the European Scots pine (*Pinus sylvestris* L.) and Colorado spruce (*Picea pungens* Engelm.). The persistance of these planted conifers, even in non-irrigated areas of dry prairie, demonstrates that they are highly tolerant of drought.

In a previous study, Hogg and Schwarz (1997) concluded that conifers are naturally absent from the Canadian prairies because the climate is too dry to permit natural regeneration from seed. This conclusion was based on the results of surveys showing that seedlings rarely occur around mature planted conifers on abandoned prairie farms in southern Saskatchewan. In contrast, seedlings were abundant around conifers planted in comparable habitats on farms situated in cleared areas of boreal forest. Given that natural regeneration is the main factor preventing conifers from colonizing the Canadian prairies, there appears to be no reason why conifer species could not be good candidates for large-scale agroforestry and afforestation projects in this dry region, provided that they can be successfully established after planting.

The objective of the present study was to examine the impact of prairie drought on the growth of conifers in previously established plantations on the Canadian prairies. Conditions during the 1980s were especially dry in this region, and 1988 was one of the most severe drought years since the "dust bowl" period of the 1930s (Trenberth et al. 1988; Herrington et al. 1997). This provided an ideal opportunity to determine the ability of planted conifers to withstand, and recover from periods of extreme drought that might also serve as an analog for the future, if conditions in this region become drier under human-induced climate change (Hogg and Hurdle 1995). In this preliminary investigation, we conducted tree-ring analysis at three conifer plantations in southern Saskatchewan to examine past growth responses to changes in moisture over the period 1960-1993, including impacts of major drought years such as 1988.

METHODS

The three conifer plantations selected for this study were located on the plains of southern Saskatchewan, Canada, where conifers are naturally absent (Figure 1). This region is heavily cultivated, and the native tree cover is restricted mainly to stunted groves of trembling aspen.

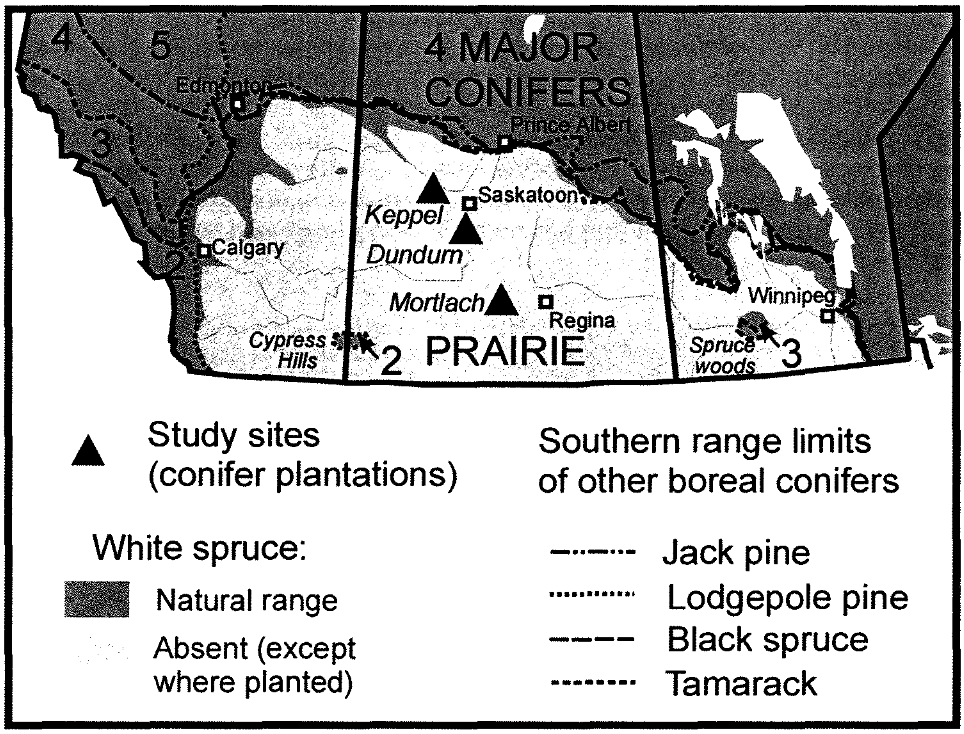


Figure 1. Map showing the location of three prairie conifer plantations where tree-ring analysis was conducted, in relation to the natural distribution of the five major species of boreal conifers in the Canadian prairie provinces of Alberta, Saskatchewan and Manitoba (from Zoltai 1975).

The Mortlach plantation (50° 28'N, 106° 03'W) is situated on the prairies west of Moose Jaw, Saskatchewan, and consists of an 800 x 300 m block planting (25 ha) on sandy soils where a total of about 47,000 conifers and 17,000 deciduous trees were planted between 1945 and 1961 (G. Howe, PFRA Shelterbelt Centre, pers. comm. 1993). When sampling was conducted for this study (early September 1993), there was little evidence of past conifer mortality. Increment cores were collected from ten trees of each of the following four conifer species: white spruce, jack pine, Colorado spruce and Scots pine.

The Dundurn plantation (51° 50'N, 106° 39'W) is situated on the Dundurn military base (Department of National Defence) south of Saskatoon, Saskatchewan. It occupies a total area of approximately 5 ha on sandy soils, where about 37,000 jack pine, 5,000 Scots pine, and 300 white spruce were planted in 13 blocks between 1916 and 1929, as part of an experimental forestry initiative by the Canadian federal government. Subsequent surveys in 1948 showed overall survival rates of 6-8% for the pine, and only 1% for the white spruce (Johnson 1953). In late August 1993, increment cores were collected in this plantation from ten jack pine and ten Scots pine.

The Keppel plantation (52° 27'N, 107° 56'W) is located in the aspen parkland zone northeast of Biggar, Saskatchewan. It occupies a total area of 120 ha, where a total of about 350,000 conifers were planted on sandy loam to clay loam soils between 1934 and 1946. The plantings originally consisted of 60 blocks of equal size (about 2 ha), including 42 blocks of white spruce and 6 blocks each of jack pine, lodgepole pine, and Scots pine; however, subsequent surveys showed that nearly all of the pine had died prior to 1948 (Johnson 1953). Of the blocks planted with white spruce, most showed low survival but the 9 blocks that were planted in 1934 had an overall survival rate of about 27%. In July 1994, increment cores were collected from ten white spruce in this plantation.

For the trees sampled at the three plantations (as indicated above), increment cores were collected from two sides of each stem at sampling heights ranging from 30 to 130 cm. Cores were placed in labelled straws and dried (50°C) prior to mounting in grooved boards using a slow-drying hide glue. After the glue had dried, cores were polished using a palm sander with progressively finer sandpaper, and ring widths were measured with an ocular micrometer under a dissecting microscope. The ring width measurements were used to estimate annual values of basal area increment (BAI, in cm^2 per year) for each tree (Hogg and Schwarz 1999), which serves to reduce the trend for decreasing ring widths over time that typically occurs as trees grow in circumference (Kolb and McCormick 1993). For each plantation, average values of BAI were calculated annually for the ten trees of each species sampled. Annual values of relative growth were then determined as a percentage of the 30-year mean (period 1964-1993) for each of the species sampled in each of the three plantations.

The impact of drought on year-to-year variation in conifer growth was assessed through linear correlation analysis of relative growth (dependent variable) versus annual values of a Climate Moisture Index (CMI) developed by Hogg (1997). The CMI is based on the quantity P minus PET, where P is the annual precipitation and PET is the annual potential evapotranspiration (i.e., expected loss of water vapor loss from a well-vegetated landscape when soil moisture is not limiting) using a simplified form of the Penman-Monteith equation. Negative values of the CMI denote the dry climatic conditions that typically occur in the aspen parkland or prairie grasslands, whereas positive values indicate the moister climatic conditions that are normally associated with boreal and cordilleran forest in western Canada (Hogg 1994).

Monthly values of mean daily maximum and minimum temperature, and monthly precipitation were obtained from Environment Canada, for climate stations adjacent to each plantation. The stations used were Moose Jaw and Chaplin (average of both stations for the Mortlach plantation), Dundurn (Dundurn plantation) and Biggar (Keppel plantation). Values of PET were calculated monthly for each plantation from the estimated vapor pressure deficit, which was in turn estimated from the average daily maximum and minimum temperature for each month (Hogg 1997). Precipitation and moisture conditions late in a calendar year (September-December) were assumed to have a negligible effect on the ring width for that year because radial growth of conifers is normally completed by late summer (Belyea et al. 1951; Fraser 1956). Thus values of annual precipitation and the CMI were calculated for various12-month periods ending in mid summer to early fall.

RESULTS AND DISCUSSION

The characteristics of trees sampled at the three plantations is shown in Table 1. Patterns of relative growth based on tree-ring analysis were generally similar among the three plantations, and among the conifer species sampled at the Mortlach and Dundurn plantations (Figure 2). In correlation analyses of growth versus the CMI, the strongest overall relationships were obtained using a "tree water year" beginning on 1 August of the previous year and ending on 31 July of the current year.

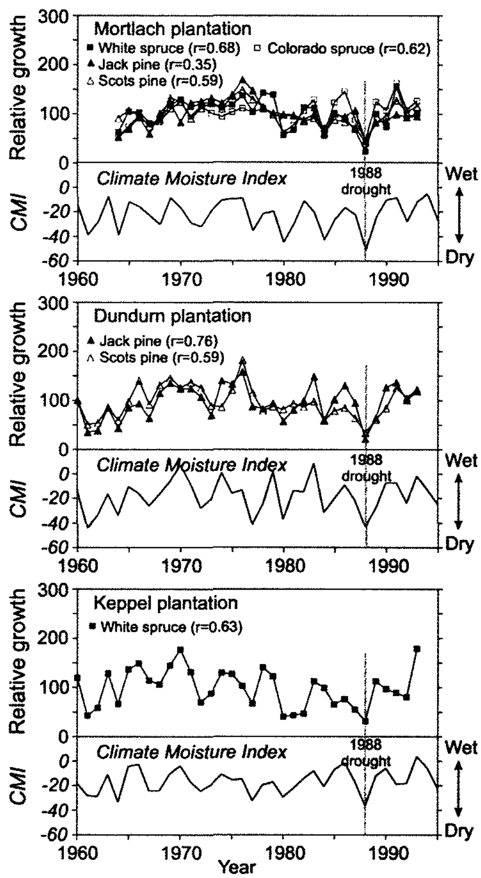
Table 1
Characteristics of trees sampled in three conifer plantations

Plantation (when planted)	Spcecies	Mean Height (m)	Mean DBH* (cm)	Earliest ring (year range)
Mortlach (1945-1961)	White spruce	10.4	18	1952-1968
	Jack pine	10.8	17	1957-1967
	Colorado spruce	11.5	24	1954-1961
	Scots pine	11.6	18	1957-1967
Dundurn (1916-1929)	Jack pine	12.0	20	1937-1944
	Scots pine	10.9	27	1922-1941
Keppel	White spruce	15.3	18	1939-1947

*Diameter at breast height (1.3 m)

For the 30-period of analysis (1964-1993), the correlations between relative growth and the CMI were statistically significant ($P<0.05$) for each of the species at the three plantations, with the exception of jack pine at the Mortlach plantation ($P<0.10$) which had the lowest correlation coefficient ($r = 0.35$). In contrast, jack pine at the Dundurn plantation had the greatest correlation coefficient ($r = 0.76$). Correlation coefficients for the other species (white spruce, Colorado spruce and Scots pine) ranged from 0.59 to 0.68 (Figure 2).

Figure 2. Changes in relative growth of conifers at three plantations, based on tree-ring analysis. Relative growth for each year



is the average increment in stem cross-sectional area (cm² per tree per year), expressed as a percentage of that recorded over the period 1964-1993. Also shown are annual values of the Climate Moisture Index (CMI, for 12-month period ending on 31 July of the current year). Correlation coefficients (r) are given for the relationships between relative growth and the CMI, for each conifer species sampled at each plantation.

Values of the CMI show that the 12-month period ending 31 July 1988 was the driest recorded over the 30-year period of analysis. This year was especially dry at Mortlach, when total precipitation was only 196 mm and a CMI of -51 was recorded. Other drought years included 1961, 1964, 1977, 1980 and 1984. Growth was reduced in each of these drought years, especially in the most severe drought year of 1988 (Figure 2). However, growth showed a rapid recovery in all species after each drought. Growth recovery appeared to be most rapid in the white and Colorado spruce (often within one year), whereas the jack and Scots pine often required 2 or 3 years to recover.

The rapid growth recovery of these conifers following these prairie droughts is remarkable, because these events are much more severe than the species would normally encounter in their native habitats in the Canadian boreal forest (white spruce and jack pine), subalpine forests in the Rocky Mountains (white spruce and Colorado spruce), or the temperate and boreal forests of Eurasia (Scots pine). The results further suggest that conifers have excellent potential for agroforestry applications on the prairies and parklands of western Canada, provided that reforestation practices can be successfully modified to minimize drought losses of seedlings during first few years after planting. Although rotation lengths are generally greater for conifers than for high-yielding cultivars of hybrid poplar, the risk of losses due to crown dieback following drought may be less. Further investigations are warranted to determine the feasibility of large-scale planting of conifers on the Canadian prairies, from both ecological and socioeconomic perspectives (Johnston et al. 2000). Such investigations would strongly benefit from the rich legacy of conifer plantations that were established throughout the last century across the Canadian prairies and parklands, many of which have been well documented in the archives of federal and provincial land management agencies.

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