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# RECENT ENVIRONMENTAL CHANGE IN THE SOUTHWESTERN CANADIAN PLAINS

*This paper examines 20th-century environmental change in the subhumid southwestern Canadian Plains, specifically in relation to the dominant agricultural landscape and to the climate of the past millennium as reconstructed from proxy data. Anthropogenic landscape change in the last century has been dominated by the conversion of grasslands to ranchland and cropland. This has heightened landscape vulnerability to climatic fluctuations, especially drought. Instrumental climate records, extending back to the 1880s, highlight the variability of precipitation in this region. Proxy environmental records, derived from lake cores and tree-ring analysis, extend this picture into the last millennium and show that drought has been a recurring theme of the Prairie climate. Tree-ring records suggest that some droughts in the last millennium may have exceeded in severity any in the instrumental record. The sustainability of Prairie agriculture depends on adaptation to the amplitudes of climatic change and variability evident in these proxy records.*

*Key words*: climatic change and variability, southwestern Canadian Plains, proxy records, tree rings

*Dans cet article nous examinons les changements environnementaux qui sont survenus pendant le 20$^{ème}$ siècle dans les plaines canadiennes sèches du sud-ouest, spécifiquement par rapport au paysage agricole dominant et au climat du dernier millénaire qui a été déterminé à partir de données de procuration. La transformation des prairies en* ranchland *et* cropland *est le changement du paysage le plus important dont l'homme est responsable, pour le dernier siècle. À cause de ce changement, le paysage est plus vulnérable aux fluctuations climatiques – à la sécheresse en particulier. Les enregistrements instrumentaux de climat, qui reculent jusqu'aux années 1880, mettent en évidence la variabilité des précipitations dans cette région. Les enregistrements environnementaux de procuration, dérivés d'échantillons pris dans les lacs et de la dendroanalyse, étendent cette image dans le dernier millénaire et prouvent que le thème de la sécheresse est apparu souvent dans les analyses du climat du prairie. Les enregistrements de boucles d'arbre suggèrent que, dans le dernier millénaire il y avait des sécheresses qui étaient peut-être si sévères que les instruments n'ont pas pu les enregistrer. Si l'agriculture veut survivre comme entreprise dans les prairies, il faudra qu'elle s'adapte aux amplitudes de changement et de variabilité du climat qui ont été constatées dans les données de procuration.*

*Mots-clés*: amplitudes de changement et de variabilité du climat, les plaines canadiennes du sud-ouest, les données de procuration, les boucles d'arbre

The subhumid Southwestern Interior Plains of Canada can be variously defined as the area corresponding to

The Canadian Geographer / Le Géographe canadien 42, no 4 (1998) 337–53

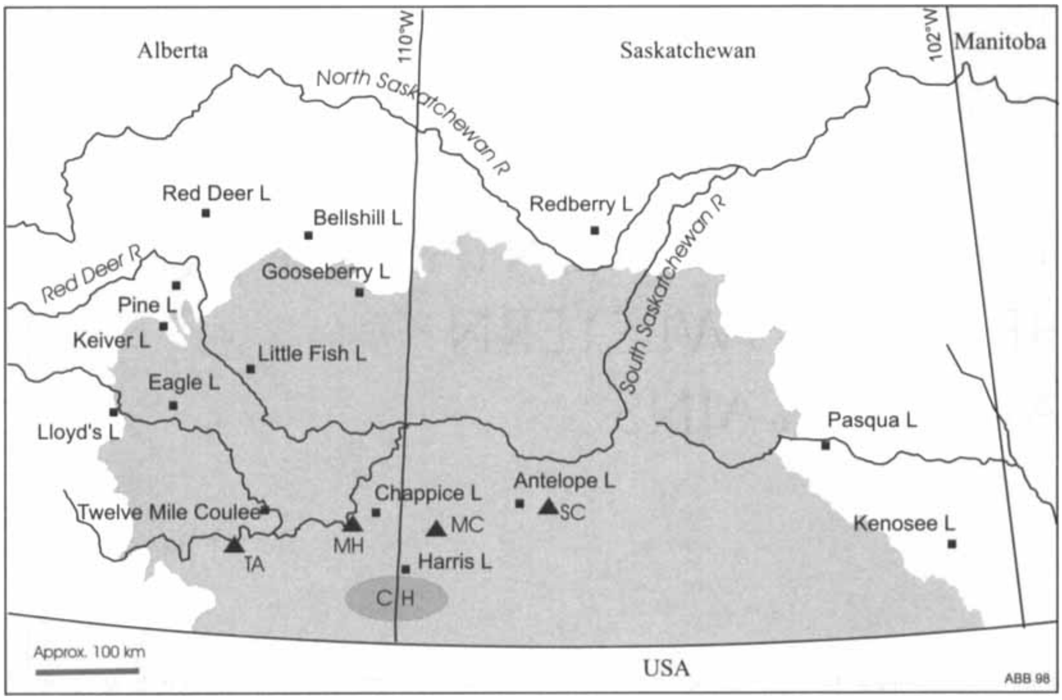


**Figure 1**
The Southwestern Canadian Plains showing the Prairie ecozone. The shaded area excludes the Aspen Parkland and Manitoba Uplands, which ESWG includes in the Prairie ecozone. Palaeoecological sites relevant to the last millennium: Pine Lake (Campbell 1997); Chappice Lake (Strong 1977, 1991; Vance et al. 1992, 1993); Redberry Lake (Van Stempvoort et al. 1993); Antelope Lake (Last and Vance 1996); Pasqua Lake (Campbell et al. 1994a; McAndrews 1998); Harris Lake (Sauchyn and Sauchyn 1991); Kenosee Lake (Vance et al. 1997); Keiver Lake, Red Deer Lake, Bellshill Lake, Gooseberry Lake, Little Fish Lake, Eagle Lake, Lloyd's Lake, Twelve Mile Coulee, West Block. Other locations: MH – Medicine Hat; TA – Taber; MC – Maple Creek; SC – Swift Current; CH and enclosing oval – Cypress Hills. BASED ON: Ecological Stratification Working Group 1995.

the Mixed Grass Prairie Ecoregion or the Brown Soil Zone (Canada. Agriculture and Agri-Food Canada. Ecological Stratification Working Group (ESWG) 1995, Figure 1), the Palliser Triangle (Ruggles 1993; Spry 1995), or the Canadian Dry Belt (Villimow 1956). In terms of physiography and vegetation, it forms the northernmost portion of the Interior Great Plains Grasslands of North America (Scott 1995, 144). Politically, it encompasses southeastern Alberta and southwestern Saskatchewan. Agriculture is the original source of wealth in this region and a major sector of the present economies. It dominates the landscape; Saskatchewan alone has 40% of Canada's cropland and produces 60% of the wheat. As a result, the human aspects of weather and climate, including most studies of the potential impacts of climatic change (e.g., Wheaton 1984; Williams et al. 1987; Schweger and Hooey 1991; Wilhite and Wood 1995), usually involve agriculture as a major theme.

This paper examines 20th-century environmental change in relation to the agricultural landscape and the climate of the past millennium. Euro-Canadian settlement of this region has occurred mostly within the last 100 years. Therefore, conversion of the Prairie to agricultural land has happened during the postindustrial revolution interval, characterized by a significant anthropogenic component to global climatic change. Proxy records of presettlement environmental change are available from tree-ring and lake-sediment research. These records are reviewed following descriptions of the Prairie climate and the most important 20th-century environmental change: the introduction of dryland agriculture.

## The Present Agricultural Landscape

The identity of the Southern Prairies is related largely to agriculture and climate. Crop and ranching disasters in individual years (e.g., 1906, 1961) or for the better part of decades (the 1930s and the 1980s) punctuate the short history of modern settlement. The human responses to these extreme conditions are a major part of the natural, social, and political history. Drought, rapid snowmelt, large variations in temperature and precipitation, strong winds, and occasional tornadoes, hail, intense thunderstorms (e.g., Paul 1992), and blizzards account for nearly all the damage inflicted by natural hazards. When Captain John Palliser deemed the grassland unsuitable for settlement, he triggered a debate that continues to this day (Paul 1991). His proclamation was countered by bureaucrats and speculators who heralded the region as the world's breadbasket. Failure to recognize the hazardousness and variability of Prairie climate predestined the historical response of settlers and governments: an initial poor adjustment to climate (Jones 1987), subsequent rural depopulation, and many government programs and entire agencies (e.g., the Prairie Farm Rehabilitation Administration or PFRA) created to first salvage and then sustain Prairie agriculture.

In April 1938, the PFRA's E.W. Stapleford submitted a 'Report on rural relief due to drought conditions and crop failures in western Canada' (Stapleford 1939). He suggested (p. 123) that '[t]here will be groups of years within a period of 50 years that will be extremely dry, constituting a serious drought.' Between 1985 and 1991, the Canadian government dispensed $22 billion to Prairie grain farmers in total direct payments (Canada 1989–91), to offset the devastating impacts of drought, particularly in 1988, exactly 50 years following Stapleford's prediction. Even in 1991, a year of record high wheat production, emergency payments (i.e., above regular assistance and insurance programs) were still in excess of $700 million. These are the recent costs of sustaining an economic sector that is sensitive to climate.

Sustainable dryland agriculture depends on adjustment of land use and production systems to climatic variability, to the periodic fluctuation of atmospheric conditions (e.g., drought, early frosts, major storms) and to climatic change – a significant departure from previous average conditions (Canada. Environment Canada 1995). The history of Prairie agriculture has been characterized by adaptations to climatic variability (Hill and Vaisey 1995, 52), including the development of drought- and frost-tolerant crops and farming practices that conserve soil moisture. Some of these developments were fortuitous. In 1886, on his farm near Indian Head, Saskatchewan, Angus MacKay obtained an unusually high wheat yield from a field that was fallow the previous year, because the hired hands were preoccupied with the Riel Rebellion (Anderson 1975). He had discovered the virtues of summerfallow, and this farming technique soon spread across the northern Great Plains (Carlyle 1997). This and other dryland farming techniques (Gray 1967) have enabled cereal crop production to continue in this region.

Although Prairie agriculture adjusts to seasonal and interannual variability, it has not yet begun to grapple seriously with longer-term adaptations to global environmental change. Global climate records suggest that mean annual temperature (MAT) has risen steadily since the early 1900s, with the warmest years on record in the 1990s (Jones 1996). The Canadian Climate Centre's general circulation model (GCM) predicts that, in southern Canada, the largest $CO_2$-induced rise in mean surface temperature will occur in the Interior Plains (Boer et al. 1992). The impacts of this climatic change will be greatest at the margins of land and climate suitable for annual crop production – that is, the subhumid Palliser Triangle. This potential for change has generated considerable interest in the Holocene paleoecology and paleolimnology of this region (Lemmen et al. 1993; Vance and Last 1994), providing analogues for evaluating the impact of current and predicted environmental change.

Human history in this region, however, does not begin with Euro-Canadian settlement and the area's transformation into an agricultural landscape. When Henry Kelsey visited the eastern margins of the Palliser Triangle in 1691 (Ronaghan 1993), he encountered people who were living successfully in the landscape that Palliser later described as likely to be 'forever ... comparatively useless' (Spry 1968, 538). Indeed, the archaeological evidence suggests that this was an important region for Aboriginal people, who have made use of the Canadian Plains throughout postglacial time (Vickers 1986; Wright 1995). Of the 23 429 recorded archaeological sites in Alberta, for example, 15 402 (or almost 66%) are recorded from southern Alberta (south of 52°N; Damkjar, pers comm). Aboriginal people had a mobile lifeway that allowed them to exploit food resources in different areas. This permitted some flexibility in the face of variable climatic and environmental conditions, and forms a strong contrast to later Euro-Canadian occupation, which is so firmly tied to specific settlement locations and their related infrastructure.

## Recent Landscape Change

Euro-Canadian settlement of the Canadian Plains initiated the most significant environmental changes since

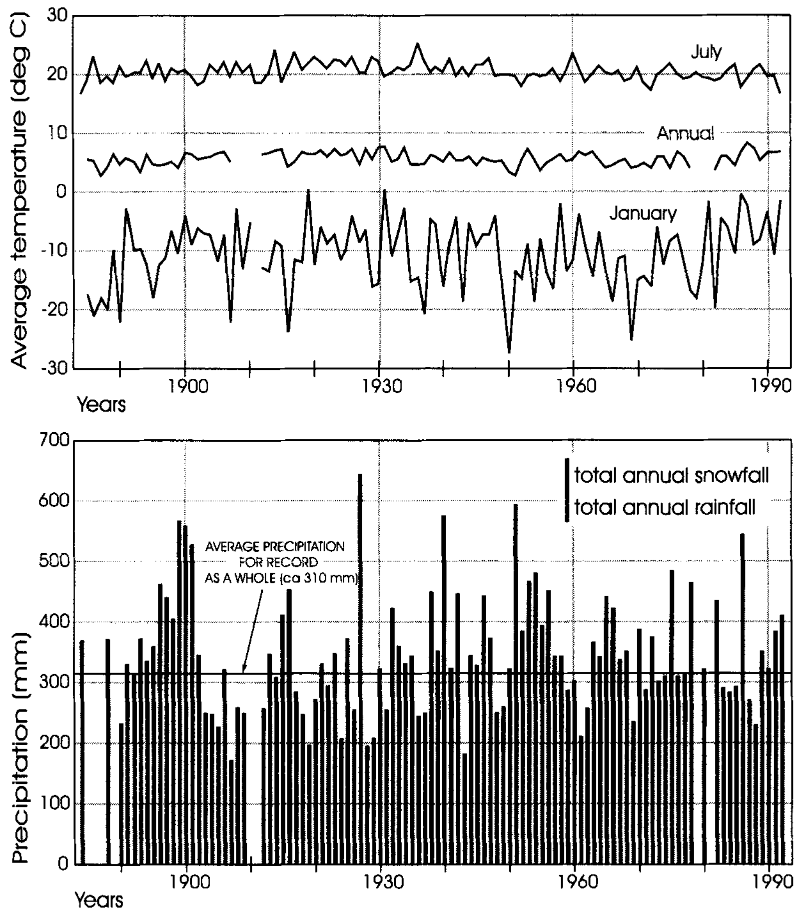


**Figure 2**
Instrumental climate data for Medicine Hat, Alberta. The record extends back only to 1883, with some missing data in the early years. SOURCE: Raw data from Canadian Monthly Climate Data and 1961–1990 Normals (1994 Release CD-ROM), Environment Canada

the retreat of the Laurentide Ice Sheet. Conversion of the Mixed Grass Prairie to farmland has occurred mostly in this century. In the first census of 1906, the five census divisions in southeastern Alberta (nos 1, 3, and 5) and southwestern Saskatchewan (nos 4 and 8) had a total population of only 14 418 (Canada 1938). The population was 125 934 by 1916 and peaked at 148 053 in 1931. With favourable climate and as yet undegraded soil, the prophecies of optimistic speculators and bureaucrats were fulfilled. However, the rapid expansion of cereal crop production in 1911–17 coincided with precipitation that was generally above the long-term average annual precipitation (Figure 2). After 1917, the climate resumed its characteristic variability, with devastating impacts in the 1930s, forcing Prairie grain farmers and agricultural institutions to make radical adjustments, including water-supply projects and shelterbelt planting (Anderson 1975). The soil and water conservation practices implemented after the 1930s and more favourable climatic conditions permitted expanding crop production from the 1940s through the 1970s, notwithstanding periodic crop failures (e.g., 1961).

Between 1961 and 1976, the area of farmland in western Canada expanded by 2.5 million hectares, whereas east of Manitoba there was a net loss of more than 3.9 million hectares (McCuaig and Manning 1982). These data indicate greater exposure of Canadian agriculture to the climatic hazards of the Interior Plains.

**Table 1**
Summary Climate Data for Taber, Alberta, 1961–1990 Normals

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Daily max | -3.6 | 0.4 | 5.2 | 12.3 | 18.4 | 22.8 | 26.3 | 25.9 | 19.9 | 14.4 | 5.0 | −1.7 | 12.1 |
| Daily min | −15.2 | −11.6 | −7.4 | −0.9 | 4.7 | 9.2 | 11.3 | 10.4 | 5.3 | 0.5 | −6.7 | −12.9 | −1.1 |
| Daily mean | −9.3 | −5.5 | −1.0 | 5.8 | 11.6 | 16.0 | 18.8 | 18.2 | 12.6 | 7.5 | −0.8 | −7.3 | 5.5 |
| Rain (mm) | 0.5 | 0.8 | 3.8 | 18.8 | 41.9 | 58.5 | 33.8 | 37.6 | 35.7 | 9.5 | 2.0 | 1.2 | 244.3 |
| Snow (cm) | 23.9 | 14.7 | 18.9 | 14.4 | 0.9 | 0.0T | 0.0 | 0.0 | 2.9 | 5.7 | 15.8 | 23.0 | 120.3 |
| Total ppt (mm) | 24.4 | 15.6 | 22.9 | 34.2 | 42.8 | 58.6 | 33.8 | 37.6 | 38.7 | 15.2 | 17.8 | 24.2 | 365.8 |

SOURCE: Canada, Atmospheric Environment Service 1993

Whereas most of the new farmland was on the northern margins of the western agricultural heartland, the other region with significant gains was southern Alberta and extreme southwestern Saskatchewan (McCuaig and Manning 1982, 26). Similarly, Hansen (1984) demonstrated that, even though more than 10 million hectares of good-quality arable land in Canada are not currently cropland or built-on, the area of cropland in Saskatchewan actually exceeds the area of good-quality arable land. This situation is unique to Saskatchewan and suggests that, in some areas, crops are produced on marginal cropland, at the risk of crop failure and soil degradation. In fact, land capable of sustaining crop production (Canada Land Inventory classes 1 to 3) represents only 86% of the cropland in Saskatchewan. McCuaig and Manning (1982, 34–35) identified the Palliser Triangle as a Canadian anomaly, 'having substantially more land in improved agricultural practice than area with supposed cropping potential.' They noted the extent of irrigated land of otherwise low agricultural capability and the conversion of unimproved pasture to improved pasture and cropland in many parts of Alberta and Saskatchewan.

The drought years of the 1980s, in conjunction with changes in agricultural policy, have caused further land-use change, in particular larger areas of permanent cover or continuous cropping. With all adjustments of land use, the vulnerability of Prairie agriculture to climatic hazards is a central issue. Institutional land-resource planning and management will be done increasingly within the context of projected global economic and environmental change (Williams et al. 1987; Wong et al. 1989; Nemanishen 1998).

## The Instrumental and Documentary Climatic Record

The regional continental climate of the southwestern Canadian Plains is characterized by long, cold winters and warm summers, exemplified by the latest 30-year normals (1961–1990) from Taber, Alberta (Figure 1; Table 1). About two-thirds of the average annual precipitation falls as rain, mainly in the summer months (May to September). These numbers disguise the considerable variability of climatic conditions in this region, where winter chinooks in southwestern Alberta can raise temperatures rapidly in a few hours, melting snow and reducing soil moisture reserves in the spring. Taber, for instance, shows extreme January temperatures of 17.8°C and −43.3°C (Canada. Atmospheric Environment Service 1993). Summer temperatures can also show a large range; July extremes at Taber can vary from 40.6°C to 2.8°C. The most arid region of the southern Canadian Plains is in southeastern Alberta and southwestern Saskatchewan, with the uplands of the Cypress Hills being noticeably moister. While prolonged sunshine and warm summer temperatures provide potentially good growing-season conditions, moisture remains a limiting factor for crop growth. Gillespie (1997, 288) estimated that 'less than 60 per cent of atmospheric demand for moisture is met by precipitation on the Prairies.' Agricultural crops suffer moisture stress in the growing season in most years. To mitigate these effects, irrigation projects are a common feature of the region. Strong winds sweep across the landscape, often stirring up dust clouds from newly ploughed fields in spring. Dry summer conditions and removal or breaking of vegetation cover make aeolian erosion particularly effective in this region (Muhs and Wolfe (forthcoming); Wolfe 1997).

Systematic long-term instrumental weather records on the southwestern Canadian Plains date from the establishment of permanent settlements in the 1880s. The Medicine Hat record (Figure 2) shows little change in MAT since 1883 but pronounced fluctuations in precipitation. The sustained run of moist years of the late 1890s and early 1900s, with 12 years of average or above-average precipitation, stand out clearly. A similar, though less pronounced, pattern is seen in the precipitation record for Swift Current (Figure 3). These wetter years

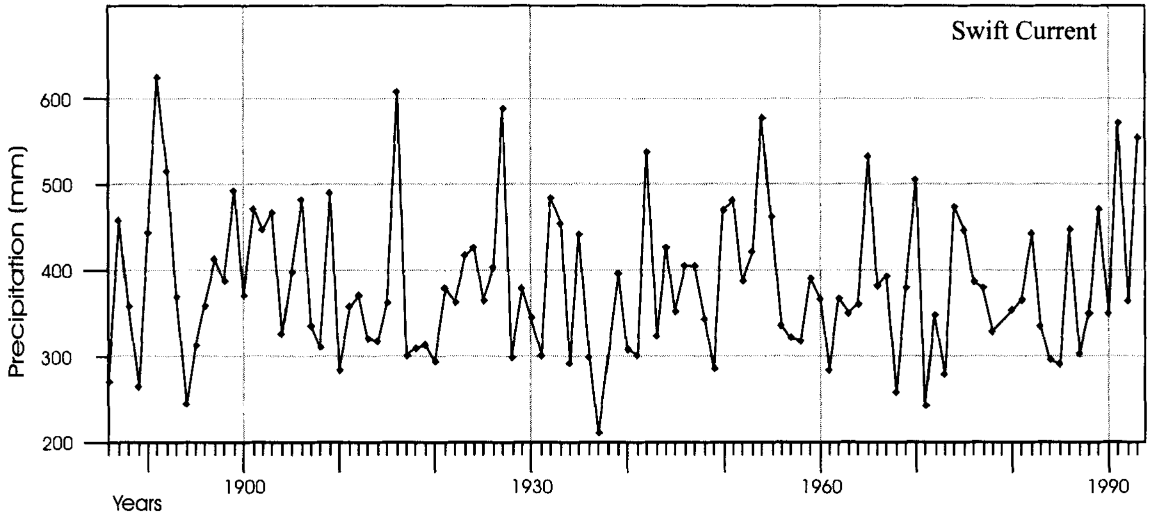


**Figure 3**
Instrumental precipitation record from Swift Current, Saskatchewan. The mean annual precipitation for 1886–1993, with some missing years, is 384 mm.
SOURCE: Raw daily climate data from Environment Canada

increased soil moisture reserves and provided for good crop yields, and in some cases, such as 1915 (Gray 1967, 12), bumper harvests. Another bumper crop year, 1905, was celebrated in a promotional pamphlet issued by the Federal Government (Canada. Department of the Interior 1905). The success of the harvests in the early years of settlement in this region encouraged further agricultural expansion and population increases. Since then, however, the longest sustained interval of average or above average precipitation (nine years) in the Medicine Hat record occurred in the early to mid-1950s, followed by well-below-average precipitation in the early 1960s. Again, at Swift Current, there is a similar pattern, although the dry interval began earlier, in the mid to late 1950s. The recent climate record has been marked by short runs of dry years, interspersed by occasional moist years. Climate records across the Prairies therefore show considerable spatial and temporal variability. Generally, precipitation records seem to show greater variability than mean temperatures, an observation that also seems to apply to the equivalent proxy records.

These precipitation fluctuations are occurring against a background of well-documented global temperature increases over the last 80 years (Jones 1994). Jones and Briffa (1992) estimate that global surface air temperature has increased by 0.5°C since the mid-19th century. In Canada, the increase in mean annual temperature between 1895 and 1991 was 1.1°C nationally and 0.9°C in the Prairie provinces (Gullett and Skinner 1992). The Medicine Hat temperature data show strong seasonal differences, with the winter temperatures being far more variable than summer temperatures (Figure 2). A similar pattern is seen in the northern hemisphere temperature data since 1851 (Figure 4 in Jones 1994). Warm winter temperatures, especially in the chinook-influenced Western Plains (Alberta), will affect the amount of winter snowfall remaining to replenish soil moisture reserves in spring runoff. Conversely, intensely cold winters, under the influence of stable, dry Arctic air masses, when it is 'too cold to snow,' also result in low spring runoff. Thus, soil moisture and, hence, crop success or failure is a delicate interplay between precipitation inputs and their seasonal distribution, and seasonal temperature fluctuations. The impact of climate fluctuations on Prairie agriculture is therefore far more complex than a simple inspection of total precipitation values suggests.

The instrumental record can be extended from documentary sources such as diaries and Hudson's Bay Company records. Euro-Canadian weather records in the southern Canadian plains began with the earliest travellers and fur traders in the 17th century (Milne 1997). These records are obviously fragmentary and of variable quality. Nevertheless, some useful climatic data, including numerical estimates, can be extracted from them.

The dates of winter freeze-up and spring break-up were important to Hudson's Bay Company traders who relied on river transport from the interior to the Hudson Bay coast or Montreal (Rannie 1983). Freeze-up and break-up show a good relation to air temperature. Catchpole (1992) and Ball (1992) have extracted information on winter ice from the early to mid-18th century for western Hudson Bay. Although some rivers entering Hudson Bay cross the southern Canadian Plains, such data are difficult to relate to conditions in the interior. From documentary sources extending to 1814 for the Red River at Winnipeg, Manitoba, Rannie (1983) determined that the median date of winter freeze-up was 12 days earlier and the median date of spring break-up was 12 days later in the 19th compared to the 20th century, and that mean spring and fall temperatures were perhaps about 2.5°C cooler. These data suggest generally cooler 19th-century climate conditions, with the years 1861–1880 standing out as particularly severe.

The frost-free season and, hence, growing season, also appears to have varied, according to sowing and harvest records from the Red River Settlement in Manitoba (Rannie 1992). These documentary records suggest a shorter growing season in the mid-1800s. Instrumental data from southeastern Saskatchewan and southwestern Manitoba also suggest a two- or three-week-longer frost-free season at present, compared to the late 1800s (Blair and Betze 1992). Rannie (1990) noted that the length of the frost-free season was influenced by the change in the date of the first fall frost (an average of 10 days later at Winnipeg in 1911–1988, compared to 1872–1910), rather than the last spring frost.

Working to the South, in the U.S. Great Plains and particularly the Nebraska Sandhills, Muhs and Holliday (1995) found evidence of 19th-century dune reactivation in written accounts from early European travellers, including Zebulon Pike. The documentary accounts showed good correspondence with a proxy precipitation record, based on tree rings, derived for the Great Plains by Meko (1992). Thus, dune reactivation was probably tied to drought intervals and consequent disruption of surface vegetation cover. A similar pattern may be expected in the southern Canadian Plains, although the documentary evidence for this is limited, as few travellers left written accounts of sand dune areas (Wolfe and David 1997).

Extreme events (e.g., a very wet summer, an unusually harsh winter) are likely to stand out in people's memories and, hence, appear in documentary sources. For example, Blair and Rannie (1994) compiled information for an unusually wet and cold spring and summer of 1849 in the Red River area of Manitoba. Exceptionally cold years, such as 1816 – the 'year without a summer' (Stommel and Stommel 1979) – also stand out (e.g., Catchpole 1985). Documentary accounts of extremely cold weather in the spring of 1826 are supported by an inferred mean March-April temperature of −8.2°C for Winnipeg, the coldest from the winter ice records examined (Rannie 1983). In fact, the early 19th century as a whole appears to have been noticeably colder throughout the interior. This correlates well with glacier evidence from the Canadian Rockies showing maximum Little Ice Age (LIA) glacier advances in the early to mid-19th century (Luckman et al. 1993).

## Proxy Environmental Records for the Last Millennium

Because the instrumental climate record extends for barely a century, and many climate phases appear to have much longer periodicities than this, we must turn to proxy environmental indicators to derive longer-term climate records, as a context for 20th-century environmental change. Proxy environmental records are obtained from biotic remains and abiotic indicators that respond to contemporary climate. Among the biotic indicators are terrestrial vegetation (through the medium of pollen and plant macrofossil records and tree rings) and aquatic vegetation (through diatom and pigment records). Abiotic indicators include changing landforms, sediment redistribution, lake geochemistry, and lake-level fluctuations. The basic regional paleoenvironmental framework has been derived from pollen records obtained from lake sediment cores (Figure 1). The resolution, both temporal and spatial, of such proxy data varies considerably.

Generally, the proxy paleoenvironmental data suggest two major climatic phases in the last millennium: between 1000 to 600 or 500 yr BP (950–1350 or A.D. 1450), and from about 500 yr BP (A.D. 1450) to present. The earlier phase is marked by indications of greater drought severity; the later phase appears to have been generally cooler. Vance et al. (1992), among others, point out that the interval of increased drought severity corresponds well with the 'Medieval Warm Period' (MWP), an interval that has been identified mainly from historic records in Europe (Lamb 1982). The later cooler phase corresponds to the Little Ice Age, marked by renewed glacier advances in the Canadian Rockies, which in many instances were the most extensive since Late Wisconsinan deglaciation (Luckman et al. 1993; Smith et al. 1995).

Lake-level fluctuations can be used as a proxy indicator of aridity, especially in the southern Canadian Plains, where lakes are very sensitive to climate (Campbell et al. 1994b). Generally, lower lake levels suggest drought, although the situation may be complicated by contributions from groundwater (e.g., Vance et al. 1997). Dramatic changes in lake water levels over the last 50 years, such as those at Antelope Lake (Last and Vance 1996), can be documented by comparison of air photographs (Campbell et al. 1994b). Recent lake-level changes, however, cannot necessarily be ascribed solely to climate because the hydrologic system has been so modified by human activity, such as irrigation and other agricultural uses of water.

Plant macroremains and geochemical data from Chappice Lake north of Medicine Hat (Figure 1) indicate low water and high salinity phases between 1000 and 600 yr BP, implying regular drought intervals (Vance et al. 1993). From similar data, Kenosee Lake in southeastern Saskatchewan (Figure 1) shows 'development of relatively deep, stable, hyposaline to freshwater conditions in a topographically-closed basin in the last ca. 2000 years,' compared to much shallower saline conditions in the previous millennium (Vance et al. 1997, 387), with lower lake levels and higher salinity before about 600 yr BP, and higher lake levels and freshwater conditions in the last 600 years. At Redberry Lake in central Saskatchewan, Van Stempvoort et al. (1993) identified an interval of greater evaporation between about 2500 to 1500 yr BP, based on stable isotope and pigment analyses. From 1500 yr BP to present, the record suggests generally more humid conditions. Based on a 2300-yr diatom record from Moon Lake, North Dakota, Laird et al. (1996) concluded that, before A.D. 1200, droughts were more extreme and of greater intensity than the 1930s drought. They identified A.D. 1000–1200 as an interval of particular drought severity. At Redberry Lake (Van Stempvoort et al. 1993), the moister conditions of the last 1500 years were broken by two intervals of warmer / drier climate at 1000–900 yr BP (ca. A.D. 950–1050) and 500–200 yr BP (ca. A.D. 1450–1750).

Between 600 and 100 yr BP, Chappice Lake experienced relatively high water levels, suggesting moister and / or cooler climatic conditions. Vance et al. (1993) note that the low water levels documented in the last century of record at Chappice Lake correlate well with droughts identified from the instrumental record. The Moon Lake diatom record shows some intervals of greatly reduced salinity, suggesting higher water levels and wetter conditions, especially between A.D. 1240 and 1440 and about A.D. 1800 and 1850. Laird et al. (1996) concluded that the last ca. 750 years have been wetter and / or cooler than the preceding ca. 1500 years.

The record from Devils Lake, North Dakota, stands out as quite different. Fritz et al. (1994, 71) examined a 500-year proxy record of salinity changes based on fossil diatoms, ostracode-shell geochemistry and bulk-carbonate geochemistry, and concluded that the lake 'was a very saline system from the sixteenth through the mid-nineteenth centuries, reflecting an arid climate and drought conditions at least as extreme as those in the Dust Bowl era.' They further suggested that 'the low salinities of the last three to four decades are unparalleled during the rest of the 500 year record' (p. 72). These interpretations were challenged by Wiche et al. (1996; see also reply by Fritz et al. 1996), primarily on the basis of documentary data. Fritz et al. (1991, 1996) interpret increased salinity as a reflection of reduced lake levels; some evidence presented by Wiche et al. (1996, 1997) suggests high water levels at times during the 19th century. At Kenosee Lake, Vance et al. (1997) noted a salinity maximum, inferred from ostracodes and stable isotopes, at a time (ca. 2800–2300yr BP) when the plant macroremains suggested increasing water depth. In this case, the discrepancy was resolved by positing an influx of saline groundwater.

Clearly, there is much yet to be learned about the dynamics of Prairie lakes. Multiple proxy indicators may help to resolve ambiguities. However, the general pattern of wet / dry phases within the last millennium does appear similar in most lake-sediment-based proxy records from a wide region in the southwestern Canadian Plains and adjacent areas. Whether differences in the timing and intensity of these intervals reflects real regional spatial variability or is a function of the varying proxy indicators, local hydrologic factors, record resolution, and chronologic control remains to be seen.

Additional indications of recent lake-level fluctuations within the Prairie ecozone have been found in a preliminary investigation of tree stumps exposed along the shores of White Bear (Carlyle) Lake in southeastern Saskatchewan (Sauchyn 1995). The radiocarbon age of two *Populus tremuloides* (aspen poplar) stumps were 100 ± 150 yr BP and modern. These results indicate that the relict tree stumps are remnants of a forest that occupied the lake basin within the past 200 years. Although these imprecise age estimates do not reveal the exact timing of flooding and mortality of the trees, the events were relatively recent and thus can be corroborated from historical records. The analysis of aspen stumps from Basin Lake north of Saskatoon also yielded a modern radiocarbon age and supported local accounts of 'trees having been drowned during the late to middle decades of the past century' (S. Stine, California State University, pers comm).

Drought can occur because of higher temperatures or lower precipitation or both. Muhs et al. (1997) found evidence of at least three episodes of sand movement in the last ca. 800 years in the Nebraska Sandhills, within the LIA. Based on carbon isotope analysis, Muhs et al. (1997) concluded that temperatures were not significantly cooler than present. If this is the case, then it suggests that drought on the Plains may be more a function of moisture inputs than temperature increases. This is especially critical in view of GCM simulations, which suggest increased precipitation inputs for the Canadian Plains, although offset by higher temperatures, under a $2 \times CO_2$ regime (Saunders and Byrne 1994).

The transition to an agricultural landscape is recorded in short cores (spanning only the few centuries) from nine lakes in southern Alberta (Strong 1977; Figure 1) and from Pasqua Lake in the Aspen Parkland of Saskatchewan (McAndrews 1988). These provide details of vegetation change, rather than proxy climate data. Agricultural clearance is indicated by increased pollen from exotic weeds (e.g., Russian thistle (*Salsola kali*) or dandelion (*Taraxacum officinale*)). Strong (1977) identified an expansion of Short Grass Prairie at the expense of Mixed Grass Prairie in southern Alberta and suggested that it was due to post-settlement overgrazing. Strong (1977, 1991) also noted the coincidence of changes in the pollen assemblages and the sediment characteristics of his cores – in particular, major post-settlement increases in the amount of silt, which he attributed to increased wind erosion.

Changes in land use are also reflected in limnological indicators, especially those related to water quality. Pasqua Lake shows changes in fossil pigments, diatoms, and chironomid assemblages that reflect changes in productivity and oxygen concentrations within the lake itself (Hall et al. 1996; Quinlan et al. 1996). Hall et al. (1996) noted a threefold increase in algal biomass at Pasqua Lake now, compared to the presettlement portion of the record. Similarly, Leavitt and Vinebrook (1996) reported a threefold increase in pigments from cyanobacteria at Antelope Lake (Figure 1) since about A.D. 1890, the beginning of intensive agriculture. In the case of the Qu'Appelle Valley, these changes may be related both to agricultural practices and to inputs of sewage effluent within the drainage system. Changes attributed to land use may mask those attributable to climate events in the recent record (Leavitt and Vinebrook 1996).

Other Euro-Canadian activities that undoubtedly affected terrestrial vegetation were fire suppression and the elimination of bison as an important component of the Prairie ecosystem. Considerable evidence exists to suggest that some areas, especially the parkland margin around the Southern Plains and the Cypress Hills, are more treed now than they were prior to Euro-Canadian settlement (Archibold and Wilson 1980; Hildebrand and Scott 1987). Anecdotal evidence from landowners and residents corroborates these findings. Opinion is divided as to whether bison extirpation (Campbell et al. 1994a), fire suppression, or climate change are responsible (Hildebrand and Scott 1987).

As expected, vegetation in the southwestern Canadian Plains shows a marked relationship to moisture availability, with the most xeric grassland species occurring in areas with the greatest differential between precipitation and potential evapotranspiration (Scott 1995, Figure 5.8). Although parts of the southwestern Canadian Plains, especially the more arid areas, are still under grassland, species composition has been affected by agricultural development. Pasture improvements, overgrazing, and the introduction of exotic species, such as crested wheatgrass, have altered the Prairies' composition to the extent that few areas of 'natural' grassland are left (Bailey (forthcoming)). These compositional changes may affect the grassland's resilience to drought and disturbance and, in turn, soil erosion by wind and water, such that its response to climate change may differ from that of grasslands prior to Euro-Canadian settlement. This may complicate attempts to assess the impact of future climate warming on the southwestern Canadian Plains, especially the application of analogues derived from earlier arid intervals identified in proxy paleoenvironmental records.

The climate of the last millennium needs to be viewed from the perspective of the longer-term, Holocene record. The last millennium falls within a generally cooler and moister interval (the Neoglacial) that began several millennia earlier. Most proxy climate indicators concur in showing an interval of warmer and drier climate in the early to mid-Holocene on the southwestern Canadian Plains, followed by a change to cooler and moister conditions that is most marked in about the last 4000 years (Vance et al. 1995). At Harris Lake, for example, on the northern flanks of the Cypress Hills, increasing amounts of pine pollen since about 5000 yr BP, suggest that trees were growing further downslope in areas that had previously been too dry, with the establishment of pine-dominated forest after about 3200 yr BP (Sauchyn and Sauchyn 1991). Certainly, the scope of mid-Holocene droughts identified at sites such as Chappice Lake exceed in length and inferred severity anything recorded in the last millennium.

Records obtained from pollen and plant macroremains

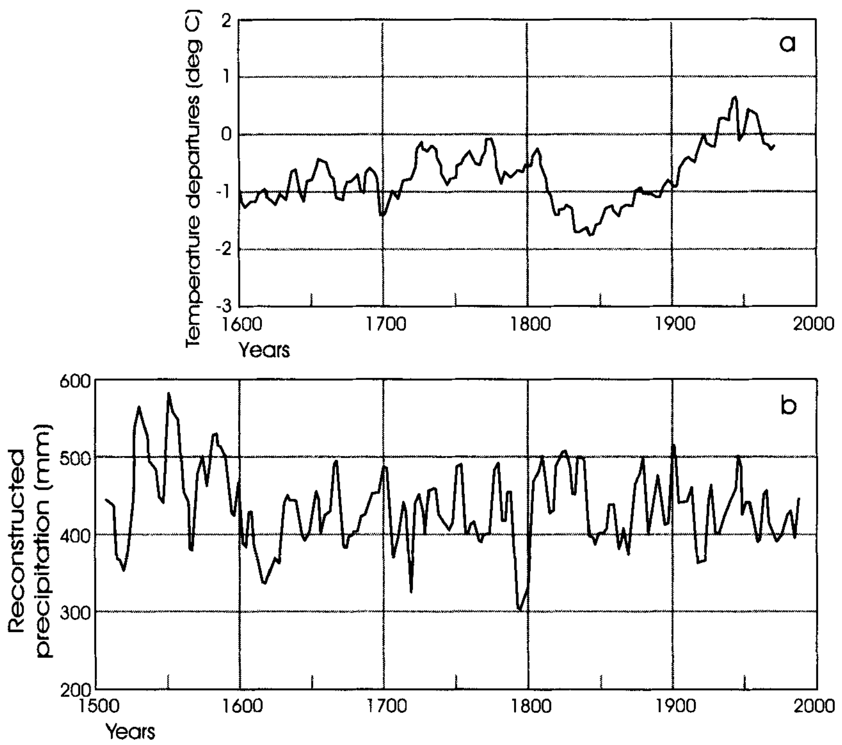


**Figure 4**

Reconstruction of climatic parameters from proxy data: (a) temperature reconstructed from tree-ring records at northern treeline (D'Arrigo and Jacoby 1992); (b) precipitation reconstructed from tree-ring records from southwest Alberta (Case and MacDonald 1995).

rarely provide high (subdecadal or annual) resolution. Tree-ring records, however, do yield annual data, although their temporal scope is limited by the maximum ages of suitable trees and the fortuitous preservation of subfossil wood. Moreover, because tree-ring records are site-specific and can be shown to be responding to a particular climatic parameter (e.g., moisture or mean summer temperature), it is possible to derive numerical proxy data for specific climatic variables. None of the present records available from the southwestern Canadian Plains and their margins extend beyond about 500 yr BP. Thus, all fall within the general interval of the cooler and moister climate of the LIA. Nevertheless, these records show intervals of drought, indicating that the LIA encompassed considerable climatic variability.

Proxy temperature data have been derived from tree-ring studies at the alpine treeline (Luckman 1993; Luckman et al. 1997; Luckman, this issue) and Northern Boreal Forest treeline (Jacoby and D'Arrigo 1989; D'Arrigo and Jacoby 1992; Szeicz and MacDonald 1995), where tree growth is temperature-limited. Based on seven boreal treeline records across North America, D'Arrigo and Jacoby (1992) reconstructed mean annual temperature back to A.D. 1600 (Figure 4). Their reconstruction shows substantially reduced temperatures in the early 1600s and in the early 1700s but the longest and most sustained interval of reconstructed colder temperatures is evident between about 1820 and 1880. The lowest temperatures occur in the 1840–50 decade. Szeicz and MacDonald (1995) derived a proxy summer temperature record extending to A.D. 1638, based on white spruce (*Picea glauca*) from the Yukon and Northwest Territories. Their age-dependent reconstruction of June-July temperatures shows close similarities with the record of D'Arrigo and Jacoby (1992), with low summer temperatures in the early 1700s, and through the early to mid-19th century, succeeded by a warming trend, which has been most marked since the early 1900s.

Luckman et al. (1984) reported living Engelmann spruce (*Picea engelmannii*) and whitebark pine (*Pinus albicaulis*) aged about 700 years in the Canadian Rockies. Living trees can be cross dated with dead snags and, together with work on other taxa, including subalpine fir (*Abies lasiocarpa*) and alpine larch (*Larix lyallii*), have been used to derive proxy climate data. Luckman et al. (1997) presented a proxy summer temperature record extending for almost a millennium (A.D. 1073–1983) for the Columbia Icefield area, based on composite records from *Abies*, *Picea*, and *Pinus*. They noted that the last few decades (1961–1990) have had the warmest summers in the last 900 years, except perhaps for the late 11th century A.D. A 'striking feature of the reconstruction is the severity of conditions during the 19th century which contains 8 of the 10 coldest years and 4 of the 10 coldest decades' for the record (Luckman et al. 1997, 382–3). Indeed, the coldest year in the entire record was 1813. Shorter, very cold intervals are also evident just before 1700 and around 1780. Other cold intervals are around A.D. 1190–1250, 1280–1340, 1440–1500, and the 1690s. The warmest intervals are 1073–1110 and 1921–80, with other warm intervals identified around A.D. 1160–80, 1260–80, 1350–1440, and 1710–70 (Luckman et al. 1997). The complexity of this record shows that a subdivision of the last millennium into a Mediæval Warm Period and a Little Ice Age is too simplistic.

Case and MacDonald's (1995) analysis of limber pine (*Pinus flexilis*) tree rings from lower treeline in southwestern Alberta, on the margin of the southwestern Canadian Plains, has yielded a proxy drought record extending back to A.D. 1505 (Figure 4). This shows clusters of drought years in the early 1600s, the A.D. 1790–1800 decade, in the early 1860s, and again around 1920. The late-18th-century drought is apparently the most severe in this record, suggesting that 'resource planning based on the past 100-yr instrumental record may underestimate the potential intensity and duration of natural droughts on the Canadian Plains' (Case and MacDonald 1995, 275).

Farther south, Meko (1992) compiled a regional proxy climate record for the U.S. Great Plains based on tree rings, extending to A.D. 1750. This reconstruction also shows intervals of severe drought in the last 200 years, with the years around 1860 being most extreme. Other droughts are apparent in the 1820s, 1890s, 1930s, and 1950s. This record shows a sustained interval of generally wet years between about 1905 and 1925. During the latter part of this interval (1917–1920), the Medicine Hat instrumental record (Figure 2) already shows drought conditions. These observations suggest that the change to drought conditions in the early-mid-20th century (the 'Dirty Thirties') was spatially and temporally variable, occurring earlier in the southwestern Canadian Plains than farther south. Attempts at regional reconstructions may therefore blur local variability.

### A Dendroclimatic Record from the Heart of the Southwestern Canadian Plains

Near the geographic centre of the driest part of the Canadian Plains, the western Cypress Hills support an extensive white spruce (*Picea glauca*) and lodgepole pine (*Pinus contorta*) forest, thus providing a unique opportunity for tree-ring research in an otherwise treeless landscape. Unfortunately, the length of a tree-ring chronology is constrained by the age of the living trees, less than 200 years, reflecting their relatively short life spans, frequent presettlement fires, and post-settlement demand for wood. This probably discouraged previous tree-ring research. Older wood is available, however, from log buildings constructed by the North West Mounted Police and early Euro-Canadian settlers, who had access to trees that predated the fires of the 1880s, which almost completely destroyed the forest of the Cypress Hills (Halliday 1965). These logs, harvested in the 1870s to 1890s, tend to have more growth rings than the current oldest trees, suggesting that the forest of the Cypress Hills has been heavily affected first by fire and then by Euro-Canadians. The age of this wood can be determined from local written and oral history and from cross-dating, the fundamental technique in dendrochronology, whereby distinctive series of narrow and wider tree rings are identified and matched among wood of different ages.

The tree-ring chronology discussed here is based on 43 ring-width series: 13 from living trees and 30 from archaeological wood, that is, derived from log structures in the Cypress Hills or nearby to the east and north, towards Maple Creek, Saskatchewan (Figure 1). Sampling and processing of the wood and analysis of the ring-width data followed standard field and laboratory procedures (Stokes and Smiley 1968; Ferguson 1970; Schweingruber 1988; Grissino-Mayer et al. 1993).

Climatic reconstruction is based on the statistical relationship between ring-width indices and meteorological data. Various instrumental records exist for the Cypress Hills, but they are relatively short and discontinuous (Sauchyn and Porter 1992). Furthermore, the climate of the Cypress Hills is not as relevant here as an extrapolation of the tree-ring record onto the surrounding subhumid plains, where climatic variability has much environmental and economic significance. Thus the best meteorological records are from Maple Creek, about 50 km northeast of the western Cypress Hills and just 25 km north of the Centre Block. Even though these data extend back to 1884, prior to 1941 only 15 years have complete records. After 1941, there are 9 years of missing data. Therefore, 45 years of mean monthly data from the period 1941–94 were used to construct a model of tree-growth response to climate.

Standardized ring widths and August-July precipitation are the most strongly correlated variables (0.616, $p < 0.01$). None of the correlations involving temperature variables were significant, as expected, because the climate is subhumid and the living trees were selected from the driest sites. Over most of the interior plains, including the Southern Boreal Forest (Larsen and MacDonald 1995), tree growth is limited by the availability of water. Thus these trees preserve a record of precipitation variability. Regression of August-July precipitation against the standardized ring widths ($n$ = 45 years) produced the model (adjusted $R^2$ = 36.5%)

$$\text{precipitation} = 220.83 * \text{SWR} + 140.22$$

where SWR is standardized ring width. This growth-response model was then used to reconstruct August-to-July precipitation for the period 1682–1994 (Figure 5).

A correlation between reconstructed and instrumental precipitation is visually evident in Figure 5 from the extreme years of the 20th century: the droughts of 1937 and 1961, and the generally above-average annual precipitation of the first two decades that corresponded with the period of expanding population and crop production as described above. The most significant results are the dry periods of the 18th and 19th centuries. These droughts were of longer duration than the most prolonged drought of the 20th century, during the 1930s. The droughts of the early and late 18th century also appear in the dendroclimatic record from southwestern Alberta (Case and MacDonald 1995, Figure 4). The anomalous precipitation of 1691 may just reflect the small sample size (three trees) prior to 1711, although this apparent drought warrants the collection of more old wood to verify its possible significance. Besides these possibly spurious data from 1690–91, the driest 12-month period (242 mm) in the tree-ring record is August 1773 to July 1774. The drought centred on 1820 is prominent in tree-ring records from the American Plains (Meko 1992). Finally and notably, reconstructed precipitation for August 1857 to July 1858 (313 mm) was well below the average (373 mm) for the 313-year tree-ring record. The Palliser expedition traversed the southern Prairies during 1857–59 (Spry 1995).

Although not as prominent as the other drought phases, there are indications of a succession of relatively dry years around 1890 (Figure 5). This correlates with the recognition of drought at this time from other areas, such as in the salinity record from Moon Lake (Laird et al. 1996) and in documentary sources (Jones 1987, 16–19). The 1890s drought stood out in people's memories, which is significant in view of its lesser severity than other droughts from the last few centuries. Certainly, the recent occupants of the Palliser Triangle have not yet experienced prolonged dry spells like those of the 18th and 19th centuries. Although Prairie agriculture has historically adapted to climatic variability (Hill and Vaisey 1995), there is a perpetual adjustment to weather and climate. The agricultural industry needs reliable estimates of the probability of specific growing-season weather, including extreme events. The relatively short instrumental climatic records, usually less than 100 years, in western Canada are an inadequate basis for forecasting the severity and duration of future climatic extremes. The knowledge base for drought forecasting includes proxy data on the frequency and intensity of presettlement climatic extremes that can be derived from the trees of the uplands and sheltered coulees of the subhumid plains (Stockton and Meko 1975, 1983; Meko 1992).

## Geomorphic Evidence for Environmental Change in the Last Millennium

Hydroclimatic events (runoff and wind) are the principal agents of geomorphic activity in the subhumid, tectonically stable southern Canadian Plains (Lemmen et al. 1998). Because subhumid landscapes are sensitive to changes in the climatically driven surface-water balance, the climatic forcing of geomorphic processes can be interpreted from landform and stratigraphic records. However, the response of terrestrial geomorphic systems to climate change is still not well understood or well dated in this region. The timing of a geomorphic response to climate can depend on the structure and history of a landscape (Sauchyn (forthcoming)).

An estimated 70% of the mean annual discharge of the major river systems draining the southern Canadian Plains and the South Saskatchewan River and its tributaries is derived from snowmelt in the Rocky Mountains (Campbell 1996). Hence, their minor tributaries, fed wholly from sources within the Plains, may be expected to be more responsive to changes in precipitation. Ghostpine Creek, a tributary of the Red Deer River, cut down 4–5 m from a former terrace level and aggraded, partly simultaneously, up to 3 m since about 2600 yr BP (Rains et al. 1994). In the Falcon Creek Valley, Dinosaur

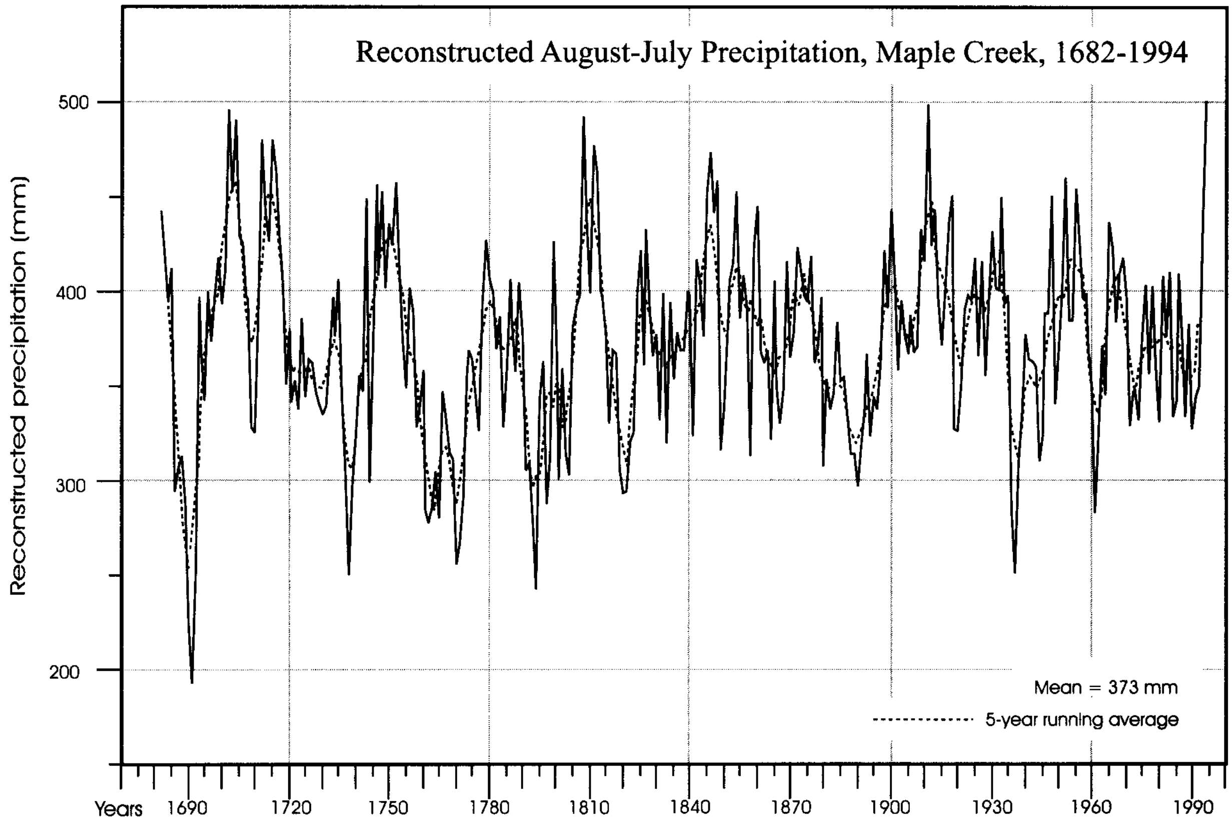


**Figure 5**
August-July precipitation, 1682–1994, Maple Creek, Saskatchewan. Reconstructed from standardized white spruce (*Picea glauca*) growth-ring widths from the Cypress Hills.

Provincial Park, an interval of channel aggradation beginning around 800–600 yr BP and lasting until sometime after around 300 yr BP was preceded by a mid-late Holocene interval of incision and followed by renewed incision after about 300 yr BP (O'Hara and Campbell 1993). It is tempting, though premature, to match these changes at Falcon Creek with the two main climate phases recognized from the lacustrine records.

In the Cypress Hills, late Holocene landsliding has been attributed to rising regional water tables with moister climate (Sauchyn and Lemmen 1996; Sauchyn (forthcoming)). Landslides affect related systems. At Harris Lake (Figure 1), for example, Last and Sauchyn (1993) noted a change in the character of sedimentation in the late Holocene beginning about 4000 yr BP, as landslides blocked streams flowing into the basin yet provided large episodic influxes of siliciclastic sediment. A similar association between moisture inputs and landsliding was identified by Campbell and Evans (1990) in the valley of Little Sandhill Creek, a Red Deer River tributary. Here, recent landslide reactivation was attributed to increased water inputs from irrigation on the adjacent Prairie surface.

Erosion during drought phases should be reflected in the character and amount of clastic sediment accumulating in lake basins. Campbell (1997) examined grain-size distribution of sediment accumulated over about 4000 years in a core from Pine Lake (Figure 1). She hypothesized that increases in coarser particles reflected increased streamflow into the lake and thus could be used as a proxy indicator of effective precipitation. On this basis, she identified decreases in mean grain size and therefore probable drought phases, in the 1980s, 1960s, late 1920s and 1930s, and 1890s. Other decreases were seen at about 750–1250 cal yr BP and before about 2000 cal yr BP.[1] Campbell (1997, 143) observed that 'the median grain size shows fluctuations corresponding with the wet Little Ice Age ... with peak discharge *ca.* 330 years ago; the dry Medieval Warm Period ... with lowest discharge *ca.* 990 years ago; [and] the wet early Neoglacial ... with peak discharge *ca.* 1950 years ago ...'

Extensive areas of sand dunes characterize the more arid areas of the southern Canadian Plains, especially between 50°N and 51°N, and include the Great Sand Hills of southwestern Saskatchewan (David 1993). Activation of sand dunes is related to aridity and reduced vegetation cover (Vance and Wolfe 1996). Wolfe et al. (1995) have documented the critical role that soil moisture plays in the stabilization of dunes, showing that dunes in the Great Sand Hills have a rhythm of reactivation in the last 50 years matching the pattern of droughts. Significantly, dates from this region define an interval of no dune activity between 560 and 220 years ago, perhaps due to moister LIA conditions. Conversely, dates indicate sand dune activity between about 1000 and 900 years ago and also since about 200 years ago – the latter being possibly related to the drought of the 1790s that stands out in the tree-ring records. In the Brandon Sand Hills, David (1993) identified ten intervals of drought in the last 4300 years, including three (1100, 850, and 400 yr BP) in about the last millennium.

## Summary and Conclusion

The instrumental, documentary, and proxy records highlight the importance of scale and resolution in the study of environmental change. The scale of a human lifetime captures only part of the complexity of the system, especially where climate phases, such as droughts, can be measured in decades. Similarly, the instrumental record, although over a century in length, captures only the close of the LIA and the warming of the present century. To set these trends in proper perspective, a multicentury view is necessary. From this viewpoint, both the cold 19th-century conditions and the rapid warming of recent decades can be seen as anomalous. Conversely, the drought conditions experienced in the present century are considerably less severe than the dry spells of the last millennium. Place these observations together to form a scenario for the future – a reversion to more intense and severe droughts in the context of higher temperatures – and the environmental consequences for the southwestern Canadian Plains look grim.

The apparent complexity of the paleoenvironmental record depends partly on the resolution of the proxy data examined. Coarse-scale data, such as those derived from most lake-sediment-based studies, tend to produce smooth trends and hence the identification of gross-scale chronological subdivisions, such as the MWP and the LIA. Higher-resolution data, such as tree-ring records, show much greater complexity. Indeed, these records are so complex and encompass so much year-to-year variance ('noise'), that they are often filtered using, for example, running means. Neither the MWP nor the LIA are simple intervals characterized by uniformly warm or cold conditions. The proxy paleoenvironmental data have a fractal character, where zooming into higher resolution reveals new levels of complexity.

Despite evidence from proxy records and the experiences of the last century, there is a persistent attitude that regards drought in these regions as somehow abnormal or an anomaly. The proxy records teach us that periodic drought is the norm for these landscapes. All proxy data concur in showing that drought conditions prior to Euro-Canadian settlement far exceed anything experienced in the last century – a salutary observation for those concerned with land management in this region (Lemmen et al. 1997). The warnings from the proxy records are clear. For Kenosee Lake, Vance et al. (1997, 388) remarked that water-level and salinity fluctuations in the last two millennia 'did not in any way approach the scale of changes recorded in early lake history.' With global change, the extent and severity of droughts is likely to increase. The development of policies for sustainable agriculture in this region will need to take these lessons into account.

## Acknowledgments

Thanks to Wendy Johnson (Johnson Cartographics Inc.) for drafting the original versions of Figure 2 and Figure 4 and to Ryan Bayne for measuring tree-ring widths. The tree-ring data from the Cypress Hills were the product of research funded by the Geological Survey of Canada and the Prairie Farm Rehabilitation Administration. This paper is contribution 47 to the Palliser Triangle Global Change Project.

## Notes

1 These latter ages are estimated using a radiocarbon date calibrated following Stuiver and Reimer (1993). Elsewhere in this paper, ages are given in uncalibrated years BP.

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