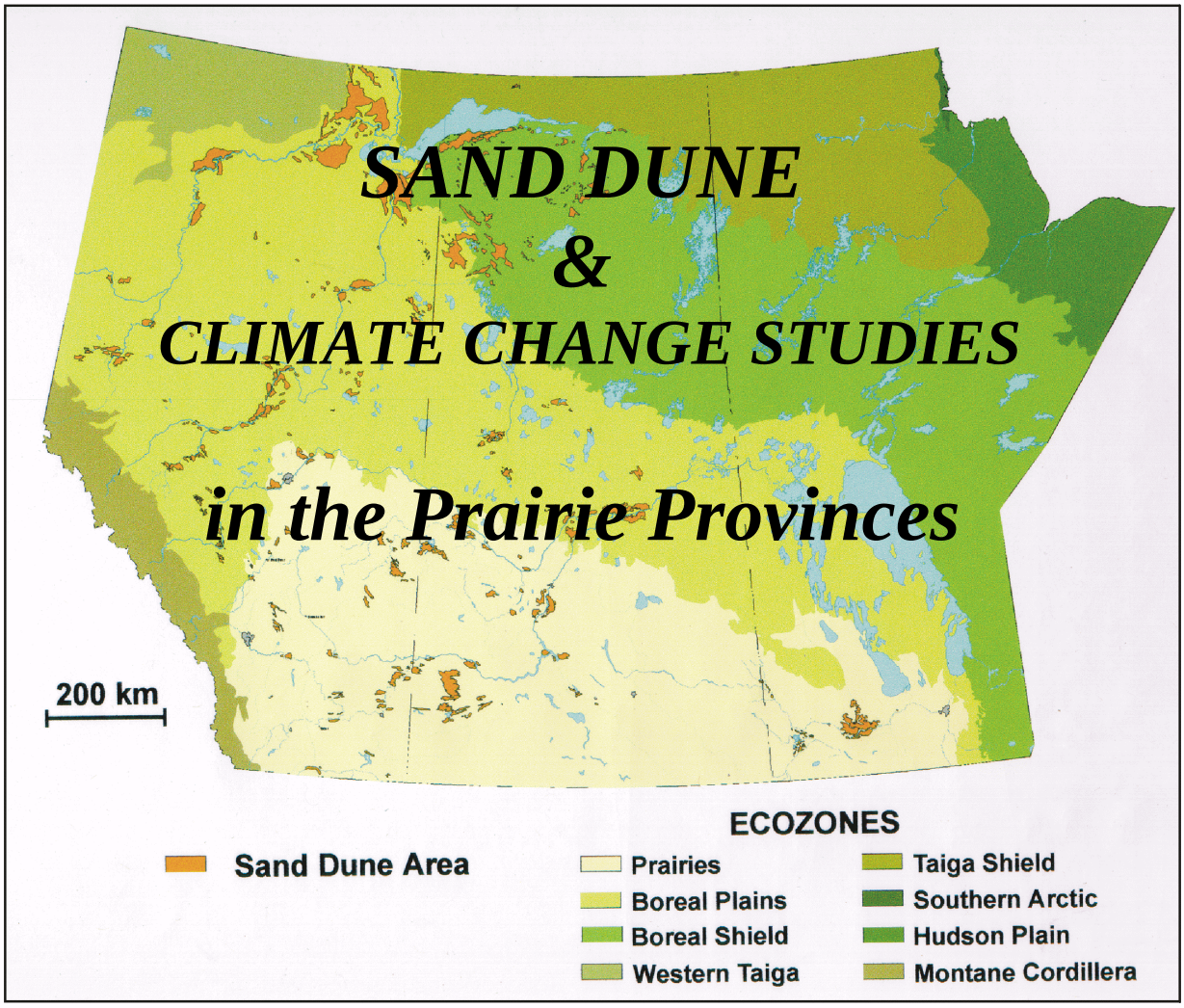
Natural Resources Canada | Ressources naturelles Canada

SAND DUNE & CLIMATE CHANGE STUDIES in the Prairie Provinces



Prepared by:
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario
K1A 0E8

January 2001

SAND DUNE & CLIMATE CHANGE STUDIES

INTRODUCTION

Summary

Ongoing climate change studies focussing on sand dunes in the Prairie Provinces may be divided into four main themes: **Drought Impacts**, **Historical Changes in Land-Cover**, **Past Dune Activity**, and **Land-use Management**. This research, undertaken by the Geological Survey of Canada in collaboration with universities and other government organizations, contributes to an improved understanding of drought and climate change impacts on the prairies. Many of these investigations focus on the southern prairies, an area that has historically experienced the most severe drought-related impacts in Canada.

Active sand dunes. Great Sand Hills, southwestern Saskatchewan.

Climate Change Impacts

General Circulation Models predict significant warming in the mid-latitudes of central North America as a consequence of increased atmospheric concentrations of greenhouse gases. Historical temperature trends indicate a warming of nearly 1°C over the last century on the prairies. In addition, extreme conditions such as the 1987-88 drought produced annual temperatures 3 to 4°C warmer than average, with regional precipitation deficits causing major economic losses. Warmer temperatures and less available moisture in the future would have a significant impact on the landscape and the economy of the prairies. Therefore, a sound understanding of the potential impacts of climate change is needed in order to develop strategies that could minimize any potential losses and maximize any potential benefits of climate change on the prairies.

Why Study Sand Dunes?

There are over 120 sand dune fields in Alberta, Saskatchewan and Manitoba occurring throughout the prairie and boreal ecozones (Cover Page). These dune areas have been less modified by human activities compared to much of the prairie landscape. Dune areas are not cropped because of their low soil fertility and low soil moisture holding capacity. They are also at a high risk of erosion by wind. These same attributes make sand dunes an important environmental indicator of climate change impacts. That is, they can act as "barometers" to assess the stability of the prairie landscape as a whole. Dune areas are also important to the people, flora and fauna that use them. They are presently utilized as resources for rangelands, provincial and national parks and recreation areas, forest reserves, military reserves, native reserves, wildlife reserves and hunting areas. While management plans exist for many dune areas, the potential impacts of climate change may require new strategies be developed to ensure sustainable resource management in the future.

For further information, or to develop opportunities for research and partnerships with the GSC, contact:

S.A. Wolfe (613) 992-7670 swolfe@nrcan.gc.ca
D.S. Lemmen (613) 992-5861 dlemmen@nrcan.gc.ca
R. McNeely (613) 995-4241 mcneely@nrcan.gc.ca
R.Rainbrid (613) 943-2212 rrainbir@nrcan.gc.ca
I. Girard (613) 992-6609 igirard@nrcan.gc.ca

Our collaborators are:

J.E. Campbell: Alberta Geological Survey
P.P. David: Université de Montréal (emeritus)
D.J. Huntley: Simon Fraser University
O. Lian: Simon Fraser University
G. MacDonald: UCLA
D.R. Muhs: USGS
W.G. Nickling: University of Guelph
J. Ollerhead: Mount Allison University
D.J. Sauchyn: University of Regina
J. Thorpe: Saskatchewan Research Council

We wish to acknowledge the assistance of:

Kristina Kamichaitis
Jennifer LeBlanc
Joe Park
Zoe Pfeiffer
Dmitri Ponomarenko
Mark Smith
Sonya Utting

Web sites:

To learn more about climate change research by the GSC's Terrain Sciences Division, please browse our web-site at: http://sts.gsc.nrcan.gc.ca

Program Managers:

For further information on the Division's programs and climate change research contact:

Paul Egginton
Director
Terrain Sciences Division
(613) 992-2451
pegginto@nrcan.gc.ca

or

Dr. Donald S. Lemmen
Chief, Hazards and Environmental Geology
Terrain Sciences Division
(613) 992-5861
dlemmen@nrcan.gc.ca

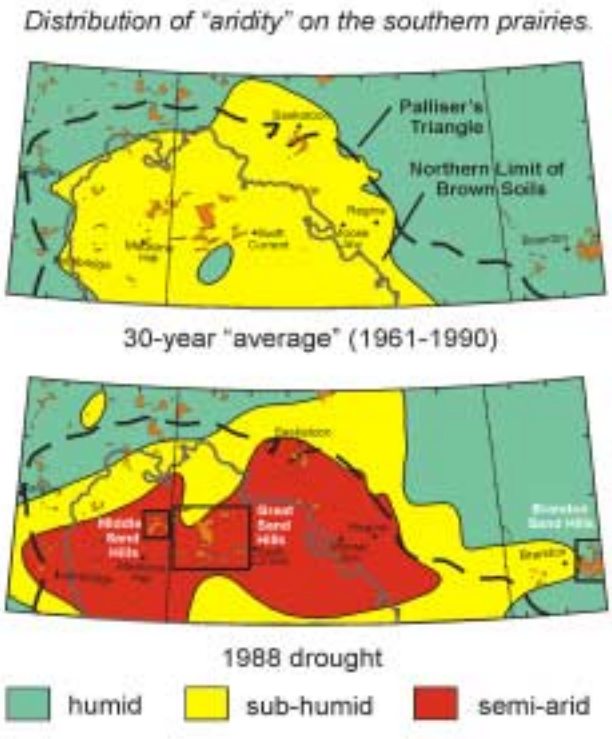
SAND DUNE & CLIMATE CHANGE STUDIES

1. DROUGHT IMPACTS

S.A. Wolfe

Drought has historically been the main climatic concern on the prairies. In order to assess the impacts of climate change on the prairies, the potential impacts of future droughts need to be addressed. Studies of the impacts of drought need to include, the changes in the distribution of arid conditions during drought, the potential impacts of drought on the prairie landscape, and climate change projections indicated by various computer simulations, known as General Circulation Models.

The 1987-88 Drought



Contrary to the common belief that the southern prairies are semi-arid, the "average" climate of the region is, in fact, humid to sub-humid. The sub-humid zone is almost entirely contained within the Palliser Triangle, delineated by Captain John Palliser in the 1850s as the driest region of the prairies. The Brown Chernozemic soils that characterize much of the southern prairies are also found almost entirely within this sub-humid zone (figure to right).

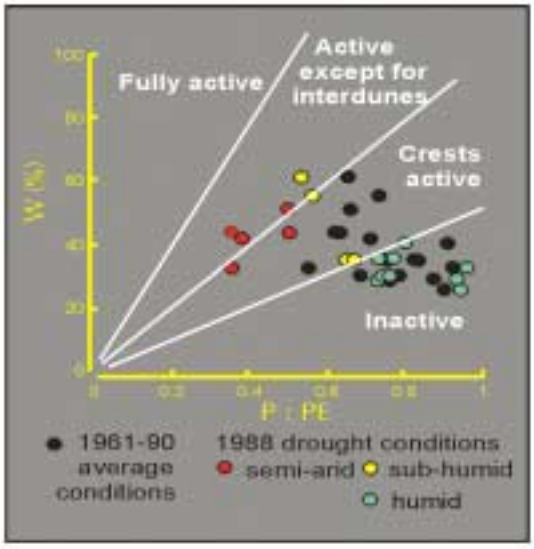
During periods of drought, such as those observed in 1987 and 1988, much of the southern prairies are dominated by semi-arid conditions. These conditions are related to warmer temperatures and reduced precipitation, causing reduced moisture availability. Therefore, although the average climate of the southern prairies is sub-humid, droughts create extreme conditions that are distinctly semi-arid. These recurrent extremes necessitate that the flora, fauna, and people of the region be well-adapted to semi-arid conditions.

Source: *Wolfe, S,A. 1997. Impact of increased aridity on sand dune activity in the Canadian Prairies. Journal of Arid Environments, v. 36, p. 421-432.*

The Effect of Drought on Sand Dunes

Increased aridity caused by prolonged drought or climate warming could result in greater sand dune activity in the southern prairies. In areas where semi-arid conditions could prevail, this would likely result in an increase in blowout activity, re-activation of stabilized dunes and the merging of presently active sand dunes to form nearly continuous bare sand in some areas. Stabilized dunes would also be more sensitive to disturbance. Diligent management practices including alteration of grazing intensities, and land-use activities would likely be required to reduce further erosion of these sensitive sandy areas.

Effect of increased aridity on sand dune activity in the southern prairies -- example from the 1988 drought.



Prolonged drought or climate warming could cause increased dune activity, forming nearly continuous bare sand in some semi-arid areas.

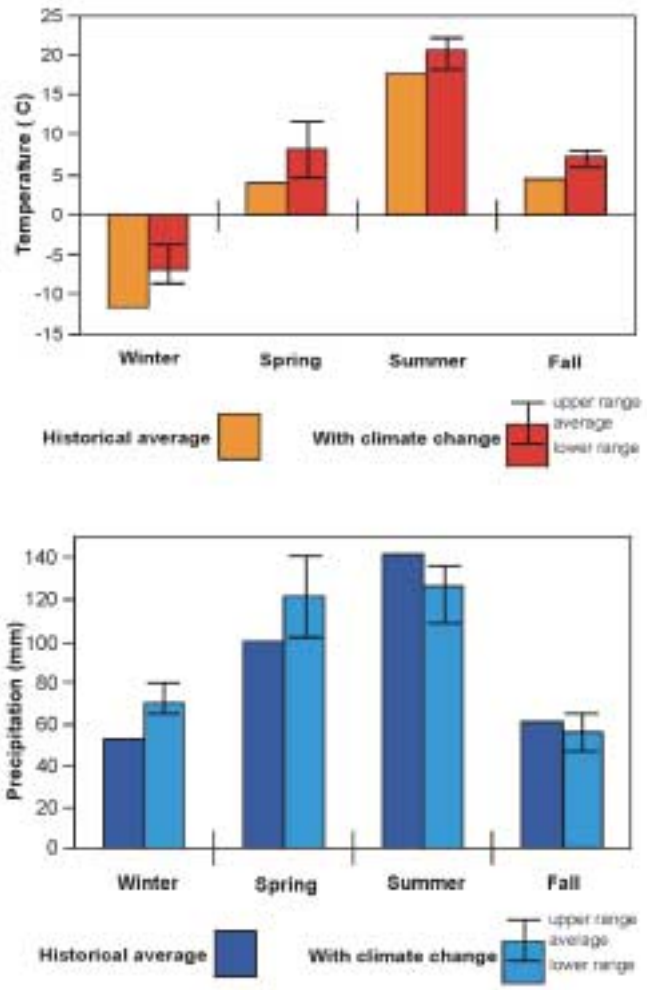
Although the 1987-88 drought was severe, it was insufficient to cause widespread re-activation of sand dune areas. It is presently believed that a period of drought on the order of a decade or more would be required to cause widespread dune activity on the southern prairies. The actual impact of drought also greatly depends upon the climatic conditions occurring before the drought. If a drought occurs during an otherwise moist period, the impact will be less than if it occurs during a time that has been generally dry. The 1990s have generally been moist, so that the impact of drought has not been as significant as in previous decades. However, the possibility of a warmer and potentially drier climate raises the concern that droughts could have a greater impact on the prairies in the future.

Source: *Wolfe, S,A. 1997. Impact of increased aridity on sand dune activity in the Canadian Prairies. Journal of Arid Environments, v. 36, p. 421-432.*

Wolfe, S.A, Huntley, D.J., David, P.P., Ollerhead, J., Sauchyn, D.J., and MacDonald, G.M. 2001. Late 18th Century drought-induced sand dune activity. Great Sand Hills, Saskatchewan. Canadian Journal of Earth Science, v. 38, p.1-13.

Climate Change Scenarios

Potential changes in temperatures and precipitation with climate change in Grasslands National Park, Saskatchewan.



With the exception of the arctic, the prairie provinces are projected to experience the greatest temperature increase under doubled-CO_2 conditions. Using computer-based General Circulation Models, climate change scenarios for the southern prairies project higher temperatures in every season (figure to right). These models also project increased winter and spring precipitation, but generally decreased precipitation in summer and fall. This could possibly cause increased evaporation rates and lower soil moisture levels. Analysis of drought risks also indicates that the frequency of droughts could increase dramatically. However, there may also be wetter periods when temperatures are cooler. Such changes could have significant impacts in dune soil areas including reduced vegetation cover and increased wind erosion during drought, greater variability in shallow groundwater levels, and increased water erosion during wet periods.

Climate models provide only projections of possible future climate scenarios. Therefore, it is also important to use observed climate records and to determine actual impacts associated with changes in climate in the past or in other areas. This can include historical impacts such as the 1930s drought and impacts occurring prior to European settlement. In this way, it is possible to establish benchmarks or "thresholds" to help determine the significance of potential impacts associated with future climate change.

Source: *Scott, D., and Suffling, R.(Eds.). 2000. Climate Change and Canada's national park system: a screening level assessment. Environment Canada, En56-155/2000E, 183 pp.*

2. HISTORICAL CHANGES IN LAND-COVER

S.A. Wolfe

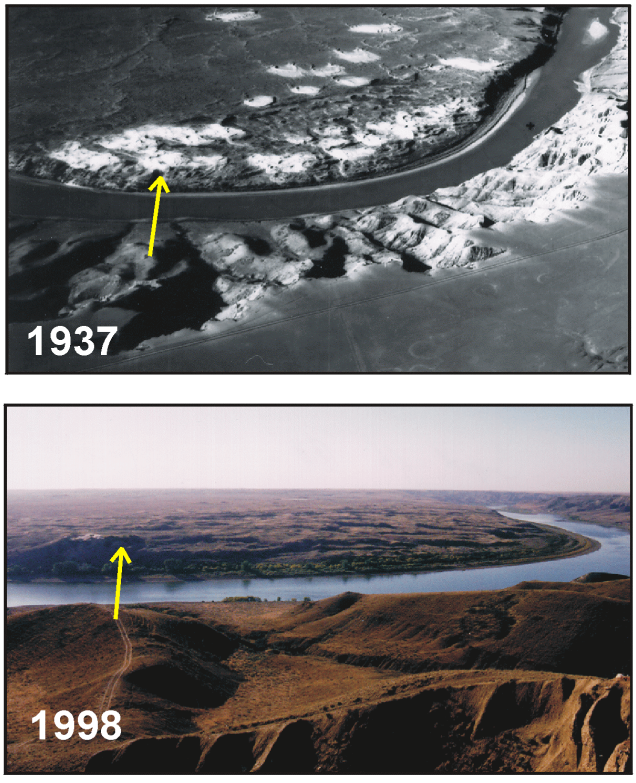
Vegetation cover on the prairies has changed considerably since European settlement of the region. The introduction of agriculture transformed much of the grasslands into cropland, while less productive lands such as dune soils are commonly used as rangeland. Land-cover in dune areas has also changed dramatically over the last century, with most dunes showing increased vegetation cover and, consequently, decreased areas of bare active sand. Early explorers accounts, survey records, aerial photography and satellite imagery provide documentation of these changes in dune areas across the prairies.

Middle Sand Hills, Alberta

The Middle Sand Hills are located about 50 km north of Medicine Hat, on the west side of the South Saskatchewan River. This dune field covers an area of nearly 400 km^2, most of which lies within the Suffield Military Reserve. The remainder is private or leased rangeland.

The photographs to the right show identical areas of the Middle Sand Hills along the South Saskatchewan River. In 1937, active sand dunes were migrating towards the river. By 1998, all of the dunes, except for a very small portion near the river, were vegetated and stabilized. This illustrates how land-cover on these dune areas can change dramatically over a relatively short time period.

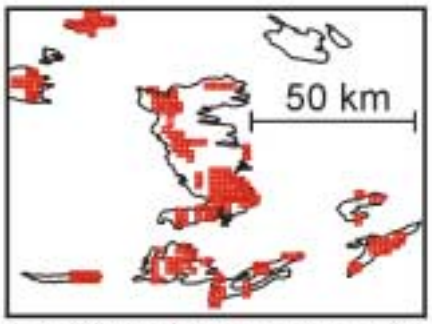
The Middle Sand Hills along the South Saskatchewan River north of Medicine Hat Alberta. Nearly all of the sand dunes stabilized between 1937 and 1998.



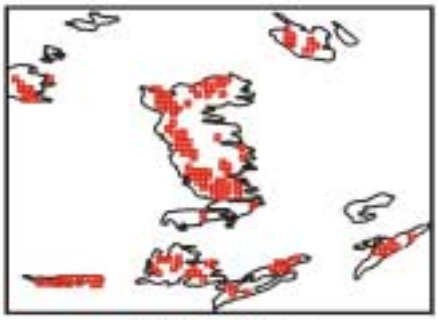
Source: *Muhs, D.R. and Wolfe, S.A. 1999. Sand dunes of the northern Great Plains of Canada and the United States. In: Holocene Climate and Environmental Change in the Palliser Triangle. D.S. Lemmen and R.E. Vance (Eds.), Geological Survey of Canada, Bulletin 534, p. 183-197.*

Great Sand Hills, Saskatchewan

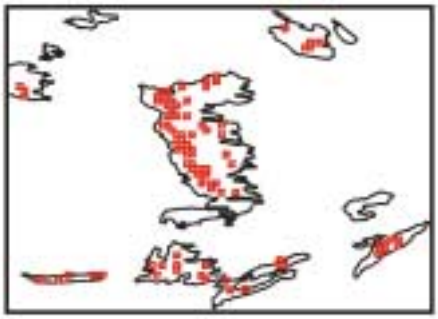
Great Sand Hills Region. Historical change in land area containing bare, exposed sand.



ca. 1880 Dominion Land Surveys
~264 sections = 33%



1944 Airphotos
158 sections = 20%



1987 Satellite Imagery
102 sections = 13%

The Great Sand Hills region is located near the centre of the Palliser Triangle, approximately 100 km northwest of Swift Current, Saskatchewan. It is the largest dune area in the southern prairies, comprising over 2000 km^2. It is used almost exclusively for grazing, with some recreational use and oil and gas development. Due to the sensitivity of the environment, development in the Great Sand Hills is controlled by a regional planning commission and development plan. Oil and gas development is presently restricted or prohibited across most dune areas.

Land surveys from the late 1800s show that over 260 sections of the Great Sand Hills region, or about one-third of the sand hills, had some bare blowing sand. This is likely an underestimate, as some areas were not well-surveyed. Between then and the late 1980s, the number of sections with bare blowing sand decreased by more than 60%, to about 100 sections. Diligent management practices have contributed to the reduction in bare blowing sand, and to the increase in vegetation cover in sensitive dune areas. Even after more than 100 years, however, there are still areas with bare blowing sand, indicating that it requires considerable time for some dune areas to stabilize once they have become active.

Numerous questions arise from these observations. For example, why were dunes very active in the 1880s, prior to European settlement? Was it because of drought or climate change, natural disturbance by bison, fires started by lightning or native people, or some combination of these?

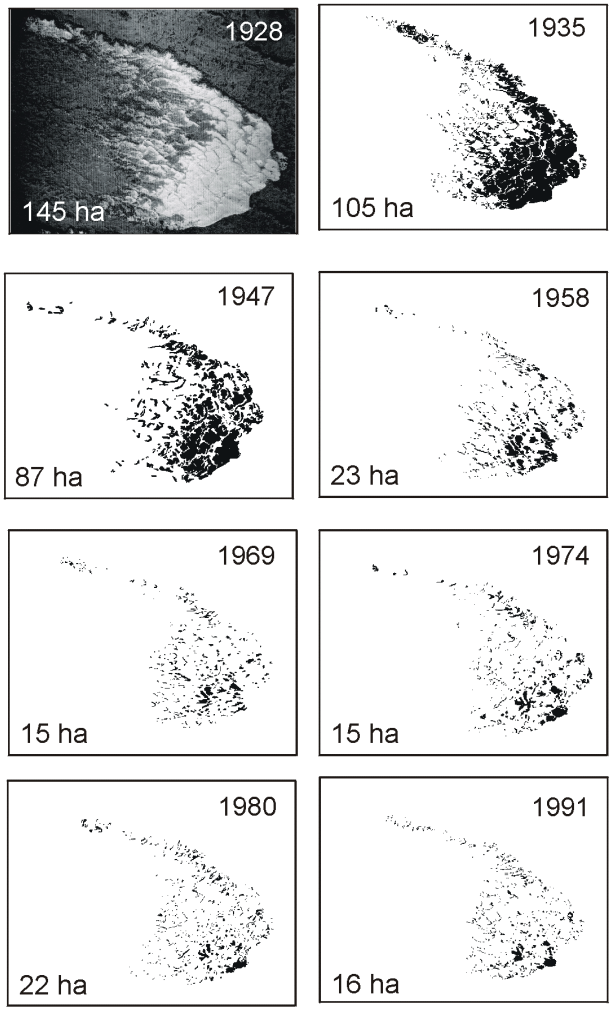
Source: *Wolfe, S.A., Huntley, D.J. and Ollerhead, J. 1995. Recent and late Holocene sand dune activity in southwestern Saskatchewan. Current Research 1995-B, Geological Survey of Canada, p. 131-140.*

Spirit Sand Hills, Manitoba

The Spirit Sand Hills represent an active portion of the Carberry Sand Hills east of Brandon, Manitoba. Most of the sand dunes in the larger region are stabilized by forest vegetation including white spruce, aspen, balsam poplar, bur oak and larch. The primary land uses in the dune areas include the Shilo Military Reserve, Spirit Sands Provincial Park, and cattle rangeland.

As with the Middle and Great Sand Hills, the bare sandy areas of the Spirit Sand Hills have become progressively more vegetated since the earliest airphoto observations were made in the late 1920s (figure to right). Since about the 1960s, however, there has been very little change in the overall area of active sand.

Spirit Sand Hills -- Northern Dunes. Stabilization of these dunes has occurred between 1928 and 1991.



Early explorers also described this area in the 1800s. For example, on July 12, 1806 Alexander Henry wrote:

> this " ridge of barren sandy hills, is a body of sand several miles in length ... several miles in circumference, and level on top, where no kind of vegetation grows ... westward lies a sandy waste for three miles, where nothing grows but a few stunted epinettes (*spruce trees*), that tumble down when the sand are blown from about their roots. "

From this account, it is clear that these dunes were more active in the early 1880s, than at any time between the 1920s and today.

Source: *Wolfe, S.A., Muhs, D.R., David, P.P. and McGeehin, J.P. 2000. Chronology and geochemistry of late Holocene eolian deposits in the Brandon Sand Hills, Manitoba, Canada. Quaternary International, v. 67, p. 61-74.*

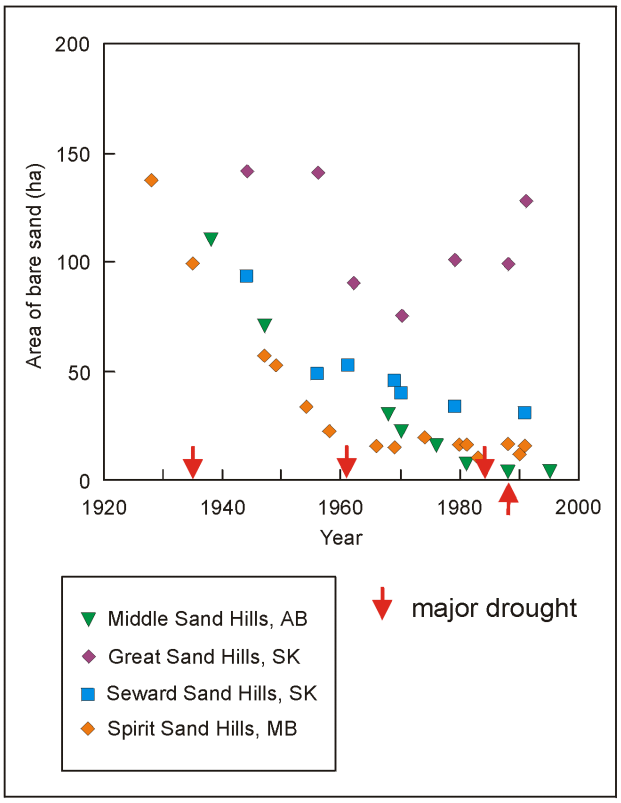
Coues, E. (Ed.) 1897. New light on the Early History of the Greater Northwest, the Manuscript Journals of Alexander Henry, Fur Trader of the Northwest Company, and of David Thompson, Official Geographer of the Same Company, 1799-1814. 2 Vols. Francis P. Harper, New York.

Summary of Historical Changes

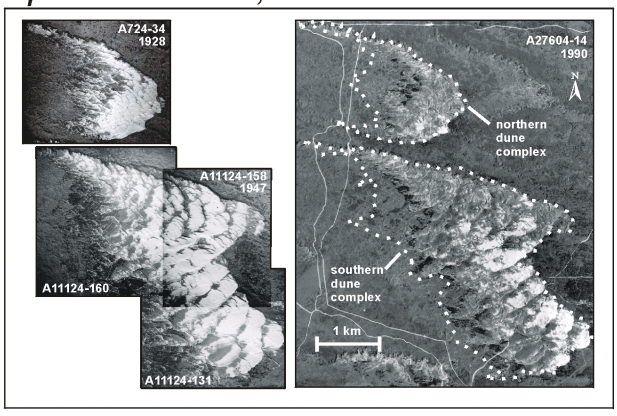
In summary, most active dunes fields in southern Alberta, Saskatchewan and Manitoba have become more stable throughout the last century. Many active dune areas have vegetated at a rate of 10% to 20% per decade, and some have nearly completely stabilized over the last century. This has occurred in spite of droughts in the 1930s, 1960s, and 1980s. While these droughts imposed major impacts in agricultural areas, they appear to have had only minor impacts in dune areas, with the exception of the Great Sand Hills, where activity increased in some parts of the sand hills following droughts in the 1980s (graph to right).

These observations suggest that most sand dune areas on the southern prairies were more active prior to European settlement than they are today. This can be viewed as a positive trend since it suggests that dune areas can withstand the impacts of several drought years without being re-activated. However, this raises the question as to whether these historical changes have been due to changes in land use activities and the frequency of natural disturbances, or due to changes in climatic conditions on the prairies over the last century.

Regional trends in dune activity.



Spirit Sand Hills, Manitoba.



Source: *Vance, R.E. and Wolfe, S.A. 1996. Geological indicators of water resources in semi-arid environments: southwestern interior of Canada. In: Geoindicators: Assessing rapid environmental changes in earth systems. Berger, A.R. and Iams, W.J. (Eds). A.A. Balkema, p. 251-263.*

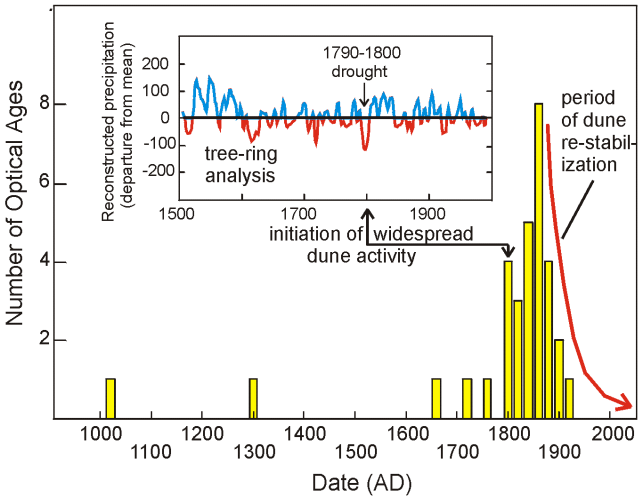
3. PAST DUNE ACTIVITY

S.A. Wolfe, P.P. David, D.R. Muhs, D.J. Huntley, O. Lian, J. Ollerhead, D.J Sauchyn and G. MacDonald

In addition to understanding the historical changes in land cover, it is important to understand the changes in dune activity that have occurred in pre-settlement and geologic times. It is also important to determine the causes of these changes. In this respect, drought appears to have played a major role in dune activity and land-cover change in the past.

Pre-settlement Dune Activity in the Great Sand Hills Region

Evidence of widespread drought-induced sand dune activity in the Great Sand Hills.

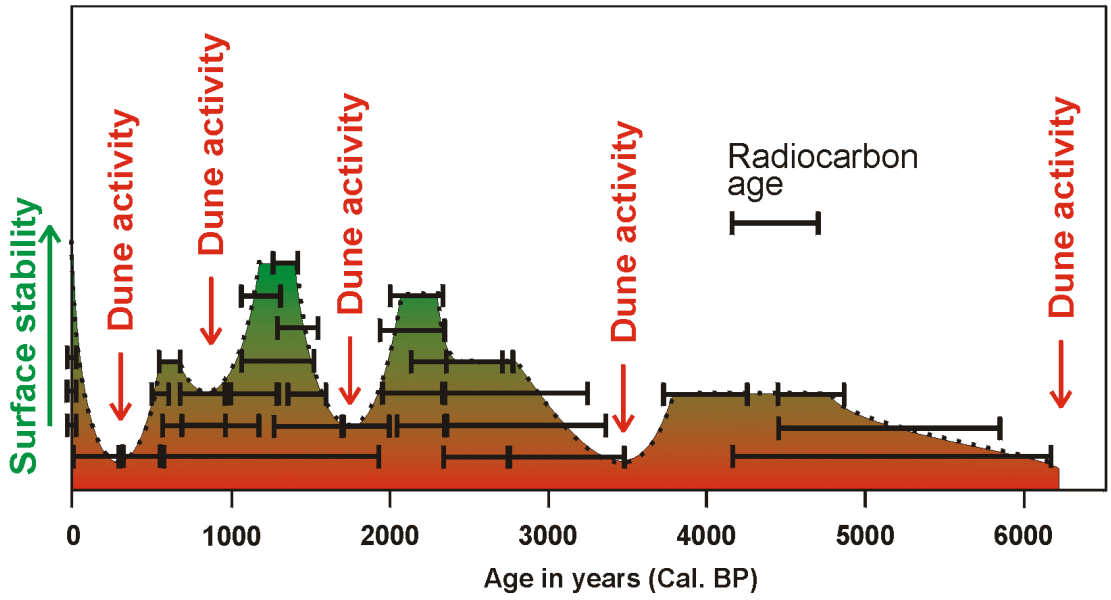


Geologic investigations in the Great Sand Hills region have determined when stabilized sand dunes were last active (by determining the last time sand was exposed to sunlight). These studies have revealed that widespread sand dune activity began around AD 1800 and continued, at levels higher than observed at any time in the 20th century, for a period of about 80 years. Additional data from tree-ring records in the Cypress Hills and in the Rocky Mountain foothills indicate that the most likely cause of this widespread activity was below-average precipitation during much of the 1700s, culminating in drought in the 1790s. It further appears that dunes in this area have been stabilizing from this event throughout the 19th and 20th centuries.

The most important conclusions from this study are that: i) droughts occurring in pre-settlement times (eg. 1790s) have been more severe than any in historic times; ii) these droughts have had significant impacts on the landscape, which may require many decades, if not centuries, to recover; and iii) the magnitude of the impact of drought also depends upon the climatic conditions preceding the event.

Source: *Wolfe, S.A, Huntley, D.J., David, P.P., Ollerhead, J., Sauchyn, D.J., and MacDonald, G.M. 2001. Late 18th Century drought-induced sand dune activity. Great Sand Hills, Saskatchewan. Canadian Journal of Earth Science, v. 38, p.105-117.*

Past Dune Activity in the Brandon Sand Hills, Manitoba



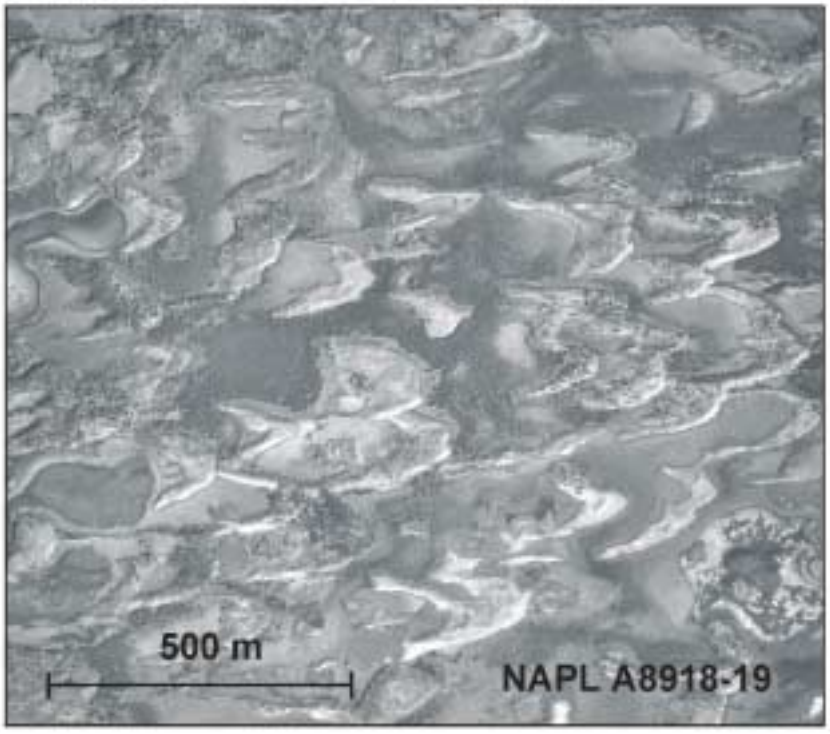
Geologic studies have been conducted in the Brandon Sand Hills of southwestern Manitoba to determine when dune activity and stability occurred in the geologic past. These studies investigated past soil development and determined the ages of soils buried in dune deposits. The ages revealed that the area had been subjected to recurrent intervals of dune activity and stability in the past 5000 years. Notable periods of soil development occurred around 500 to 600, 1000 to 1400, and 2000 to 2300 years ago, with major periods of dune activity occurring around 300, 800, 1800 and 3500 years ago. The episodes of dune activity may correspond to periods of regional drought, whereas the buried soils indicate periods of increased moisture availability and stabilization by vegetation.

It is also significant to note that most of the Brandon Sand Hills are presently stabilized by forest vegetation cover. An exception is the Spirit Sand Hills area which is presently active, but is in the process of stabilizing. Dune activity in this area may be attributed to pre-settlement droughts that were more severe than those in post-settlement times. The rapid stabilization of these dunes may also be related, in part, to the spread of forest cover over the past few hundred years.

Source: *Wolfe, S.A., Muhs, D.R., David, P.P. and McGeehin, J.P. 2000. Chronology and geochemistry of late Holocene eolian deposits in the Brandon Sand Hills, Manitoba, Canada. Quaternary International, v. 67, p. 61-74.*

Earlier Dune Activity

Stabilized sand dunes in the Peace River lowlands, southeast of Grande Prairie, Alberta



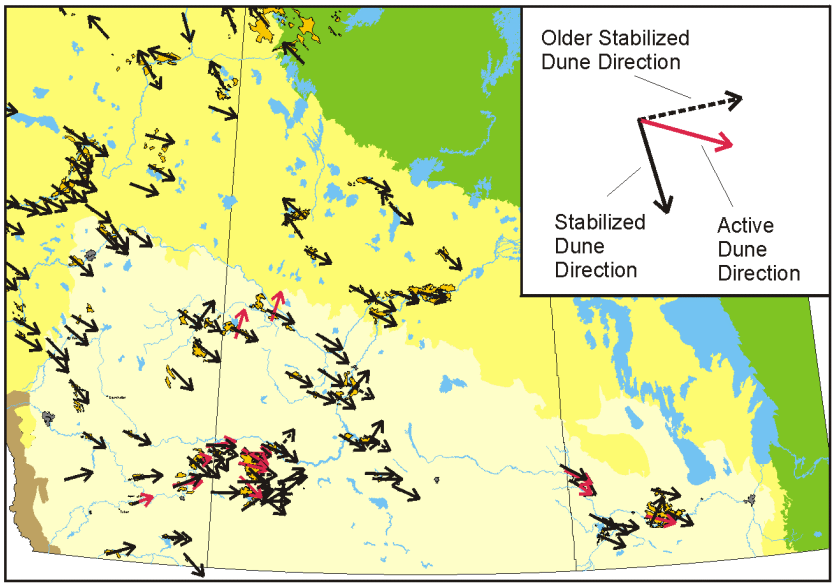
With the exception of the Athabasca Sand Dunes, which is the largest region of active dunes in Canada, most of the sand dunes in the northern parts of the Prairie Provinces are stabilized by forest vegetation cover. At present, little is known about when these dunes were last active or what the environment was like during their activity. In the most northerly regions of the provinces, it is believed that the dunes were probably active during deglaciation, when strong off-ice winds blew in a northwesterly direction. Dunes in other parts of this region are oriented towards both the northwest and the southeast, suggesting that two different, and opposite, winds moved the dunes in this area. It is generally inferred that all of these dunes were active between 8000 and 11000 years ago, and that most stabilized soon after deglaciation when the strong winds abated and vegetation colonized the region. Detailed geologic studies are presently underway to determine the timing of past dune activity and provide a better understanding of the environment that prevailed when these dunes were moving.

Source: *David, P.P. 1981. Stabilized dune ridges of northern Saskatchewan. Canadian Journal of Earth Sciences, v. 18, p. 286-310.*

Halsey, L.A., Catto, N.R. and Rutter, N.W. 1990. Sedimentology and development of parabolic dunes, Grande Prairie dune field, Alberta. Canadian Journal of Earth Sciences, v. 27, p. 1762-1772.

Prairie Drought and Surface Winds from Eolian Deposits

Sand dune orientations on the southern Prairies



Geological information from sand dunes helps determine the timing and impacts of past droughts on the southern prairies. In addition, because sand dunes are formed by wind-related processes, they also provide direct evidence of wind directions during their time of formation. By combining the age of dune activity with their orientations, data from sand dunes can be used to determine records of past climatological and circulation patterns.

The figure above depicts the pattern of sand dune orientations in the Prairie Provinces. Most of the dunes show that surface winds were blowing from the northwest when these dunes were active, much as they do today. Presently, however, most of these dunes are stabilized by vegetation, and the wind is unable to move them. Additional geologic studies will determine when these dunes were active, and what the past climate conditions were at the time of their activity. In southern Saskatchewan and Alberta, dune orientations indicate that winds have blown from the northwest and the southwest at different times. Today, most of the active dunes in this area are oriented with the winds from the southwest, and it is these winds that bring most of the dry conditions responsible for droughts on the prairies. Further studies will help to determine how circulation patterns have changed over time in this drought-prone part of the Prairie Provinces.

Source: *Wolfe, S.A. and Ponomarenko, D.S. 2000. Identifying Extreme Events from Proxy Records: prairie drought and surface winds from eolian deposits. Interim report to Environment Canada. 387 pp.*

4. *LAND-USE MANAGEMENT*

S.A. Wolfe, J.E. Campbell, J. Thorpe

The study of climate change is a study of uncertainties, and efforts are needed to address these. New initiatives should address the need for management strategies to be based on realistic evaluations of the impacts of climate change, and on the vulnerability of present land-use practices to these changes.

Land-Management Issues

Sand dunes are undeniably some of the most sensitive landscapes on the prairies. This sensitivity is well-recognized among people utilizing these lands. Many dune areas are managed as large institutional units (parks, pastures, military bases, forest and wildlife reserves) that have formal management plans in place to maintain the integrity and sustainability of these areas (figure to right).

Sand dunes are also among the most sensitive areas to the potential impacts resulting from climate change. As a result, it is important to assess the vulnerability of existing land uses in these areas and to consider the range of land-management practices that may be required to cope with impacts of climate change. This may be achieved by becoming aware of the potential impacts climate change along with the need to adapt to these impacts, by evaluating existing management plans for the vulnerability to climate change, and by developing management plans that consider the impacts of climate change.

Management plans are an essential component of maintaining sustainable land use activities on sensitive dune soils.

Source: *Wolfe, S.A. and Nickling, W.G. 1997. Sensivity of Eolian Processes to Climate Change in Canada. Geological Survey of Canada, Bulletin 421, 30 pp.*

ADDITIONAL REFERENCES

Abouguendia, Z.M. 1990. A practical Guide to Planning for Management and Improvement of Saskatchewan Rangeland: Rangeland Plan Development. Saskatchewan Rural Development, Regina, Saskatchewan. 52 pp.

Herrington, R., Johnson, B., and Hunter, F. 1997. Responding to Global Climate Change in the Prairies, Volume III of the Canada Country Study: climate impacts and adaptation. Environment Canada. 270 pp.

Lemmen, D.S. and Vance, R.E.. (Eds.) 1999. Holocene Climate and Environmental Changes in the Palliser Triangle: a geoscientific context for evaluating the impacts of climate change on the southern Canadian prairies, Geological Survey of Canada, Bulletin 534, 295 pp.

Lemmen, D.S., Vance, R.E., Campbell, I.A., David, P.P., Pennock, D.J., Sauchyn, D.J., and Wolfe, S.A. 1998. Geomorphic Systems of the Palliser Triangle, Southern Canadian Prairies: description and response to changing climate. Geological Survey of Canada, Bulletin 521. 72 pp.

Lemmen, D.S., Vance, R.E., Wolfe, S.A., and Last, W.M.
1997. Impacts of future climate change on the southern Canadian Prairies: a paleoenvironmental perspective. Geoscience Canada, v. 24, p. 121-133.

Prairie Farm Rehabilitation Administration. 1998. Drought in the Palliser Triangle (a provisional primer). Prepared by W. Nemanishen. Agriculture and Agri-Food Canada. 58 pp.

Saskatchewan Environment and Public Safety. 1991. Great Sand Hills Land Use Strategy. 72 pp.

Saskatchewan Environment and Resource Management. 1996. Manitou Sand Hills Integrated Resource Management Plan. 32 pp. Plus appendices and maps.

Thorpe, J. and Godwin, R. 1992. Regional Vegetation Management Plan for Douglas Provincial Park and Elbow PFRA Pasture. Saskatchewan Research Council Publication No. E-2520-1-E-92. 156 pp.

Wolfe, S.A. and David, P.P. 1997. Parabolic dunes of the Great Sand Hills, southwestern Saskatchewan. Canadian Geographer. v. 41, no. 2, p. 207-213.

ACKNOWLEDGMENTS

Climate change studies on this and other themes have been funded in part by the Geological Survey of Canada, through its proposal approval system. Additional funding has been received from the Canadian Climate Action Fund, through the Climate System Science sub-component and the Prairie Adaptation Research Centre (PARC).