PRAIRIE PERSPECTIVES:
GEOGRAPHICAL ESSAYS

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Preface

The 25th annual meeting of the Prairie Division, Canadian Association of Geographers was hosted by University of Regina in Moose Jaw, Saskatchewan between September 28 – 30, 2001. Conference facilities and accommodation were provided at the Temple Gardens Mineral Spa Resort Hotel. The conference attracted a record of over one hundred delegates including several from outside the Division. Fifty papers were presented in a series of four concurrent sessions spanning Saturday morning. Two field trips were staged on Saturday afternoon. In the first of these Alec Paul and Randy Widdis guided a group of art connoisseurs, train spotters and fellow imbibers on a tour of Moose Jaw's mural district, rail yards and selected hostelries. A second field trip led by Janis Dale and David Sauchyn set out to examine the Pleistocene geomorphology of The Dirt Hills. Breakdown of the bus transportation resulted in a pleasant sunny afternoon hike along the gravel to the small community of Spring Valley. After a couple of hours delay the arrival of replacement transportation enabled completion of the field trip with a visit to the Claybank Brickworks Museum. At the Saturday night banquet Professor John Warkentin of York University delivered a warmly received keynote address on *How Canada got its Regions*. This was followed by the customary high spirits of the annual slide competition in which Brandon University presented the winning slide in most categories.

Of the fifty conference papers, twenty-one are presented in this volume. In keeping with tradition in *Prairie Perspectives* they include several authored in whole or in part by graduate students. As such they represent their first contributions to scholarly publication. As a whole the papers reflect the wide diversity of interest of prairie geographers and the wide range of research tools and methods employed in modern geography. Beckey Hamilton uses evidence from personal correspondence to account for the pattern of homestead choices among French-speaking settlers in the Gravelbourg-Meyronne area. William Rannie trawls the Hudson's Bay Company archives to establish the relationship between historic floods on the Red and Assiniboine Rivers. The perceptions of focus groups are central to Doug Ramsey, Bob Annis and John Everitt's study of community and health care provision in southern Manitoba. Dendrochronology and dendroclimatology feature in Irene Hanuta's reconstruction of climate over the last 120 years at a site in southern Manitoba. At a much broader scale, Ge Yu and Xiankun Ke use pollen analysis to reconstruct Canada's climate during the last millennium. Remote sensing is employed by Xulin Guo to delimit Saskatchewan's prairie ecosystem. The utility of geographic information systems (GIS) is demonstrated by Greg Lewis, John Everitt and Dion Wiseman in their analysis of crime in Brandon.

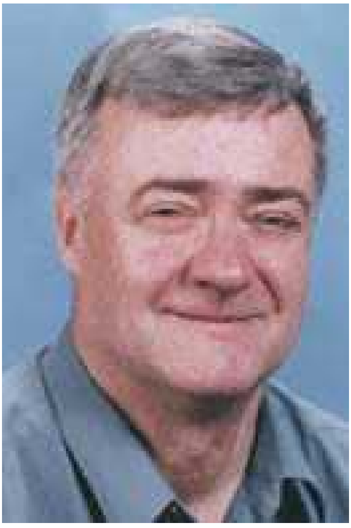
The large number of papers precludes detailed introduction of each in this section. Instead, the reader's attention is drawn to a number of themes around which the volume is organized. In the first of these several papers focus on aspects of fluvial geomorphology and water management. For example, Nathen Richea's study of streamflow characteristics in Duck Mountain provides base level data through which water resource managers can establish strategies for dealing with competing development pressures and climate change. A second theme focuses on the reconstruction of past geographic environments. Roderick McGinn's interpretation of the sedimentary sequence in the Glacial Lake Proven basin fits this theme. A number of papers focus on environmental impacts stemming from urbanization processes or resource development activities. This theme is evident in Eva Sadowski's paper on the impact of road de-icing salts on amphibian populations in Toronto's Humber and Don River watersheds. Several papers focus on regional identity or regional delimitation. Ben Moffat, for example, provides a cartographic and tabular synopsis to explain the origins of western Canadian identity and alienation. Rural restructuring forms the basis of yet another theme. In this context Bob Walberg and Doug Ramsey draw attention to the political process and socio-economic issues attending the establishment of a large-scale hog processing plant in Brandon. Last but not least the opening and closing papers in this volume represent two of the last collaborative works of Paul Simpson-Housley. Both papers focus on one of Paul's major research interests, namely the representation of geography in works of literature. In the opening paper Paul combines with Allison Williams to examine the concept of sense of place as conveyed in Grey Owl's (Archie Belaney) *Pilgrims of the Wild*. The volume closes with Paul and Elizabeth Scarborough transporting the reader to Peru. Here in José María Arguedas' novel *El Zorro de Arriba y El Zorro de Abajo* they explore the use of the sierra and costa as metaphors for contrasting aspects of the human condition.

The success of the Moose Jaw conference would not have been possible without the assistance of many individuals. Alec Paul and Randy Widdis are to be commended for their primary role in arranging the conference facilities and designing the program. Marilyn Lewry and Linda Paul did much to ensure a relaxed atmosphere for delegates by providing a trouble free registration process. Mark Coté's management of the

technical equipment enabled smooth running of the paper sessions. A special thanks is extended to the Prairie Adaptation Research Collaborative (PARC) for providing funds to help defray the cost of the field trips and banquet.

The editorial process has been a lengthy one. I would like to thank the many reviewers from Canada, the United Kingdom and Australia for providing their critical assessments of the papers. I thank the authors for their attention to scholarship and their patience in responding to my many emails. Special praise is reserved for Teri Rogoschewsky who worked tirelessly in providing secretarial assistance both prior to the conference and during the editorial process. Finally, publication of this volume would have been impossible without the technical and production assistance of Weldon Hiebert at University of Winnipeg.

Bernard D. Thraves
University of Regina
August 2002



Paul Simpson-Housley 1943-2002

Paul Simpson-Housley, who passed away in March 2002, had been a professor of geography at York University in Toronto since 1984.

Paul's academic career started with a B.A. from Bristol University in England in 1964 where our paths first crossed, and a Dip. Ed. from Liverpool in 1965. He taught school in Glasgow, Scotland and in New Zealand. His long association with the prairies began around the end of the 1960s when he spent a couple of years teaching high school in Briercrest, a small town about 40 km southeast of Moose Jaw. In 1974 he became the first student to complete a Master's in geography from the young department at the University of Regina. His record of completing the program in sixteen months still stands, and following the immortal advice of Ed Dale, then professor and head at Regina, he decided to "go straight to the Ph.D." at University of Otago in New Zealand.

Growing up in D.H. Lawrence country in the Notts/Derbyshire coalfield of England's East Midlands left its mark. Paul developed an abiding interest in geography and literature which stretched to environmental perception and hazards and the psychology thereof. Although he had a series of short-term appointments – mostly at University of Regina, but also at Bishop's and Concordia – between 1978 and 1984, it was the tenure-track appointment at York which finally gave him the opportunity to pursue his writing and research agenda and to work productively with a stream of graduate students. Geography became his life, and he became a geographer of distinction.

He loved conferences and came to as many Prairie CAG meetings as he could. It was fitting that his final PCAG meeting was the September 2001 25th Anniversary event in the Temple Gardens Mineral Spa in Moose Jaw, the first Canadian city that he had come to know well thirty-odd years earlier. Meetings of the Great Plains-Rocky Mountain Division of the AAG he liked too. At his first of these, in Boulder, Colorado in 1983, he organized a special session on geography and literature which provided the seed for his first book, co-edited with Bill Mallory and entitled simply Geography and Literature – A Meeting of the Disciplines.

His sabbaticals and research leaves at Cambridge University were especially beloved. He worked at The Scott Polar Research Institute and wrote books on both Arctic and Antarctic explorations. He loved his teaching too, and almost always brought one or two of his graduate students to conferences. Those of us who were privileged to attend the Devil's Lake, North Dakota PCAG meeting in 2000 saw him give a masterful after-dinner speech – or was it a poetry recital? – on polar exploration – or was it environmental perception?

Paul had many friends on the prairies. One of his greatest pleasures was to visit with Elroy Trithardt in Kipling and enjoy the rural and small town life that had been his introduction to Canada. He had telephoned me a few days before his untimely death and shared another of his passions, talking about the upcoming World Cup of soccer. He was a faithful friend and a valued colleague. We will miss him very much.

Alec Paul
University of Regina

Sense of place: the case of Canada′s provincial norths

Paul Simpson-Housley, York University
Allison M. Williams, University of Saskatchewan

Abstract: Meaning, value and experience are found in those environments that have a strong sense of place. Sense of place defines the identity, significance, meaning, intention, and felt value that are given to places by individuals (Pred 1983) as a result of experiencing it over time (Relph 1976; Tuan 1977). By making use of literary narratives, geographers are able to provide a more nuanced view of human-environment relationships, such as sense of place. The sense of place experienced by Grey Owl (Archie Belaney), who lived throughout Canada's provincial norths, is explored in this paper through his writings. Grey Owl's writing provides a better understanding of the spiritual, physical and emotional connection that individuals have to northern regions.

Keywords: cultural geography, sense of place, Canada's provincial norths, Grey Owl

Canada's northern region, divided as it is among both provincial and territorial jurisdictions, is often perceived as a marginalized space (Jordan 1994). It operates first and foremost as a recognizable parcel of geography, but has multiple meanings, as discussed by Riegel *et al*. (1997, ix) in their collection of essays on regionalism, entitled *Sense of Place*:

> For most North Americans, identity is a complex mix of a feeling of community, a shared cultural, ethnic and social background, and an attachment to place – a mix that is much more localized than the feeling of being Canadian or being American.

In keeping with the idea of attachment as a localized phenomenon, Bone (1992, 3) discusses regional consciousness as "an appreciation of local natural features, cultural traits, and economic issues…. the basis of commonality which provides a distinctive regional 'personality'". This regional consciousness is often best expressed in literature and is evident in numerous collections found throughout the social sciences and humanities (Riegel *et al*. 1997; Jordon, 1994; Simpson-Housley and Norcliffe 1992).

This paper examines the literary work of Grey Owl to explore the representation of Canada's northern regions, and the particular sense of place he experienced while residing in Canada's provincial norths. A humanistic emphasis on the subjective perceptions of the regional landscape, and specifically the sense of place experienced from the author/novelist's point of view will operate as the main thrust of the paper. To best frame the paper, sense of place is first discussed, followed by a brief description of Canada's northern regions. A short biography of Grey Owl precedes an examination of his experience of Canada's north as illustrated in his autobiography, *Pilgrims of the Wild* (Grey Owl 1935a).

Sense of Place

Sense of place has two meanings within the field of geography. It is sometimes understood as a characteristic of a place that is memorable or distinctive, having a high 'imageability' (Lynch 1960, 1972). Symbolic or sacred locations such as Mecca and Stonehenge have this strong sense of place since they have significant meaning for large numbers of people. More commonly, sense of place is viewed as "the consciousness that people themselves have of places that possess a particular significance for them, either personal or shared" (Gregory 1991, 425). It is a clear example of the link between place, the individual and society, as it encompasses both the connection with the physical landscape and those who share that physical space. Geographers have described sense of place as operating within three intertwining dimensions:

> …the perceptual realm of awareness, attitudes and memories; the emotional realm of feelings preferences, and values; and the experiential realm of bodily and sensory contacts, insider/outsider, and journeys… It is an individually based, but group informed, localized, personal means of relating to the world, transforming mere space into personal space (Hay 1988, 160).

Many geographers, including Tuan (1974), Buttimer (1976, 1980, 1993), Relph (1976), Porteous (1990), Seamon (1979), and Hay (1988) have researched life-worlds and place, describing insider/outsider divisions, networks of concern, sacred space, home, homeland, habit fields, and a variety of other similarly abstract place-related phenomena (Raffan 1993).

Home is a good example of a conscious placefulnesss, as a strong sense of being 'in place' is felt; it exemplifies the "internal knowledge – knowledge of emotion, knowledge of the heart – that comprises sense of place" (Raffan 1993, 4). Home place also establishes a source of reference from which judgments may be made. Tuan (1974, 3) describes this as:

> …security…: we are attached to [it]… There is no place like home. What is home? It is the old homestead, the old neighbourhood, hometown, or motherland.

Love of place, or topophilia "can develop at a grand scale as national identity and even as imperial patriotism, but it can also become manifest at a much more local scale as attachment to neighbourhood or home town" (Simpson-Housley and Norcliffe 1992, 5); this is evident in the local patriotism voiced by Shakespeare (1964) in the play, *Richard II*:

> This happy breed of men, this little world,
> This precious stone set in the silver sea,
> Which serves it in the office of a wall
> Or a moat defensive to a house
> Against the envy of less happier lands,
> This blessed plot, this earth, this realm, this
> England … (Act 2, Scene 1)

Places with a personal history, where significant biographical events have occurred, also have a strong sense of place. Humanistic geographers have referred to this fusing of location and human life into centres of human meaning (Gregory 1991, 425) as a personal connection with place, built-up over years of residence and involvement in the community (Hay 1988). This connection is also made through historical association, as suggested by Lucas (1960, 176):

> The first time I saw the cloud-topped mountain ridges of Acroceraunia from the Adriatic, or the Leucadian Promontory white with sun and storm, or Hymettus, purpled with the

> sunset, from the Saronic Sea, was something intenser even than poetry. But the same shapes and colours would not have seemed the same in New Zealand or the Rockies. Half their transfigured splendour came from the poetry of two thousand years before, or the memory of that other sunset on Hymettus when the hemlock was brought to Socrates.

Getting at these meanings has proven to be a challenge for social scientists.

Owing to the difficulty of transforming the concept of sense of place into defined concepts subject to verifiable study (Davies and Herbert 1993), social scientists have sought out literary and visual art forms that express this sense of belonging to place. Within geography, it has given rise to the examination of place sensibility and evocation by writers, painters and poets, as they have been particularly skilled in providing perceptive descriptions of places by defining their distinctive, idiosyncratic character. This is summarized by Porteous (1990, 201) in his book entitled *Landscapes of the Mind: Worlds of Sense and Metaphor*:

> It is my contention that literary and artistic expression, whether ours or that of others, is essential in helping us to experience the world around us in a richer more authentic way.

Geographers have most commonly used various forms of literature to interpret and understand landscapes (Pocock 1981; Mallory and Simpson-Housley 1987; Simpson-Housley and Norcliffe 1992). By making use of literary narratives, geographers are able to provide a more nuanced view of human-environment relationships, such as the territorial bases of human subjectivity – the sense of place (Lando 1996). Fewer geographers have extended the boundaries of landscape interpretation through the sole use of visual art (Carter-Park and Simpson-Housley 1994; Simpson-Housley and Norcliffe 1992; Cosgrove and Daniels 1988; Prince 1984; Rees 1982). The use of visual art is in keeping with Ruskin, who understands artists' quest to endlessly pursue knowledge about relations between phenomena, in an attempt to understand their meaning, their purpose, or in Ruskinian terms, their moral connections (Cosgrove 1979; Cosgrove and Thornes 1981).

Canada's Norths

> A culture which is the expression of a specific community is in contrast to a mass culture which ends towards uniformity rather than unity, and towards the obliterating of the specific and distinctive…every part of Canada is shut off by its geography. Everywhere…we find solitudes touching solitudes: every part of Canada has strong separatist feelings, because every part of it is in fact a separation (Frye 1977, 7).

Canada's provincial norths are, owing to their geography, 'solitudes touching solitudes'. They are not only distinct from one another but, as a group, are distinct from the southern regions upon which they, for the most part, depend. They are described as long-ignored, politically weak and economically unstable, and are characterized as containing many of the country's poorest and most disadvantaged citizens. They hold much of Canada's resource wealth, and hence good portions of its economic future (Coates and Morrsion 1992), but are highly susceptible to the rises and falls of international demand.

Cold, ice and snow permeate depictions of Canada's north by poets, novelists, and artists. Canada yields its wealth only reluctantly, and manifold difficulties and hazards are encountered in harnessing resources. Indeed, stubbornness is a prerequisite to survive Canada's elemental fury. There are, however, pieces of hidden beauty among the hostile elements and the opposing forces, giving scope to artists (Simpson-Housley and Norcliffe 1992). Patrick Anderson's poem touches upon Canada's image as a cold, hard and unforgiving land:

> …And the North was. With winter the snow came. Whole folios of it.
> Yet nothing written except one thing, a bleak expectancy – the possible
> with its strenuous shade of whiteness where an intuition almost without
> equipment could trek into the faint wind of the future…
>
> What are you…? they ask, in wonder.
> And she replies in the worst silence of all her woods:
> I am Candida with the cane wind.
>
> What are you…? they ask.

> And she replies: I am the wind that wants a flag. I am the mirror of your
> picture until you make me the marvel of your life. Yes, I am one and none,
> pin and pine, snow and slow, America's attic, an empty room,
> a something possible, a chance, a dance that is not danced. A
> cold kingdom (Anderson 1946, 35, 42, 43).

Many of Canada's provincial norths are Precambrian, containing bare rocks, great forests, and numerous lakes, all of which provide much to attract writers and artists, such as Canada's beloved Group of Seven. It is a land apart from the remainder of the country, with many isolated regions having hinterland status. Given that Grey Owl spent most of his time in northern Ontario, this province will be examined in most detail herein.

The culture of the vast landscape called northern Ontario, which comprises approximately ten percent of the population while making up approximately eighty-six percent of the province's total area (Beggs 1991), is distinct from that of the south. As suggested by Frye above, this has engendered separatist feelings; within northern Ontario there has been sporadic talk of secession since as early as 1891, and in 1906 a petition requesting the establishment of a new province of Algoma was forwarded to the Laurier government (Coates and Morrison 1992). These and other movements have been based on dissatisfaction with the alleged mistreatment of the north and its people by the provincial government, which is understood by northerners as representing the needs of the populated south. Residents of Sudbury proposed a new province of Huronia in the early 1900s and, in the post-World War II years, a city councilor agitated for the province of Aurora. The most sustained campaign for a new province was headed by a motel owner and civic booster from North Bay, who in 1977 registered his Northern Ontario Heritage Party as an official party within the province (Coates and Morrison 1992). Many southerners are perplexed as to what keeps people wanting to continue to live in the north; in addition to the obvious reasons of work and family, many people maintain their home in the north because of feeling a strong 'sense of place.'

Like all provincial norths, northern Ontario is made up of a series of somewhat isolated places that have little contact with each other; as a consequence, cultures are locally defined. In his novel *Loon* Plumstead (1992, 76) explores this isolation in the following passage:

> To be isolated by geography and race on an island Indian reserve with twenty-seven students to teach in grades one through eight, at the bottom of the pay scale (if you were new at it), with little to do when winter darkness was ink black soon after the school day ended, and transportation to the mainland (which was miles from anywhere when you did get there) was a matter of begging and luck such considerations did not add up to an enticing prospect for young graduates of teachers' college.

Due to the isolation experienced, many northern places have become strong communities where residents have come to develop a strong attachment that goes beyond mere economics. As a result, many struggle to keep their communities alive in the face of inexorable pressures to shut them down (Coates and Morrison 1992). This is in keeping with one of Bone's (1992, 2-3) two suggested visions of the North:

> Canadians hold a number of visions of the North. Two dominate current thinking: the northern frontier, and the northern homeland… The northern frontier image is of a place where people are pitted against a harsh environment that contains great wealth…. Northerners, particularly Native northerners, hold a homeland image of the North … By living, working, and playing in a northern environment, they have developed a deep and lasting attachment to their surroundings.

Strongly related to this attachment is the sense of place that many of those living in these northern communities feel.

The spirit of the land is a strong contributor to this attachment for many, as illustrated by the pantheism assumed by some native writers. Tomson Highway reveals this in the following passage from his play *Dry Lips Oughta Move to Kapuskasing*:

> I have my arms around this rock, this large black rock sticking out of the ground, right here on this spot. And then I hear this baby crying, from inside this rock. The baby is crying out my name. As if I am responsible for it being caught inside that rock (Highway 1989, 44).

Plumstead also refers to this concept in his novel, *Loon*:

> Protect the land and her spirits. Never let Shagunash take it away. He may borrow pieces of it but it must never be traded away. The gods are in the land as well as the sky. You know that (Plumstead 1992, 10).

Nature, wilderness and the natural landscape make up a large component of northerner's sense of place. The remainder of this paper explores the northerner's sense of place through an examination of Grey Owl's autobiography, *Pilgrims of the Wild* (Grey Owl 1935a). This is preceded by a brief description of Grey Owl, his life and his writing.

The Life of Grey Owl

Born in 1888, Grey Owl (Archie Belaney) upheld the myth that he had Scottish and Indian parents. He spent time in England but returned to Canada to participate in the 1905 Cobalt (Ontario) silver rush. He then spent his life as a trapper, canoe man and packer. The Ojibway Indians adopted him and bestowed on him the name Grey Owl because he adored nocturnal travel. They taught him their language and their forest lore, and from them he derived his love of Canada's provincial norths. As Eayrs observed if the foreword to the *Pilgrims of the Wild* "A canoe is to Grey Owl what a horse is to a cow-puncher or a good vessel to a sailor" (Grey Owl 1935a, ix). He was a guide and explorer of the north country. In winter he trapped but was also an Ontario Government forest ranger for some summers. His greatest contribution is, however, to conservation. After falling in love with Anahareo, an Iroquois girl, Grey Owl moved to northern Québec. Together, they gave up the trap lines to work towards the protection of animals and the conservation of the land they both loved. Here he began his writing career, which continued in their adopted home in Saskatchewan's Prince Albert National Park, where Grey Owl worked as a park ranger. The wilderness was his world. He died in 1938. In addition to his autobiography, *Pilgrims of the Wild*, Grey Owl wrote a number of other books (many of them children's), including *The Men of the Last Frontier, The Adventures of Sajo*, *Tales of an Empty Cabin* and (Grey Owl 1931, 1935b, 1936).

Plumstead (1997) laments the fact that the Canadian academic community has largely ignored Grey Owl. Criticisms of him are legion and include the facts that he wrote for children and popular audiences, that he did not fit into established genres, that he was a bigamist, and that he lied in his books (Plumstead 1997). Thus, many academics distrust him. Plumstead, however, advocates a different perspective, where Archie Belaney's *Pilgrims of the Wild* operates as a work of fiction wherein he tells the truth of art – a different form of truth. Similar accusations could be made at Daniel Defoe (1719) in his rendition of *Robinson Crusoe*, where many details are fabricated. For example, Defoe's rendition did not follow Alexander Selkirk's stay on Juan Fernandez Island accurately. Rather than being located west of Chile, Crusoe was on an island that seems to have been in the Caribbean. Defoe was also denied the status of an Augustan author since his book was deemed popular and lacking sophistication, criticisms also attributed to Grey Owl. One would surely not dismiss Defoe. *Robinson Crusoe* is widely acclaimed as a prototype of the English novel. Similarly, one could defend *Pilgrims of the Wild* if it is viewed as a work of literature rather than pure autobiography. It has been dramatized, fictionalized and heightened for effect. Even Mark Twain admitted there were some things he stretched.

There are things in common with Bunyan's *Pilgrim's Progress* (Plumstead 1997). Both are books where the hero is depicted as groping for hope and love in a world that is full of despair and death. Both are fallen worlds. In *Pilgrims of the Wild*, the beavers as surrogate children help redeem this lost world and help metamorphose Archie Belaney, the trapper, into Grey Owl the conservationist. If we take off our masks we can see *Pilgrims of the Wild* as a creative work of fiction and nature writing. It is a classic text that sits on many Canadian bookshelves.

Grey Owl's Sense of Place

Although much of what Grey Owl wrote took place in the boreal forest of Prince Albert National Park, northern Saskatchewan, it is difficult to determine which 'provincial north' he alludes to in his work. Having spent time in Manitoba, Québec, the Maritimes, Saskatchewan, and for the most part, Ontario, his recollections of the past are placed throughout much of the Canada's vast northern region. In *Pilgrims of the Wild*, Grey Owl describes the strong sense of place he now has in his adopted land of the early 20th century Canada:

> The feel of a canoe gunnell at the thigh, the splash of flying spray in the face, the rhythm of the snowshoe trail, the beckoning of far-off hills and valleys, the majesty of the

> tempest, the calm and silent presence of the trees that seem to muse and ponder in their silence; the trust and confidence of small living creatures, the company of simple men; these have been my inspiration and my guide. Without them I am nothing (Grey Owl 1935a, xvi)

This strong sense of place results from the many years Grey Owl lived in the North, together with the many intense experiences he had while living there. The two main themes that make up his strong sense of place, as depicted in *Pilgrims of the Wild*, are: the relationship with the wilderness and the wildlife which resided there (specifically the beaver), and the associational practice of animism.

Although once a trapper, Grey Owl had a close affinity with the wilderness, and specifically the wildlife found in the northern environments he frequented. Even though the relationship he had with nature can be defined as psychological, there is also a strong spiritual and social component that is evident:

> I had long ago invested the creatures of the forest with a personality. This was the inevitable result of a life spent wandering over the vast reaches of a still, silent land in which they were the only form of animate life, and sprang from early training and folklore (*ibid*., 24).

Once a strong supporter of wildlife conservation, he wrote about the need for balance in his beloved wilderness, particularly when it came to the species he most loved, the beaver:

> These beasts [beaver] had feelings and could express them very well; they could talk, they had affection, they knew what it was to be happy, to be lonely – why, they were little people! And they must be all like that. All this tallied with the incredible stories I had heard in younger days, and perhaps accounted for the veneration that our people, when savage, had held them in, calling them 'Beaver People,' 'Little Indians' and 'Talking Bothers' (*ibid*., 42-43).

Beaver stood for something vital, something essential in this wilderness, were a component part of it; they *were* the wilderness. With them gone it would be empty; without them it would be not a wilderness but a waste (*ibid*., 48).

Anahareo was very proud of having all these creatures around the house, and they somehow gave the place a lively appearance, and made us feel that we had been accepted as friends and fellow citizens by this company of furred and feathered folk (*ibid*., 133).

His growing affinity for the preservation of animals brought about a different view of them:

> And now I no longer wished to kill. I had beaten and abused the North that now I found I loved, and could I but live without this slaughter, this unnecessary brutalizing cruelty, I would be forever glad (*ibid*., 140).

Some may agree that the distinctive gift of Belaney was to see the life qualities inherent in every place he inhabited, but his writing shows a clear northern bias. It was when Grey Owl was away from the north country that he missed it most. Similar to his close travel companions, urban places, whether towns, villages or cities, were understood as places to frequent only if one had to – for supplies, services, financial opportunities, or the odd evening of entertainment. When away from the north, whether on business or pleasure, Grey Owl and his closest companions found themselves wishing for it:

> …we all began to pine for our North country, and most of our conversations drifted around to reminiscences of it and the making of plans to get back there (*ibid*., 172).

> …free to return to our harsh, untamed, beloved North with its romance, its wild freedom and its gold; free at last to leave this sad disfigured country with its tortured ravaged forests and its memories and grief and tribulation (*ibid*., 178).

A temporal separation from his beloved north country is also evident in his writing, as he recalls the experiences of days past:

> …and somehow the writing of that manuscript had partially appeased the feeling of loneliness and home-sickness that had overcome me whenever I saw, smelled or heard anything that brought quick stabbing memories of the trails of yesterday. For now the North was not so far away. It was I my hand, ready at my call to leap into action… as I lived over again the joys and the triumphs, the struggles and the hardships that had made life so worth living, while my soul slipped back to

> wander once more, at will, in a land of wild romantic beauty and adventure that would soon, by all the sings, be gone beyond recall… A feeling of kinship for all the wild that had been growing on me for years, at this time seemed to have reached its culmination (*ibid*., 139).

His love for the wilderness of northern Ontario was particularly strong, due to his many formative years spent there. This is evident in the following description, written while residing in the northern region of Saskatchewan. In keeping with a holistic understanding of the multi-sensory concept of sense of place, the following description includes experiences that proved to satisfy many of his senses – sight, smell and hearing, among others:

> And ever my mind turned back to Mississauga, roaring between its looming maple-crested mountains – the wild Forty Mile rapids, the swift rush of the Three Mile, the flashing mane of the White Horse, the Cheneaux with its toll of human lives, the heavy thunderous roar of Aubrey Falls over its redstone cliffs, the Gros Cap with its sheer towering walls of granite and gnarled distorted jack-pines jutting out from precarious ledges, the dark, cavernous pine forests, the smell of drying leaves of birch and ash and poplar, the rhythmic, muffled thud of paddles on hardwood gunnels, blue smoke trailing up from the embers of slow fires, quiet, observant Indians camped beneath the red pines, beside its racing flood – (*ibid*., 210).

> The rock-bound Mississauga roars on between its palisades of pine trees. The Elephant Mountain still stand sat the portals of Touladi. Somewhere in the wild Laurentian uplands are little mountain lakes on whose shores the ashes of my camp-fires still remain.
> Some day I hope to see them all again (*ibid*., 280).

> Once again I must hear the Mississauga Dance and tread a measure to the drum of Mato-gense, called Little Child, the Conjuror. For the call of the River comes often upon me, in the evenings, at dawn and when I am alone… All these things will I do in the fullness of time, but it cannot be for very long... My duty lies beneath these Western skies (*ibid*., 280).

The spiritual union that Grey Owl experienced with his beloved Northland is evident in his practice of animism wherein inanimate objects are made animate. This is evident in the way he described trees, streams and, of course, beavers. The trees were understood to not only have a mind, but a memory:

> And the aged trees whose great drooping crowns loomed high above our heads, standing omniscient in the wisdom of the ages, seemed to brood and to whisper, and look down upon our useless vigil, in a mighty and compassionate comprehension… For they were of the Wild as we were, the Wild to which in our desolation we turned for a solace and a refuge, that ageless Wilderness that had ever been and would, somewhere, always be… (*ibid*., 162-163).

> …the great pines still stood towering, mighty in their silence; and standing there immovable in their impenetrable reticence, they seemed to meditate, and brood upon the past (*ibid*., 201).

> …followed the old disused lumber roads... There was never anything but an old deserted camp surrounded by stumps and stark dead trees, ghosts of a forest that was gone. There were small blocks of timber, and here and there a lone pine tree, diseased perhaps and spared on that account. I always made my dinner fire near one of these and tried to feel at home. But it was beyond my imagination; they were destined for the axe in any case and I could only pity them. And on leaving I would look back a dozen times at the moving smoke of my lunch fire, as though it were something there that was alive and kept the old tree company when I was gone. All Northern people loved the pine trees, perhaps because those of us of any age at all, had lived the forepart of our lives amongst them (*ibid*., 249).

The streams were found to have the ability to make music, and thereby hear:

> …it mutters in the sound of sleepy streams, and murmurs in the rumour of the river, in the endless tolling of the waves upon a lake-shore – each and everyone a note from the composite of Nature's harmony, chords struck at random from that mighty Symphony of the Infinite that echoes forever on, down the resounding halls of Time (*ibid*., 164).

In Grey Owl's eyes, the beaver seemed to represent the inherent spirit of the wilderness, most likely due to the time and energy invested in the intimate relationship he had nurtured with them:

> And here it was borne upon me why they had so much impressed themselves upon us, these little beasts [beavers]. They had been like little Indians in their ways, and had seemed emblematic of the race, a living link with our environment, a living breathing manifestation of that elusive Something, that spirit of the Waste Lands that so permeated our own lives, that had existed always just in its entirety. In some tangible way they and their kind typified the principle that is inherent in all Nature. The animal supreme of all the forest, they were the Wilderness personified, the Wild articulate, the Wild that was our home, and still lived embodied in the warp and woof of it… I had lived with nature all my life, yet had never felt so close to it before, as I better understood the Spirit that had fashioned it – nor yet so far a part from it, in the sudden knowledge of my own unfitness to interpret or describe it (*ibid.*, 203).

Not a man of deep religious faith, the presence of the spiritual was understood as residing in nature:

> He, who to us was not the awful unapproachable Presence of more than one of their theologies, but was the Unseen Musician whose melodies whispered in the singing of the pine trees, or resounded in the mighty symphony of the tempest; Whose purpose was made manifest in the falling of the leaves and in their budding, and in the ceaseless running of the waters, and in the rising and the setting of the sun – Who could point a lesson in the actions of a lowly animal (*ibid.*, 258).

Another sign of his belief in animism was the solemn rituals that Grey Owl upheld after killing animals on the hunt. Many of these rituals were adopted from the Native Peoples who he came to know well:

> No bear was killed without some portion of the carcass, generally the skull or shoulder bones, being hung up in a prominent place somewhere in his former range… All these ceremonies are practised by semi-civilized, and even more advanced Indians over a wide area; and should anyone be

> tactless enough to enquire the reason why they do these things, the answer if any, will be: 'Ozaam tapskoche anicianabé, mahween – because they are so much like Indians' (*ibid*., 25).

There is no question that Grey Owl was at home in Canada's provincial Norths. His heart and soul were strongly attached to the wilderness, with which he related beyond the mere physical – in social, spiritual, and psychological ways.

Conclusions

Although the deep human connections that are characteristic of people's functional relationships to places remain very much uncharted in geographical research, literature is a medium which provides an interpretation of the world of emotions and people's relationship with place. It is by further examining the felt sense of place experienced by authors such as Grey Owl, who lived throughout Canada's provincial norths, that a better understanding of how sense of place can inform the behaviour of those who continue to reside there.

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A rating curve based on lake levels: evaluating outlet flow for Clear Lake, Riding Mountain National Park, Manitoba

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Abstract: The stage-discharge relationship or 'rating curve' represents the integrated effect of stream geometry and hydraulic parameters, and is of fundamental importance in hydrologic studies as a means to convert records of water level to flow rates. At many hydrometric sites, the primary assumptions of stream regime (equilibrium or grade) and uniform flow require several years of measurement for validation. In 1993, record high water levels in Clear Lake, Manitoba spilled over the outlet berm and eroded an outlet channel that flowed into Clear Creek. The outlet channel has undergone significant geometric adjustment during the first three years of operation. This observation is supported by periodic discharge measurements (1994-1996) indicating significant variation in both channel geometry and stream flow. Attempts at developing a rating curve for Clear Creek in 1995 encountered problems associated with the measurement of stage. Specifically, beaver dam flooding and backwater submergence. This study employs recorded lake levels, channel staff gauged stage measurements and discharge measurements to develop rating curves for the outlet of Clear Lake. Results indicate that lake levels can be used as an effective alternative to channel stage in the construction of a rating curve for lake outlet streams. In the case of Clear Lake this eliminates the problems related to the measurement of stage caused by beaver dam flooding and backwater effects. The resulting curve and mathematical model can be employed to estimate daily outflow from the lake.

Key words: Clear Lake, lake levels, outlet discharge, stage/discharge, rating curve

Introduction

The Clear Lake watershed is centrally located on the Riding Mountain Uplands in southwestern Manitoba (Figure 1). The watershed drains an area of 142.18 km^2 of which over 65% is located in Riding Mountain National Park (RMNP). Clear Lake represents approximately 20.7% of the watershed area. Park managers have recognized the need to determine the hydrologic water balance of Clear Lake and the associated watershed (Dubois 1997). This scientific knowledge is fundamental to understanding the physical, chemical and biological processes, which occur in the watershed. The collection of baseline data will ultimately provide a sound foundation for the development of both short-term and long-term park management plans to preserve the natural state in the Clear Lake watershed.

Clear Lake covers an area of 29.37 km^2 and has a maximum recorded depth of 34.2 m with a mean depth of 11.5 m (Figure 2). The lake is oriented west-east, with a wider and shallower western portion and narrower and deeper eastern end. It is approximately 12,095 m in length along a mid-lake line and 4,524 m wide, and is estimated to hold approximately 338,075 dm^3 of stored water (McGinn *et al*. 1998).

Surface runoff drains into Clear Lake by way of Octopus Creek, Pudge Creek, Bogey Creek (Ministic Lake Creek), Picnic Creek (Glen Beag Creek) and six intermittent streams located along the north shore of the lake (Figure1). Three of the most prominent of these intermittent streams have been named Spruces Creek, Aspen Creek and North Shore Creek (McGinn *et al*. 1998). Although there is little information at this time, groundwater is also believed to contribute to the storage volume of Clear Lake.

Clear Creek, the outlet stream, is located at the western end of Clear Lake (Figure 1). Clear Creek had not been gauged by the Water Survey of Canada until recently, however, periodic observations suggest that the outlet stream can flow year round and that the mean discharge values are relatively small (0.0 - 2.0 $m^3 s^{-1}$). Clear Creek drains into the Little Saskatchewan River approximately six km upstream of Horod, Manitoba. Until 1993, the stream channel was overgrown and the flow impeded by numerous beaver dams and associated storage ponds. It is suspected that groundwater discharge may represent a significant outflow from Clear Lake particularly when the outlet channel has a beaver dam stair-step profile and is overgrown.

The Recent History of the Clear Lake Outlet

In the spring of 1993, record high lake levels spilled over a sand and gravel berm at the western end of Clear Lake and began to erode the outlet channel towards the west. There had been no recorded flow along this channel (Clear Creek) since the 1970s and the stream channel was overgrown and clogged with sediment and debris. At first the new channel

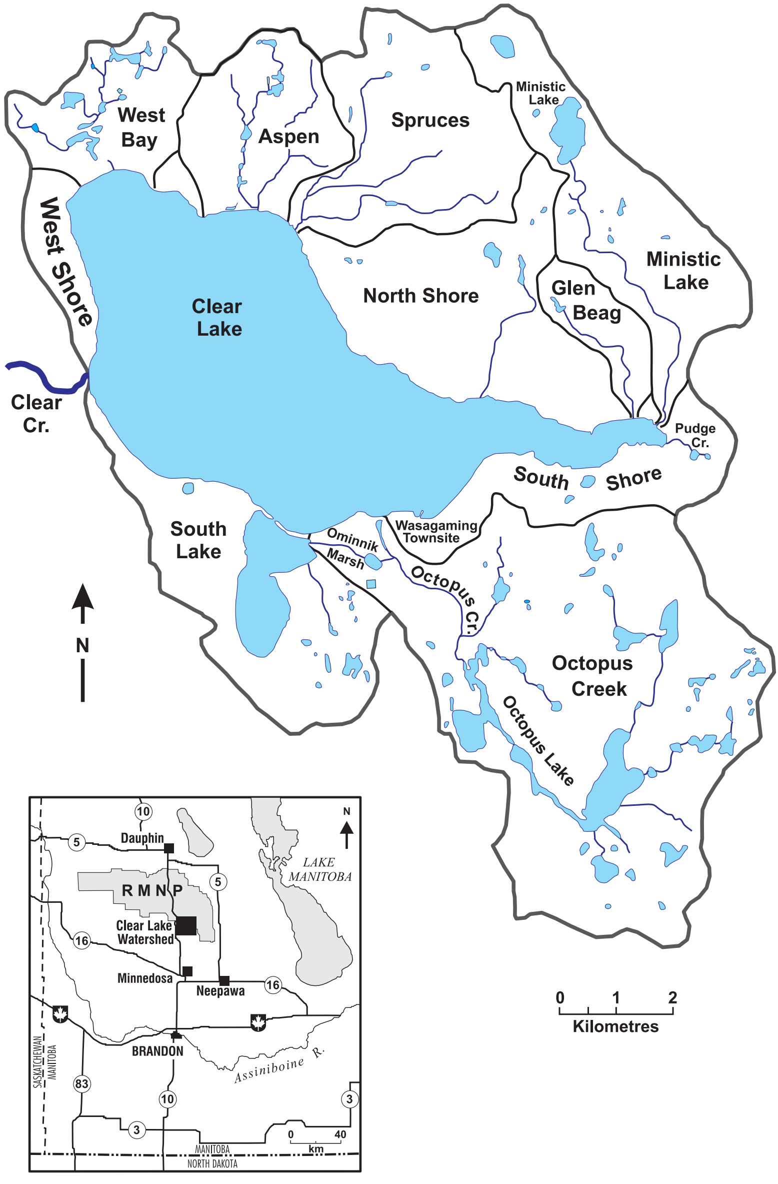
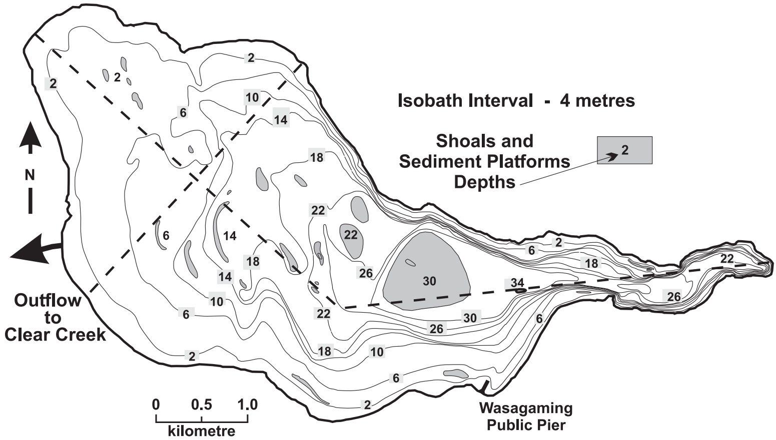


Figure 1: *The Clear Lake watershed.*



Clear Lake Statistics

Length	**12,095 m**
Width	**4,524 m**
Mean Depth	**11.51 m**
Maximum Depth	**34.20 m**
Maximum Fetch	**10,095 m**
Surface Area	**29.37 km^2**
Volume	**338,075.015 dm^3**
Flushing Period	**10.72 yrs**

Figure 2: *Clear Lake bathymetry.*

was less than 1.0 m in width and only a few centimetres deep (McGinn *et al*. 1998). Over the next two years the channel widened and deepened significantly working towards equilibrium (regime). By the spring of 1995, the flood stage channel width was recorded to be in excess of 10 m and the maximum channel depth exceeded 0.5 m.

In 1994, the Clear Lake Project was initiated to understand the water balance of Clear Lake. This involved primary research regarding the principal water balance parameters particularly, moisture inputs (rainfall and snowmelt), inflows, evapotranspiration loss, annual and long-term changes to lake storage volumes and outflow. As a consequence, Environment Canada began monitoring water levels on Clear Lake. From 1994-1997, a Stevens stage recorder (A-71) charted the instantaneous fluctuations in lake level and Environment Canada provided calculations of the mean daily lake level. Supplemental stage data were obtained from a staff gauge, read by Park officials. On March 24 1997, the stage recorder was converted to an automated Accubar pressure transducer. Water levels were averaged every two minutes and sent to a VADAS environment data acquisition system, housed in the pump house located in the town of Wasagaming (Figure 1), from which Environment Canada calculated the mean daily water levels. The Stevens stage recorder was removed in the spring of 1998. Park officials metered outlet discharge periodically throughout the 1994 and 1995 open water season and occasionally in 1996.

In the spring of 1995, at the request of officials from Riding Mountain National Park, Environment Canada personnel attempted to develop a rating curve (based on channel stage and metered discharge) for Clear Creek near the outlet. The gauging station was located approximately 90 m downstream of the outlet sill, at a site with a walking bridge and easy trail access. Upstream of the site, wetlands predominate and accessibility to the stream channel was difficult. Downstream, the channel has been modified by a series of beaver dams and is characterized as having a stair-step profile. A stilling well, 'doghouse,' Stevens stage recorder (A-71) and staff gauge were installed at the selected site and the stage surveyed to a temporary benchmark.

In 1995, Environment Canada was successful in developing the rating curve for Clear Creek during the spring freshet conditions when outlet discharges exceeded 0.8 m^3s^{-1}. At these discharges, the stream channel was relatively straight and clean. Most beaver dams downstream of the gauging site had failed and could not be repaired at flows exceeding 1.0 m^3s^{-1}. As outlet discharges dropped below 0.8 m^3s^{-1}, however, the beaver began to re-establish storage dams and the resulting backwater flooding generated significant problems in recording an accurate channel stage. Levelers were inserted into the newly constructed dams and in extreme cases the dams were removed. Levelers, based on the Clemson Leveler model (Clemson University 1991) were 8, 10 or 12 inch diameter drainage pipes inserted through the beaver dam and extended several metres into the storage pond. The upstream (pond) end was protected from beaver access by a wire basket approximately 1 m^3. Levelers could, more or less, control pond stage and backwater effects. Continual monitoring and maintenance, however, was required to attain the desired effect. It is important to note that stream discharge measurements during 1994 and 1995 were conducted approximately 75 m upstream of the stage recorder, 15 m from the lake outlet sill. This was necessary due to beaver dam backflooding at the stage recorder. The metering site, however, was considered unsuitable for the installation of a stage recorder.

Environment Canada stopped gauging operations in the fall of 1996 due to continual problems with the recording of channel stage (backwater effects and icing conditions). The stilling well and gauging equipment were removed in early 1997. As a result daily outlet discharges are, at best, informed estimates. By fall of 1997, lake levels had fallen significantly (one standard deviation) below the long-term average of 615.275 m elevation and during the low water months of October and November the outlet sill was exposed. This (fall of 1997) was the only time since 1992 that there has been no recorded flow from the Clear Lake outlet down Clear Creek.

Objective of the Study

The objective of this study is to explore the use of lake levels as an alternative to channel stage in deriving the rating curve for a lake outlet stream.

Theoretical Considerations

The traditional rating curve:

A rating curve is a graphical representation of the stage-discharge values for a specified stream section (Lo 1992) which is considered to be 'in regime' or at equilibrium. The fundamental assumption for establishing a rating curve is the principle of regime. Channels, which are in regime tend to adjust themselves to average widths, depths, slopes and meander lengths, depending on the sequence of discharges, sediment loads and the conditions of the boundaries (Blench 1969).

The traditional rating curve based on channel stage and discharge values uses the channel stage or gauge height as a function of the discharge (Herschy 1985). That is, the channel stage is assumed to be dependent on the stream discharge. A sufficient number of discharge measurements (approximately 25), suitably distributed throughout the range in stage, are required to establish this stage-discharge relationship. The observations are plotted on arithmetic paper, with channel stage on the ordinate and discharge on the abscissa. A trend line is fitted to the scatter plot. The method of least squares has become the preferred procedure used to compute the line of best fit. Generally a linear plot in the form $S = m Q + b$ is preferred; where, 'm' is the slope of the straight line and 'b' is the intercept value (channel stage) when discharge (Q) is zero. The straight-line plot is described by a simple mathematical model, can be analysed for uncertainties and easily extrapolated.

The logarithmic rating curve:

When the initial scatter plot appears curvilinear, it is common to plot the logarithms of stage against the logarithms of discharge. Alternatively, the data can be plotted on logarithmic paper. In either plot the data are fitted with a straight line using the method of least squares. The equation of this plot, called a power function, is $S = a\,Q^{m}$; where, 'm' is the arithmetic slope of the line and 'a' is the intercept (channel stage) when discharge (Q) equals unity. As in the traditional plot, the power function (straight line) is described by a simple mathematical model, can be analysed for uncertainties and is easily extrapolated.

The lake stage rating curve:

A lake stage-outlet discharge rating curve is fundamentally different from the traditional rating curve. In this case, discharge is dependent on lake stage. Consequently the plot requires, at least in theory, outlet discharge to be plotted on the ordinate and channel stage on the abscissa. As with a traditional rating curve, a sufficient number of discharge measurements are required to establish this discharge-stage relationship. Either an arithmetic or logarithmic plot is acceptable.

Procedures and Methodology

A hydrometric metering site was established 15 m downstream from the lake outlet sill. At this site, the channel was well-formed, partly armoured, with bank to bank flow and little evidence of seepage loss to the surrounding wetlands. The site lay beyond the influence of lake waves. Measurements began on May 8, 2001 and continued weekly until October 10, 2001. Discharge measurements followed the mid-sectional method (15-20 verticals) employed by Environment Canada as outlined by Terzi (1981). Velocity was measured with a calibrated Price AA meter at 0.6 m depth in each vertical until mid-September. When the mean cross-sectional flow depth was less than 0.15 m, a calibrated Pygmy meter was employed. The hydrometric data were used to calculate mean outlet discharge (m^3s^{-1}). Lake stage for the date of the discharge measurement was recorded, as an elevation (m) above sea level, at the Wasagaming lake stage recording site (Figure 1). The gauge height (staff gauge), located at the 'old'

Environment Canada gauging site was also recorded. These measurements were recorded as metres above a selected base elevation.

Results

Table 1 summarizes the hydrometric measurements recorded during the 2001 study period. Outlet discharge during the study period ranged from a high of 1.4846 m^3s^{-1} on May 15, 2001 to the lowest value recorded (0.0090 m^3s^{-1}) on October 10, 2001. Calculation of the mean outlet discharge for the open water season in 2001 was 0.7587 m^3s^{-1} ± 0.52 m^3s^{-1}. Outlet discharge exceeded 1.0 m^3 s^{-1} throughout the spring and early summer, falling below 1.0 m^3s^{-1} on August 9 and below the annual mean on August 24, 2001. Outflow discharges continued to decline in September and by mid-October were near the limit of meterable flows (0.0090 m^3s^{-1}).

Table 1: *Hydrometric measurements at Clear Creek gauging site (2001 data).*

Date	Lake Stage m	Site Stage m	Trend	Discharge m^3 s^{-1}	Mean Velocity m s^{-1}	X-Area m^2	Top Width m	Mean Depth m
5/08/01	615.601	0.2650	rising	1.3430	0.7299	1.8400	6.69	0.28
5/15/2001	615.623	0.2900	rising	1.4846	0.5637	2.6337	8.96	0.30
5/22/2001	615.613	0.2750	falling	1.3976	0.5337	2.6185	9.00	0.29
5/29/2001	615.582	0.2680	falling	1.2273	0.7671	1.5999	5.11	0.32
6/05/01	615.559	0.2460	falling	1.1012	0.6781	1.6240	5.26	0.31
6/12/2001	615.543	0.2240	falling	1.0405	0.6747	1.5426	5.27	0.29
6/19/2001	615.541	0.2140	falling	1.0195	0.6544	1.5579	5.37	0.31
6/28/2001	615.583	0.2650	rising	1.1920	0.6838	1.7432	5.28	0.32
7/06/01	615.541	0.2290	falling	1.1653	0.7342	1.5872	5.28	0.32
7/13/2001	615.513	0.1960	falling	1.0069	0.6811	1.4824	5.28	0.29
7/20/2001	615.532	0.2300	rising	1.1849	0.7628	1.5534	5.28	0.29
7/27/2001	615.521	0.2060	falling	1.1554	0.7859	1.4701	5.27	0.29
8/03/01	615.489	0.1650	falling	1.0412	0.7728	1.3473	5.27	0.26
8/09/01	615.484	0.1420	falling	0.9195	0.7465	1.2318	5.26	0.24
8/17/2001	615.433	0.0840	falling	0.5367	0.6287	0.8536	4.88	0.19
8/24/2001	615.395	0.0420	falling	0.4610	0.5990	0.7696	4.80	0.23
8/30/2001	615.373	0.0170	falling	0.3215	0.5274	0.6096	4.55	0.21
9/06/01	615.331	0.2500	falling	0.1846	0.4062	0.4545	3.45	0.17
9/12/2001	615.329	0.3180	falling	0.1512	0.3296	0.4588	3.53	0.19
9/20/2001	615.306	0.2890	falling	0.1084	0.2800	0.3872	3.30	0.16
9/26/2001	615.291	0.2980	falling	0.0873	0.2732	0.3195	3.19	0.15
10/4/2001	615.275	0.2100	falling	0.0521	0.2365	0.2203	1.87	0.10
10/11/01	615.240	0.0360	falling	0.0157	0.1266	0.1240	1.65	0.09
10/18/01	615.228	-0.0860	falling	0.0090	0.1488	0.0605	1.05	0.07
Mean	615.455	0.2069		0.7586	0.5552	1.1704	4.79	0.24
Std. Dev.	0.128	0.0873		0.5165	0.2133	0.7342	1.89	0.08
Maximum	615.623	0.2980		1.4846	0.7859	2.6337	9.00	0.32
Minimum	615.228	-0.0860		0.0090	0.1266	0.0605	1.05	0.07
Range	0.395	0.3840		1.4756	0.6593	2.5732	7.95	0.25

There were no recorded lake outflows during November and December 2001.

With the exception of the October lake stages, lake levels, recorded for the open water season, were above the long-term mean of 615.275 m elevation (McGinn *et al*. 1998). Following the spring freshet in mid-May, lake stages generally fell throughout the year with the exception of lake stage responses to two periods of heavy rainfall on June 28 and July 20.

Two rating curves were constructed (Figures 3 and 4). Figure 3 illustrates the traditional plot of channel stage (staff gauge at the 'old' Environment Canada gauging site) and stream discharge for Clear Creek. The plot clearly illustrates the influence of beaver dam flooding and variable backwater submergence on the stage-discharge correlation at low flows. Two trend lines have been constructed based on least squares techniques. The linear equation S = 0.08 Q + 0.13, shown by the solid black line in Figure 3, clearly is not representative of the stage-discharge relationship. Correlation analysis indicates a weak positive correlation (r = 0.4) and an explained variance (r^2) of 16.4%. The ellipse highlights those low water discharges and variable stages influenced by the construction of beaver dams. The second trend line S = 0.25 Q - 0.06, the

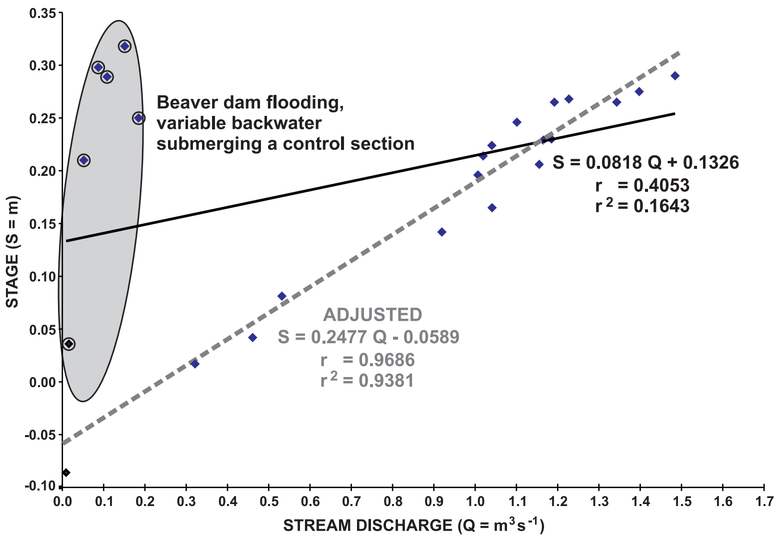


Figure 3: *Rating curves: Clear Creek near the outlet of Clear Lake (2001 data).*

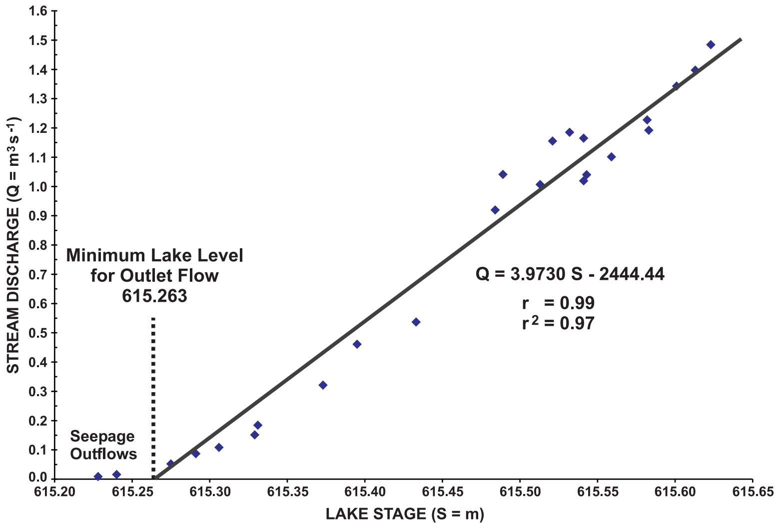


Figure 4: *Rating curve: Clear Lake outlet (2001 data).*

dashed grey line in Figure 3, represents the least squares regression function for the 2001 data excluding the highlighted low flow discharges and associated staff gauge heights. The r^2 value for this linear equation (0.94) indicates that a non-beaver-affected rating curve can be constructed for Clear Creek.

Figure 4 illustrates the constructed rating curve for lake stage and outlet discharge. The plot deviates from the traditional model in that stream discharge is dependant on lake stage. Consequently, discharge is plotted on the ordinate and lake stage on the abscissa. A linear trend line has been constructed based on least squares techniques. The linear function Q = 3.97 S - 2444.44, best represents the lake stage-discharge relationship. Regression analysis indicates a 0.99 positive correlation coefficient and 97.1 percent variance explained.

Discussion

In the traditional rating curve linear model where S = m Q + b, gauge height or stage is a function of stream discharge plus a constant. The slope (m) represents the rate of change in stage as a response to variation in the stream discharge. But in the lake stage-outlet discharge linear model, Q = m S + b, the slope (m) represents the rate of change in outlet discharge as a function of changes in lake stage. Parameters that account for lake stage variation are associated with the water balance of Clear Lake. These factors include: precipitation (rain and snow) directly deposited on the lake, rainfall and snowpack water equivalent depths over the watershed, runoff volumes, net groundwater effects, and evapotranspiration losses.

In the traditional rating curve, the intercept value (b) is indicative of zero outlet flow. The correlative in the lake stage-outlet discharge model is the intercept with the abscissa (b/m), which is representative of the elevation of the lake outlet sill. For the 2001 data lake stage rating curve, the intercept value representative of the Clear Lake outlet is 615.26 metres above sea level (Figure 4). The lake stage must be at a higher elevation for significant flow over the outlet sill. This critical elevation may be affected by many factors such as lake-ice effects, channel armouring and outlet scour, all of which have varied over the first nine seasons of operation. In 1994 and 1995, the mean elevation of the outlet sill was 615.39 m. ± 0.01 m. During the 1996 open water season the sill was eroded 15 cm to a base elevation of 615.24 m. In 1997, expanded lake-ice was observed to shove quantities of sand, pebbles, large cobbles and the occasional boulder on top of the outlet berm. This process raised the mean elevation of the outlet sill 4 to 8 cm. Higher outflows associated with the 1997 spring freshet winnowed the fines from the channel near the lake outlet and created a channel armour resistant to scour under normal flow conditions.

A grain size analysis of the outlet channel armour using the Wolman (1954) sampling methodology (N = 500 pebbles), indicated a median pebble size of 30.0 mm and a mean size of 33.2 ± 20.0 mm. The D_{65} and D_{90} percentile values (‘b’ axis diameter of the 65th and 95th largest rock) were 36 mm and 66 mm respectively. Galay (1971) suggests that bed material in this size range requires a mean cross-sectional velocity exceeding 1.13 m s^{-1} for entrainment (the critical erosion velocity). In 2001, the maximum recorded daily mean cross-sectional velocities during the spring freshet were calculated to be less than 0.8 m s^{-1}, a value well below the estimated critical erosion velocity of the bed armour. While there were no outlet discharge measurements recorded from 1998-2000, it appears that the Clear Lake outlet has been stable and has remained at the elevation of 615.26 m ± 0.02 m for the past five years (1997-2001).

The data set was expanded to include the discharge measurements recorded in the channel regime adjustment years 1994, 1995 and 1996 and the corresponding lake stage measurements. Figure 5 illustrates the

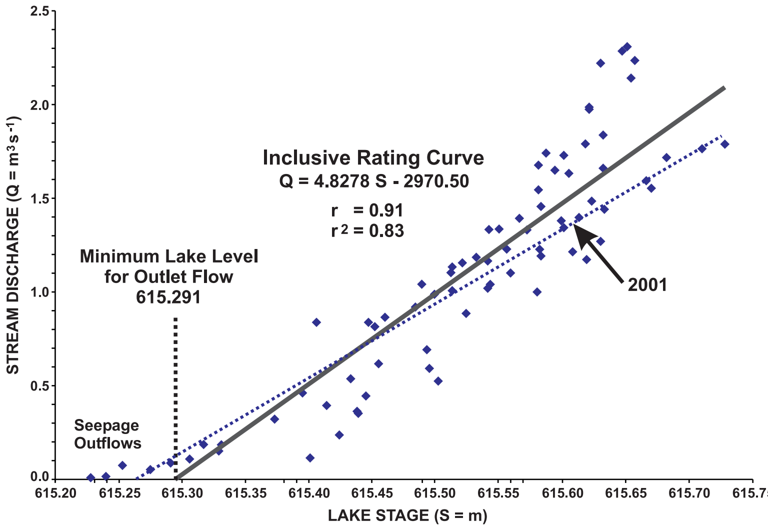


Figure 5: *Rating curve: Clear Lake outlet (1994, 1995, 1996 and 2001 data).*

constructed lake stage rating curve (the inclusive rating curve) and the results of the correlation and regression analyses. The linear model Q = 4.83 S - 2970.50 best fits the plot. The r^2 value indicates that the regression equation accounts for 83% of the variation in the data set. The calculated slope (4.83) is similar but steeper than the calculated slope (3.97) of the 2001 rating curve (the dashed line). The intercept value (615.291 m) is 2.8 cm higher than the intercept value calculated for the 2001 rating curve.

The inclusive rating curve, illustrated on Figure 5, has been influenced significantly by the 1994 and 1995 data. The calculated rating curve equation for these years (Q = 5.372 S - 3305.53) is similar in slope and intercept values to the Figure 5 inclusive plot. The 1994-1995 rating curve equation has a calculated r^2 value of 0.84, also similar to the 0.83 r^2 value for the inclusive rating curve. While these r^2 values (explained variance) are acceptable and imply that the inclusive rating curve is a reliable model for predicting outflow discharges, the fundamental assumption for the construction of a rating curve, that of channel regime, appears to have been violated. From 1994-1995, Clear Creek was not in regime, but degrading as it adjusted the stream channel geometry, specifically the elevation of the outlet sill, to accommodate outlet flows from Clear Lake. Consequently, the inclusive rating curve for Clear Creek should not be used for the estimation of outflow discharges from Clear Lake. In 1996 the rating curve intercept value was 615.24 m. The comparative value, five years later, in 2001 was 615.26 m, suggesting that the average outlet sill elevation had not changed significantly since 1996 and that Clear Creek had achieved regime. That being so, it is the 2001 rating curve (Figure 5) that should be used to estimate outflow discharges from Clear Lake.

Conclusion

From 1993 to 1996, Clear Creek has adjusted its geometry (average width, depth and slope) to the sequences of outlet discharges from Clear Lake. Since 1997, the outlet stream has achieved regime, predominantly by stabilizing the elevation of the outlet sill with a channel armour resistant to normal spring outflow discharges.

This study indicates that lake levels can be used as an effective alternative to channel stage in the construction of a rating curve for lake outlet streams which have achieved regime. In the case of Clear Lake this eliminates the problems related to the measurement of stage caused by beaver dam flooding and variable backwater effects. The resulting curve and mathematical model can be employed to estimate daily outflow from the lake.

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Reconstructing the historical stream flow from stream morphology in Duck Mountain, Manitoba

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Abstract: Stream flow data have been collected in the Prairie Provinces for nearly 100 years. However, records are incomplete in some regions as a result of budgetary and voluntary cuts. One such region is Duck Mountain, Manitoba. The hydrology of this upland is critical to its surrounding area because it houses headwaters for a large number of local streams. For a number of these streams, channel features such as width, depth, slope and bed material were measured. Using Manning's equation these data were analyzed to reconstruct bank and scour flows. Flow records for these streams were used to help establish inter-annual variability and trends. Flood frequency graphs were created to assist flow predictions and to augment records. The purpose is to create a regional analysis that can help define natural conditions. Since commencement of water data collection in the region there has been increased human development. This paper discusses the methodology as well as some results of the research.

Key words: flood frequencies, stream morphology, flow probabilities, Manning's equation, reconstructing streamflow, Duck Mountain

Introduction

Channel width, depth, slope and scour are a direct result of previous stream flows. Leopold and Maddock (1953) recognized that as discharge changes, the channel adjusts to accommodate the flow by changing morphology. In the Prairies, snowmelt events have particular influences on stream dynamics and channel morphology (Newbury and Gaboury 1993). The proposed research uses channel features along with flow records to reconstruct historical flow. By interpreting regional stream channel dynamics and regional hydrologic records, the natural hydrology for the associated area can be reconstructed (Thorne 1998).

As suggested by Thorne (1998), stream morphology can be used to augment flow records and can provide more accurate analysis. By combining flow records and stream morphology researchers can predict trends (Yang and Stall 1973). Predicting outputs from watersheds enables the simulation of impacts of land use and climate change on water resources.

Human activities such as engineering, agriculture and forestry have altered the natural state of lands and rivers. In the Prairies, parks and parkland make up most of the area having minimal human impact. The hydrology of Duck Mountain, Manitoba is significantly different from but very important to the surrounding plains. Because of flooding and wet conditions in Duck Mountain, local populations and water managers divert streams and drain much of the land. Agricultural producers are pressuring local authorities to divert and dam natural streams to better suit their needs (Whitney *et al.* 1988). At the same time on the upland, the forest industry may be altering natural watersheds.

There has been an increasing concern about the effects of possible global warming on stream flow (Dvorak *et al.* 1997; Boorman and Sefton 1997; Whitfield and Cannon 2000). Nemec and Schaake (1982) noted that climate change would make it even more difficult to predict future flows when designing water resource structures. Yulianti and Burn (1998) investigated climatic change impacts on stream flow conditions in the Canadian Prairies and noted that flow decreased as temperature increased. Muzik (2001) concluded that there is a high probability of increased frequency and magnitude of storm events. In Britain, Arnell (1996) studied the impacts of warming trends on river flows and water demands concluding that demand would probably exceed supply. Such effects could dramatically affect water management projects in the Duck Mountain region.

Objective

The objective of this research is to determine the natural stream flow characteristics and to reconstruct the magnitude and frequency of historical floods in the Duck Mountain region based on historical data and field measurements. With the reconstruction of natural stream flow, impacts from forest harvesting, agriculture and climate change can be assessed. The goal is to contribute to the development of practices and strategies for water resource managers that account for the natural variation in geomorphic and hydrologic systems.

Study Area

The Manitoba Escarpment, which separates the Saskatchewan Plains from the Manitoba Plains, has four distinct physiographic units: Pembina Hills, Riding Mountain, Duck Mountain and Porcupine Hills. This research concentrates on the Duck Mountain region. Duck Mountain has steep slope gradients on the north and east sides, whereas the south and west sides have gradual slopes. Total relief is approximately 500 m. The top of the escarpment is topped by glacial drift, which can reach 300 m in thickness (Chapman 1987).

Because the surficial geology consists of glacial till there are high infiltration rates. The storage capacity of the hilly topography is evident in the numerous bogs and springs throughout the upland region (Whitney *et al.* 1988). Duck Mountain is strewn with numerous lakes and streams, is completely forested and considered part of the Boreal Plains Ecoregion. The escarpment is located within the humid continental climate zone with generally less than 60 cm of precipitation per year, of which one-third is winter snowfall (Chapman 1987). It was not until the completion of the Canadian National Railway to Swan River in 1899 that settlement occurred and soon after agricultural and forestry activities began (Manitoba Natural Resources 1997).

Methodology

Data used in the analysis include digital maps of topography, soils, surficial geology, and forest cover. Environment Canada has supplied hydrometric data dating back to the early 1900s for numerous stations in and around Duck Mountain. A digital elevation model (DEM) was used to determine slopes, elevations and drainage basin areas. Field data were included such as stream slope, depth, width, velocity and channel shape. As well, bedload size was measured to reconstruct scour and bankfull flows.

Before any field data were collected, mean annual, mean monthly and maximum monthly hydrographs were constructed for each gauged river using data from Environment Canada (Environment Canada 1996). Figure 1, shows the mean annual hydrograph for Swan River indicating wet and dry periods and extreme years. Figure 2, shows the mean and maximum monthly hydrograph for North Duck River indicating the magnitude and length of spring runoff.

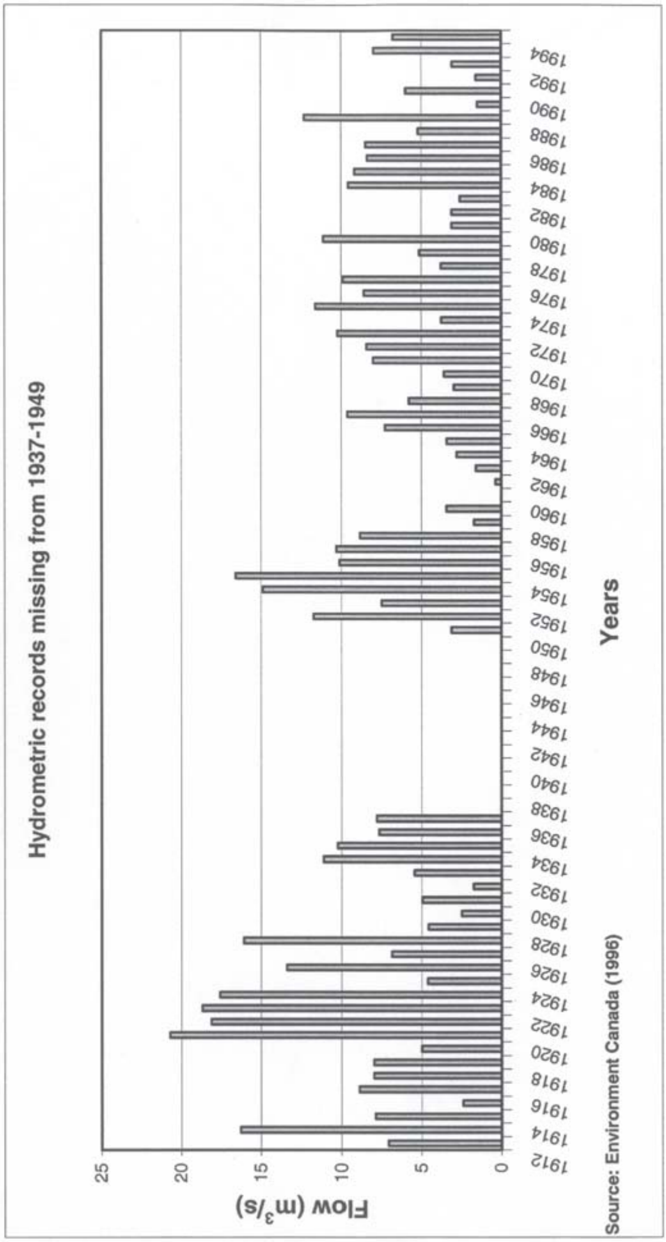

Figure 1: *Mean annual flow hydrograph for Swan River at Swan River, Manitoba, 1912-1994.*

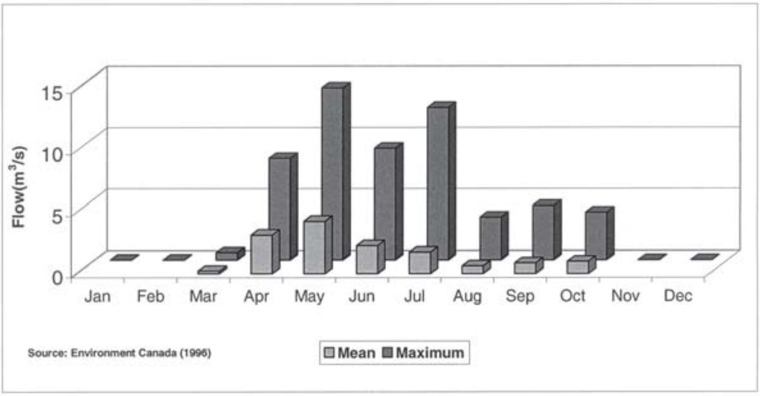

Figure 2: *Mean monthly flow hydrograph for North Duck River at Cowan, Manitoba (05LG004).*

Reference sites were located for each stream according to the following criteria (Harrelson *et al.* 1994): 1) what do we want to know about the stream or drainage; 2) what geographic variations (geology, elevation, land use) exist in the area; 3) what is the most useful comparison with the fewest sites; 4) how can this site contribute in determining natural hydrologic conditions; and, 5) how much can be accomplished with present resources? Reference site selection also depended on the size of the stream, accessibility, stability and hydraulic conditions (Herschy 1985). Sites were ruled out if there seemed to be disturbances from humans and wildlife. To maximize reliability of these sample sites, the reach lengths were set at 100 m to include an entire meander with hydraulic evidence sufficient to accurately characterize the streams (Herschy 1985). In all 12 streams were selected and a total of 42 reference sites were established. The cross-sections were then located where the best evidence exists for the channel boundaries. The procedures and techniques for surveying stream cross-sections are common (Herschy 1985; Harrelson *et al*. 1994; Thorne *et al.* 1996; Thorne 1998). The field manual compiled by Newbury and Gaboury (1993) was followed.

Cross-sections representative of the stream reaches and channels were created for all research streams. On larger streams, Environment Canada has predetermined reference sites and gauging stations. Wherever possible these predetermined reference sites were used in the analysis. Figure 3, shows the cross-sections for Roaring River. Cross-sections were surveyed using a stadia rod and automatic level. Special attention was paid to

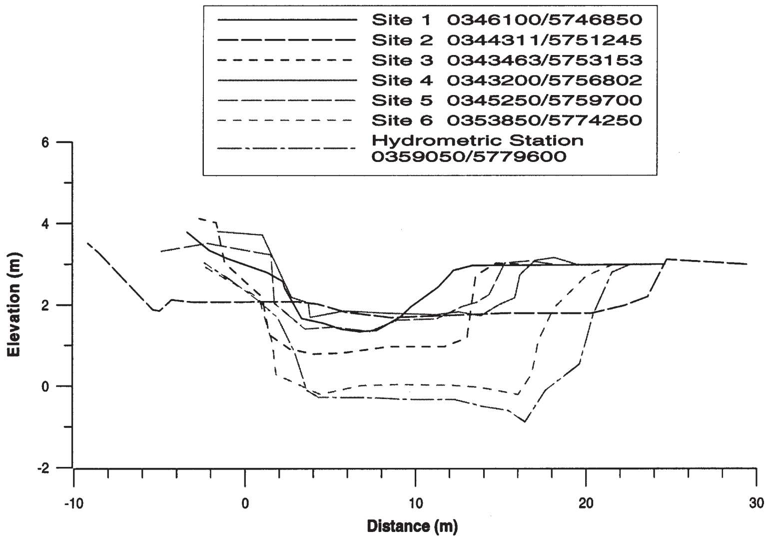

Figure 3: *Cross sections at reference sites and hydrometric station on Roaring River, Manitoba.*

determining banks and locating scour marks. Cross-sections were then overlain to compare channel shape and symmetry among reaches.

At each reference site depth, width, velocity, discharge, slope and bed load were measured. Depth and width were measured using a measuring tape, stadia and automatic level. To determine discharge, a *Price 1210 AA* flow meter was used to measure velocity. Velocity was measured at 6/10^{ths} the depth across the stream in a number of equally sized increments based on uniform bed conditions. Discharge (Q = VA) was determined for each reference site by summing the unit discharges across the stream (Newbury and Gaboury 1993).

Slope was determined using the automatic level and stadia. Measurements were taken at the water's surface from pool to pool or riffle to riffle. Where possible the measurements included at least two complete meanders in order to get a true reading of the slope. In some cases two to three slope measurements were averaged in order to determine true slope in short river bends.

Bedload was sampled and measured by wading through the channel and selecting clasts at random intervals (Newbury and Gaboury 1993). Each sample consisted of thirty clasts of various sizes and shapes. For

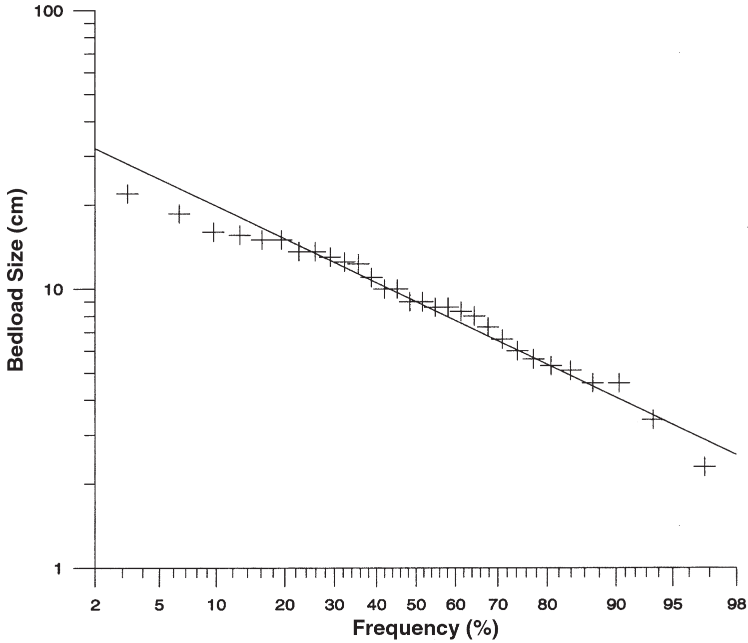

Figure 4: *Bedload frequencies of Site 1 for Fishing River, Manitoba (0391850/ 5700010).*

each sample the tri-axial mean was calculated. Figure 4 shows the frequency distribution of bed material at one site on the Fishing River. Bed materials smaller than certain sizes are moved and deposited during channel maintenance flow or bankfull flows (Hickin 1995; Baker 1973; Newbury and Gaboury 1993).

Bank flow discharge was then estimated using Manning's equation (Herschy 1985; Newbury and Gaboury 1993; Harrelson *et al.* 1994; Newson 1994; Petts and Amoros 1996):

$$v = \frac{R^{2/3} s^{1/2}}{n}$$

$$R = A / p$$

v = mean velocity
R = hydraulic radius of flow
s = average reach slope
n = Manning's roughness factor
A = cross-sectional area of flow
p = wetted perimeter of flow

When applying Manning's equation a channel resistance or roughness factor 'n' must be determined. This resistance factor can be directly related to bedload size using the empirical relationship derived by Strickler in 1923 (Newbury and Gaboury 1993). When the depth of flow is three or more times greater than median size of the bed material:

$$n = 0.04 \times d_{50}^{1/6}$$

n = Manning's roughness factor
d_{50} = median bed paving material size

Bank flow discharge 'Q_b' and scour discharge 'Q_s' can then be calculated from the estimated bank flow velocity and cross-sectional area ($Q = VA$). Annual flood frequency graphs were created for each stream by ranking the highest flows and assigning frequencies. The magnitude and frequency were graphed to indicate probabilities. The flood frequency for Shell River, Figure 5, includes the bankfull and scour discharges calculated using Manning's equation.

Results

The mean annual hydrographs show extended wet and dry periods and extreme years of the past century. The mean monthly hydrographs provide response times and duration of spring runoff while the maximum values give an indication on the magnitude of runoff events. As noted, this region receives a moderate amount of snow but the temperatures usually do not increase to above freezing until mid to late April. As shown in the monthly hydrograph in Figure 2, the runoff response begins in April and in most cases continues until June. By analyzing the maximum monthly flow values the severity of spring events can be compared to those of summer months.

The cross-sections created indicate the symmetry of the channels within each reach and can indicate deviations from the overall channel shape. This can signify stress on the system as well as possible alterations by humans or wildlife. In Figure 3 the cross-section at Site 2 for the Roaring River differs from the other surveyed channel shapes. Site 2 is near a farmhouse the occupants of which may have altered the channel.

From the bedload plots one can determine the frequencies of bed paving material and estimate the size of material moved during channel maintenance flow. From the constructed bedload frequency graphs materials within the 50% to 70% frequencies corresponds to material being

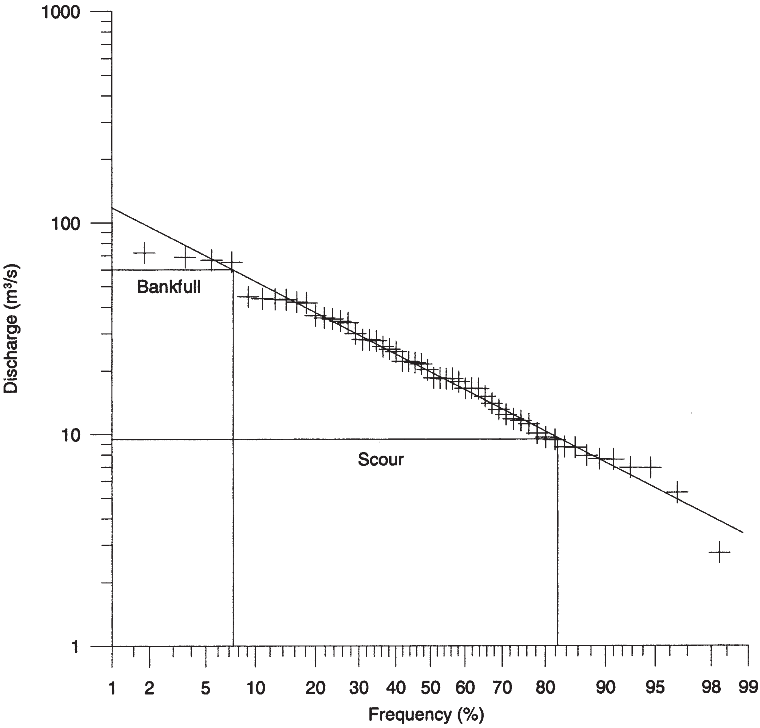

Figure 5: *Annual flood frequency of Shell River at Asessippi/Inglis, Manitoba (05MD001/05MD005).*

moved during bankfull flow. Figure 4, indicates that these frequencies correspond to mean bedload sizes ranging from 6 to 8 cm.

Using Manning's equation, the bank flow and scour discharges for Shell River were 60.4 m^3/s and 9.42 m^3/s, corresponding to approximately 7% and 82% of historical flows. The bank and scour discharges indicate the historical magnitude of floods in the Duck Mountain region. Table 1 shows the calculated bankfull and scour discharges for all of the reaches studied. The undetermined values for the scour discharges were the result of absent or conflicting scour marks within the channel. Where possible the scour and flood values were graphed with the flood frequencies to help determine associated probabilities.

Table 1: *Hydrometric variables and calculated bank and scour flow values.*

			Scour					Bank				
Stream	**Location**	**Site**	**w (m)**	**d (m)**	**A (m^2)**	**V (m/s)**	**D (m^3/s)**	**w (m)**	**d (m)**	**A (m^2)**	**V (m/s)**	**D (m^3/s)**
Pine River	0375200/5739750	1			undetermined			12.10	1.02	12.34	2.64	32.58
	0379250/5740300	2			undetermined			21.93	0.89	19.41	3.78	73.37
	0381850/5739600	3			undetermined			21.39	1.22	26.10	3.60	93.96
	0384950/5738990	4			undetermined			21.29	1.58	33.52	4.51	151.18
	0389350/5739600	5			undetermined			20.37	1.64	33.30	1.60	53.28
	0392300/5740100	6	13.70	0.63	8.63	1.50	12.95	20.01	1.10	21.91	2.17	47.54
Site # 05LG001	0394350/5742100	7			undetermined			15.00	1.50	22.49	0.91	20.46
Roaring River	0346100/5746850	1	9.70	0.95	9.22	2.98	27.50	17.20	1.12	19.18	3.32	63.60
	0344311/5751245	2			undetermined			23.80	1.56	37.13	4.42	164.10
	0343463/5753153	3			undetermined			14.30	1.91	27.31	2.68	73.19
	0343200/5756802	4			undetermined			15.40	1.55	23.87	2.25	53.71
	0345250/5759700	5			undetermined			15.03	1.43	21.42	1.90	40.59
	0353850/5774250	6	15.00	1.07	16.05	4.68	75.11	21.95	2.52	55.20	6.07	335.06
Site # 05LE005	0359050/5779600	7	16.50	1.12	18.48	0.75	13.86	22.00	1.72	37.85	0.99	37.47
Ruby Creek	0335500/5744200	1	5.50	0.39	2.17	3.18	6.90	8.25	0.60	4.97	4.22	20.96
	0335650/5744600	2	4.10	0.52	2.13	1.16	2.47	8.30	0.71	5.92	1.43	8.46
	0334300/5747450	3	4.20	0.16	0.66	1.89	1.24	10.02	0.63	6.31	4.78	30.16
	0340100/5753500	4	7.30	1.03	7.52	0.41	3.08	9.70	1.14	11.06	0.44	4.87
	0343250/5760000	5	6.70	0.59	3.95	0.49	1.94	16.23	1.64	26.62	0.96	25.56
East Favel River	0362971/5758525	1	7.20	0.47	3.38	3.32	11.22	10.81	0.76	8.22	4.58	37.65
	0360950/5765650	2	7.90	0.70	5.54	1.17	6.48	13.63	1.17	15.88	1.65	26.20
	0359500/5773650	3	9.20	0.93	8.52	1.79	15.25	13.93	1.89	26.33	2.88	75.83
West Favel River	0359950/5758450	1	11.30	0.69	7.74	3.47	26.86	20.28	1.35	27.28	5.43	148.13
	0357350/5763950	2	11.60	1.03	11.95	3.07	36.93	17.36	1.20	19.83	3.42	67.88
	0358400/5775800	3	9.20	0.96	8.83	1.82	16.07	15.04	2.11	31.73	3.08	97.73
Favel River	0360600/5781500	1	11.20	1.13	12.66	1.32	16.83	13.23	2.48	32.80	2.29	75.11
Fishing River	0391850/5700010	1	3.10	0.26	0.82	2.87	2.34	12.52	1.15	14.40	5.62	80.93
	0393550/5797150	2	4.50	0.26	1.17	1.28	1.50	18.75	0.67	12.62	3.38	42.66
	0401750/5701950	3	5.60	0.69	3.84	2.02	7.76	9.95	0.84	8.36	6.22	51.99
	0404950/5702550	4	4.60	0.60	2.77	0.87	2.37	15.50	0.79	12.20	2.66	32.45
Sclater River	0381200/5753700	1	10.20	0.69	7.04	4.60	32.38	16.11	1.22	19.57	6.71	131.31
	0389850/5755050	2	10.00	0.92	9.16	2.39	21.90	14.41	1.49	21.47	3.31	71.07
	0385700/5755000	3	7.70	0.74	5.67	1.98	11.23	12.62	1.06	13.31	2.52	33.54
North Duck River	0377940/5764290	1	16.80	1.27	21.25	3.85	81.80	18.65	1.48	27.51	4.27	117.47
	0384050/5764300	2			undetermined			20.77	1.41	29.29	2.87	84.06
Site # 05LG004	0386850/5765670	3	16.30	0.99	16.17	0.52	8.40	18.60	1.44	26.78	0.67	17.95
Garland River	0386800/5724250	1	5.70	0.47	2.70	2.02	5.45	24.80	1.60	39.68	3.88	153.96
	0391000/5724970	2	5.10	0.57	2.93	2.10	6.15	13.10	1.49	19.52	3.97	77.49
	0393990/5725250	3	6.80	0.70	4.77	1.05	5.01	8.85	1.51	13.36	1.75	23.38
Valley River	0360763/5685330	1	20.50	0.81	16.56	1.48	24.51	23.00	1.02	23.40	1.73	40.56
	0360368/5681458	2	14.20	0.82	11.60	3.67	42.57	23.20	1.44	33.40	5.35	178.69
	0370800/5672500	3	12.10	0.69	8.32	2.90	24.13	23.30	0.76	17.70	3.10	54.87
Fork River	0388210/5710750	1	7.10	0.54	3.83	3.26	12.49	12.52	1.15	14.40	5.62	80.93
	0391010/5710700	2	5.80	0.41	2.36	2.42	5.71	18.75	0.67	12.62	3.38	42.66
Shell River	0337280/5648090	1	15.00	0.44	6.54	1.44	9.42	27.00	0.94	25.27	2.39	60.40
South Duck River	0391200/5749850	1	5.70	0.52	2.96	1.14	3.37	8.89	1.22	10.85	2.01	21.80

Summary

The goal of this research was to determine the frequency and significance of previous floods in Duck Mountain. Data on the cross-sectional geometry of stream channels, and the distribution of flood deposits enable the reconstruction of peak stream flows, thus augmenting the existing hydrometric records. The results can be used to predict thresholds associated with future runoff and storm events. Combining geomorphological reconnaissance with historical records provides the best route in understanding and predicting natural streams (Thorne 1998).

The research design suggests that a program of long-term monitoring of runoff be developed in close consultation with forestry, agriculture and water authorities such that they will inherit the program by using the established reference sites and the sampling protocols to analyze ongoing human effects on the hydrology of these regions. Long-term hydrometrical and morphological monitoring represents the best way to understand fluvial systems and study reaches (Downs and Thorne 1996).

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Meander migration rates and age of the lower Assiniboine River

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Abstract: A 36-km reach of the lower Assiniboine River west of Winnipeg was studied to determine the age of its modern channel and rates of meander migration. The age of the modern channel was established by collecting samples from alluvium for radiometric or dendrochronological dating. *Bison bison bison* (Linnaeus) bones, removed from a depth of 2.4 m in a 2.6-m thick section of overbank and backswamp deposits, were dated at 2115 +/- 50 yrs BP (BGS-2318) and represent a minimum age for the channel. To establish rates of meander migration, four subfossil *Quercus macrocarpa* (Michx.) logs were collected from within two point bar sequences for dating, and meanders shown on aerial photographs from 1948, 1959 and 1968 were measured. Two logs, 45 m apart, had outermost ring dates of AD 1555 and 1622, indicating a lateral accretion rate of 0.61-0.67 m/yr. Two logs, 104 m apart, had radiocarbon dates of 480 +/- 40 yrs BP (BGS-2317) and 305 +/- 40 yrs BP (BGS-2316) indicating a lateral accretion rate of 0.41-1.09 m/yr. Migration rates for six meanders between 1948 and 1968 ranged from 0 to 1.0 m/yr, with mean and median rates of 0.4 and 0.3 m/yr respectively. Migration rates vary with differences in bank material on the concave sides of meanders, as the river is partially confined by Lake Agassiz clays. Migration rates of meanders eroding into glaciolacustrine clay ranged from 0 to 0.1 m/yr, while meanders eroding into alluvium had rates ranging from 0.3 to 1.0 m/yr.

Key words: Assiniboine River, fluvial geomorhology, meander migration, paleochannels, dendrochronology, radiocarbon dating

Introduction

Downstream of Portage la Prairie, the Assiniboine River has deposited an unusual floodplain fan (Rannie 1990) through a process of repeated alluvial ridge development and abandonment. As a result it has, at different times, flowed into either Lake Manitoba or the Red River (Rannie *et al.* 1989). A spatially dynamic history such as this brings into question the exact age of the lower Assiniboine River's modern channel, as it has implications for both the hydrological and sedimentological histories of

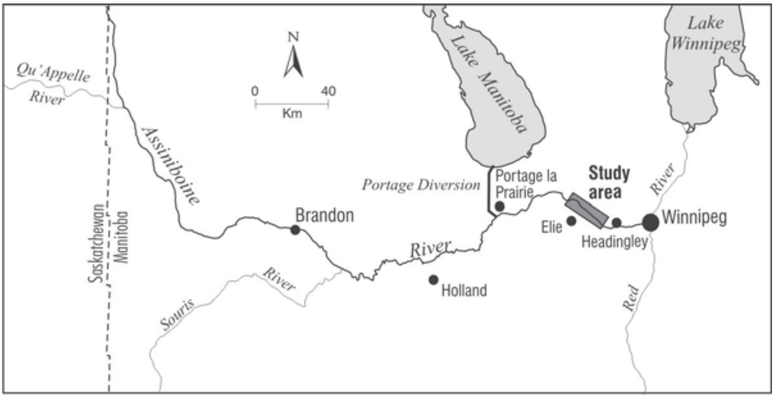

Figure 1: *The central and lower Assiniboine River.*

Lake Manitoba and the Red River, and for the geomorphological history of the landscape east of Portage la Prairie. Another aspect of the river's past is its rate of meander migration. This is of interest from a geomorphological perspective because lateral accretion sediments are a major component of a river's floodplain. However, rates of lateral migration may be of greater concern from a human perspective, because many people living next to the Assiniboine River have lost valuable land as a result of erosion of the concave banks of meanders (Riesen and Brown 1958). Thus, the goals of this study were: 1) to determine the age of the lower Assiniboine River's modern channel; and, 2) to measure its rates of meander migration.

The Setting

The Assiniboine River is a 1,290-km long perennial, meandering, suspended load stream with a gross drainage basin at Headingley, Manitoba, of 153,000 km^2 in eastern Saskatchewan, northwestern North Dakota and southwestern Manitoba (Rannie 1990) (Figure 1). However, much of the basin is internally drained, reducing the river's effective drainage area to approximately 60,000 km^2 at Headingley (Ashmore 1990). The flow regime of the Assiniboine River is almost entirely dependent on prairie runoff during the spring snowmelt (Figure 2). The Qu'Appelle and Souris rivers account for 64% of the Assiniboine River's effective drainage area; however, because of the relative dryness of the region, these tributaries accounted for only 38% of the mean annual discharge at Holland

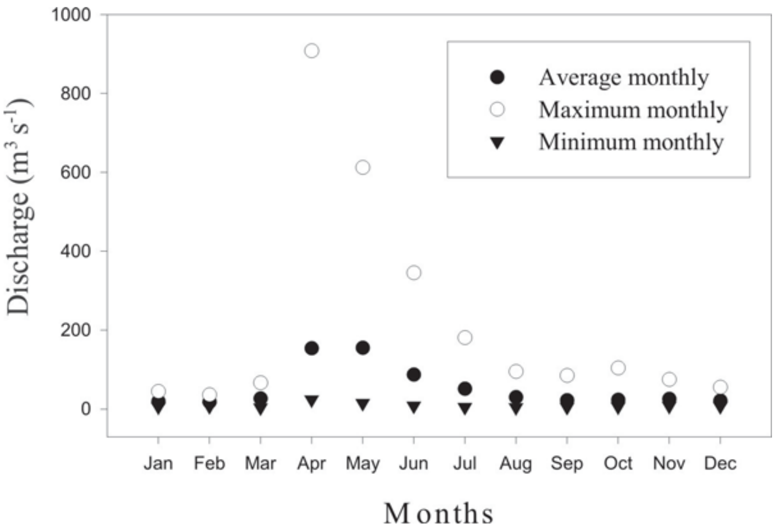

Figure 2: *Mean monthly flows at Holland, Manitoba, 1961-1998 (Environment Canada 2000).*

between 1975 and 1984. Thus, the streams draining the moister uplands of Manitoba are critical for maintaining flow (Ashmore 1990).

Between Brandon and Portage la Prairie, the Assiniboine River is confined by the Pleistocene glaciodeltaic sediments of the Assiniboine Delta, and it is probably in this reach that the river entrains most of its sediment (Rannie 1990). Downstream of Portage la Prairie, the river is not confined and experiences a reduction in slope as it encounters the Lake Agassiz clay plain, resulting in the deposition of an atypical alluvial floodplain fan through a process of repeated alluvial ridge building and avulsion. This process has left at least seven Assiniboine River paleochannels poised above the landscape east of Portage la Prairie and south of Lake Manitoba (Rannie 1990).

The grain sizes of suspended and bed loads decrease downstream. At Holland, bed material is approximately 20% gravel, but at Portage la Prairie and Headingley it is almost entirely sand (Rannie 1990). On average, the suspended load is more than 50% silt from Portage la Prairie to Headingley, and the sand fraction decreases from about 25% at Holland, to 15% at Portage la Prairie, to 3% at Headingley (Rannie 1990).

In 1970 the Portage Diversion and Reservoir began operation, significantly altering the downstream hydrology and sedimentology of the river. The Diversion and Reservoir have: 1) more than doubled the river's ability to convey discharges without overbank flooding; 2) reduced average daily discharge during April and May; 3) augmented flows during the summer, fall, and winter; and, 4) intercepted approximately 40% of the river's sediment load (Ashmore 1990). Furthermore, the Diversion and Reservoir have resulted in the cessation of alluvial fan building by almost eliminating the possibility of avulsion during low frequency discharges (Rannie 1990).

History

Nielsen *et al.* (1993) believed that by 7490 +/- 80 yrs BP (GSC-4839) (Table 1) the Assiniboine River occupied the same position as it does today based on the radiocarbon dating of a wood sample found in silty clay, in association with water-worn bison bones and freshwater pelecypod shells, and overlying fluvial gravels. Following this initial route to the Red River, the Assiniboine River has what is essentially a two-phase history.

Rannie *et al.* (1989) reconstructed a chronology of events based on radiocarbon dates, channel cross-cutting relationships, and soil maturity which showed the Assiniboine River draining into Lake Manitoba from approximately 7000 BP to 4500 BP, and then into the Red River from 3000

Table 1: *Selected radiocarbon dates from sites along the Assiniboine River and blind channel.*

Location	Age (years BP)	Lab No.	Depth (metres)	Material	Reference
Assiniboine River in Winnipeg	7490+/-80	GSC-4839	10.7	Wood	Nielsen *et al.* 1993 Morlan *et al.* 2000
Blind Channel	4230+/-70	BGS-1851		Wood	Morlan *et al*. 2000
Assiniboine River South of Marquette	2450+/-80	BGS-1635	1.0	Paleosol	Morlan *et al.* 2000
Site CWB-01-9	2115+/-50	BGS-2318	2.4	Bone	This paper
Site CWB-00-3	1660+/-45	BGS-2267	0.7	Bone	This paper
Site CWB-00-7	595+/-40	BGS-2304	5.0	Wood	This paper
Site CWB-00-4	520+/-50	BGS-2268	4.0	Wood	This paper
Site CWB-00-2	310+/-40	BGS-2266	4.2	Wood	This paper
Site CWB-00-5	125+/-40	BGS-2269	2.5	Wood	This paper
Site CWB-00-5	110+/-40	BGS-2303	3.6	Wood	This paper
Site CWB-00-8	480+/-40	BGS-2317	4.0	Wood	This paper
Site CWB-00-8	305+/-40	BGS-2316	3.3	Wood	This paper

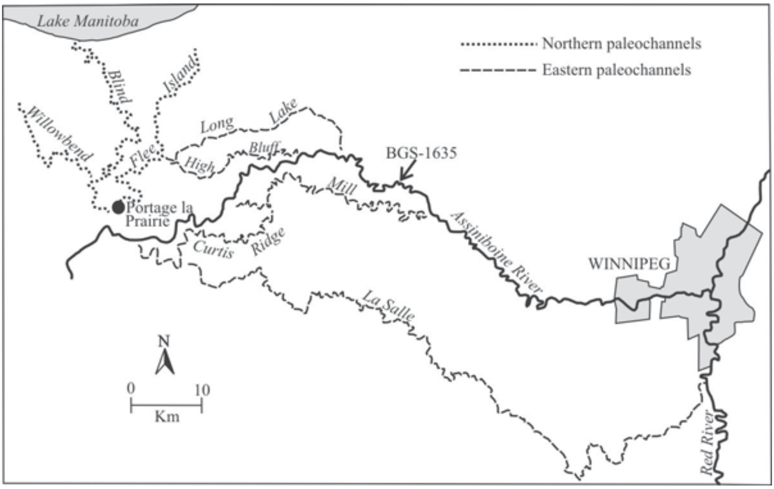

Figure 3: *Assiniboine River and paleochannels (redrawn from Rannie et al. 1989; Morlan et al. 2000).*

BP to the present (Figure 3). The initial drainage into Lake Manitoba was through the Willowbend and then Flee Island channels. This may have been interrupted by a period of eastward drainage into the Red River via the undated Long Lake and High Bluff channels, which may have had their outlets at the Forks in Winnipeg where the modern Assiniboine River joins the Red River. Drainage into Lake Manitoba had resumed by 4500 BP via the Blind channel (Rannie 1989), and in 1995 Nielsen collected a sample from that paleochannel, dating it at 4230 +/-70 yrs BP (BGS-1851; Morlan *et al.* 2000).

Rannie *et al.* (1989) determined that the Assiniboine River was draining into the Red River through the La Salle channel at about 3000 BP, and believed that the present channel on the lower portion of the floodplain fan, with its outlet at the Forks in Winnipeg (and the reach that concerns this study), was established sometime before 1300 BP via the Mill channel. However, a paleosol, formed on Lake Agassiz varved clay on the bank of the modern Assiniboine River (Figure 3), was dated by Nielsen and suggests that overbank sedimentation had begun by 2450 +/- 80 yrs BP (BGS-1635; Morlan *et al.* 2000). Nielsen (2001) noted that this date may be old because of the possible presence of old carbon, yet radiocarbon dates obtained from archaeology sites at the Forks also suggest that the channel was established prior to 1300 BP, and possibly soon after 3000 BP (Rannie 1999). By 700 BP the river was flowing through the Curtis Ridge channel immediately east of Portage la Prairie, and the entire modern channel of the

Assiniboine River was established sometime after 700 BP (Rannie *et al*. 1989).

Thus, the history of the Assiniboine River west of Winnipeg is complex. However, it seems certain that its most recent channel was in place by 1300 BP at the latest, and possibly soon after 3000 BP if the date obtained by Rannie *et al.* (1989) for the La Salle channel represents that phase's maximum age (Rannie 1999).

Study Area

The study area is a 36-km reach of the Assiniboine River located 45 km upstream of Winnipeg on the margin of the river's floodplain fan (Figure 4). The reach was chosen because it is easily accessible, there are numerous sections that exhibit alluvial deposits, and it was utilized by all of the paleochannels that followed the La Salle phase. As a result, samples collected from the area indicate a maximum age for the La Salle phase, and a minimum date for the initiation of the modern junction at the Forks in Winnipeg.

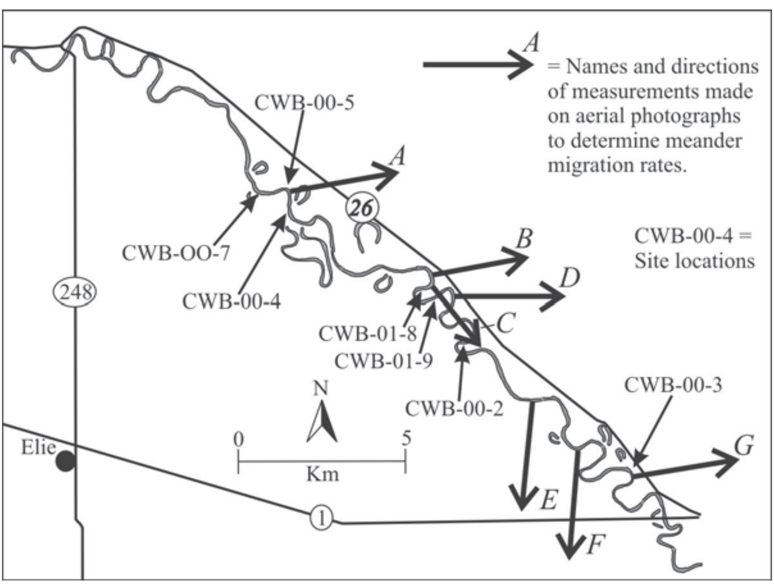

Figure 4: *The study area, site locations, and positions and directions of meander migration rate measurements.*

The reach has an unnaturally low sinuosity of 1.6 due to the large number of artificial channel cutoffs that have been constructed during the 20th Century to reduce flooding (Riesen and Brown 1958). In places, the channel is bounded by Lake Agassiz clay, which impedes its ability to meander freely (Figure 5). In many sections, glaciolacustrine sediments are found at the surface, while in others they are capped by overbank silts and clays. Channel deposits consisting of ripple cross-laminated sands and silts are common throughout the study area. The presence of Lake Agassiz sediments, coupled with the generally fine calibre of alluvium, can present a challenge when determining the provenance of sediments. A key indicator of fluvial deposition is the presence of fossil molluscs, which as a rule do not occur in Lake Agassiz sediments in Manitoba (Nielsen 2001).

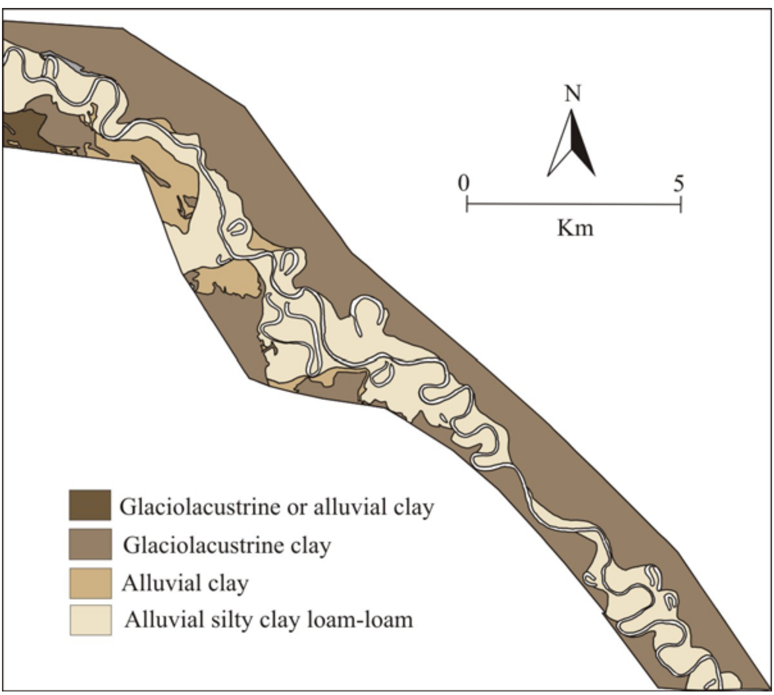

Figure 5: *Surficial materials of the study area (modified from Michalyna et al. 1975).*

Methodology

Age of the Channel:

To determine an age for the lower Assiniboine River's modern channel, material was collected from alluvium for radiocarbon or dendrochronological dating. The sections were then mapped and interpreted to establish a depositional and chronological context for the dates.

Meander Migration Rates:

The measurement of meander migration rates is at best a crude affair, as meanders may move laterally very rapidly over a short period of time and then remain static for decades (Wolman and Leopold 1957; Hickin 1974). Thus, rates of lateral movement should be measured over a long period of time. Two methods were employed in this study to measure meander migration.

The first involves dating subfossil bur oak (*Quercus macrocarpa* Michx.) logs. At site CWB-00-5, two logs were found 45 m apart in lateral accretion sediments of a point bar (Figure 6). The presence of dipping lateral accretion surfaces indicated the direction of bar growth (Miall 1992). The logs were dated using a combination of radiometric and dendrochronological methods, and the distance between them was measured so that an average rate of meander migration could be calculated. In a second point bar sequence (site CWB-01-8), two logs were collected 104 m apart and radiocarbon dated.

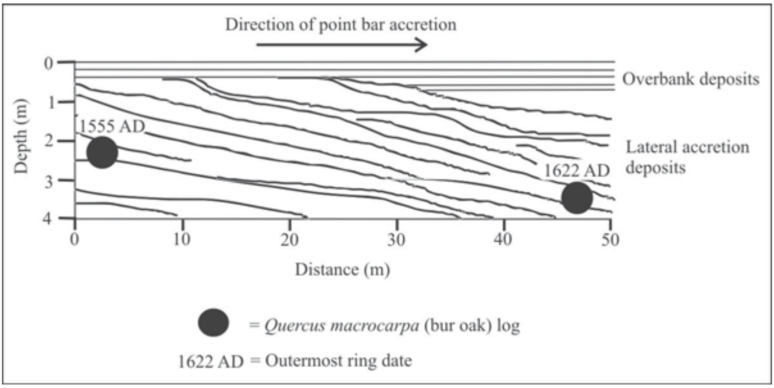

Figure 6: *Relationship between two subfossil logs dated to determine meander migration rate at site CWB-00-5.*

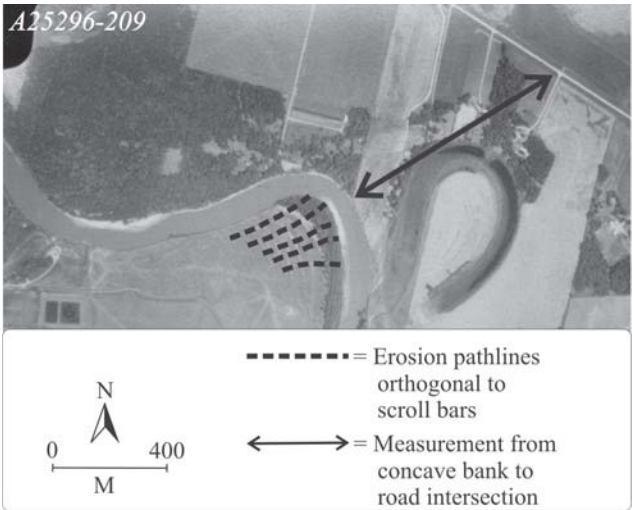

Figure 7: *Methodology used to measure meander migration rates from aerial photographs (after Hickin 1974).*

The second approach involved measuring meanders from aerial photographs taken in 1948, 1959 (scales = ~1:15,840) and 1968 (scales = ~1:20,000). Only photos predating 1970 were used to ensure that the measured rates were 'natural' and not influenced by the Portage Diversion. Because the photographs were not intended for this type of application, scales were recalculated in the vicinity of the meanders from 1:50,000 topographic maps or 1:20,000 township photographs. Meander migration rates were calculated for six meanders, with one meander having two determinations performed in different directions (Figure 4). Meanders were selected for measurement based on three considerations (Figure 7). First was the absence of any obvious human structures (such as roads) in proximity to the channel that may have produced artificial confinement. Second, meanders were examined for the presence of scroll bars, indicating that migration had occurred. The direction of these movements occurs orthogonal to the surfaces of scroll bars and can be represented by erosion pathlines (Hickin 1974). The longest orthogonal represents the direction of maximum erosion and is termed the 'erosion axis' (Hickin 1974). Third, meanders were selected based on the presence of road intersections in the vicinity of the channel, which acted as fixed points from which to measure the amount of lateral movement from photographs of different years. Thus, the angle of measurement was based roughly on the direction of migration as indicated by scroll bars. All measurements were made from the concave banks of meanders as these tend to be more vertical than the convex banks, facilitating the identification of the edge of the channel from the photographs.

Results and Discussion

Age of the Channel:

Samples collected to determine the age of the channel had radiocarbon dates of 2115 +/- 50 yrs BP (BGS-2318), 1660 +/- 45 yrs BP (BGS-2267), 595 +/- 40 yrs BP (BGS-2304), 520 +/- 50 yrs BP (BGS-2268), and 310 +/- 40 yrs BP (BGS-2266; Table 1). Two of these dates are older than those obtained by Rannie *et al.* (1989) and will be discussed below.

The oldest sample collected was from site CWB-01-9, where a 3.5-m section exposes 1.0 m of horizontally bedded overbank silts overlying a 1.6 m thick massive clay deposit. A paleosol occurs between 1.0 and 1.7 m, and the section is slumped below 2.6 m. Gastropod macrofossils were sampled from the paleosol at a depth of 1.25 m. The shells lacked spires and so could only be identified as *Physa* spp, a genus found in a wide variety of aquatic habitats (Clarke 1981). Numerous <0.01-m thick charcoal seams were present in the otherwise massive clays below 1.7 m. A bone horizon (*Bison bison bison* Linnaeus), located at 2.4 m, was dated at 2115 +/- 50 yrs BP (BGS-2318). The lack of diagnostic facies below 1.0 m makes classifying the lower portion of the section difficult. However, the presence of molluscs indicates that the deposits are alluvial in origin (Nielsen 2001), while the fine texture of the sediments, the presence of charcoal seams, and the substantial paleosol suggest that these sediments were deposited by overbank flows (Miall 1992; Nielsen *et al.* 1993) and probably accumulated in a backswamp environment (Miall 1992).

The second oldest sample was collected from site CWB-00-3. The 4.5-m section exposes 3.1 m of horizontally bedded overbank sediments overlying 0.90 m of Lake Agassiz clay. A *B. bison bison* radius was located at 0.70 m, between two paleosols at depths of 0.53-0.62 m and 1.00-1.40 m, and was radiocarbon dated at 1660 +/- 45 yrs BP (BGS-2267). Four shells were collected between 1.6 and 2.2 m and identified as two *Vallonia cyclophorella* (Sterki), one *Nesovitrea electrina* (Gould), and one *Succinea* sp., terrestrial gastropods whose presence indicates that this was a moist, low lying environment (Harris and Pip 1973; Pip 2001). The fine texture, horizontal bedding, presence of paleosols, and the occurrence of molluscs indicate that the upper 3.1 m are overbank deposits (Miall 1992; Nielsen *et al.* 1993).

The 2.4 m of alluvium below the bone does not necessarily imply a long period of deposition prior to the emplacement of the bone, as these sediments could have been deposited rapidly after the initiation of fluvial activity. However, the presence of a 0.40-m thick paleosol immediately below the bone suggests that a lengthy hiatus in alluvial deposition occurred prior to about 1700 BP. These lower sediments may have been deposited during the Long Lake/High Bluff phases of the river's history, in which case the paleosol may have developed during the La Salle phase. Alternatively, the paleosol may represent a reduction in sedimentation rates that occurred during the current phase of the Assiniboine River. For example, Nielsen *et al.* (1993) found comparable soil development within sections along the Red River, a stream that has occupied the same channel throughout its entire history.

The date of 2115 +/- 50 yrs BP (BGS-2318) implies that the present channel of the Assiniboine River was initiated much earlier than the minimum age of 1300 BP suggested by Rannie *et al.* (1989). This modification fits within the chronology established by Rannie *et al.* (1989) for a maximum age, but suggests that the Mill phase had commenced and the La Salle phase had ended prior to about 2100 BP. An approximate age of 2100 BP also suggests that older radiocarbon dates, such as Nielsen's 2450 +/- 80 yrs BP (BGS-1635; Morlan *et al.* 2000), and those that were obtained at the Forks (Rannie 1999; Morlan *et al.* 2000), may indicate that the Assiniboine River occupied its present channel prior to 2100 BP. Though younger than 2100 BP, the additional date of 1660 +/- 45 yrs BP (BGS-2267) serves to strengthen the notion that the Assiniboine River's present channel is much older than 1300 BP.

Meander Migration Rates:

Logs found in the point bar sequence at site CWB-00-5 were analyzed dendrochronologically and have outermost ring dates of AD 1555 and 1622. As a result of exposure to mechanical erosion, both logs lacked their outer sapwood, so seven to fourteen years must be added to their respective outermost ring dates (Nielsen 2001). The AD 1555 log was also radiocarbon dated at 125 +/- 40 yrs BP (BGS-2269). This radiocarbon date was rejected because it was too young to calibrate and does not agree with the tree-ring analysis. A third bur oak log, collected 89 m upstream of the first log in the same point bar section, was radiocarbon dated with an uncalibrated age of 110 +/- 40 yrs BP (BGS-2303), but its tree-rings could not be cross-dated. Based on the results of BGS-2269, this radiocarbon date was also rejected. The two logs, 45 m apart and dated at AD 1555 and AD 1622, indicate a rate of lateral accretion of 0.61-0.67 m/yr. The logs removed from the point bar sequence at site CWB-01-8 were 104 m apart and had calibrated radiocarbon dates of 480 +/- 40 yrs BP (BGS-2317) and 305 +/- 40 yrs BP (BGS-2316), both of which were considered good age estimates. Their stratigraphic relationship and ages indicate a rate of lateral accretion of 0.41-1.09 m/yr.

Over a twenty-year period, meander migration rates measured from aerial photographs had mean and median rates of 0.4 and 0.3 m/yr respectively, and ranged from 0 to 1.0 m/yr. Amounts of movement were variable, with one meander migrating 17 m between 1948 and 1959, and another showing no appreciable movement in twenty years. Variations in migration rates are probably the result of the different types of bank material on the concave sides of meanders, as the river channel is partially confined by Lake Agassiz clays (Table 2). Between 1948 and 1968, migration rates of meanders bounded by glaciolacustrine clay ranged from 0 to 0.1 m/yr and averaged 0.05 m/yr, while those meanders cutting into alluvium had rates ranging from 0.3 to 1.0 m/yr and averaging 0.6 m/yr.

There is good agreement between the meander migration rates established by the subfossil bur oak logs and the aerial photographs, particularly with those modern meanders whose concave banks are composed of alluvium. Thus, meander migration rates do not appear to have changed appreciably over the last 450 years (at least prior to the operation of the Portage Diversion).

Conclusion

Table 2: *Meander migration rates and associated surficial materials of the concave banks.*

Measurement	Rate of migration, 1948-1968 metres per year	Material of concave bank
A	1.00	Alluvium
B	0.05	Glaciolacustrine clay
C	0.65	Alluvium
D	0.10	Glaciolacustrine clay
E	0.00	Glaciolacustrine clay
F	0.60	Alluvium
G	0.30	Alluvium

The occupation of the modern lower Assiniboine River was dated at 2100 BP, an age that modifies that established by Rannie *et al*. (1989). However, this date does not alter the overall structure of their chronology. Rannie *et al*. (1989) determined that the Assiniboine River was using the La Salle channel at about 3000 BP and had initiated the Mill channel by 1300 BP. Thus, a substantial gap between dates existed, and exactly when the river switched positions was unclear. The additional date of 2100 BP indicates that the Mill channel was in use approximately 800 years earlier than was previously believed. A date of 2100 BP is also in agreement with other, older radiocarbon dates associated with an active Assiniboine River (Rannie 1999; Morlan *et al*. 2000), and does not preclude the possibility that the channel was initiated shortly after 3000 BP.

Prior to the 20th Century, two point bars accreted at rates of 0.61-0.67 m/yr and 0.41-1.09 m/yr respectively. Between 1948 and 1968, meander migration rates averaged 0.4 m/yr. Modern rates were heavily influenced by the composition of the concave banks, with those meanders eroding into glaciolacustrine clays averaging 0.05 m/yr, and those eroding into alluvium averaging 0.6 m/yr. The similarity between all of the meander migration rates suggests that they may not have changed appreciably over the last 450 years.

Acknowledgements

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The role of the Assiniboine River in the 1826 and 1852 Red River floods

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Abstract: Hydrologic conditions in the Assiniboine River basin during the extreme Red River floods of 1826 and 1852 are evaluated from historical sources. In both years, commentaries suggest that extreme floods also occurred in the Assiniboine, with the dominant source of water being the Souris River; in 1852 (and possibly 1826), the Qu'Appelle River discharge was also very high. It is concluded that the Assiniboine made large contributions to each of the epic historic floods, in contrast to its minor contribution to 'natural' flow in 1997. If reasonable allowance is made for the Assiniboine's contribution to the estimated total historical flows of the Red, it is likely that the 1997 discharge of the Red alone (upstream of The Forks) was larger than in 1852, but still much smaller than in 1826.

Key words: Assiniboine River, Red River, flood history, return period, 1826, 1852

Introduction

The historic floods of 1826 and 1852 which devastated the Red River Settlement are the benchmarks against which modern floods in Winnipeg are judged. Until 1997, these floods had discharges far beyond any in the period of gauge records (Table 1), and even the third largest historic flood (in 1861) paled in comparison.

The 1997 'natural' (i.e., uncontrolled) discharge in Winnipeg almost equalled the normally-accepted value for the 1852 flood and precipitated planning to increase the level of Winnipeg's protection to encompass a recurrence of 1826-magnitude or even larger floods. An improved understanding of the historic floods will add perspective to the 1997 event. Because the focus of the increased protection is on the Red River south of the city, the question of the relative contributions of the Red and Assiniboine Rivers to the total flows in the historic floods is especially relevant.

The 1997 flood was predominantly a Red River event, principally the result of an early April blizzard which blanketed the basin upstream of Winnipeg. The Assiniboine basin largely escaped the blizzard and the

Table 1: *Discharges of the Red River at Winnipeg during the 'Big Four' floods.*

Year	m^3/sec	ft^3/sec	Comment
1826	6,372	225,000	Calculated (Red River Basin Investigation 1953c)
1852	4,673	165,000	Calculated (Red River Basin Investigation 1953c)
1997	4,588	162,000	Natural flow[1]
1861	3,540	125,000	Calculated (Red River Basin Investigation 1953c)

[1] Natural flow is the flow which would have occurred without the operation of the Red River Floodway, Assiniboine Diversion or Shellmouth Dam

Assiniboine's discharge, although high, had peaked prior to that of the Red. Its natural flow had been reduced by storage in the Shellmouth Dam and as the Red's crest approached Winnipeg, the Assiniboine River was essentially 'shut down' at Portage la Prairie by diverting almost its entire flow northward to Lake Manitoba via the Assiniboine Diversion. Of the peak 'natural' discharge of 4,588 m^3/sec (162,000 cfs) in Winnipeg, 3,908 m^3/sec (138,000 cfs) arrived at the Floodway from the south and with local additions between the Floodway and the Forks, the Red River component was probably about 4,000 m^3/sec (141,000 cfs) or about 88% of the total combined flow.

Effective evaluation of the 1997 flood, then, should take account of this dominance of the Red River component. Ideally, the actual flows of the two rivers in each of the floods should be compared. The discharges during the 1826 and 1852 events, however, are not measured values but were calculated by the Red River Basin Investigation (1953a) using slope-area procedures based on water surface profiles obtained by the CPR in the 1870s. Thus they represent the combined flow of both rivers. The Red River Basin Investigation did not attempt to partition the relative contributions of the Assiniboine and Red and paid little attention to conditions in the Assiniboine basin during the floods.

Warkentin (1999) argued against the possibility of coincident major floods on the Red and Assiniboine Rivers, based on meteorological considerations and the absence of such coincident events in the gauged history of the two rivers.

> It is ... unlikely that causal flood parameters would be extreme over both the Red River and Assiniboine River watersheds for any given spring event. Weather systems simply are not

> large enough to produce very heavy precipitation over the entire area. If extreme inputs are used for the Red River Watershed south of Winnipeg, then it is very unlikely that they will also be extreme for the Assiniboine River Watershed, except perhaps for the downstream area from Brandon to Winnipeg. There is no reliable record of coincident major floods on the Red River and the Assiniboine River... The odds of coincident major floods on the Red and Assiniboine rivers are therefore very low based on observations as well as on the meteorological considerations ... (Warkentin 1999, V, 19-20).

Warkentin made these comments in the context of generating 2000 artificial spring peaks on the Red River from randomized combinations of flood-forming factors. Some assumption about the Assiniboine's contribution was necessary, and for this purpose his observations are reasonable. The correlation between annual peak discharges on the two rivers is indeed modest (r = 0.40 between the Assiniboine at Portage la Prairie and the Red at Emerson) and the two basins exhibit considerable independence. Low probability, however, does not preclude such an occurrence having happened in the past, especially since the historic floods themselves had low probabilities (the 1826 event had an exceedance probability of about 0.2%). Warkentin further argued that some evidence for high Assiniboine flows presented by Rannie (1999) do not necessarily suggest conditions as extreme as were postulated.

In this paper, historical observations of the state of the Assiniboine River in 1826 and 1852 are reviewed and their implications for the relative magnitude of the 1997 flood in the Red River Valley are discussed.

Sources of Floodwater in the Assiniboine Basin

The Assiniboine River at Portage la Prairie drains 153,000 km^2 of western Manitoba, south-central Saskatchewan and northwestern North Dakota (Figure 1). The watershed can be divided into four principal regions, namely: the upper basin above Kamsack, Saskatchewan, the Riding/Duck Mountain uplands, the Qu'Appelle River watershed, and the Souris River watershed. These together account for more than 85% of the total basin area and individually contribute to major Assiniboine floods in varying proportions.

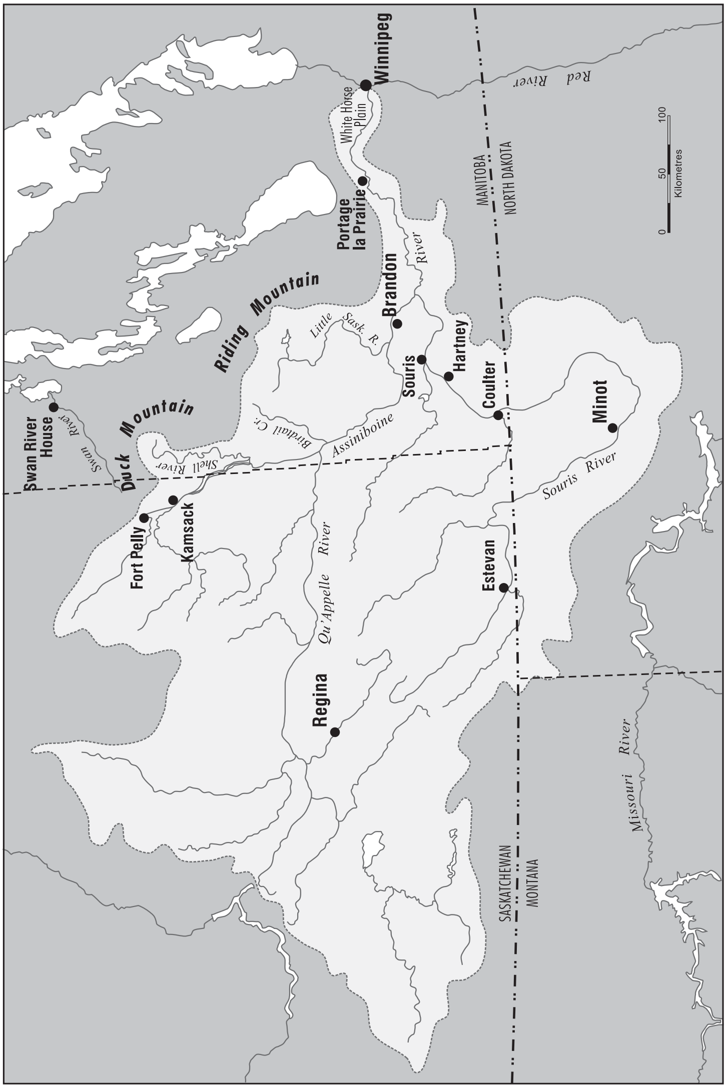

Figure 1: *The Assiniboine basin.*

Peak flows during eleven major events are given in Table 2. The peaks in 1882, 1902 and 1904 are estimated values at Brandon, derived by PFRA (1952) using the Manning Equation and water elevations. The possibility that they overestimate discharge is offset by the fact that they do not include contributions from the Souris which joins the Assiniboine downstream of Brandon. Annual peak discharges of the Assiniboine (at Brandon) and the Souris are strongly correlated ($r = 0.90$). It should be noted that the individual peaks are given only to illustrate the variability in the contributions from each sector from flood to flood. Differences in the timing of the peaks on individual rivers and the routing of the flow downstream would alter their actual contributions to the peaks along the Assiniboine. In some years (e.g., 1913, 1922, 1923, 1927), the majority of the flood water originates in the upper basin; in others, the Souris is the dominant contributor (e.g., 1882, 1904, 1969, 1974, 1976). The Riding/ Duck Mountain and Qu'Appelle contributions are normally the smallest components, but in some years (as in 1955) they may account for a large part of the flood discharges at Brandon.

Discharges for a range of frequencies for each sector are given in Table 3. The pivotal role of the Souris in the extreme floods on the lower Assiniboine is clear from Tables 2 and 3. In the largest recorded event, in 1976, the Souris peak was higher than any *recorded* discharge on the Assiniboine itself prior to 1974 and transformed a 25-year event at Brandon

Table 2: *Sources of peak flows for selected floods of the Assiniboine River.*

	Peak Flow (m^3/sec)										
	1882	1902	1904	1922	1923	1927	1955	1956	1969	1974	1976
Upper Assiniboine (Kamsack)	---	---	---	504	411	357	239	203	64	190	273
Qu'Appelle (Tantallon#/Hyde=)	---	---	---	56#	---	---	240#	157#	84=	122=	206=
Souris (Wawanesa)	646[1]	---	340[2]	58	167	65	116	205	323	345	742
Riding/Duck Mountain tributaries*	---	---	---	---	---	---	88	116	139	155	188
Assiniboine at Brandon	1,218[3]	692[3]	904[3]	603	651	484	541	430	360	309	617
Assiniboine (Holland#/Portage la Prairie+/Headingly=)	---	---	---	547=	626=	578=	629+	637+	626+	909#	1,460#

* Riding/Duck Mountain tributaries = Little Saskatchewan + Birdtail + Shell
[1] estimated flow at Minot, ND (Long 1976)
[2] measured flow at Minot, ND (Long 1976)
[3] estimated flow at Brandon (PFRA 1952)

Table 3: *Discharge (m³/sec) for selected return periods on the Assiniboine River and its major tributaries.*

	Return Period (years)					
	10	25	50	100	150	200
Assiniboine at Kamsack	225	365	500	650	760	850
Qu'Appelle at Tantallon/Welby	87	128	160	195	220	235
Riding/Duck Mountain tributaries						
Shell at Inglis	49	66	80	95	104	111
Little Saskatchewan near Rivers	75	100	119	136	148	155
Birdtail near Birtle	38	52	64	76	84	105
Souris at Wawanesa	225	400	570	800	960	1,150
Assiniboine at Brandon	470	660	830	1,010	1,130	1,220
Assiniboine at Portage la Prairie	620	840	1,010	1,210	1,350	1,420

Source: frequency curves provided by D. Kelln, Manitoba Surface Water Management

into a >200-year flood downstream. In 1882, the Souris discharge at Minot, ND (far upstream of the junction with the Assiniboine with a drainage area only about 45% of the full basin) was estimated to have been 646 m^3/sec and, in combination with the extraordinary discharge at Brandon, it is likely that on the lower Assiniboine this event was even larger than the record gauged flood of 1976. In 1904, the measured peak at Minot (340 m^3/sec) and the estimated peak at Brandon also indicate a very large discharge below the confluence. It should be noted that the large discharges for the Souris in the 1955 to 1976 floods occurred despite increasing regulation of the river from the 1930s onward.

Assiniboine in 1826

The only direct observations of the Assiniboine's status during the 1826 flood come from the Red River Settlement at the river's mouth and from Fort Pelly in the upper basin. At the Red River Settlement, little direct mention was made of the Assiniboine but the use of the plural 'rivers' in several of the abundant descriptions of rising stages implies very late breakup and high water in concert with the Red.

> May 1: ...showers of snow, sleet and rain throughout the day-The ice in the Rivers begins to rise in consequence of the flush of waters pouring into them from the plains and

> mountains, caused by the melting of the snow... (*Red River Journal*, HBCA [Hudson's Bay Company Archives] B.235/a/7 1825/26).
>
> May 3: The ice in the Rivers has attained the height that the floods reached at the highest pitch last summer, and the water in several places has overflowed the banks and many houses are surrounded thereby (*Red River Journal*, HBCA B.235/a/7 1825/26).
>
> May 4: The water in the Rivers rose about 5 feet perpendicular during the last twenty-four hours, and the ice is now on a level with the highest banks, but it is still so thick and strong that even the present flush of waters have not sufficient force to break it... (*Red River Journal*, HBCA B.235/a/7 1825/26).
>
> May 7: About 4 A.M. the ice in the Assiniboine River broke up, and the waters therein rose as high as those of the Red River. The immense discharge of ice poured in from the former, into the latter mentioned rivers, made the scene as destructive as terrific. The whole population were again in motion, flying to such situations as might afford them a temporary security, leaving in many instances their cattle to perish, and most of their other effects to be swept away; happy in escaping with their lives... (*Red River Journal*, HBCA B.235/a/7 1825/26).
>
> May 8: The rivers have become almost clear of ice, but the waters increase apace (*Red River Journal*, HBCA B.235/a/7 1825/26).

These comments cannot be taken at face value, however, because observations of the Assiniboine from the Red River Settlement are within the backwater zone of the Red River and, given the stages of the Red, the Assiniboine would have been described as high regardless of its own discharge. More definitive data, then, must be sought upstream of the backwater zone.

The only *direct* upstream observations come from Fort Pelly in the upper Assiniboine basin near the modern settlement of Kamsack, Saskatchewan (Figure 1). There, breakup of the river was also very late and initial water levels were described as high.

> April 24: Rivers much Swollen the water running on the Ice which has not moved yet (*Fort Pelly Journal*, HBCA B.159/a/9 1825-26).
>
> April 29: ...the Ice in the Red [meaning Assiniboine] River beginning to move the River much Swollen (*Fort Pelly Journal*, HBCA B.159/a/9 1825-26).
>
> May 1: the Ice Still strong in Red [meaning Assiniboine] River (*Fort Pelly Journal*, HBCA B.159/a/9 1825-26).

As the flood on the Red River grew to epic proportions, however, the Fort Pelly Journal made no mention of the state of the Assiniboine. Daily entries after May 1 contain only brief and benign routine weather observations with no further attention to the river until May 17 when water levels were still described as high.

> May 17: Stormy weather the wind blew from all points of the compass-some thunder and rain...[Buffalo are] now within two Days march of us but the water is so high that it is impossible to get to them some rain in the after noon (*Fort Pelly Journal*, HBCA B.159/a/9 1825-26).

These references to "high" water are difficult to interpret in terms of actual water levels but a comment made four years later suggests that the level of the upper Assiniboine in the vicinity of Fort Pelly was not nearly as extreme as in the Red River and indeed was possibly not even overbank.

> May 14, 1830: Keen frost in the night...The country in our vicinity all overflowed the Red River [meaning Assiniboine] not known to be so Hi in this quarter for many years, it did not overflow its banks Here the Year the Colony was overflowed (*Fort Pelly Journal*, HBCA B.159/a/11 1829-30).

In the Red River watershed, the 1826 flood was caused by the preconditions which typically lead to large floods. As Alexander Ross wrote in his classic description of the flood:

> The previous year had been usually wet; the country was thoroughly saturated. The lakes, swamps, and rivers at the fall of the year were full of water; and a large quantity of snow had fallen in the proceeding winter (Ross 1856, 106).

The Assiniboine basin also experienced spring flooding and heavy late-summer rainfall in 1825, and by late September both the Red and Assiniboine Rivers were rising. Frequent rain (and snow) was reported at Fort Pelly in October and it is concluded that at freeze up, the basin in the Fort Pelly region was in a saturated state. However, the daily weather entries at Fort Pelly from November 1825 to April 1826 do not suggest especially severe or abnormal winter weather conditions in the upper basin. Intense cold certainly occurred but was broken by periods of more moderate temperatures. Snow or rain was reported on only 24 days from November 1 to March 31, a modest total, with about two-thirds of the observations indicating light amounts (Rannie 2001). Several apparently heavy falls in late February, mid-March, and on April 7 would have increased runoff potential (especially given the moisture status of the basin in the autumn). In summary, although the Fort Pelly data provide some support for moderately high spring runoff, there is little in the record from the upper Assiniboine basin which would indicate spring conditions of the magnitude experienced in the Red River Valley. Entries for Fort Pelly after May 17 are also routine weather observations with no mention of the state of the river, suggesting that it was not sufficiently high to warrant comment.

The first mention of excessively high water *in the region* came from reports received from Swan River House (approximately 90 km to the northeast) on May 14.

> May 14: ...the [Swan] River has overflowed its banks and [the men there] are under great apprehension for the safety of the property (*Fort Pelly Journal*, HBCA B.159/a/9 1825-26).

On May 28, the Fort Pelly party left for Swan River House. They encountered very difficult conditions along the route, and at Swan River House (May 31) they observed first-hand the effects of severe flooding of the Swan River.

> May 28: rained much all day [en route to Swan River] (*Fort Pelly Journal*, HBCA B.159/a/9 1825-26).

> May 29: fine weather to day...the roads are impassable the carts are often aflote & the water & mud continually up to the knees [en route to Swan River] (*Fort Pelly Journal*, HBCA B.159/a/9 1825-26).

> May 30: march very slow owing to the high state of the water...Rained very much all Day the weather most stormy [en route to Swan River] (*Fort Pelly Journal*, HBCA B.159/a/9 1825-26).

> May 31: [Swan] River...[was] a most dismal looking place the water having washed away all the [houses]...rained much all Day (*Fort Pelly Journal*, HBCA B.159/a/9 1825-26).

The Swan River drains the Duck Mountain and it is reasonable to assume that similar conditions occurred in Riding Mountain immediately to the south. Both of these regions make important contributions to the Assiniboine downstream of Fort Pelly via such tributaries as the Shell, Birdtail, and Little Saskatchewan which join the Assiniboine between Fort Pelly and Brandon. It is probable, then, that whereas flow in the Assiniboine in the vicinity of Fort Pelly may have been relatively high, it was excessively so in the Riding/Duck Mountain tributaries and would have significantly increased Assiniboine levels downstream.

Other second-hand reports also suggest conditions on the Assiniboine which were as severe as those on the Red, apparently as a consequence of very high flow from the Souris basin.

> May 17: This morning I was conversing with an old Indian whose tent joined ours when I asked him if he had seen such a flood as this before, he said “No my father, I once saw the site of the Company’s Fort an island, but that was nothing to this”...Intelligence has just arrived from Brandon House which states that the country is all a sea between the sources of The Assiniboine and The Missouri; and that the waters of the latter are now passing by us to the Lake Winnipeg (*David Jones Journal*, PAM [Provincial Archives of Manitoba] CMS 18 A92 1825-26).

> May 20: Some freemen arrived from the upper part of [the Assiniboine] river, and report that the waters in that quarter are as high as with us. The Missouri River it appears by their accounts, has overflowed its banks, so as to drive part of its waters this way. They also say that a number of the natives of that quarter have been drowned in consequence. The waters continue rising... (*Red River Journal*, HBCA B.235/a/7 1825/26).

> August 21: Since my last we have received further accounts of the recent flood and I very much fear for the safety of the American Settlements on the lower parts of the Missouri and St. Peter's Rivers. Report says that some of their military posts have been overwhelmed and many soldiers drowned. We are also informed that several Indian villages have fallen victims to these destructive waters. It is now clearly ascertained that they flowed from the Rocky Mountains and passing over the banks of the Missouri (their usual channel to the Gulf of Mexico) overflowed the adjacent country; and were conducted here by the Riviere a La Souris which falls into the Assiniboine River about one hundred miles from this place. (extract from a letter by John Pritchard of the Red River Settlement cited by his grandson [S.P. Matheson] in Matheson, S.P., 1947 'Floods at Red River' *Transactions,* Manitoba Historical Society, Series III, No. 3, 5-13).

All three comments attributed the high flow of the Souris to overflow from the Missouri, suggesting that the information may have come from a single source. A Missouri origin for the water can be dismissed on topographic grounds but such an impression may have been created by widespread flooding along the loop of the Souris closest to the Missouri combined with extensive inundation of the land surface and filling of depressions by overland runoff. For example, notes from an aerial reconnaissance during the epic 1976 flood described this region as follows:

> Fields adjacent to Plum Creek near Souris were covered with water... The Souris River upstream of Hartney appeared to be one large lake area... The land east of the Souris River and south of Coulter was a myriad of lakes with only small patches of land showing. The Souris River by the International Boundary appeared to be one long endless lake stretching north and south. Road and railway crossings were barely discernable (Long 1976, 17).

In summary, although the Assiniboine at Fort Pelly was described as "swollen" in late April and "high" on May 17, the lack of mention of the river during most of the severe flood period on the Red is striking and the 1830 comment suggests that the upper reach of the river may not have exceeded bankfull stage. It seems likely, then, that runoff in the upper basin was high but not at all comparable in severity to the conditions in the Red River Valley. Nevertheless the other reports from the Brandon and downstream reaches indicate very high water and are explicit about the extreme state of the Souris. Thus it is concluded that the main sources of the high waters on the Assiniboine were the Souris and Riding/Duck Mountain sectors. The contribution of the Qu'Appelle is unknown but the strong correlation between the Qu'Appelle and Souris annual peak discharges (r = 0.88) suggests that it may also have been significant.

Assiniboine in 1852

The 1852 flood in the Red River basin was caused by very heavy snowfall in March with cool temperatures during much of April, a late breakup (April 26-27), a rapid transition to warm temperatures, and rain during the rising phase. Unfortunately, there are no weather observations from the Assiniboine basin during the winter and there is no way of knowing whether similar conditions occurred there.

In the vicinity of the Red River Settlement, the great majority of comments on river levels referred to the Red River but the Assiniboine was included in a number of observations.

> April 24: ...river rose last night about 2 inches ice unmoved...Ice has moved this evening in both rivers... (Diaries of Dr. William Cowan, PAM MG2 C15 M154).
>
> April 26: Ice unmoved on main river started about ½ past 8, and clear water as far as visible up and down. Assiniboine fast... (Diaries of Dr. William Cowan, PAM MG2 C15 M154).
>
> April 27: both rivers pretty clear of ice. Small river has fallen a little (Diaries of Dr. William Cowan, PAM MG2 C15 M154).
>
> April 28: River has risen more than a foot during the night...Ice commenced to run about 10 o'clock in the Assiniboine & still continues. river rising very fast... (Diaries of Dr. William Cowan, PAM MG2 C15 M154).
>
> May 19: ...The water gained upon us all day... a rise in the Assiniboine of 5 ½ inches during the night... (Anderson, D., 1852. *Notes of the Flood at Red River* 1852 by the Bishop of Rupert's Land. PAM MG7 B2 CMS A83).

Again, because of the backwater effect of the very high stage of the Red none of these comments positively indicate that the Assiniboine itself was high. Confirmation that the river was extremely high, however, comes from three comments by Abraham Cowley as he canoed down the lower Assiniboine at the time the Red was reaching its peak and beginning to fall.

> May 22: Reached Portage la Prairie; Here the people have been flooded out of their houses & we learn that the RR Settlement is also overflowed (*Journal of Abraham Cowley*, PAM MG7 B2 CMS A86).
>
> May 24: Left Portage la Prairie & descended the river till nearly sun set when finding a favourable place we encamped. It has become difficult to land when one wishes the banks being overflowed (*Journal of Abraham Cowley*, PAM MG7 B2 CMS A86).
>
> May 25: reached White Horse Plain much of it is overflowed learned more particulars of R. River flood it is I fear very extensive and destructive (*Journal of Abraham Cowley*, PAM MG7 B2 CMS A86).

When Henry Youle Hind explored the region in 1858, he made several comments on the severity of 1852 conditions in the Assiniboine basin. Particularly interesting are his observations which indicate exceptional flooding of both the Qu'Appelle and Souris Rivers.

> Leaving Prairie Portage ... we took the trail leading to the Bad Woods, a name given to a wooded district about thirty miles long, by the buffalo hunters in 1852, who, in consequence of the floods of that year, could not pass to their crossing place at the Grand Rapids of the Assiniboine by the Plain or Prairie Road... [and were] compelled to cut a road through the forest of small aspens which forms the Bad Woods, to enable them to reach the high prairies (Hind 1860, 283-84).
>
> In 1852... the Indians represent the Qu'Appelle Valley as filled with a mighty river throughout its entire length... (Hind 1860, 329).

> The country [adjacent to the Souris River near the HBC Sand Hills post] becomes very low after passing the last sand-hills, and over a large extent of prairie south of them, drift timber is distributed, showing the extraordinary rise in the waters of the [Souris] river during the floods of 1852 (Hind 1860, 295).

The region of the Souris described in the latter comment was approximately the same as that noted above as being observed from the air in 1976. The fact that the effects were still evident and noteworthy six years after the flood suggests an extremely large event.

Clearly the discharge of the lower Assiniboine in the spring of 1852 was extraordinarily high with very large contributions from the Souris and Qu'Appelle basins. Although no information is available for the upper basin or the Riding/Duck Mountain regions, high flows may also have occurred there.

Discussion

Antecedent conditions are particularly important for flood formation on the Assiniboine where a large portion of the basin which is normally non-contributing because of topography becomes contributing or 'effective' area when saturated. The 1826 flood occurred after the basin had been saturated by spring flooding and heavy late-summer rainfall in 1825. Antecedent conditions in the Assiniboine basin in 1851-52 are not known but unusually abundant rainfall and a large flood occurred in the Red River basin in the summer of 1851. A comment by Provencher suggesting flooding at White Horse Plain in July, 1851, implies that these conditions may also have applied in the Assiniboine basin and it is concluded that the basin was probably in a saturated state prior to freeze up in 1851.

> July 21, 1851: L'eau monte toujours et pourrait détruire la recolte dans les terres peu élevées; déjà c'est la cas a la Prairie du Cheval Blanc (Letter, J.N.Provencher, Evêque du Nord-Ouest, to L'Archevêque du Quebec, 21 Juillet, 1851, in 'Lettres de Monseigneur Joseph-Norbert Provencher, Premier Evêque de Saint-Boniface' *Bulletin de la Société Historique de Saint-Boniface* (1913) III, 279, Imprimerie du Manitoba, Saint-Boniface, Manitoba).

Table 4: *Flow conditions in major sectors of the Assiniboine Basin in 1826 and 1852.*

Sector	1826	1852
Upper basin (above Kamsack)	moderate	unknown
Qu'Appelle	unknown	very high
Riding/Duck Mountain	high	unknown
Souris	very high	very high

Thus, in the autumns preceding both floods, the Assiniboine basin had been primed for maximum effective area and high runoff in the following spring, conditions which were similar to those which led up to the maximum recorded flood in 1976. Based on the historical evidence, flow conditions in the major sectors of the Assiniboine watershed in 1826 and 1852 may be summarised as in Table 4.

As was noted above, the largest known floods on the lower Assiniboine have been associated with very large flows from the Souris basin (Table 2) and the historic sources strongly implicate the Souris in both the 1826 and 1852 floods. In 1826, the Riding/Duck Mountain region probably also made a significant contribution; the state of the Qu'Appelle in that year is unknown but the strong correlation (r = 0.88) between the peak flows of the Qu'Appelle and Souris makes a large contribution likely. In 1852, both the Souris and the Qu'Appelle were extremely high and the conditions of the upper basin and Riding/Duck Mountain sectors are not known.

Despite Warkentin's concern about the improbability of coincident major floods on the Red and Assiniboine Rivers, the historical evidence points to such an occurrence in both 1826 and 1852. Moreover, the evidence suggests that the Assiniboine flows were of the same order of severity as those of the Red. Unfortunately, the historical commentaries provide no physical basis for estimating the actual discharges and a cautious paper might end here without attempting to do so. Nevertheless, it is difficult to resist speculating, particularly about the place of the 1997 flood in the history of the Red River.

The historical descriptions seem compatible with a flood of perhaps 100-year Return Period magnitude which modern flood frequency curves at Portage la Prairie indicate to be about 1,200 m^3/sec (Table 3). This value was exceeded in 1882 and 1976 by a wide margin and possibly also in 1904. Given the apparently extreme state of the Souris in 1826 and 1852, and of the Qu'Appelle in 1852 at least, this may be a conservative figure and the 1882 and 1976 floods (>1,400 m^3/sec) might provide better models for the historic events. It is assumed then, that the Assiniboine discharge in the vicinity of Portage la Prairie in each of the historic floods was in the range 1,200-1,500 m^3/sec.

Assessment of the Assiniboine's actual contributions to the Red River in 1826 and 1852 is further complicated by two additional factors: the timing of the Assiniboine peak with respect to the Red and the fact that under extreme conditions some Assiniboine water escapes to Lake Manitoba.

Timing:

The dates for the 1826 and 1852 flood peaks were very late compared with modern floods, approximately May 22 and May 18-20 respectively (Red River Basin Investigation 1953b). The historical evidence (particularly in 1852) provides no basis for inferring significantly different dates for the Assiniboine peaks. The Red River Basin Investigation (1953c, 102-103) concluded that "Owing to the fairly flat peaks of both rivers at high stages, a lag of one week would not materially affect the magnitude of the combined discharges at the Redwood Bridge... (and) the later the peak on the Red River, the greater is the discharge from the Assiniboine." It is assumed here that the hydrographs of the two rivers were sufficiently in-phase that timing differences can be ignored.

Lake Manitoba component:

At Portage la Prairie and for about 60 km downstream, the Assiniboine channel is elevated above the adjacent land on an alluvial ridge as it crosses the Portage la Prairie alluvial fan. During high flows, overbank water would travel away from the channel northward toward Lake Manitoba along paleochannels and overland, and southward toward the La Salle River (another paleochannel which flows into the Red at St. Norbert). The southern overflow passing along the La Salle paleochannel route would have contributed to Red River flow moving toward the Forks but the Lake Manitoba component would have 'escaped' the Red River altogether. This phenomenon was reported in 1882 (Upham 1890), in 1922 and 1923 (Morris 1955), and would have occurred in several other years without dyking and/or the operation of the Assiniboine Diversion (most notably in 1974 and 1976). By both routes, a significant proportion of the overbank flow would have bypassed the lower Assiniboine along which Cochran canoed in 1852. A part of this loss would have been made up by local additions from Sturgeon Creek, which joins the Assiniboine 11 km above the Forks and perhaps other smaller downstream sources. Peak flow in Sturgeon Creek in 1997 was 71 m^3/sec, one week prior to the Red River crest.

If the arguments presented above are even approximately correct, what do they mean for the magnitude of the 1997 flood relative to the historic events? In terms of *total natural* discharge at Winnipeg, the 1997 flood was close to but slightly smaller (98%) than the conventionally accepted value for 1852 and only 72% of 1826 (Table 1). As was noted above, however, the 1997 flood was principally an event of the Red River proper (i.e., upstream of the Forks) whereas in the historic floods the Assiniboine appears to have made a very large contribution. Assuming reasonably synchronous peaks and a (somewhat arbitrary) 20% net loss to Lake Manitoba, the Red River components of the historic floods can be approximated by subtracting the Assiniboine contributions from the total. The results for Assiniboine discharges at Portage la Prairie of 1,000, 1,200, 1,350 and 1,500 m^3/sec are given in Table 5, representing modern return periods ranging from 50 to 250 years (to avoid any pretence of false accuracy, most values have been expressed to the nearest 100 m^3/sec).

The differences between the historic floods and 1997 on the Red River for each assumed Assiniboine contribution are given in Line G. For all assumptions, the 1826 Red River component remains substantially larger than 1997, although the difference between the two is narrowed somewhat, particularly for the longer return periods. However, the data suggest that the 1997 Red River flow was larger than in 1852, making 1997 the second-largest event in the more than 200 years of documented Red River flooding. The difference was slight (and probably meaningless) at the 50-year return

Table 5: *Implied Red River peak discharges (m^3/sec) upstream of The Forks, 1826 and 1852 under various assumed Assiniboine River flows.*

	1826				1852			
A. Assumed Assiniboine discharge (m^3/sec)	1,000	1,200	1,350	1,500	1,000	1,200	1,350	1,500
Approximate Return Period at Portage la Prairie (yr)	50	100	150	250	50	100	150	250
B. Assumed net loss to Lake Manitoba	200	200	250	300	200	200	250	300
C. Net Assiniboine contribution to Red River (A-B)	800	1,000	1,100	1,200	800	1,000	1,100	1,200
D. Total combined Red/Assiniboine flood discharge	6,400	6,400	6,400	6,400	4,700	4,700	4,700	4,700
E. Red River upstream of The Forks (D-C)	5,600	5,400	5300	5,200	3,900	3,700	3,600	3,500
F. 1997 Red River natural flow upstream of The Forks	4,000	4,000	4,000	4,000	4,000	4,000	4,000	4,000
G. 1997 vs historic floods on Red River (F-E)	-1,600	-1,400	-1,300	-1,200	+100	+300	+400	+500

period but rises to about 10 to 15% for the larger assumed Assiniboine contributions.

A final caution is in order. The only known value in Table 5 is the 1997 Red River natural flow upstream of the Forks. Any analysis such as this is dependent not only on the perilous interpretation of conditions on the Assiniboine and its contribution to the Red River peak attempted in this paper, but ultimately on the accuracy of the discharge estimates of the historic floods themselves. These were derived by the Red River Basin Investigation (1953a) using modern (1951) channel dimensions and roughness coefficients, and assuming the validity of the water surface profiles reported by Fleming for the CPR in 1879. The historical estimates are averages of slope-area calculations for multiple reaches on the lower Red River. For the 1852 event, the estimates ranged from an anomalously low value of 3,512 m^3/sec to three values between 4,970 and 5,100 m3/sec; if the anomalous low value is disregarded, the true discharge may have been closer to 5,050 m^3/sec. The value adopted for 1826 was the approximate average of two estimates of 5,660 and 7,250 m^3/sec. The conventional Red River Basin Investigation values used in Table 5 have been accepted in all subsequent studies and it is certainly not the purpose of this paper to critically evaluate them. Nevertheless, the range in estimates should be borne in mind when the implications of Table 5 are assessed.

Conclusions

Historical observations from 1826 and 1852 suggest that large floods occurred in the Assiniboine basin coincident with the better-known extreme events in the Red River valley. In both years, the commentaries identify the Souris as a major source of the water and in 1852 at least, the Qu'Appelle is also implicated. The relatively large contribution of the Assiniboine in these years is unusual in the modern record in which simultaneous major floods in both the Red and Assiniboine Rivers have not occurred, and are in sharp contrast to the 1997 flood which was overwhelmingly a Red River event. If allowance is made for the Assiniboine's contribution in 1852, it is likely that the 1997 flood was larger than the 1852 event in the Red River valley.

Acknowledgements

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Dendrochronology and dendroclimatology from bur oak trees in Birds Hill Provincial Park, Manitoba

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***Abstract*:** Living bur oak (*Quercus macrocarpa*) trees were cored at two sites in Birds Hill Provincial Park, Manitoba and used in the construction of chronologies and analysis of dendroclimatic relationships. The first site was situated on a silty calcareous substrate associated with poor water infiltration. Trees were stunted with gnarled branches, generally reaching heights not much taller than 4 to 5 m. A total of 15 trees were cored with the oldest dated tree being 93 years. At the second sampling site, trees were growing on a sandy substrate with excellent drainage. Trees sampled at this site had trunk diameters of 25 cm and larger, and were taller than 10 m. The time interval covered by 13 core samples was 117 years, 1883 to 1999. Standardized ring widths for the entire period of each chronology were correlated with monthly mean temperature and precipitation data for the months of January to December of the current growing year and for May to December of the previous growing season. While both sites produced statistically significant correlations with temperature and precipitation, the relationships did not always appear in the same months. It is hypothesized that different site physical characteristics affect ring growth response to climate variables.

Key words: dendrochronology, dendroclimatology, bur oak, Manitoba

Introduction

Annual growth rings occur in trees in the mid- and high latitudes environments where there are distinct wet and dry seasons or where there is marked seasonality in temperature (Fritts 1976). Variations in ring width are related to age and size of a tree, climate, individual tree and stand disturbance and unexplained variability unrelated to any of the above factors (Nowacki and Abrams 1997). When a tree trunk is viewed in cross-section, concentric bands or rings are visible. Every ring corresponds to a period of vegetative growth. The science of dendrochronology analyses tree rings to establish dates for these rings (Fritts 1976). Samples from a number of trees at a site are cross-dated and measured. This process provides reliable, accurate and exact dating. Dendroclimatology is an application of dendrochronology using dated tree rings to study relationships between the rings and climate and to reconstruct past climate.

Dendrochronology and Dendroclimatology in the Prairies

Commonly, in Canada, trees in mountainous or foothill areas and northern locations are sampled for dendroclimatological studies (Luckman 1993, 1998; Case and MacDonald 1995; Szeicz and MacDonald 1995; Feng and Epstein 1996; Watson and Luckman 2001). Tree growth in these locations is limited by harsh environmental conditions making them sensitive to climate changes (Bradley 1999). Tree-ring width, therefore, frequently manifests some response to the environment.

In the Prairie ecozone, tree species sampled for dendroclimatic research include white spruce in the Cypress Hills Saskatchewan (Sauchyn and Beaudoin 1998), bur oak in Manitoba (St. George, personal communication), Ponderosa pine in South Dakota (Brown and Sieg 1999) and bur oak, pine and juniper in the U.S. northern plains (Sieg *et al*. 1996).

Bur oak samples from North Dakota have provided a tree-ring record to 1676 AD (Sieg *et al*. 1996). This study correlated ring widths to total annual precipitation and spring/summer precipitation of the current growing season. Correlation coefficient (r) values ranged from 0.36 to 0.69 for total annual precipitation and from 0.31 to 0.63 for spring/summer precipitation.

In Manitoba, a flood history reconstruction for the Red River has been completed using bur oak tree ring data collected from riparian forests (St. George and Nielsen 2000). The Manitoba bur oak chronology spans 536 years, 1463 AD to 1999 AD (St. George *et al*. 1999). Living bur oaks found adjacent to the river display sensitivity to variations in river water levels. In a sample of 194 bur oaks, an anatomical ring anomaly, unusually small earlywood vessels, was associated with high magnitude floods in the 19th century. These 'flood rings' appeared in the high magnitude flood events of 1852 and 1826 (Rannie 1998). Similarly formed rings in 1747 and 1538 revealed the occurrence of previously unknown extreme floods on the Red River for those years. The relationship between bur oak ring development and flooding, however, is not simple. For the 1826 event, 24% of the samples showed flood rings and only 5.9% of the samples in 1852 had visible flood rings. Flood ring development, therefore, may depend on a tree's location in the Red River flood plain. In addition, only trees at two sites displayed flood rings. It is, therefore, difficult at this time to conclude whether any characteristics of these sites or proximity to the river played roles in flood ring development. If additional sites reveal flood ring signatures, site characteristics can be analyzed to evaluate flood impact on tree ring development. Flood rings have not yet been discovered for the 1997 flood, one with a discharge similar to 1852. This suggests that flood ring development may be dependent on time of inundation and possibly duration of inundation.

Oxygen isotope analysis of tree rings from two bur oaks sampled along the Red River in Manitoba is in progress (Buhay 2001). This research has revealed a seasonal change in oxygen isotope composition (*^{18}O) in the tree rings. Increased *^{18}O reflects increased moisture input (and potential for spring flooding) and milder temperatures. Occurrence of higher *^{18}O values in winter months, just prior to earlywood growth or in autumn months during latewood formation has been discovered in some years. It is hypothesized that the lack of a signal at one site for some high flow years in the Red River may reflect differing hydrologic regimes between the two sites. One site is at a slightly higher elevation and receives more input from groundwater recharge, especially at times of high water, while the second site may receive a more homogenous input of moisture. Further analysis is still required to investigate relationships between *^{18}O variations and different site characteristics.

Study Area and Site Descriptions

Birds Hill Provincial Park is located in south central Manitoba, approximately 15 km north east of the city of Winnipeg (Figure 1). This part of Manitoba is characterized by a continental-type climate with long, cold winters and short, mild to hot summers. The air temperature range is large and although highly variable, the majority of precipitation falls as rain during the summer months. Limited instrumental climate data are available for the park. Temperature, precipitation and wind were briefly recorded between August and October 1969 and again from May 1988 to November 1992. Climate normals for Winnipeg, the nearest climate station with the longest record were, therefore, used to compare ring width variations with temperature and precipitation data.

Pleistocene continental glaciation shaped the current landscape depositing glacial sediments of clay, silt, sand and gravel. Terrain is relatively flat with some rolling hills and valleys. Gently rolling till capped

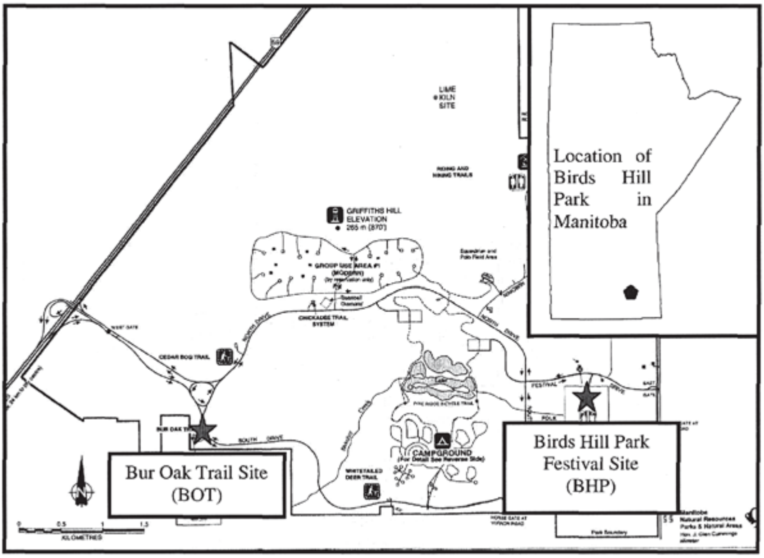

Figure 1: *Location of the Bur Oak Trail (BOT) and Birds Hill Park Festival (BHP) sites in Birds Hill Provincial Park (Source: adapted from Manitoba Natural Resources 2000).*

with prominent glaciolacustrine sediments (an esker) comprises most of the park (Matile *et al*. 2001). The soil is a black chernozem (Scott 1998).

Birds Hill Park is in a Transitional Grassland ecoclimatic region (Scott 1998). Land cover includes patches of prairie grass interspersed with Parkland vegetation dominated by aspen (*Populus tremuloides*) and bur oak (*Quercus macrocarpa*) with shrub undergrowth. Broadleaf, deciduous forests are found along streams and wetlands in areas with poor drainage. Patches of coniferous woodland are also found in the park. Tree ring sampling occurred at two separate stands of trees where bur oak dominated.

Bur oak, a deciduous, hardwood tree common to Manitoba can grow to 15 m high with a trunk diameter of 60 cm in areas of deep, rich soils (Johnson *et al*. 1995). However, in sites with a shallow soil layer, trees are shrubby when young and typically stunted as they age (Farrar 1999). Bur oak can grow for 200 years or longer. They are a drought-resistant species with deep and wide-spreading roots. Because bur oak is also fire-resistant, this tree is well adapted to the Prairie and Parkland environment where fire previously was a common occurrence.

Living bur oak trees were sampled at two sites (Figure 1). The Bur Oak Trail (BOT) site has a silty calcareous substrate with poor water infiltration (Matile *et al*. 2001). Wetland areas were in proximity to this site. Trees were stunted with gnarled branches, generally reaching heights not much taller than 4 to 5 m. There was also a dense distribution of trees at this site with heavy shrub undergrowth. The Birds Hill Park Festival (BHP) site has a sandy substrate with excellent drainage (Matile *et al*. 2001). Trees sampled at site BHP had trunk diameters of 25 cm and greater, and were taller than 10 m. Trees were more widely separated interspersed with grassy patches and only light shrub undergrowth.

Chronology Construction

A total of 13 trees were sampled at site BHP and 15 from site BOT. Trees were cored with a 16-inch or 24-inch Swedish increment borer. Coring involved inserting the boring tool into the tree at about breast height and penetrating the tree through its centre pith to ensure growth rings for the life span of the tree were acquired. The coring procedure was the same as used by St. George *et al*. (1999) to develop a bur oak chronology for the Red River Basin. Core samples were inserted into straws, labeled, and allowed to dry for approximately 10 weeks before being mounted in wooden, grooved blocks. Samples were then sanded and polished to make the rings more visible under a microscope.

Generating a tree-ring chronology for each site and measuring ring width involved using a Velmex Tree Ring Measuring System. Each core was placed on a moveable platform under a Nikon photomicroscope connected to a television camera displaying an image of the tree rings. Dating was accomplished by counting growth rings beginning at the bark and proceeding inward. An ordinary ink pen was used to label reference dates. On a core, the outermost ring, nearest the bark was known to be 2000, the year sampling was conducted. The start of each decade (i.e., 1990, 1980, 1970, and so on) was shown by one dot on the core sample. At the 50-year age of a tree, two dots were drawn on the sample, and at 1900 and 2000, three dots indicated a new century. The time interval covered by core samples from the BHP site was 117 years, 1883 to 1999. The BOT samples spanned 93 years from 1907 to 1999. Nine of the 13 trees from the BHP site started growing early in the 20th century, prior to 1911 (Table 1). No BOT sample was dated earlier than 1901; in fact the oldest tree had a date of 1907 (Table 1). The BOT samples displayed a larger range of decades when growth began for a tree, with some samples

Table 1: *Number of trees in chronologies beginning in each decade.*

Site	Total number of trees cored	number of trees in chronology beginning						
		1900 or earlier	1901-1910	1911-1920	1921-1930	1931-1940	1941-1950	1951 or later
BHP	13	2	7	2	1	1	0	0
BOT	15	0	2	2	3	2	4	2

starting in each decade. This may reflect a higher incidence of forest canopy openings and increased opportunities for germination.

The tree ring measuring system included a digital counter connected to a computer enabling measurement and recording of ring widths for use in cross dating. Cross dating was accomplished using the computer program COFECHA developed by Grissino-Mayer *et al.* (1996). Trees in a particular area can be expected to show similar patterns of growth since they will be influenced by similar environmental factors (Nowacki and Abrams 1997). Cross dating with the COFECHA program involved comparing ring widths of each core sample at a site to find similar patterns of growth among the trees. When similarities were identified among the samples, dates of ring formation were confirmed and a chronology established based on the synchronization of ring width patterns. Table 2 lists a selection of COFECHA program summary statistics for each sample.

For the 13 BHP samples, measured mean raw ring width was 1.75 mm with a standard deviation of 0.70 indicating moderate to fast growth (St. George, personal communication). The smallest ring width measurement was 0.32 mm in 1980; the largest was 5.21 mm in 1923. Mean raw ring width for the 15 BOT samples was 1.0 mm with a standard deviation of 0.40 mm. The lower mean signifies slower growth and less wood added annually than the BHP trees (St. George 2001, personal communication). BOT extreme measurements were smaller than BHP values, ranging from a minimum of 0.22 in 1964 and a maximum of 3.17 mm in 1955.

The sensitivity statistic (Table 2) compares width values of two successive years and expresses how reactive a tree species is to annual growth stimuli based on ring width variability (Schweingruber 1988). Values for sensitivity range from 0 to 2.0, lower values indicating less response to environmental stimuli (complacency) or fairly stable ring width sizes over the years. Larger values indicate a higher degree of annual variability (sensitivity) to environmental conditions or widely fluctuating ring widths year to year (Fritts 1976). Mean sensitivity for trees at the

Table 2: *A selection of chronology statistics for samples at the BHP and BOT sites.*

sample number	chronology	mean ring width (mm)	standard deviation	mean sensitivity	auto correlation
BHP1a	1883-1999	1.62	0.712	0.188	0.842
BHP2a	1901-1999	1.32	0.490	0.174	0.806
BHP3a	1888-1999	2.25	0.989	0.176	0.854
BHP4a	1901-1999	1.64	0.667	0.180	0.830
BHP5a	1919-1999	2.21	0.994	0.224	0.789
BHP6a	1906-1999	3.07	0.690	0.179	0.458
BHP7a	1901-1999	1.35	0.643	0.270	0.706
BHP8a	1923-1999	2.05	1.023	0.188	0.858
BHP9a	1911-1999	1.34	0.613	0.208	0.666
BHP10a	1934-1999	1.07	0.396	0.144	0.869
BHP11a	1901-1999	1.15	0.502	0.234	0.702
BHP12a	1908-1999	1.98	0.682	0.179	0.775
BHP13a	1904-1999	1.66	0.700	0.212	0.786
All samples		1.75	0.702	0.197	0.765
BOT1a	1913-1999	0.70	0.212	0.241	0.391
BOT1b*	1922-1999	0.73	0.281	0.241	0.682
BOT2a	1942-1999	0.83	0.507	0.290	0.788
BOT3a	1945-1999	1.09	0.308	0.308	0.575
BOT4a	1922-1999	0.63	0.225	0.250	0.595
BOT5a	1929-1999	0.96	0.327	0.185	0.755
BOT6a	1907-1999	1.31	0.644	0.212	0.846
BOT7a	1943-1999	1.33	0.381	0.193	0.601
BOT8a	1935-1999	1.27	0.309	0.178	0.618
BOT9a	1919-1999	1.08	0.468	0.246	0.774
BOT10a	1910-1999	0.96	0.525	0.288	0.691
BOT11a	1932-1999	0.81	0.430	0.213	0.739
BOT11aa**	1973-1999	0.68	0.263	0.180	0.788
BOT12a	1942-1999	1.49	0.501	0.219	0.702
BOT20a	1954-1999	1.12	0.472	0.217	0.838
BOT21a	1922-1999	0.99	0.452	0.233	0.755
BOT22	1964-1999	0.87	0.289	0.192	0.720
All samples		1.00	0.397	0.228	0.690

*** A second core from the same tree** **** A partial core broken from BOT11a**

BHP site was 0.20 and slightly higher, 0.23, at the BOT site. Trees at both sites were generally complacent not showing dramatic changes in ring width related to environmental conditions although site BOT is slightly more sensitive to some growth forcing factor.

The first-order autocorrelation statistic (Table 2) quantifies the extent to which growth in one year was influenced by the previous year(s) (Fritts 1976). Higher values mean radial growth in one year was influenced by conditions the previous year. For both sites, autocorrelation values were fairly high, exhibiting a mean of 0.765 for the BHP samples and 0.690 for the BOT samples.

Tree ring widths are typically influenced by a variety of non-climatic factors and, therefore, show trends or patterns of growth related to such things as tree aging, trunk diameter increase, competition and even micro-scale site characteristics. The most common growth trend is a pattern of decreasing ring width with age (Fritts 1976). As a tree gets older, it loses vigour because increasing trunk diameter presents more surface area for a ring to form (Foster and LeBlanc 1993). The computer program ARSTAN (Grissino-Mayer *et al*. 1996) was applied to statistically standardize or remove growth trends. Figure 2 illustrates the removal of this growth trend from sample BHP9a. The growth of trees at the BHP site is influenced more by aging and decreasing ring width trends. This is probably related to the more open site conditions allowing BHP trees to grow with less competition for light and nutrients. BOT trees were all densely packed with heavy shrub undergrowth.

Figure 3 shows the completed, compiled chronologies for site BHP and site BOT. Generally, the BHP and BOT chronologies exhibited common variability at both sites although some asynchronous trends were visible.

While peaks and valleys were similar in each chronology, the BOT trees showed a stronger response in ring width variation confirming the slightly higher sensitivity value shown in Table 2. An extended period of below average ring widths appeared at both sites in the 1960s. Smaller widths also prevailed between 1910 and 1920 and in the 1930s. In the 1930s, however, BOT trees appeared to show greater sensitivity than BHP trees. Ring widths for BOT trees remained below average values for a longer period of time. Larger ring widths were visible in the 1940s, 1950s and 1970s.

For all the standardized widths, measurements were ranked listing smallest to largest rings and the year they occurred for each sample. Then, years of occurrence of the three smallest and three largest detrended ring widths were identified. The 1960s had the most trees, 28, with extremely

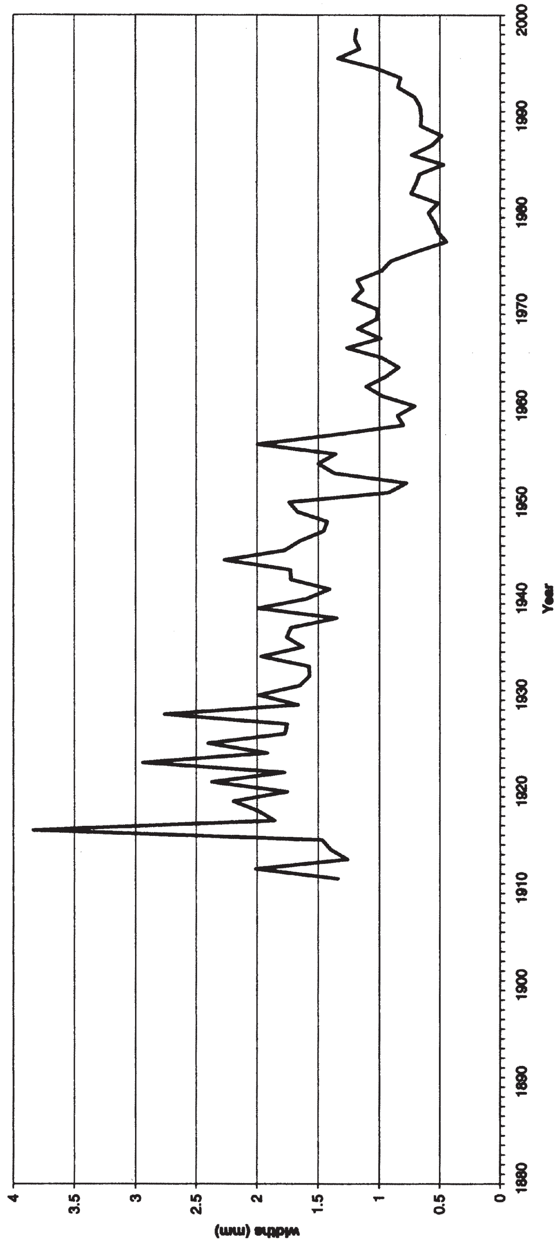

Figure 2: *Raw measured tree ring widths (top) and ring widths detrended with ARSTAN (bottom) from sample BHP9A at Birds Hill Park Festival site.*

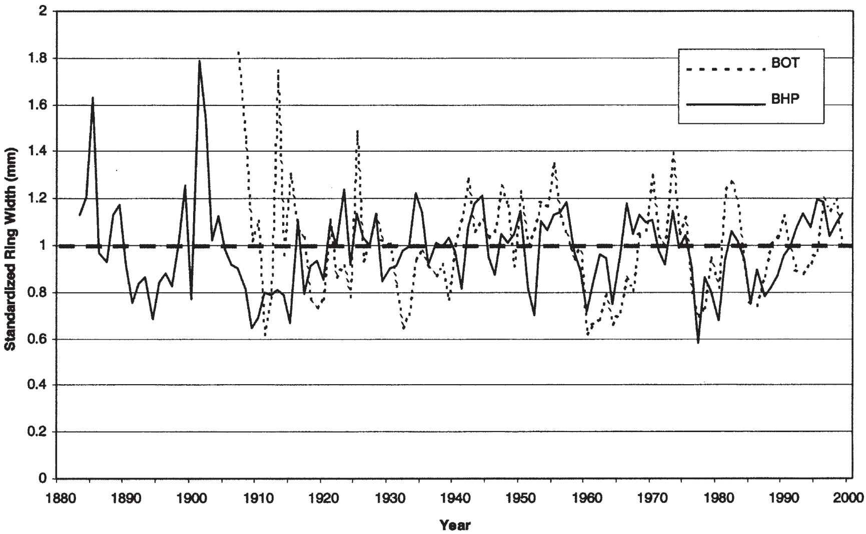

Figure 3: *Bur Oak Trail (BOT) and Birds Hill Park Festival (BHP) site chronologies.*

low widths followed by the 1930s with 13 (Figure 4). Drought in the Prairies during the 1930s and 1960s is well documented (e.g., Dey 1982; Bonsai *et al*. 1993). Environment Canada (2001) ranked 1960 and 1961 as the two driest years in the Canadian Prairies in the 20th century and annual precipitation records at Winnipeg identify 1961 as the driest year on record since 1872. The 1970s and 1980s both had 11 trees with some of their lowest widths and the decade of 1910 to 1919 had 10 trees. The 1970s also recorded some of the largest ring widths (14 trees). With a combination of some of the smallest and largest ring width chronologies, the 1970s decade showed the most variability. Large ring widths were found in the 1950s (13 trees) and 1940s (12 trees). Additional analysis is required to compare dry and wet conditions with the ring width variability shown in Figures 3 and 4.

Tree Ring Width and Climate Correlations

Correlation analysis was employed to compare ring widths at each site with temperature and precipitation parameters. Statistically significant values of *r* suggest some control by the climate variable. Correlations were tested using the one-tailed t-test. Significance levels ranged between

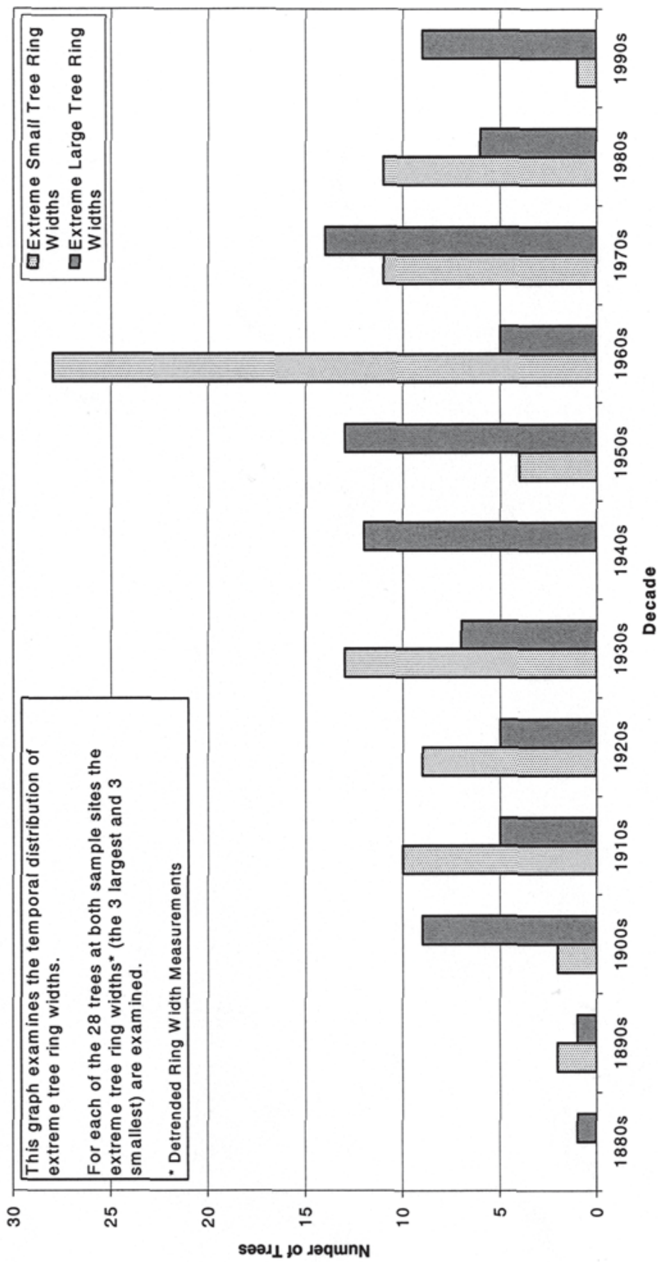

Figure 4: *Distribution of extreme ring widths by decade.*

0.0005 and 0.1 for temperature correlations and between 0.005 and 0.1 for precipitation correlations. Because *r* values were relatively small, ranging from approximately 0.1 to 0.4, other environmental factors, such as substrate composition, competition or biological agents also influenced growth response and may play a more important role in determining ring width size for bur oak at the BOT and BHP sites. These correlations with climate are, however, still relevant because they show if relationships exist and the strength of those relationships.

Standardized ring widths for the entire period of each chronology were correlated with monthly mean Winnipeg temperature data for the current growing year and for May to December of the previous year. Various studies have shown significant relationships between tree growth and climate of both the current growing season and previous years (e.g., Stockton and Meko 1983; Larsen and MacDonald 1995; Sieg *et al*. 1996; Watson and Luckman 2001).

A total of five significant negative correlations with temperature and one positive correlation were derived for the BOT site (Figure 5). One-tailed t-test significance levels for the correlations ranged between $p<0.0005$ to $p<0.1$. Perhaps the positive correlation in December is related to a combination of temperature and precipitation input, such that a warm December is a wetter December. Six significant negative correlations with temperature appeared at the BHP site (Figure 6). T-test significance levels ranged between $p<0.01$ to $p<0.1$

Both sites showed relationships with temperatures of the previous year, the BOT site with three months, May, June and July with negative correlations and the BHP site with only one significant negative correlation (July). Negative correlations with the months of May and June in the current growing year were also demonstrated at both sites. Most significant negative temperature correlations were found in May of the current growing season at the BOT site and in the previous July at the BHP site. Negative correlations signify higher temperatures produced smaller ring widths and lower temperatures resulted in larger rings. Balling *et al*. (1992) proposed significant correlations with climate variables in the previous growth year resulted because of a 'feedforward effect'. That is, the preceding year's weather had an impact on growth during that year and in the following year. Temperature and/or moisture stress during the previous season may, therefore, weaken a tree's developmental response in the following growth year(s). With warm summer temperatures increasing evapotranspiration, moisture stress in the previous year may have more impact on BHP trees as shown by the higher correlation value (Figure 6). In the current growing

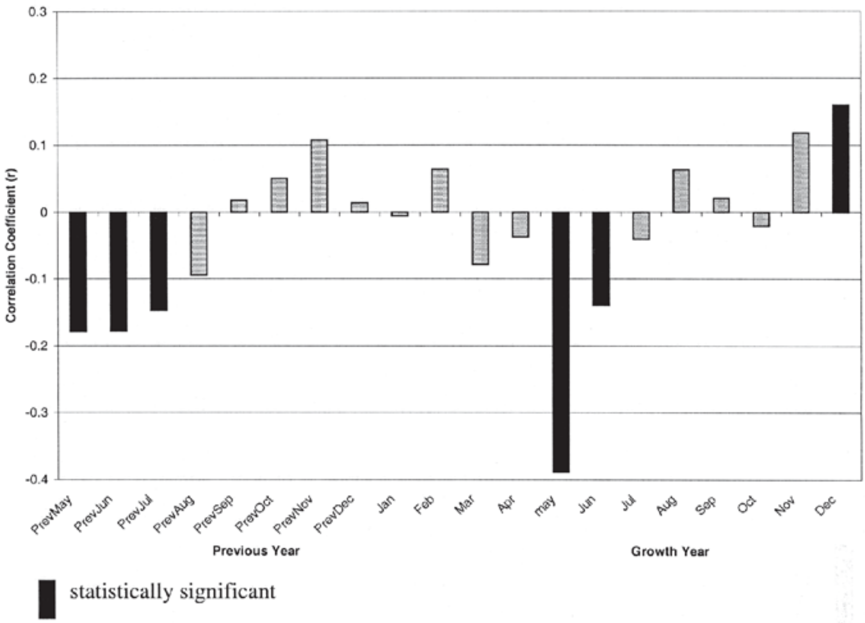

Figure 5: *Correlation coefficients between standardized ring widths and monthly mean temperature for BOT trees.*

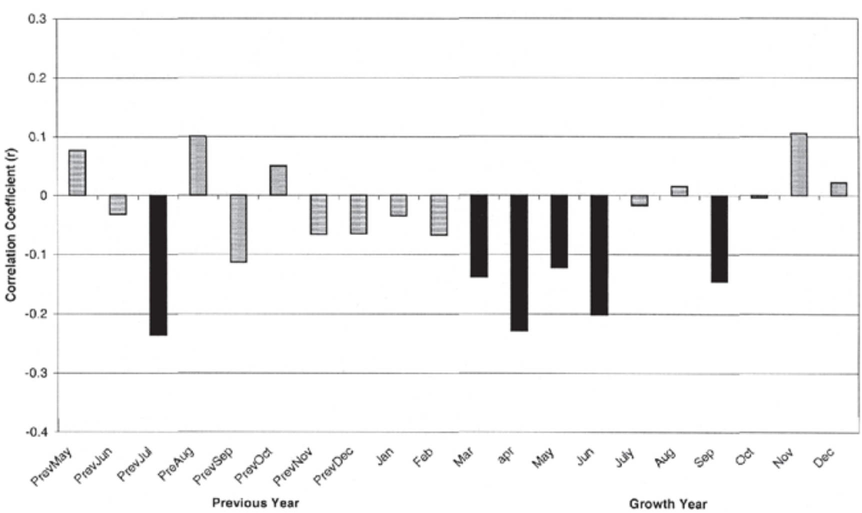

Figure 6: *Correlation coefficients between standardized ring widths and monthly mean temperature for BHP trees.*

season, trees at the BHP site became sensitive to temperature sooner and over a longer period than trees at the BOT site. Warmer temperatures in spring may melt snow more quickly but also increase evapotranspiration. Evapotranspiration rates may be more important to BHP trees because moisture from snowmelt or precipitation percolates more efficiently through the sand and gravel substrate. For BOT trees, moisture remains available to roots because infiltration is slower in silty substrate so evapotranspiration does not become important until later in the spring.

Correlations of standardized ring widths to Winnipeg monthly precipitation totals resulted in three significant positive correlations and one negative correlation at the BOT site. T-test significance levels ranged between $t<0.005$ to $p<0.1$. Three significant positive and one negative correlation also occurred at the BHP site. Significance levels ranged between $p<0.01$ to $p<0.1$. The highest significant (positive) correlation was found in January at the BOT site (Figure 7) and in June at the BHP site (Figure 8). Positive correlation values indicate higher precipitation resulted in larger ring width formation and lower precipitation resulted in smaller ring widths. Common positive correlations at each site occurred for the previous September and current growing season January. Both sites likely depend on stored moisture from months of the previous growing year and from winter snowmelt. The BOT site was slightly more respondent to winter precipitation accumulation as a moisture source for its growing season. Occurrence of positive correlations in the previous July at the BOT site could also indicate more reliance of BOT trees on stored moisture in the next year. Since the BOT site had no significant correlations during the current year, trees may be adapted to having less moisture available through direct precipitation input during the growing year. Therefore, moisture from the previous year and winter moisture are sufficient for growth requirements of BOT trees. Sand and gravel substrate at the BHP site allows better drainage so trees do not only depend on stored subsurface water but also require additional moisture from rain during the growth season (positive June correlation).

Summary

Of the 11 significant correlations between monthly mean temperature and standardized tree ring widths, 10 were negative indicating warmer temperatures were related to smaller rings. A total of six positive and two negative significant correlations were found between monthly precipitation and ring widths. Positive correlations suggest higher precipitation

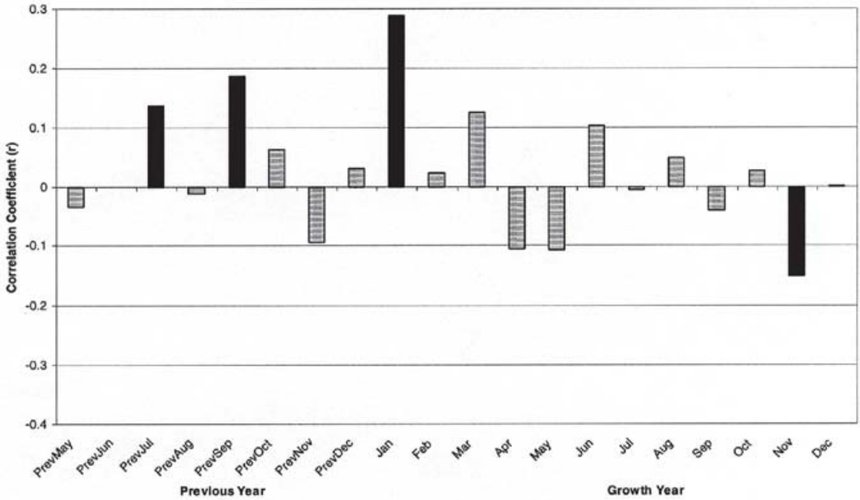

Figure 7: *Correlation coefficients between standardized ring widths and monthly mean precipitation for BOT trees.*

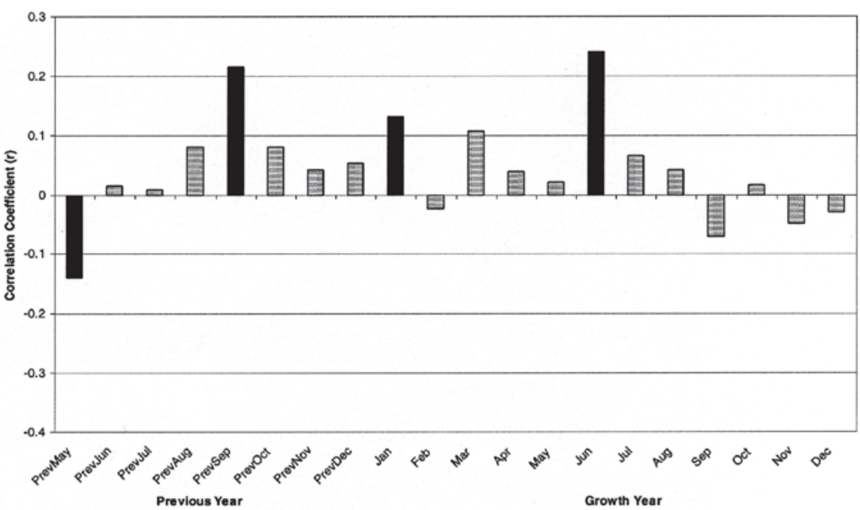

Figure 8: *Correlation coefficients between standardized ring widths and monthly mean precipitation for BHP trees.*

generated larger rings, lower precipitation smaller rings. At the BHP site, there were positive correlations with precipitation in the previous autumn and winter and during the current growing season. With the BOT trees, positive correlations with precipitation were found only in autumn or winter of the previous year. Timing of the correlations suggests that both sites relied upon soil moisture storage from any autumn precipitation and from snowmelt. With bur oaks at Birds Hill, a store of subsurface water appears to supply sufficient moisture for trees at the less permeable BOT site during the growing season since significant positive relationships with precipitation did not manifest during the current year growing season. The BHP site, however, required additional water from rain during the growing season because permeable substrate allowed moisture to percolate deeper through the ground. In fact, the most significant relationship between ring growth and precipitation at the BHP site occurred in June of the current growing season, when most earlywood development occurs.

No study has yet definitively substantiated a relationship between Manitoba bur oak growth and different surface conditions. St. George and Nielsen (2000) have hypothesized that flood ring development in Manitoba bur oak growing along the Red River may be dependent on a tree's location in the Red River flood plain and local site characteristics. After analyzing oxygen isotope concentrations in annual tree rings from two trees at two sites along the Red River, Buhay (2001) has also speculated on the response of Manitoba bur oak trees to varying moisture supplies. Because oxygen isotope concentrations measured in the rings were not synchronized at the two sites, it was hypothesized that different hydrologic regimes influenced moisture conditions at the two sites. Trees at one site sit at a slightly higher elevation and receive more moisture from groundwater recharge when precipitation input is increased. These trees appear to have a greater dependence on direct precipitation input. Trees at the second site may receive a more homogenous input of moisture. In Europe, Cufar and Levanic (1999) found oaks growing in dry sites were more reliant on direct precipitation input as a water supply. Trees growing in lowland sites with swampy conditions and sufficient soil water were not as dependent on direct precipitation input during their growing season. Foster and Brooks (2001) produced chronologies for slash pine (*Pinus elliottii*) sampled from dry and wet sites in Florida. After correlating growth rings with climate variables, they reported variations in growth response at the different sites. Pines growing on sites with shallow water tables displayed negative correlations with increased water input and pines growing on sites with deeper water tables displayed positive correlations with increased water input. Future analysis of the Birds Hill bur oak samples will involve selecting case study years with small and large ring widths to verify the correlation patterns at both sites and further investigation of site characteristics.

Bur oak tree ring width variability in the Manitoba Prairie environment is sensitive to moisture input and must be dependent on the inter-relationships of temperature and precipitation input during the growing season and in previous years. Other variables (e.g., competition for light and moisture and biological influences) also influence radial growth of tree rings. Substrate composition especially appears significant in how bur oaks respond to precipitation input at different seasons. This study has described climate-ring width relationships derived from bur oak trees at Birds Hill Park. Initial results indicate that the same tree species does not experience the same responses to the same climate forces. Bur oak trees growing in different substrate environments may be showing evidence of adaptability to the differing physiographic conditions by their water requirements. This preliminary research suggests that substrate character may have to be considered when bur oak tree ring chronologies are developed in the Canadian Prairies and U.S. northern Plains. Additional research at other sites and more detailed analysis of site characteristics is required to confirm the responses of bur oak to their environment.

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Pollen-based reconstruction of past millennium temperature in Canada

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Abstract: The climate of the last 1,000 years sets the background for 20th century climate warming. Because of this, temperature records of up to 1,000 years in length are required to better understand natural variability in the climate system. Proxy data in the form of pollen records have been used for reconstructing palaeotemperatures based upon the relationships between vegetation assemblages and historical regional climate patterns. Instrumental records are only available for the last 100 years. Since modern pollen assemblages in Canada have good responses to temperature changes, the relationships between pollen records and modern climate can be used as the basis for estimating the climate of the last 1,000 years. The present study uses the modern analogue technique to estimate temperatures for the last 1,000-year in Canada. It shows that there were four cold phases, with from 0.4° to 1.1°C negative anomalies, in the earlier half of 12th and 15th centuries, most of the 17th century, and in the mid-19th century. Also, one positive anomaly with a temperature increase of up to 1.0°C is identified at the end of 19th century. Results of the study are comparable generally to the patterns of the average temperature of the Northern Hemisphere, and show slightly greater magnitudes in temperature change than that of the Northern Hemisphere as a whole, during the last 1,000 years.

Key words: past climate, pollen data, annual temperature, past 1,000 years, Canada

Introduction

Based upon climate modeling, 41 to 64% of pre-1850 temperature variations in decadal scale are due to changes in insolation and volcanism (Crowley 2000), and more than 60% of land temperature variations in 20th century warming are due to the changes in external forcings (Stott *et al*. 2000). Therefore, there is a requirement for a longer-term perspective and a better understanding of past climate. For northern North America where observed climate records only began in the mid-19th century, a detailed pre-instrumental climate data set is needed in order to meet this requirement. Various proxy climate sources can provide such data, and the pollen record is one of them. So far, most pollen studies from North America have provided reconstructions of climate on century-to-millennium time scales (e.g., COHMAP 1988; Webb *et al*. 1993). Finer-resolution pollen records have been used to estimate climate variability over the past 1,000 years on decade-to-century time scales for north-eastern and central USA, southern Canada and the Arctic regions (e.g., Swain 1978; Bernabo 1981; Gajewski 1987, 1998; Overpeck *et al*. 1997), and to reconstruct the climate changes in time-scales of 10 to 50 year intervals (e.g., McAndrews 1988; Weninger and McAndrews 1989). But there have been few attempts to examine the patterns of regional climate change across the continent, and climate variability throughout the past 1,000 years. Therefore, the objective of this study is to fill this gap by quantitative interpretation and modeling of the existing pollen records at the regional scale for all of Canada.

To transform pollen records into units of temperature, various statistical transfer function methods have been developed (e.g., Webb and Clark 1977; Bernabo 1981; Overpeck *et al.* 1985; Gajewski 1993 *et al.*; Guiot *et al*. 1989, 1993; Yu and Qin 1997). The modern analogue approach, a more robust method with less noise, is such an example (Cheddadi *et al*. 1997). The technique is based on the principal of multiple regressions between climate variables and the pollen taxa, principal component analysis within pollen taxa, and correlation between multiple-year moving averages of the observed climate and the pollen-reconstructed climate. This approach has been successfully applied in East Africa (Bonnefille *et al*. 1990; Peyron *et al.* 2000) and Europe (Guiot *et al.* 1993; Cheddadi *et al*. 1997; Tarasov *et al*. 1999). This study attempts to apply the technique to transfer quantitative pollen data into quantitative paleoclimatic estimates, and to reconstruct the temperatures in Canada over the past millennium.

Data and Methods

Pollen data and the taxa:

Pollen data for this study are taken from the North American Pollen Database (NAPD) (COHMAP 1988; NAPD 1994). The database was compiled by Eric Grimm and John Keltner at the Illinois State Museum, starting with data originally assembled for the COHMAP project (COHMAP 1988). Screening of each NAPD site established that there are 285 fossil pollen sites and 1,050 modern pollen samples in Canada. Most fossil pollen data have radiocarbon-dates. These dates are mostly in the Holocene, and about 14% of the samples have dates within the past 1,000 years. Ages at each sample of pollen sequence have been linear-interpolated according to known radiocarbon dates.

For the data set from the NAPD sites, there are 633 fossil pollen taxa and 71 modern (surface sample) pollen taxa. To reconcile the pollen taxa, only those taxa that have occurred both in fossils and modern surface samples have been used. In total, there are 62 taxa that have frequencies higher than 95% in the total pollen counts (Table 1). The maximum and minimum percentages of each taxon are listed in Table 1 and show generally similar proportions between the past and the modern pollen percentage values although higher and/or smaller percentage values of fossil pollens do occur in comparison with those of modern pollens. Principal components analysis is used to estimate various contributions within the pollen taxa on all fossil pollen samples from 900 AD to 1900 AD. The first principal component (PC1), showing 22.14% of the total variance, was dominated by broadleaved trees (*Acer, Carya Fraxinus, Quercus, Populus, Tilia* and *Ulmus*) with positive loadings, and needle leaved trees (*Abies, Picea, Pinus* and *Tsuga*) and nonthermophilous broadleaved trees (*Alnus* and *Betula*) with negative loadings. This reflects the main contrast between the northern and the southern regions and between relatively warm and cold climates. The loading of this component (PC1)was used as a distance weighting in the analogue analyses later in the study (Table 1).

Climate data and designation of regions:

The instrument-recorded data set used in reconstructing Canada's historical air temperature is the result of several years of research at the Climate Research Branch, Meteorological Service of Canada. It is a database of homogenized, long-term time series of monthly mean temperatures and has been specifically designed for climate change studies in Canada (Vincent and Gullett 1999). Annual temperature records from 210 stations with the earliest record in 1895 AD and the latest records in 1998 are used. Most stations have recording lengths greater than 30 years.

The locations of the pollen data and the stations with instrumental records are distributed over most regions of Canada from approximately 54° to 140°W and 40° to 75°N (Figure 1). In order to obtain time slices for applying the modern analogue technique, each pollen sequence is subdivided into 20 time periods, or 50-year intervals beginning in 925±25 and ending in 1875±25 AD. The 50-year interval is arbitrary, but is set in

Table 1: *Pollen taxa used in the palaeoclimate reconstruction.*

No	Pollen taxa	Surface pollen Max. (%)	Surface pollen Min. (%)	Fossil pollen Max. (%)	Fossil pollen Min. (%)	Weight (PC1)
1	*Ulmus*	12.74	0.29	20.14	0.12	0.36
2	*Acer*	9.62	0.37	23.58	0.10	0.34
3	*Carya*	4.27	0.05	6.30	0.10	0.32
4	*Fagus*	16.41	0.53	33.94	0.13	0.31
5	*Quercus*	34.88	0.83	42.52	0.12	0.30
6	*Tilia*	2.63	0.02	9.66	0.10	0.29
7	*Fraxinus*	9.28	0.23	16.18	0.10	0.26
8	*Juglans*	2.47	0.03	5.29	0.10	0.24
9	*Platanus*	1.44	0.01	6.14	0.10	0.22
10	*Tsuga canadensis*	12.84	0.06	39.00	0.10	0.20
11	*Ambrosia-type*	47.69	1.42	52.02	0.10	0.09
12	*Castanea*	0.98	0.01	1.24	0.10	0.08
13	*Ostrya-type*	9.17	0.16	9.03	0.16	0.07
14	*Liquidambar*	0.46	0	0.81	0.10	0.06
15	*Pinus undiff.*	86.86	12.75	87.89	0.13	0.05
16	*Cerealia*	1.10	0	39.56	0.10	0.04
17	*Iva*	1.04	0	2.58	0.13	0.04
18	*Populus*	34.43	0.24	37.67	0.10	0.04
19	*Rumex*	13.14	0.15	2.68	0.10	0.04
20	*Celtis*	0.53	0	1.63	0.16	0.02
21	*Cephalanthus*	1.56	0	2.88	0.10	0.02
22	*Nyssa*	0.19	0	2.60	0.10	0.02
23	*Tsuga heterophylla*	52.36	0.18	34.00	0.13	0.02
24	*Ephedra*	0.25	0	0.75	0.11	0.01
25	*Pinus subg. Strobus*	46.30	1.45	49.87	0.16	0.01
26	*Poaceae undiff.*	95.00	5.87	90.54	0.10	0.01
27	*Brassicaceae*	75.00	0.13	2.58	0.10	0
28	*Corylus*	6.48	0.10	2.31	0.10	0
29	*Cupressaceae/Taxaceae* undiff.	50.60	0.41	0	0	0
30	*Larix/Pseudotsuga*	10.38	0.16	8.54	0.10	0
31	*Myricaceae*	15.57	0.55	0.99	0.18	0
32	*Aquifoliaceae*	8.86	0.03	2.06	0.15	-0.01
33	*Chenopodiaceae/Amaranthaceae* undiff.	37.93	0.59	5.03	0.10	-0.01
34	*Empetrum-type*	3.04	0	15.78	0.18	-0.01
35	*Rubiaceae undiff.*	63.66	0.20	0.82	0.30	-0.01
36	*Shepherdia canadensis*	1.54	0.01	73.51	0.10	-0.01
37	*Sphaeralcea*	5.56	0.01	7.69	5.61	-0.01
38	*Asteraceae subf.*	14.73	0.27	18.10	0.10	-0.02
39	*Fabaceae*	65.63	0.16	63.57	0.10	-0.02
40	*Rumex/Oxyria digyna* undiff.	2.86	0.01	9.66	0.10	-0.02
41	*Selaginella*	15.56	0.06	1.54	0.10	-0.02
42	*Apiaceae*	0.57	0	4.53	0.10	-0.03
43	*Asteraceae undiff.*	13.21	0.17	10.71	0.11	-0.03
44	*Sarcobatus vermiculatus*	10.00	0.05	6.14	0.10	-0.03
45	*Saxifragaceae*	13.73	0.11	9.73	0.16	-0.03
46	*Thalictrum*	3.81	0.04	16.81	0.10	-0.03
47	*Tsuga undiff.*	25.44	0.54	14.12	0.13	-0.03
48	*Caryophyllaceae*	50.91	0.35	1.61	0.10	-0.04
49	*Ericales undiff.*	5.08	0.06	11.59	0.10	-0.04
50	*Oxyria digyna*	25.66	0.14	20.28	0.10	-0.04
51	*Ranunculaceae undiff.*	53.77	0.09	16.67	0.10	-0.04
52	*Artemisia*	90.74	1.09	77.87	0.10	-0.05
53	*Pinus subg. Pinus*	79.48	1.81	79.48	0.18	-0.05
54	*Rosaceae undiff.*	92.68	1.55	8.16	0.10	-0.06
55	*Tsuga mertensiana*	13.25	0.03	57.41	0.48	-0.06
56	*Ericaceae*	92.70	5.86	75.61	0.11	-0.07
57	*Salix*	97.34	3.79	1.94	0.11	-0.07
58	*Betula*	91.00	19.09	87.44	0.13	-0.08
59	*Abies*	20.27	1.15	32.32	0.10	-0.11
60	*Cyperaceae*	95.18	6.24	66.67	0.10	-0.11
61	*Alnus*	83.17	9.31	87.76	0.12	-0.18
62	*Picea*	90.98	20.58	86.29	0.11	-0.20

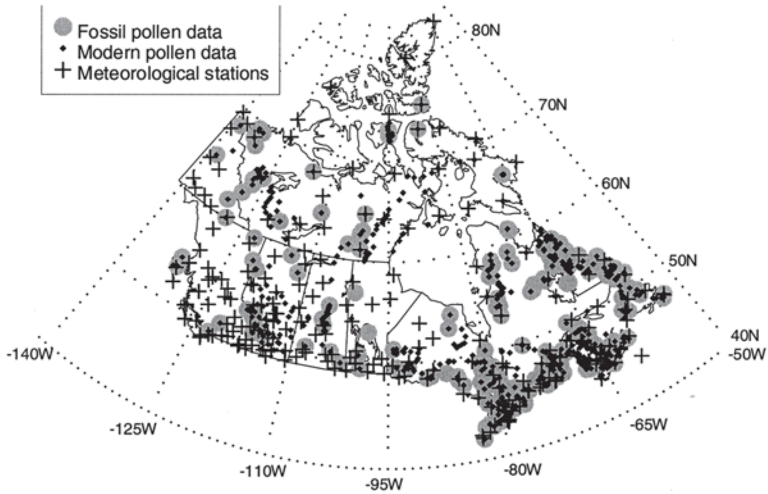

Figure 1: *Location of fossil and modern pollen data sites and meteorological stations used in the study*

consideration of the need to fit the pollen sample resolution with the current database and the numbers of statistical samples. Additionally, samples dated between 850 AD and 900 AD are also analyzed in the same manner to give the time slice of 875±25 (or pre-1000), and samples after 1900 AD at the top of the cores of the pollen sites are all grouped into the last time slice of 1925±25.

Considering that Canadian climate varies from region to region, this study presents information on climate change on a regional basis. Site-by-site correlation technique is applied to find similarities between meteorological stations and to define spatial patterns with coherent temperature records (Yu 1996; Harrison *et al.* in press). As a result, Canada is subdivided into four core-groups composed of 170 stations using the 30-year mean monthly temperature of 210 stations and a cut-off values of correlation coefficient (*r*) e"0.98. They are the west coast (Region 1), the western mountains (Region 2), central areas (Region 3) and eastern areas (Region 4). These regions are consistent with modern climate patterns in Canada based on temperature (e.g., Philips 1990). Fossil pollen sites in 21 groups (850AD to 1900AD) were then assigned to each region for purposes of plotting the regional temperature curves (i.e., 6, 25, 23, and 169 pollen sites for Regions 1, 2, 3 and 4, respectively).

Analogue method for reconstruction of climate:

The analogue method uses pollen assemblages from the past and systematically compares these with a large set of modern assemblages derived from, as wide as possible, a range of climates within the same biogeographic zones. Climate variables are then estimated from the present climate associated with those assemblages that are selected as analogues (Guiot *et al.* 1993).

First, to find a set of closest modern analogues of the fossil sample, the Euclidean distance between the pollen assemblages after square-root transformation of the pollen percentages are calculated as follows:

$$D_{it}^{2} = \sum_{j=0}^{m} W_{j}^{2} \left(M_{ij}^{1/2} - F_{tj}^{1/2}\right)^{2} \tag{1}$$

Where $\mathbf{D_{it}}$ is the distance between pollen samples, $\mathbf{W_j}$ is the weight in pollen taxon **j** (out of **m** taxa), $\mathbf{M_{ij}}$ and $\mathbf{F_{tj}}$ are the relative frequencies of pollen taxon **j** in the modern pollen sample **I,** and fossil pollen sample **t**, respectively. The taxon loading on the dominant principal components listed in Table 1 are used to weight the taxa in the calculation of the distances between pollen samples (W_j).

The reconstructed climate value for each fossil sample is the weighted distance mean of climate values:

$$R_{t} = \left(\sum_{i=1}^{s} C_{i} / D_{it}^{2}\right) / \left(\sum_{i=1}^{s} D_{it}^{-2}\right) \tag{2}$$

Where $\mathbf{R_t}$ is the reconstructed climate variable at pollen site **t**, $\mathbf{C_i}$ is the observed climate variable (out of **s** stations), $\mathbf{D_{it}}$ is the distance calculated using Equation (1). **s** is numbers of observed climate sites surrounding the pollen site **t** in a certain radius range. After several tests of different ranges, we found 9-degrees in latitude or longitude is a good radius range as it showed the best analogue.

All pollen samples at the 237 sites in 22 groups (ages falling into the periods 850AD to 1950AD) are calculated to provide palaeotemperature estimates following the above processes. Finally, if more than one sample occurs within a group at each site during the 50-year period, an average of the calculated temperature is taken.

Results

Relationship between modern pollen assemblages and instrument-recorded temperature:

The relationship between pollen taxa and climate was explored by multiple regressions between 30-year means of monthly temperature and the log-transformed frequencies of the pollen taxa in the modern pollen sites, as measured by the correlation coefficients between the climate variables and the pollen taxa at 1,050 modern pollen samples. The best fit of the pollen data is annual temperature (r = 0.82). The fit is relatively high for January, July, summer (June, July and August) and winter (December, January and February) (with r from 0.69 to 0.65) in the same samples of the series. The good correlation of the 1,050 surface samples suggests that pollen data do reflect the regional vegetation and climate for a catchment size ranging from 10^2 km^2 to 10^3 km^2.

Validation of pollen-based reconstruction is accomplished by comparison with the instrumental temperature records of the past 100 years. Two pollen sites, namely No. 102 (Humber Pond 3, Ontario (Weninger and McAndrews 1989)) and No. 48 (Crawford Lake, Ontario, data provided by McAndrews (NAPD 1994)), have broad-scale records at 10 to 30-year intervals covering the past 100 years (Figure 2a and 2b). Pollen site No. 185 (Pasqua Lake, Saskatchewan (McAndrews 1988)) is a unique site with high-resolution records for every 2 years in the last 100 years (Figure 2c). Three meteorological stations (a. M-6137287: 43.02N, 79.17W, 98 m asl., b. M-6139445: 43.00N, 79.27W, 175 m asl. and c. M-4016560: 50.43N, 104.67W, 577 m asl.) with annual temperature data are selected to compare the reconstructed temperatures. Station locations have a maximum distance of 0.7° (ca 80 km) radius range around the pollen sites. The relationships between actual temperatures and estimated temperatures are measured by correlation between the two series (Figure 2). Correlation coefficients (r) for the three sites are 0.77, 0.50 and 0.53, respectively, and are significant at the 0.95 confidence level. The good statistical fit of multiple-year moving averages suggests that the multiple-annual reconstruction is more reliable than a single-annual reconstruction in using pollen data to reconstruct temperature.

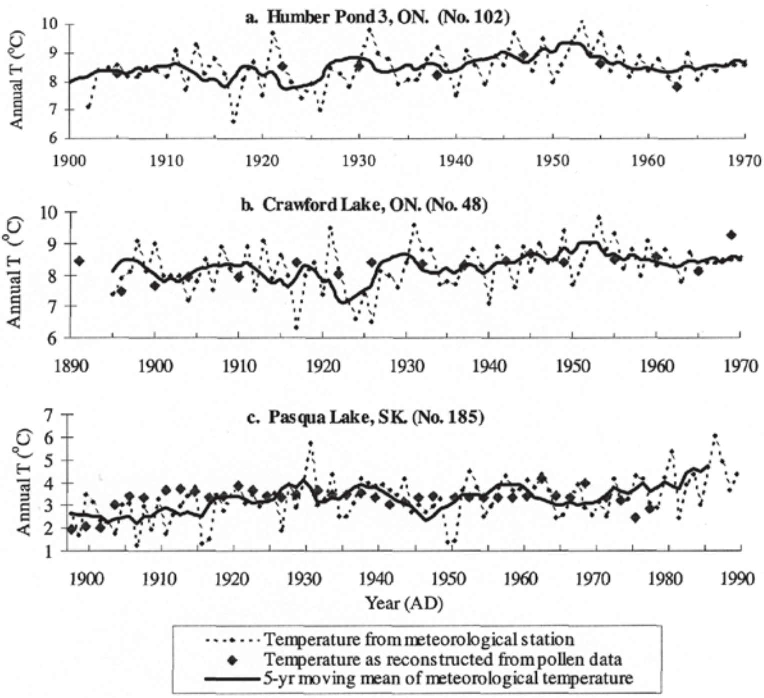

Figure 2: *Comparison of pollen-based temperature estimates and instrumental temperature data.*

Although the pollen records of the three sites have 2 to 30-year intervals, they are still low resolutions compared with 1-year intervals of instrumental records. Therefore, even if the correlations are significant at the 95% confidence level, they are still rather low as some temperatures may be inversely proportional to the pollen records. It is possible that a lower pollen resolution record may give a higher correlation with recorded temperature just because there are fewer chances of being ‘wrong’. These problems can be solved by the adoption of a high-resolution sampling scheme in future pollen studies

Temporal sequence of reconstructed climate during the past 1,000 years:

Reconstructed temperatures during the past 1,000 years are plotted in time sequence curves (Figure 3). Using each 50-year interval, the temperature anomalies are expressed by the reconstructed temperature

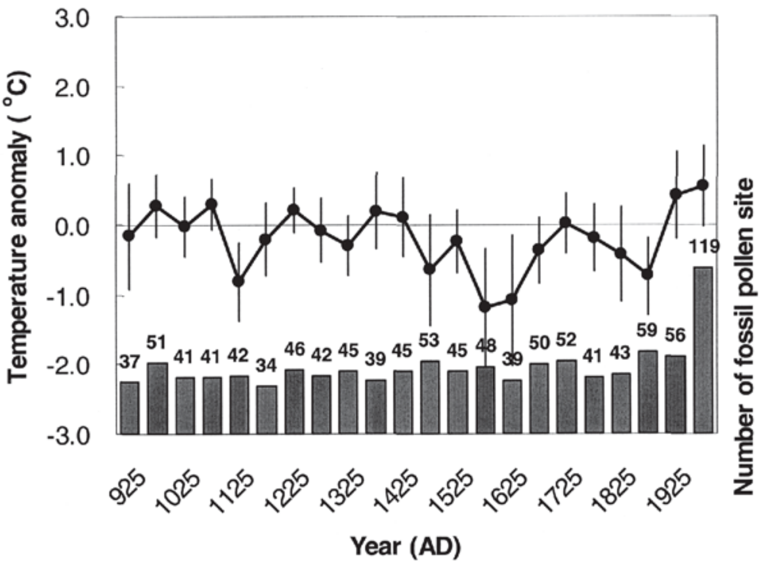

Figure 3: *Reconstruction of average annual temperature (°C) anomaly in Canada during the past 1,000 years.*

means minus that of the 1,000-year mean. The year at the X-axis is the central age of each 50-year group. The bars in the lower part represent the number of pollen sites in each interval. Vertical lines are error bars computed at the 0.95 confidence level of the data spatial series.

Figure 3 shows that the reconstructed temperature during 925-1075 AD was about 0.3-0.5°C warmer than normal. The temperature anomaly decreased 0.3°C around 1125 AD. A warm phase occurred during 1175-1425 AD with a slightly small fluctuation around 1325 AD. Afterwards, a few cold phases occurred in 1475 AD, 1575-1675 AD and 1775-1875 AD, with temperatures 0.5°C, 1.1°C and 0.5 colder than normal, respectively. The temperature increased and became much warmer after 1875 AD. This curve suggests four cold phases during the past 1,000 years with the coldest period during the 17th century and three secondary cold phases during the earlier half of the 12th and 15th centuries and the mid-19th century, and an increase in temperature at the end of the 19th century until present.

Figure 4 shows the four regional temperature anomaly curves for Canada. Vertical lines are error bars computed at the 0.95 confidence level of the data spatial series. Dash lines are for the cases with samples less than 2 and could be unreliable reconstructions. The maximum and minimum of the temperature anomalies in each region are shown in 4e. The sample sizes in each region are not equal, particularly in Region 1 (with only 6 sites, not analyzed). Three common cold phases occurred in the three regions of Canada (Figure 4b, 4c and 4d). The first was centred in the period 1075-1225 AD in Region 2, 1075-1275 AD in Region 3, and about 1125 AD in Region 4. The second occurred during 1425-1675 AD in Region 2, 1475-1575 AD in Region 3 and 1475-1674 AD in Region 4. The third cold phase was more synchronous and occurred in the three regions around 1825-1875 AD.

Discussion and Conclusions

The reconstructed temperature curve of the present study can be compared with the curve of Northern Hemisphere average surface temperature (Mann *et al.* 1999) showing a general decreasing temperature from about 1200 AD to 1900 AD. A few cold phases with negative temperature anomalies of less than -0.2°C occurred around 1340 AD, 1460 AD, 1590 AD, 1660-1700 AD and 1820-1900 AD. These have been captured by the present study with slight discrepancies in timing. The anomalies are also slightly larger (-0.4 to -1.1°C) than those for Northern Hemisphere average (-0.2 to -0.4°C). This can be explained by the fact that the hemispheric average is the result of inter-regional averages around the hemisphere. Therefore it can be expected to be much smoother than that of a region of Canada.

The regional sequences between 900 AD and 1900 AD show different temperature amplitudes (Figure 4e), with positive temperature anomaly ranges between +0.51°C and +1.79°C, and negative temperature anomaly between –1.22°C and –1.46°C. A pollen-based reconstruction of the temperature sequences (Gajewski 1988) indicated a similar timing in the eastern North America where this warm phase occurred pre-10th century and a cold phase occurred afterwards. For the regions of eastern North America (Gajewski 1998) and Canada (the present study), temperatures at the end of the 19th century are higher than at any previous time within the last millennium; this shows clearly the start of the global warming event. In comparison, however, the European Mediaeval Warm Period ca. 1000-1300 AD was not found in all regions of Canada based upon the present study, although Region 3 shows a strong warming signal pre-1000 AD.

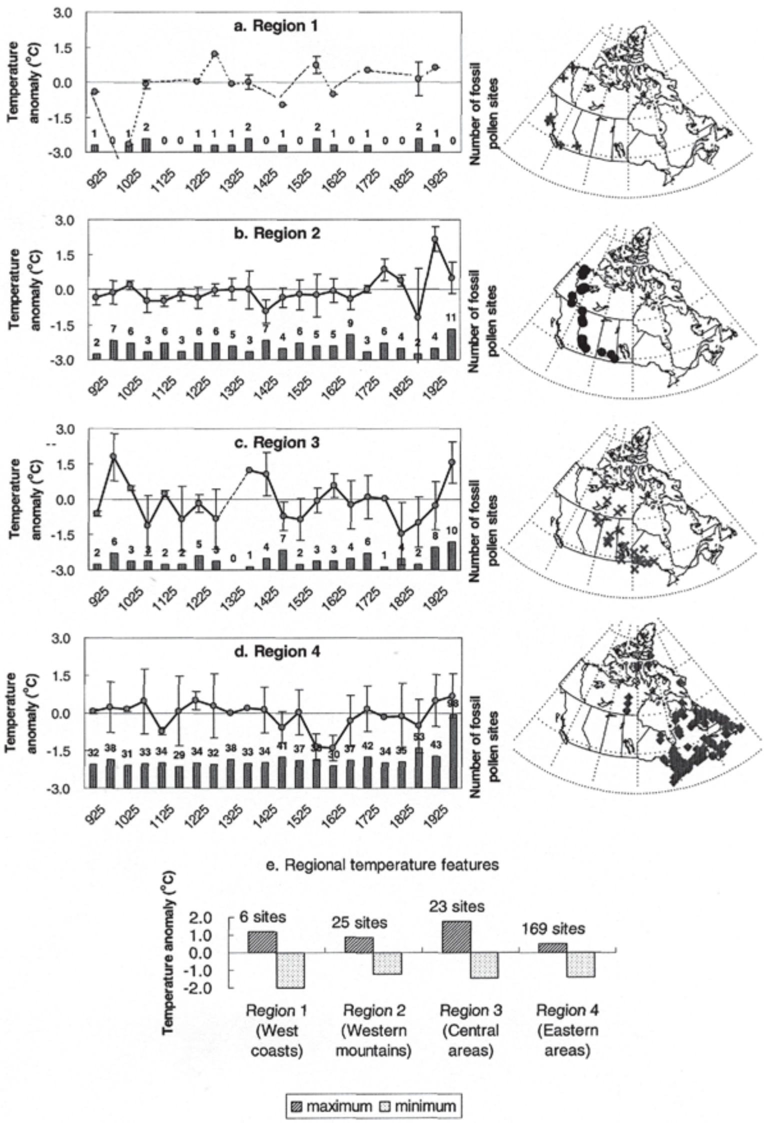

Figure 4: *Reconstruction of regional annual temperature (°C) anomalies in Canada during the last 1,000 years.*

Studies of regional temperature reconstruction based on pollen data can provide independent regional records for inter-regional comparison. The general temperature anomaly sequence from the 16th to 19th century in Region 2 (Figure 4c) is consistent with a reconstruction of ground surface temperature based upon borehole data from Northwest Territories, Alberta, Saskatchewan and Manitoba (Majorowicz and Skinner 2001), and both show a trend of decreasing temperature pre-1600 AD, slightly higher temperatures at about 1650 AD, lower temperatures during 1750-1850 AD, and higher than normal temperature after 1900 AD. However, the two curves have discrepancies in magnitudes; this could be due to the fact that the work of Majorowicz and Skinner (2001) was based on groundwater temperature records.

Monitoring of the climate system for evidence of change has a fundamental requirement of long-term homogeneous data sets. Instrumental records in Canada are only about 100 years in length. Therefore, long-term data sets will largely rely on the proxy data from sediments. This study has presented a palaeotemperature reconstruction back to 900 AD based on a pollen data set. There are still geographical gaps in the reconstruction, for example in northern Canada. The NAPD database only provided 71 modern pollen taxa; this limits the analogue to the fossil pollen taxa. Moreover, refinement of the climate reconstruction will be possible only after improvement of fine-palynological analysis and high-resolution pollen data sets, and multiple proxy data synthesis across the whole Canada.

Acknowledgements

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A sedimentary sequence in the Glacial Lake Proven basin: the Rolling River section, Riding Mountain, Manitoba

Roderick A. McGinn, Brandon University

Abstract: The Glacial Lake Proven basin covers an area of approximately 340 km^2 on the Riding Mountain Uplands in Manitoba. Four sub-stages in the history of the glacial lake have been identified based on depositional units, different outlets and associated lake levels. Near the southern margin of the basin, the Rolling River has incised into the Glacial Lake Proven sediments and exposed an 8 m section of the supraglacial lacustrine deposits. A supraglacial melting-ice facies (Zelena Formation; an ablation till) is exposed at the base of the sequence. Depositional evidence suggests that there was a rich sediment supply into Early Glacial Lake Proven depositing a supraglacial lacustrine complex that conveys an impression of alternating layers of sands. These deposits are overlain by a thick sequence of supraglacial lacustrine bottomsets consisting of sand and silt rhythmites. In the upper part of the section, the deposits exhibit the characteristics of a supraglacial lake-margin deposit. There is some regular lamination of the finer sand and silt, evidence of coarse intercalations and material supplied by mass movements or wash off, together with numerous dropstones.

Key words: Riding Mountain Uplands, Glacial Lake Proven, facies, lacustrine deposits, stratigraphic section, supraglacial lake

Introduction

The Lake Proven basin covers an area of approximately 340 km^2 on the Riding Mountain Uplands in Manitoba (Figure 1). The basin topography is less than 625 m in elevation and includes the present day Clear Lake, Bottle Lake, Proven Lake, Jackfish Lake and Otter Lake. Higher elevations, in excess of 670 m, are located to the north and east of the Lake Proven Basin. The Rolling River drains the southern portion of the basin to the south; the northern portion of the basin drains towards the west by way of Clear Creek. Both drainage routes join the Little

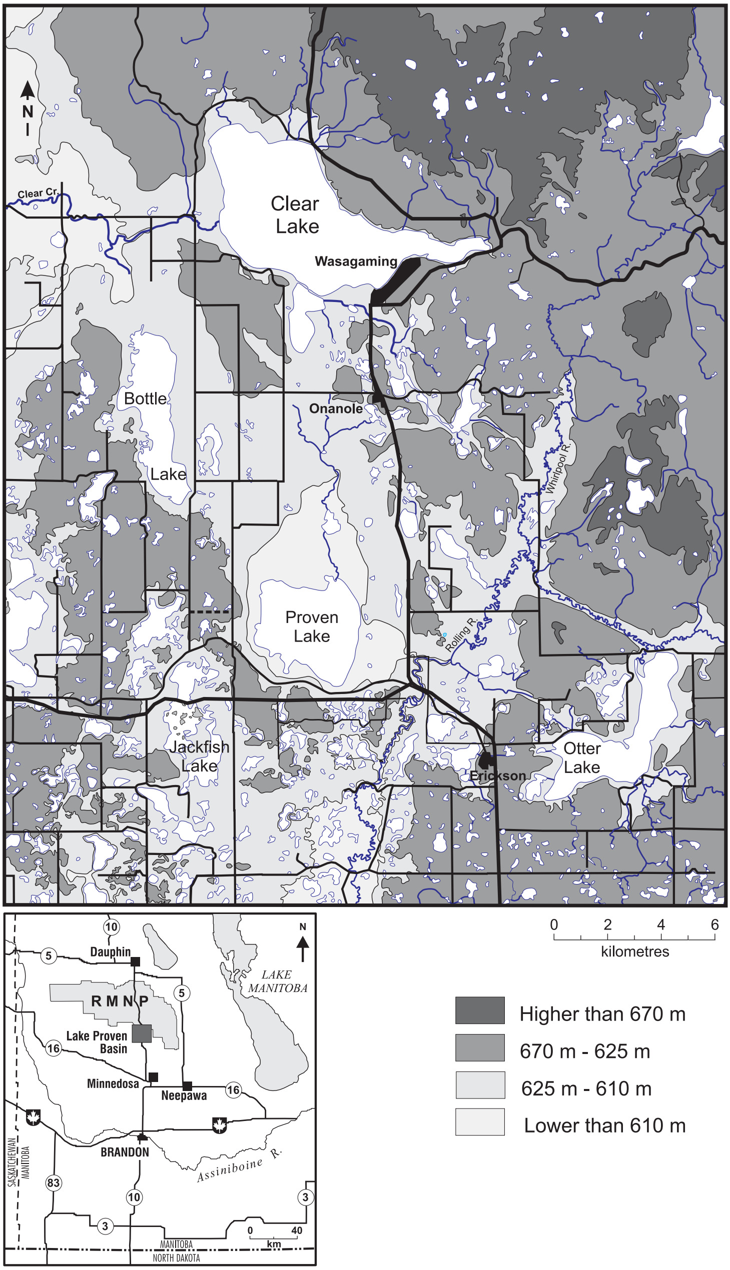


Figure 1: *The Lake Proven Basin.*

Saskatchewan River and eventually drain into the Assiniboine River to the south.

Klassen initially mapped the western third of the Lake Proven area (Figure 1) as "silt, deposited in part in a superglacial (supraglacial) lake" and later referred to this supraglacial lake as "Glacial Lake Proven" (Klassen 1966, 117). The associated 1:250,000 map published in 1965, however, makes no reference to the name "Glacial Lake Proven" or to the mode of origin of the deposits. In later work Klassen (1979) describes the supraglacial lacustrine deposits as "a gently irregular to hummocky glaciolacustrine complex composed of mainly silt and sand."[1] Associated lacustrine deposits are described as silt and clay or organic deposits on poorly drained flats. There is no mention of Glacial Lake Proven in the 1979 memoir. The Quaternary surficial map of Riding Mountain (Manitoba Energy and Mines 1980), based on Klassen's 1979 map, describes the deposits as lacustrine silt and clay deposited in basins peripheral to the main Lake Agassiz basin. It is interesting to note that this map was compiled with no additional field mapping or sediment sampling. In these small-scale surficial mapping studies there are virtually no details regarding the environmental conditions, depositional mechanisms and lithologic characteristics that are associated with the "Glacial Lake Proven" deposits. Furthermore, the actual extent of the deposit is poorly mapped due to its relatively small size and the fact that some of the sediments have been subsequently buried.

Objective of the Study

This paper reviews the sedimentary sequence found in the previously undescribed Rolling River stratigraphic section and relates the facies to the history of Glacial Lake Proven.

Glacigenic Sediments

Ashley (1989) reviewed the sedimentary processes and lithofacies units in glacier-fed lakes and established lithofacies groups with commonly occurring lithofacies units. Jurgaitis and Juozapavicius (1989) outlined the importance of the geomorphic and lithologic parameters recommended for study when investigating glaciofluvial deposits and developed a genetic classification of glaciofluvial deposits. The lithologic criteria outlined in this publication will be used in this research. Brodzikowski and Van Loon

(1991) presented a synthesis of glacigenic sediments and established a systematic classification based on the depositional subenvironment, associated facies and the characteristics of the deposits. The Brodzikowski and Van Loon nomenclature is also employed in this research.

Surficial Deposits in the Glacial Lake Proven Basin

Detailed surficial mapping (Klassen 1965, 1966, 1979; Groom 1980; McGinn 1991a, 1991b, 1997, 2000) has determined that early Glacial Lake Proven deposits (Proven I Complex) occur at elevations above 625 m in the region to the west and southwest of the topographic basin (Figure 2). These rhythmite deposits represent a supraglacial lacustrine facies. The deposits of the later phase of Glacial Lake Proven (Proven II Complex), found at lower elevations, are believed to represent a topographically controlled terminoglacial lacustrine facies, perhaps supraglacial, but with only a thin ice base (Figure 2).

To the west are the deposits of the eastern ridge of the Horod Moraine. The Horod Moraine was originally mapped as a kame-esker complex by Klassen in 1965 and later an end moraine on the Quaternary surficial map of the Riding Mountain region (Manitoba Energy and Mines 1980). The Horod Moraine Complex is classified as an ice marginal ridge (Jurgaitis and Juozapavicius 1989) deposited between the neutral ice to the west and the stagnating ice of the eastern uplands (McGinn 1997). This supraglacial melt-out complex is composed of stratified sands and gravels which frequently exhibit deformation structures and large till inclusions (McGinn 1997). To the north a glaciofluvial facies, interpreted as proglacial outwash, merges with constructional glaciotectonic features (ice-shoved hills and a composite linear ridge) in the east (McGinn 2000), the latter being surrounded by Glacial Lake Proven deposits.

In addition to the significant inflow of meltwaters from the surrounding ice during the Incipient and Early Glacial Lake Proven supraglacial lake sub-stages, there appears to have been three prominent inflowing streams operating at different times during the later supraglacial and terminoglacial lake sub-stages. Initially there was inflow from the west through a breach in the Horod Moraine (McGinn 1997). Later in the history of the lake a subglacial river entered from the east near the town of Wasagaming (Figure 2). There is also evidence that there was a Jokulhlaup inflow along the Upper Rolling River outlet during the terminoglacial lake phase (McGinn 1991a).

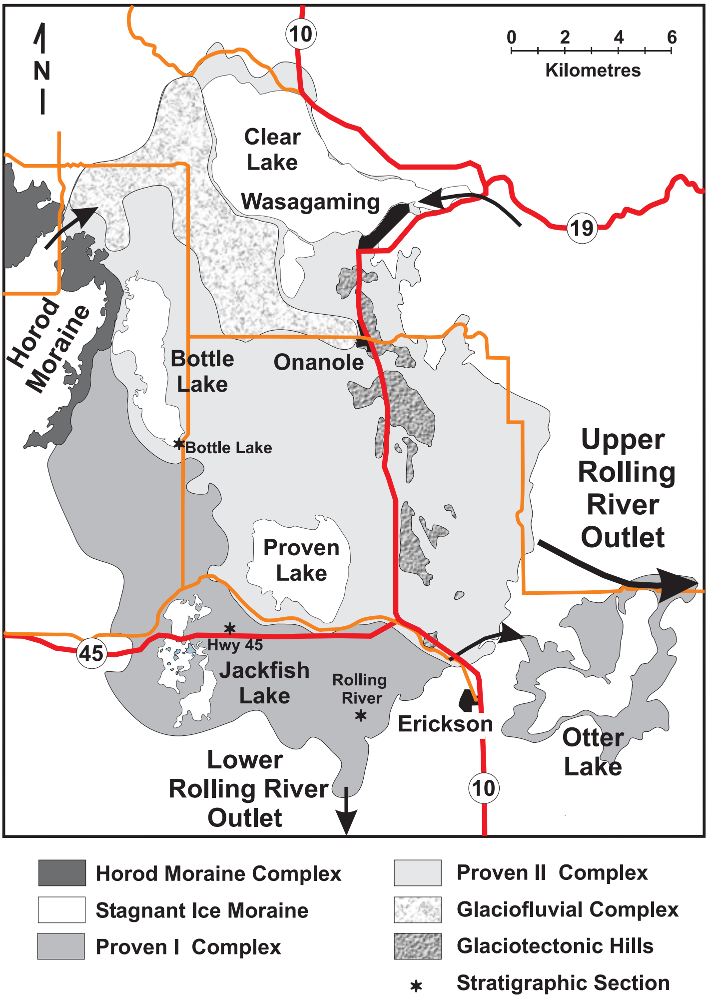


Figure 2: *Surficial deposits in the Glacial Lake Proven Basin.*

Drainage of Early Glacial Lake Proven occurred through an ice marginal channel into the Otter Lake sub-basin (Figure 2) and then into a prominent spillway system draining east and south (not shown in Figure 2). As the lake enlarged, the ice marginal channel was abandoned in favour of the Upper Rolling River outlet (Figure 2), which drained into the same eastern spillway system (McGinn 1991b). Drainage during the final stages of Glacial Lake Proven took place through the Lower Rolling River outlet towards the south (Figure 2). There is no evidence that the lake drained towards the west along the present day Clear Creek.

The Rolling River Section

Near the southern margin of the Lake Proven basin, the Rolling River has incised into the Glacial Lake Proven sediments and exposed an 8 m section of the supraglacial lacustrine deposits and underlying till. The Rolling River section (Figure 1) is on the northwestern cutbank of the Rolling River in the South Quill's Ojibway Peoples Rolling River Reserve Number 67: NTS 62 J5, Clanwilliam, Manitoba: UTM 43090 E; 55935 N.

Four subsections (W-1, W-2, W-3, and W-4) were logged along the Rolling River cutbank (Figure 3). A gully eroded at right angles to the cutbank section provides a three-dimensional view of the upper part of the section. Four subsections (N-1, N-2, SW-1 and SW-2) have been logged in this gully (Figure 3).

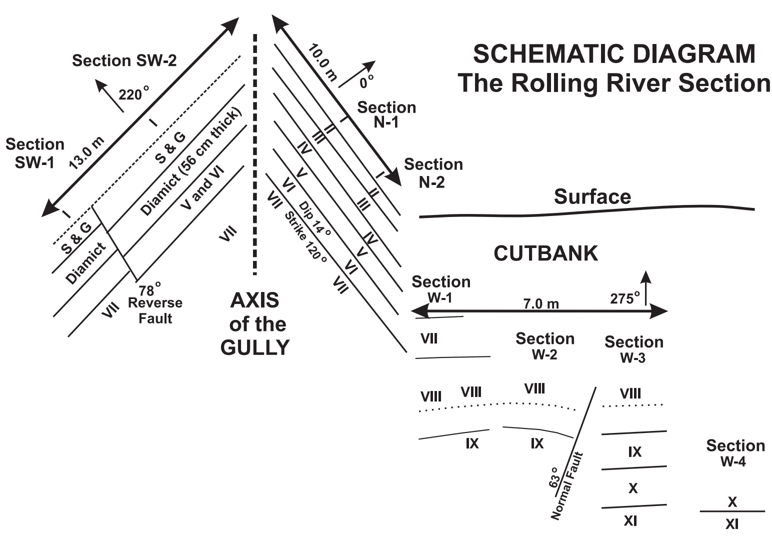


Figure 3: *Schematic diagram: the Rolling River section.*

Description of the Composite Section

The composite section, illustrated in Figure 4, has been constructed from sections N-2, W-1, W-2, W-3 and W-4 (Figure 3). Figure 4 shows the depth of each stratigraphic unit from the surface (m), thickness of each sub-unit (cm) and a description of the sedimentary facies (texture, structure and other unique characteristics).

A diamict (Sections W-3 and W-4, Unit XI) underlies the lacustrine sediments attributed to Glacial Lake Proven. Fresh exposures are moderately compact and olive grey brown in colour (Munsell Colour Chart). Carbonates and shale represent the most common clasts, although igneous and metasedimentary shield pebbles are also found. This diamict is overlain by 0.73 m of rhythmites consisting of three layers of a silty diamict alternating with clast supported coarse sand, granules and small pebbles (Section W-3, Unit X). There are no pebble size clasts present in the silty diamict. Unit X (W-3) is overlain by a 0.56 m sequence of deposits, which exhibit five laminae of massive very fine sand and silt interspaced by laminae of coarse sands and granules. Unit VIII in Sections W-1, W-2 and W-3 is a 2.14 m thick unit of laminated fine sands and silt interbedded with at least 10 ironstained laminae (less than 1.0 cm thick) composed of fine to medium sands and overlies Unit IX. An 8.0 cm thick traceable marker bed (VIIIt) consisting of coarse sands and granules is found 0.77 m from the base of Unit VIII. Unit VII (W-1) is a 0.65 m thick sequence of rhythmitic deposits consisting of a simple alternation of fine sand and silt laminae interspaced by coarser sand beds. The upper 2.22 m of section N-2 has been divided into six units for convenience of description. These units could be combined into one unit of rhythmites consisting of seven relatively thick laminae of massive fine sand and silt alternating with coarser beds consisting of sands and gravels. Calcium carbonate precipitate gives the four upper fine laminae (Units I, II, III and IV, section N-2) a whitish grey colour.

Interpretation of the Composite Section

A supraglacial melting-ice facies (Unit XI, Zelena Formation; a melt-out complex) is exposed at the base of the sequence (Figure 4). Klassen (1979) suggests that the Zelena formation was deposited during the final stages of glacial stagnation during the Late Wisconsinan. Consequently, the Zelena formation represents the uppermost tills and intertill sediments on the Riding Mountain Uplands. Oxidized Zelena till is usually yellowish

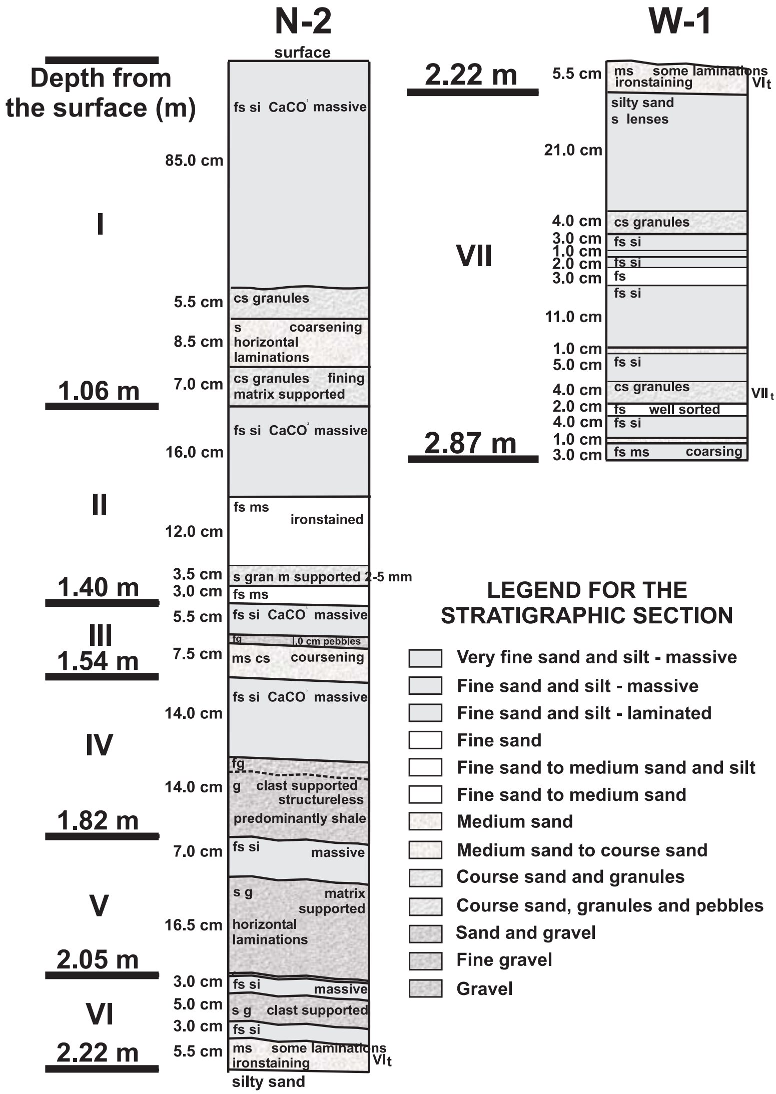
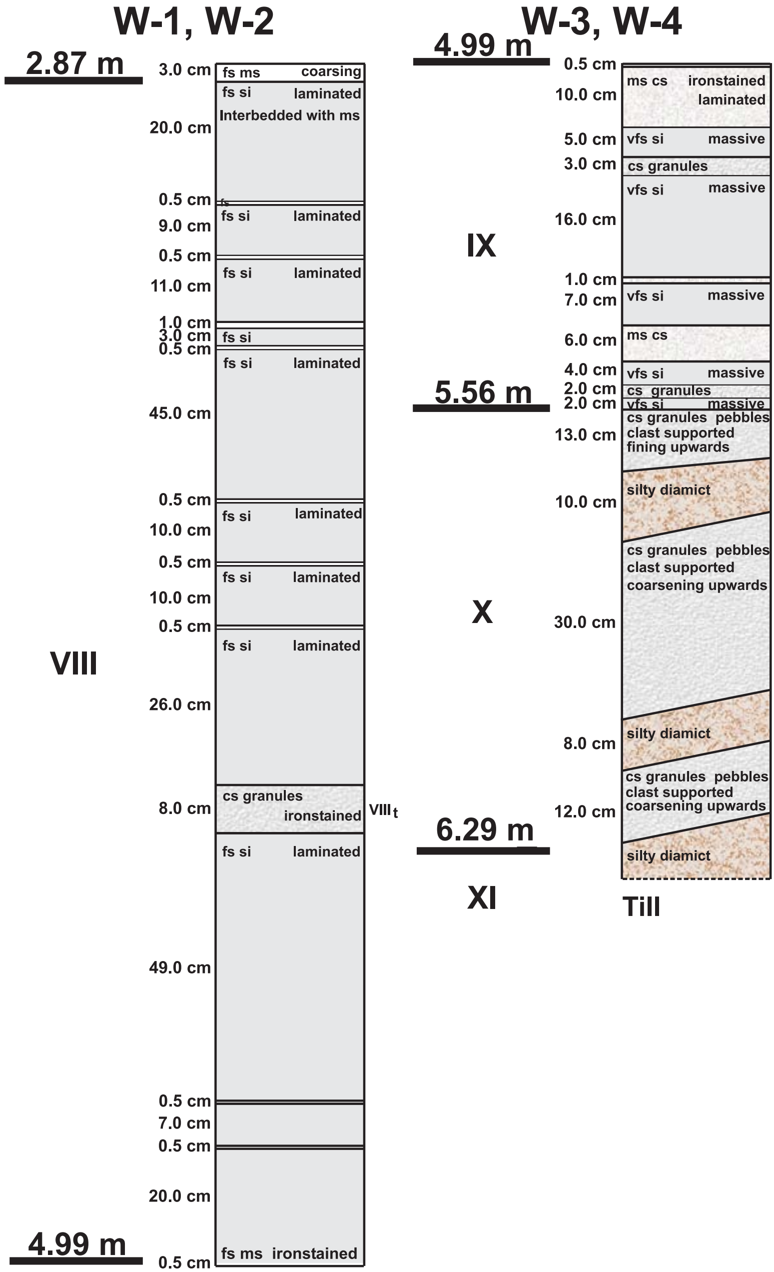


Figure 4: *A composite stratigraphic section: N-2, W-1, W-2, W-3 and W-4.*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XI
Till

brown or very dark grey brown in colour (Munsell Colour Chart). Fresh (unoxidized) exposures are dark olive grey or very dark grey (Klassen 1979). The till is massive and of moderate compaction. The prominent clasts in the till are typically the more resistant Interlake region carbonates and shield metasedimentaries as the locally incorporated and softer Odanah Shale clasts have been quickly crushed or abraded to matrix size or terminal grade during glacial transport. Some larger shale clasts are evident but difficult to remove without fracture, so it is difficult to determine a percentage composition of shales. Carbonates constitute approximately 26% - 36% of the clasts (Klassen 1979).

Depositional evidence suggests that there was a rich sediment supply into Early Glacial Lake Proven depositing a 1 m thick supraglacial lacustrine complex that conveys an impression of alternating layers of coarse sands and gravels and silty-clay diamict (Unit X, Figure 4). These relatively coarse deposits (interpreted as Incipient Glacial Lake Proven deposits) are overlain by a thick sequence of supraglacial lacustrine bottomsets consisting of sands and granules and silty-clay rhythmites (Unit IX, Figure 4), which fine upwards to a unit of fine-medium sands and silt rhythmites (Unit VIII, Figure 4). These supraglacial lacustrine bottomsets (Units IX and VIII) are interpreted as Early Glacial Lake Proven deposits and mapped as the 'Proven I Complex.' Unit VII, a supraglacial lacustrine complex consisting of alternating laminae of fine sand and silt and coarser sands, represents the transitional phase from a supraglacial lacustrine environment to the terminoglacial lacustrine environment as the ice-walled lake expanded to the north and east.

In the upper part of the section, the deposits depict the characteristics of a supraglacial lake-margin deposit (Units I, II, III, IV, V and VI, section N-2, Figure 4). There is some regular lamination of the finer sand and silt, evidence of coarse intercalations and material supplied by mass movements (for example, between Unit II and III in section SW-2, Figure 3) or wash off, and numerous dropstones. The presence of $CaCO_3$ particulate in Units I, II, III and IV suggests declining lake levels associated with periodic drought or cold periods of reduced melt.

The History of Glacial Lake Proven

Early Glacial Lake Proven: Incipient Supraglacial Lake Sub-Stage:

Glacial ice covered the entire Riding Mountain area during the late Wisconsinan (20,000 - 12,000 B.P.) with ice flow generally towards the southeast (Klassen 1966). Waning and downmelting of the last ice advance, named the Falconer Ice Advance (Fenton *et al*. 1983), resulted in the stagnation of glacial ice on the Riding Mountain Uplands, first on the higher Eastern Uplands and later on the Western Uplands. The Horod Moraine is believed to be the hinge point for this two-stage ice stagnation model first postulated by (Klassen (1966). Meltwaters ponded over the stagnant ice, creating small thermokarst supraglacial lakes (Ashley 1989) and later an integrated network of ice-walled supraglacial lakes (McGinn 1991a). Klassen (1966) named the largest of these ice-walled lakes Glacial Lake Proven.

Glacial Lake Proven was initiated as an elongated ice marginal lake formed in a transition zone between the stagnating ice of the Eastern Uplands and the neutral ice of the Assiniboine Lobe to the southwest (Figure 5a). Incipient Glacial Lake Proven drained towards the east paralleling the eastern extension of the stagnating ice - Assiniboine Lobe transition zone. The eastern ridge of the Horod Moraine was deposited at the northwestern extension of this transition zone. Stratigraphic sections in the moraine indicate that this feature is an ice marginal ridge (Jurgaitis and Juozapavicius 1988) characterized by stratified and unstratified sands and gravels, till inclusions and slump features.

Early Glacial Lake Proven: Supraglacial Lake Sub-Stage:

Early Glacial Lake Proven appears to be associated with the Horod Moraine in that both features formed between the neutral ice to the south and west (Assiniboine Lobe) and the stagnating ice of the Eastern Uplands (Figures 5a and Figure 5b). Depositional evidence suggests that there was a rich sediment supply with 5 to 8 m of silt to coarse sands exposed in two stratigraphic sections east and southeast of the Eastern Ridge of the Horod Moraine (Figure 2). The lithofacies and textural characteristics of the sediments suggest that they were deposited and remained in a subaqueous position. Some of the lacustrine deposits depict the characteristics of a supraglacial lacustrine complex (Brodzikowski and Van Loon 1991), with alternating layers of sands and silt. There is some regular lamination of the finer sand and silt, evidence of coarse intercalations and dropstones. Most of the sequence, however, can be classified as supraglacial lacustrine bottomsets. Early Glacial Lake Proven drained over the stagnant ice into the Otter Lake sub-basin and then eastward into the Upper Rolling River - McFadden Valley - Polonia Trench spillway system (only the inlet to this system is illustrated in Figure 5b). This spillway system was in operation for a long period of time, probably throughout the history of Glacial Lake Proven. At first the supraglacial meltwaters flowed east up

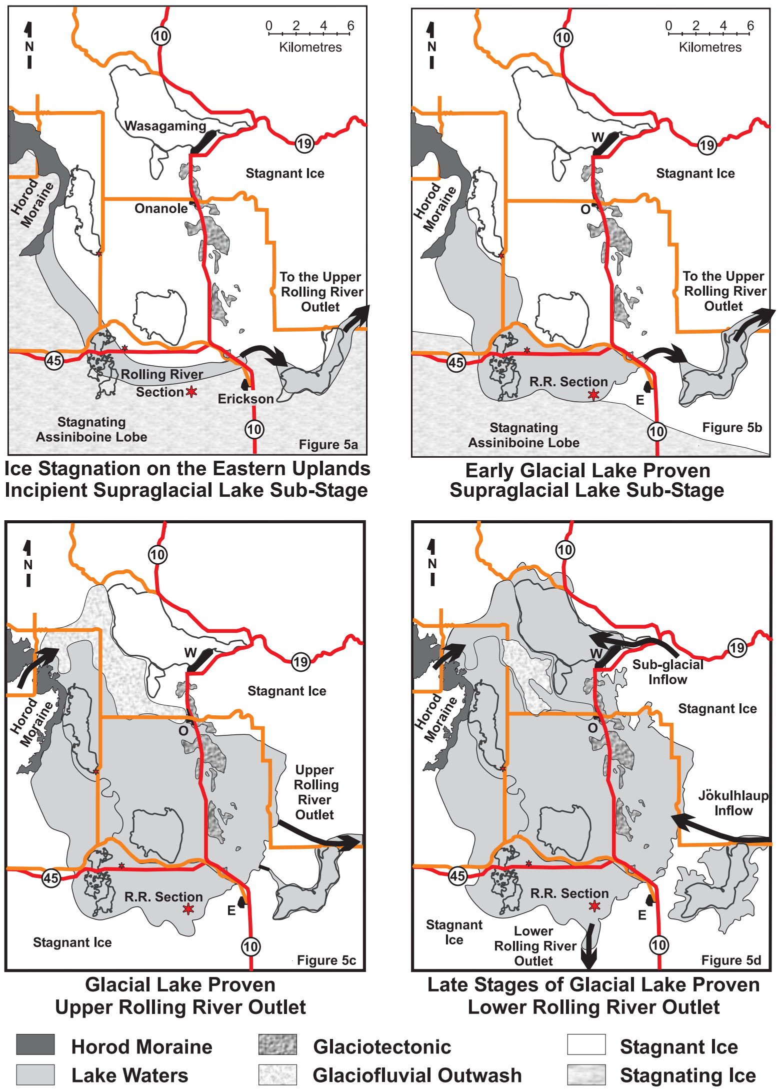

Figure 5: *History of Glacial Lake Proven.*

the regional slope to the edge of the Manitoba Escarpment and then paralleled the crest of the escarpment draining south. The meltwater channel rapidly entrenched into the substratum and a subaqueous fan was deposited as the discharge entered a small supraglacial lake southeast of Glacial Lake Proven. The entrenched Upper Rolling River - McFadden Valley - Polonia Trench spillway is 53 m deep and over 1 km wide at Polonia, Manitoba.

Glacial Lake Proven: Terminoglacial Lake Sub-Stage – the Upper Rolling River Outlet:

The Early Glacial Lake Proven deposits (mapped as Glacial Lake Proven I Complex, Figure 2) formed a steep bluff as the ice-wall northern and eastern shore of the supraglacial lake retreated towards the north and east (Figure 5c). Fluctuating water levels dropped by approximately 8 m, but these Early Glacial Lake Proven supraglacial lake deposits remained submerged beneath the waters of the enlarging lake. Glacial Lake Proven was now twice as large as the early thermokarst lake, which reduced the sediment per unit lake area ratio. Consequently, the lacustrine sediments of the Glacial Lake Proven II Complex (Figure 2) are relatively thin and in several places the underlying Zelena Till is exposed. To the north and east the sediments are fine to medium sands of varying thickness, with some regular lamination but more typically appear massive. To the west and south, the deposits are characteristic of lake-margin deposits (Brodzikowski and Van Loon 1991). There is some regular lamination of the finer sand and silt layers, evidence of coarse intercalations and material supplied by mass movement or wash-off, and numerous dropstones or consolidated sand and silt balls.

The expanded Glacial Lake Proven was now topographically controlled and draining through the Upper Rolling River into the McFadden Valley - Polonia Trench spillway system (Figure 5c). A sandur plain formed along the northern shoreline of Glacial Lake Proven. This proglacial outwash merges with a glaciotectonic composite linear ridge and a series of ice-shoved hills towards the east (Figure 5c).

Late Glacial Lake Proven: Terminoglacial Lake Sub-Stage – the Lower Rolling River Outlet:

As downwasting of the ice continued, Glacial Lake Proven expanded northward into the present day Clear Lake basin (Figure 5d). A major subglacial inlet channel is evident in the Clear Lake area near the town of Wasagaming (W, Figure 5d) and sheetflood depositional evidence near the Otter Lake sub-basin suggests that there was a flow reversal in the Upper Rolling River outlet channel; perhaps associated with a jokulhlaup discharge from a large ice-dammed supraglacial lake to the northeast (Figure 5d). Consequently, Glacial Lake Proven could not drain eastward into the Upper Rolling River - McFadden Valley - Polonia Trench system. As lake levels rose, Glacial Lake Proven spilled over the debris covered stagnant ice to the south. The overflow discharge rapidly cut a straight channel through the stagnant ice and into the underlying till. Lake waters could now drain southward down the freshly cut Lower Rolling River Outlet (Figure 5d) into the ice marginal meltwater channel which had formed along the northern flank of the Assiniboine Lobe (not shown on the maps). Sediment supply increased during this time and approximately 2.25 metres of lake-margin sediments were deposited over the Early Lake Proven sediments at the entrance to the Lower Rolling River Spillway. Winter ice cover resulted in the sedimentation of thick laminae of fine sand and silt, while coarser materials, dropstones and mass transported diamicts characterize the sediments deposited under ice free conditions. Within five years the lake level had dropped below the 625 m elevation, exposing the Early Glacial Lake Proven deposits. It is believed that the lake drained to the present day suite of sub-basin lakes relatively quickly after the entrenchment of the Lower Rolling River Spillway, which is 20 m deep and 375 m wide.

Evidence of a topographically controlled eastern shoreline and an undisturbed lake plain suggest that during the latter stages, the lake was terminoglacial, formed over very thin stagnant ice based on glacial deposits. Well-sorted terminoglacial lake-margin deposits have a limited areal extent and are relatively thin. There is some regular lamination of the finer sand and only occasional silt deposits. A melting ice facies (ablation till; Zelena Formation) is exposed in other areas of the lake plain.

Summary

Four sub-stages in the history of Glacial Lake Proven have been identified based on depositional units, correlation of outlets and associated lake levels. The Rolling River section provides supportive evidence for this temporal interpretation.

Early Glacial Lake Proven has two sub-stages. The Incipient Supraglacial Lake Sub-Stage is characterized by a supraglacial lacustrine complex that consists of alternating layers of sands and silt-clay (Unit X, Figures 3 and 4). The Supraglacial Lake Sub-Stage is represented in the Rolling River section by a thick sequence of supraglacial lacustrine bottomsets consisting of sand and silt rhythmites (Units IX and VIII (Figures 3 and 4). A third sub-stage, identified as the Glacial Lake Proven Terminoglacial Lake Sub-Stage draining through the Upper Rolling River Outlet, is represented by Unit VII (Figures 3 and 4). This unit consists of a supraglacial lacustrine complex of alternating laminae of fine sand and silt and coarser sands. The final sub-stage, the Terminoglacial Lake Sub-Stage of Late Glacial Lake Proven draining through the Lower Rolling River Outlet, is represented by Units VI - I (Figures 3 and 4). These supraglacial lake-margin deposits are characterized by regular lamination of the finer sand and silt, evidence of coarse intercalations and material supplied by mass movement or wash-off, and numerous dropstones.

Note

[1] This description is from Klassen's 1979 memoir where it appears on map 1469a.

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Factors affecting nutrient content in the winter snowfall over the Clear Lake watershed

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Abstract: A snowfall nutrient content sampling survey was conducted at five established sampling sites in the Clear Lake watershed throughout the winters of 1999-2000 and 2000-2001. Snowfall data were collected from the Environment Canada Wasagaming climate station located in Riding Mountain National Park. A high concentration of airborne phosphate is being deposited in early winter snowfalls on the Clear Lake watershed. Most of this particulate phosphate is soluble and bonded to colloidal particles. By mid-winter the accumulated snowpack has covered potential source regions for airborne nutrients and both total ammonia and phosphate ion concentrations in the snowfalls are significantly reduced. As temperatures warm, and the prairie snowpack melts, nitrogen and phosphorus concentrations increase substantially in the late winter snowfalls. The concentrations of other macronutrients (nitrate nitrogen and nitrite nitrogen) do not exceed the recommended standards.

Key words: airborne nutrients, Clear Lake watershed, phosphorus, snowfall, snow cover, total ammonia

Introduction

The Clear Lake watershed is centrally located on the Riding Mountain Uplands in southwestern Manitoba. The watershed drains an area of 142.18 km^2 of which over 65% is located in Riding Mountain National Park. Clear Lake represents approximately 20.7% of the watershed area (Figure 1).

Clear Lake is the focus of summer recreational activity in Riding Mountain National Park. Consequently water quality in Clear Lake is a fundamental concern identified in both the Park Management Plan and the Ecosystem Conservation Plan (Dubois 1997). Parks Canada regulates human activities within Riding Mountain National Park in order to minimize pollution of the natural environment. Snowmelt accounts for an

Figure 1: *Clear Lake watershed: 1999-2001 Snowfall Nutrient Content Sampling Sites.*

average runoff inflow of approximately 4,400 - 6,800 dm^3 or a mean annual rise of 18.0 cm in the lake level (McGinn *et al*. 1998). This value is estimated to represent 23% of the estimated average annual runoff into Clear Lake. For the park staff, monitoring the water quality of the snowpack over the Clear Lake watershed is seen as necessary in order to determine whether airborne pollutants are entering the Clear Lake system.

Objectives

Two objectives were identified at the onset of this study: 1) to estimate the nitrogen and phosphorus concentrations in the annual winter snowfall over the Clear Lake watershed; and, 2) to examine factors that appear to influence the concentrations of airborne phosphate in snowfalls over Riding Mountain National Park.

Theoretical Considerations

Carbon, potassium, nitrogen, and phosphorus are the common macronutrients for aquatic plant life. In most lakes either nitrogen or phosphorus is the limiting factor in plant growth (Hammer and MacKichan 1981). Nitrogen and phosphorus nutrient loading of surface runoff accelerates natural eutrophication in streams, lakes and other aquatic systems (Reid and Wood 1976). Allochthonous or outside sources of these nutrients include atmospheric concentrations of ammonia, ammonium, nitrates, nitrites, and phosphates, which can be directly deposited (dry deposition) onto water surfaces. Furthermore, these nutrient aerosols can form nuclei of condensation and wash out as precipitation, some falling onto lakes and wetlands.

Ammonia:

Ammonia is a colourless gaseous alkaline compound of nitrogen and hydrogen. It is an inorganic form of nitrogen that is very soluble in water and can be used directly by plants. Natural sources of ammonia in surface waters include the decomposition of plant material and animal waste, weathering of clays, nitrogen fixation by clays and gas exchange with the atmosphere (pure ammonia being a gas present in air). Ammonia is found in water as NH_3 (free ammonia or dissolved un-ionized ammonia gas), and as NH_4^+ (ammonium ions). In water the two forms (NH_3 and NH_4^+) exist in equilibrium and their combined concentration is referred to as total ammonia. Analytical methods are not readily available for the measurement of free ammonia. Consequently, measures of ammonium ion concentration and equilibrium relationships are used to determine total ammonia ($NH_3 + NH_4^+$) concentration. Ammonium is a major component in fertilizers and significant amounts can enter water bodies in runoff from cultivated fields. During application and post application, under the right conditions, volatilization significantly increases the ammonia concentration in the atmosphere.

The toxicity to aquatic organisms of ammonia in an aqueous solution is attributed to the un-ionized NH_3 component of total ammonia (Williamson 1988). Since it is difficult to measure free (un-ionized) ammonia concentrations in a solution, equilibrium relationships are used to estimate the free ammonia concentration from total ammonia measurements. Water temperature and pH regulate this equilibrium. As temperature and/or pH increase the percentage of free ammonia in total ammonia increases.

In unpolluted waters free ammonia and ammonium occur in small quantities usually less than 1.0 mg L^{-1} (Reid and Wood 1976) and pose little or no risk to aquatic organisms. Health Canada has no guidelines for a maximum allowable concentration (MAC) of ammonia for drinking water. However, 'Guidelines for Evaluating Quality for Aquatic Life' in the *Water Encyclopedia* recommend that free ammonia (NH_3) should not exceed 0.5 mg L^{-1} (Van der Leeden *et al*. 1990, 472). Manitoba Environment has set the free (un-ionized) ammonia concentration in unpolluted water objective an order of magnitude lower, at 0.020 mg L^{-1} (Williamson 1988).

Emerson *et al*. (1975), employ a formula to calculate the percentage of free (un-ionized) ammonia in a total ammonia solution. Using a melting temperature for snow of 0^{o}C and the mean recorded pH of the snowfalls in the Riding Mountain area of 6.4 pH units, the maximum allowable concentration of free ammonia in snowfall should not exceed 0.03 percent of the total ammonia concentration. If the concentration of toxic free ammonia in snowfall should not be greater than 0.03 percent of the total ammonia concentration, the maximum total ammonia concentration in snowfall allowable by Manitoba Environment is calculated to be 0.67 mg L^{-1}. This standard will be used as the benchmark for this study.

Nitrates and Nitrites:

Nitrate (NO_3^-) and nitrite (NO_2^-) are two inorganic forms of nitrogen found in water. Along with ammonia they are an important source of nitrogen for aquatic plants. Nitrates are used extensively as an ingredient in nitrogen fertilizers; thus runoff from cultivated land is a common source of anthropogenic nitrate. Nitrates can also form from sewage, animal waste, plant and animal decay, as well as leachate from igneous rock.

Nitrate ion concentrations in water bodies in western Canada rarely exceed 5.0 mg L^{-1} of nitrogen in nitrate form and are usually below 1.0 mg L^{-1} of nitrate nitrogen (Williamson 1988 and Van der Leeden *et al.* 1990, 422-423). Nitrate nitrogen ($N0_3^-$-N) refers to the mass of nitrogen in the nitrate form. According to Health Canada the maximum allowable concentration (MAC) for nitrates should not exceed 45.0 mg L^{-1} (Health Canada 1996). This corresponds to maximum allowable nitrate nitrogen ($N0_3^-$-N) concentration of 10.0 mg L^{-1} (Williamson 1988 and Van der Leeden *et al.* 1990, 443). The nitrate nitrogen concentration in unpolluted waters rarely exceeds 0.300 mg L^{-1} (Reid and Wood 1976).

Nitrite nitrogen ($N0_2^-$-N) is found at lower concentrations than nitrate nitrogen, approximately 0.001 mg L^{-1} in unpolluted waters (Reid and Wood 1976). Sources for nitrite include industrial effluent, sewage and animal waste. The MAC for nitrite is 3.2 mg L^{-1} of $N0_3^-$ or 1.0 mg L^{-1} for nitrite nitrogen (Williamson 1988 and Van der Leeden *et al.* 1990, 443).

Phosphorus:

Phosphorus is an essential mineral nutrient for plant and animal life. In a freshwater aquatic setting it is considered to be the most important nutrient in determining the overall productivity in an ecosystem. Phosphorus in natural waters commonly occurs as phosphate, which is classified as orthophosphate ($P0_4^{---}$), polyphosphates, and organically bound phosphates (Hammer and MacKichan 1981). These phosphate forms exist as filterable (dissolved) and non-filterable (particulate) forms. Filterable orthophosphate concentrations tend to be low in natural water bodies because living organisms assimilate phosphorus.

Total mean phosphorus content of most lakes ranges from 0.010 - 0.030 mg L^{-1} (Reid and Wood 1976). Total phosphorus (soluble phosphate phosphorus) content should not exceed 0.025 mg L^{-1} in any reservoir, lake or pond, or in any tributary at the point where it enters such bodies of water (Williamson 1988).

Airborne phosphate (PO_4^{---}):

Atmospheric contributions of phosphorus can be very significant in lakes with small drainage basins (Schindler *et al*. 1976). In the Experimental Lakes Area near Kenora, Ontario, Schindler *et al*. (1978) estimate an atmospheric phosphorus loading of 24.0 - 53.0 mg m^{-2} yr^{-1}.

Bennett (1985) provides an estimate of aeolian phosphate concentrations in the Brandon, Manitoba area ranging from 0.01 - 0.04 mg m^{-3} with a geometric mean value 0.2 mg m^{-3}, and suggests an atmospheric loading rate of 82.0 mg m^{-2} yr^{-1}. The distribution of airborne phosphate is lognormal; therefore a geometric mean is appropriate. Beck (1985) rationalizes a slightly more conservative atmospheric contribution rate of 41.0 mg m^{-2} yr^{-1} in his study of twelve lakes in the south Riding Mountain Planning District.

Methodology

Sampling sites:

In the Clear Lake watershed, five snowfall sampling sites were established. Four sites are located in Riding Mountain National Park and a fifth sampling site is situated outside the park over an agricultural field (Figure 1). The Clear Lake sites (*Aspen*, *Wishing Well* and *Townsite*) are representative of the lake surface and lowest elevation (615 m) in the Clear Lake watershed. The *Aspen Fen* site is located in a wetland area, 39 m above lake level. The site is described as standing water, with rushes, sedges, dwarf birch, willows and alder. The *Whaley* site is a cultivated agricultural field of uncut alfalfa, 640 m in elevation. Both the *Aspen Fen* and *Whaley* sites represent highland areas located near the watershed divide, the former in the north and the latter in the south.

Sampling procedure and implements:

A one metre square wooden platform was employed at each of the sites as a snow collection surface. The platform was constructed from ¾" plywood mounted on a two-by-four frame. A hole was drilled in one corner of each platform for the placement of a location indicator dowel, which extended one m above the surface.

The depth of fresh snow (fall and drift) on the platform surface constituted a sample. Nutrient content sampling occurred within 24 hours of snowfall. Samples were collected using a rectangular funneling instrument measuring 9.0 cm square at the mouth by 25.0 cm in length and tapering to 5.0 cm square at the rear. The funnel was swept across the snow collection platform, collecting snow into a large plastic bag attached to the rear end of the instrument. Depending on snow depth, multiple sweeps were required to collect the total sample. Following the collection of a sample, the platform was swept clear and placed on a level snow surface adjacent to the sampling site in preparation for the next snowfall event. Each snowfall sample was melted at room temperature into a 1,000 ml glass beaker. The melted sample was split into A, B, and C sub-samples. Each of the A, B, and C sub-samples were analyzed for ammonia (ammonium), nitrate, nitrite, and phosphate ion concentration, pH and electrical conductivity.

Water quality instruments:

The nutrient testing employed portable Ion Specific Meters (with LCD screen) made by Hanna Instruments (1999). These instruments employ a colormetric analysis based on the principle that the specific components react with others and form a colour. The colour intensity is proportional to the concentration of the substance being measured. A light emitting diode emits radiation at a single wavelength intensity and a photoelectric cell collects the radiation, converting it to an electrical current. A microprocessor employing the Lambert-Beer Law equality converts the electrical potential to concentration. The specific instruments employed in this study have a resolution of 0.01 mg L^{-1}. Samples were tested for total ammonium, nitrate and nitrite ion concentrations and soluble phosphate ion concentration. Electrical conductivity was estimated using a Hach Sens***ion*** 5 portable conductivity meter. Recorded electrical conductivity values are in micro-Seimens per centimetre (mS cm^{-1}). A Fisher pH meter, model Acumet 600, measured pH in each sample.

Airborne Nutrients in the Winter Snowfalls over the Clear Lake Watershed

Snowfalls:

Snowfall data were collected from the Environment Canada Wasagaming climate station located in Riding Mountain National Park at the Warden Stores Compound (Figure 1). Thirteen snowfall events were recorded from December 1, 1999 to March 31, 2000 (Figure 2a). There were four rainfall events in late February and March. Six of the snowfalls were considered to be significant and four of these snowfalls were sampled (Figure 2a). Twenty-three snowfall events were recorded from November 1, 2000 to March 31, 2001 (Figure 2b). Seven of the snowfalls were considered to be significant and six of these snowfalls were sampled (Figure 2b). A significant snowfall is operationally defined as a precipitation event depositing at least 3.0 mm water equivalent depth during a 24-hour period, or a multiple day event in which the water equivalent depth of the snowfall exceeds 5.0 mm. Using the 10:1 snowfall/water ratio, that would be a

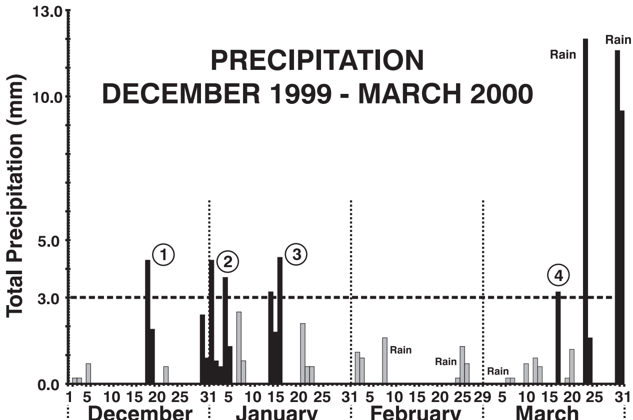

Figure 2a

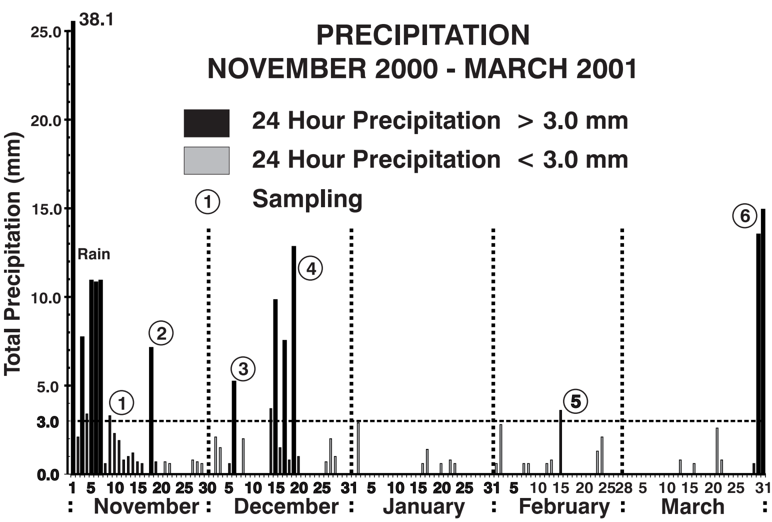

Figure 2b

Figure 2: Wasagaming climate station, Riding Mountain National Park.

snowfall exceeding 3.0 cm and 5.0 cm in depth, respectively. The final snowfall nutrient content survey was conducted on March 17, 2000 and April 5, 2001, respectively.

Total ammonia (NH_3 and NH_4^+):

The watershed mean total ammonia concentration ($NH_3 + NH_4^+$) detected in the 1999-2000 snowfalls was 0.278 mg L^{-1}, ± 0.057 mg L^{-1} (McGinn and Thompson 2001). By comparison, the watershed mean total ammonia concentration in the snowfalls sampled in 2000-2001 was 0.159 mg L^{-1} with a standard deviation of 0.089 mg L^{-1}. The total ammonia nitrogen concentration recorded for all snowfall samples (1999-2001) was less than Reid and Wood's (1976) observation for total ammonia concentration of 1.0 mg L^{-1}, but often exceeded the Health Canada (1996) reference for ammonia and ammonia compounds of 0.100 mg L^{-1}. No site was consistently higher or lower than any other site (Figures 3a and 3b). Employing the Emerson *et al*. (1975) formula for calculating percentage of free ammonia (NH_3), the maximum concentration of free ammonia in winter snowfalls was less than the Manitoba Environment standard of 0.020 mg L^{-1} (Williamson 1988).

It is difficult to establish a pattern to the total ammonia concentrations in snowfalls by comparing the 1999-2000 and 2000-2001 winter seasons. Winter drought appears to have occurred in both sampling seasons; late January to early March in 1999-2000 and January to mid-February and March, 2001 (Figures 2a and 2b). Consequently, the snowfall sampling results only can be compared on a general temporal continuum: early snowfalls (the first two or three), mid-season snowfalls and late season snowfalls (the last two). During both sampling periods, total ammonia concentrations appear to decline following the early season snowfalls (Figures 3a and 3b). In the 2000-2001 study, this decline was to virtually undetectable levels by late December (Figure 3b). In the late season snowfalls, total ammonia concentrations were found to increase to values approximating the seasonal overall mean concentration. It is speculated that this increase in total ammonia concentration could be attributed to volatilization from uncovered soil during late season thaws (Paton 2000: personal communication).

Soluble phosphate phosphorus (PO_4^{-} P):

In the 2000-2001 study, the mean soluble phosphate ion concentration in the snowfall samples was 0.191 mg L^{-1}, ± 0.130 mg L^{-1}. This recorded value is significantly less than the mean soluble phosphate ion concentration

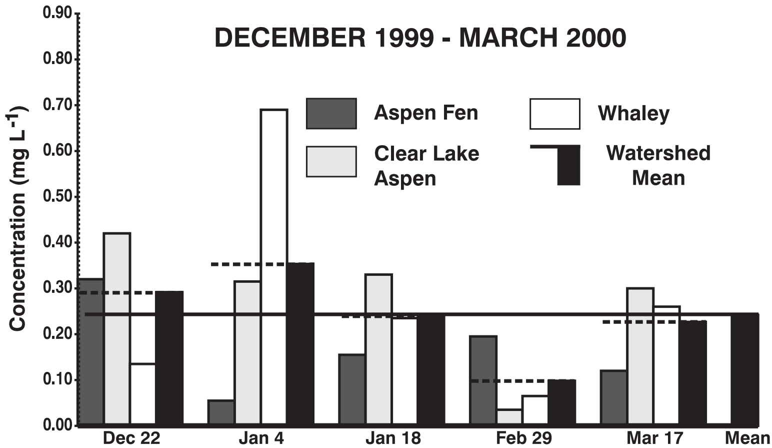

Figure 3a

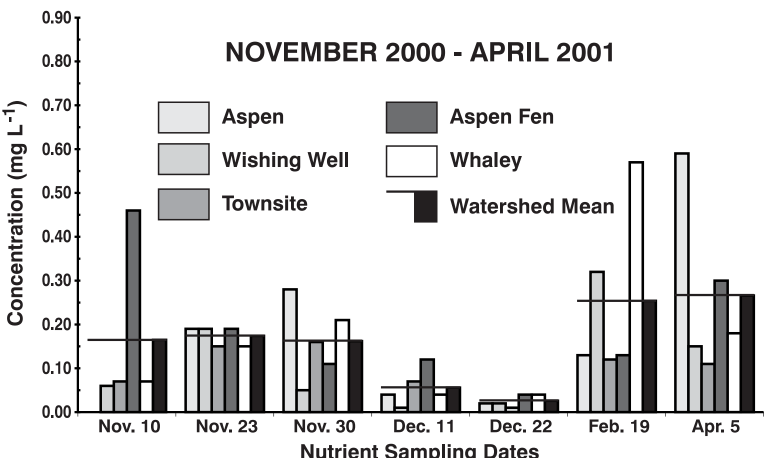

Figure 3b

Figure 3: *Total ammonia (NH_3 N + NH_4^+ N) concentration in snowfall: Clear Lake watershed.*

in the 1999-2000 snowfalls of 1.280 mg L^{-1}, ± 0.634 mg L^{-1} (McGinn and Thompson 2001). The mean soluble phosphate ion concentration in the 1999-2000 winter snowfalls on the Clear Lake watershed was significantly greater than expected and at least two orders of magnitude greater than the Manitoba Environment objective of 0.025 mg L^{-1}.

McGinn and Thompson (2001) hypothesized that the unusually high phosphate ion concentrations in the 1999-2000 snowfalls could be attributed to phosphate bonded to large (0.2 mm - 1.0 mm) diameter tropospheric aerosols. The researchers employed a two-step filtration procedure in their study to remove particulate phosphate and the soluble phosphate bonded to colloidal particles. In the 1999-2000 study, the phosphate ion concentrations were not significantly reduced following a 0.45 mm filtration to remove particulate insoluble phosphate. Mean concentrations in the snowfall samples remained greater than 1.0 mg L^{-1}. The 0.25 mm filter, however, successfully removed the particulate phosphate reducing mean sample values to expected values; approximately 0.015 mg L^{-1}. This suggested that the unusually high phosphate concentrations found in the 1999-2000 Riding Mountain Uplands snowfalls were being deposited in association with colloidal size particles.

During both the 1999-2000 and 2000-2001 sampling periods, soluble phosphate phosphorus concentrations appear to decline following early season snowfall (Figures 4a and 4b). In the late season snowfalls, however, soluble phosphate ion concentrations were found to rise above the seasonal watershed mean concentration.

Nitrate ion (NO_3^-):

Nitrate ion (NO_3^- N) concentrations were less than the accuracy specifications of the instrument employed (0.01 mg L^{-1}) and considered undetectable. During the winter, nitrate and nitrite concentrations are not expected to be significant since nitrification is dependent on temperature (Paton 2000, personal communication).

Nitrite ion (NO_2^-):

Nitrite ion (NO_2^- N) concentrations were generally less than the accuracy specifications of the Hanna Ion specific meter employed and are considered to be undetectable in the winter snowfalls 1999-2000 and 2000-2001.

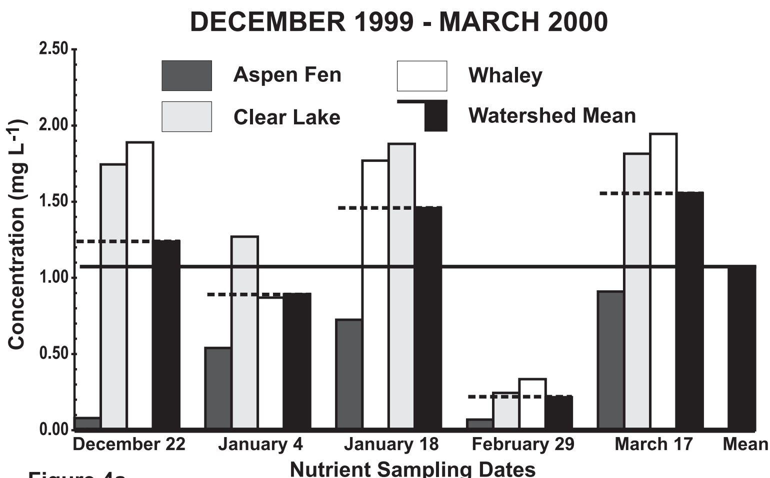

Figure 4a

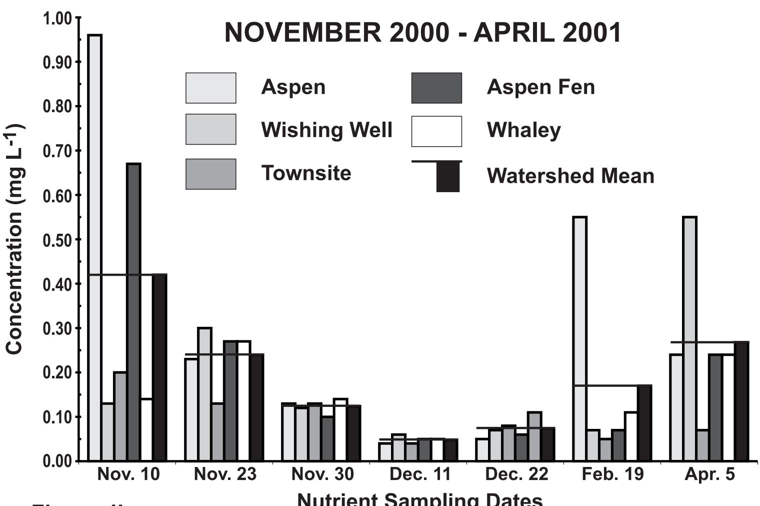

Figure 4b

Figure 4: *Phosphate (PO4— P) concentration in snowfall: Clear Lake watershed.*

Factors Affecting Airborne Nutrient Loading

The winter precipitation regimes: 1999-2000 and 2000-2001:

The winter precipitation regimes for the two sampling seasons (1999-2000 and 2000-2001) were different (Figures 2a and 2b). Total snowfall accumulation for the 2000-2001 winter season was three times the 1999-2000 accumulation (168.7 mm versus 54.1 mm water equivalent depth). The 1999-2000 winter precipitation regime began a month later than in the 2000-2001 season; December 2, 1999 versus November 1, 2000 and concluded almost a month earlier, March 17, 2000 versus April 5, 2001, respectively (Figures 2a and 2b). Four of the six significant snowfalls that occurred during the 1999-2000 winter period were sampled for nitrogen and phosphorus content (Figure 2a): the first sampling in mid-December, two samplings in January and the last sampling on March 17, 2000. By comparison, six of the seven significant snowfalls which occurred during the 2000-2001 winter were sampled for nitrogen and phosphorus content: twice in November, twice in December, in mid-February and on April 5, 2001 (Figure 2b).

The antecedent precipitation index:

Rainfall totals prior to the winter accumulation season (May-October) for the two sampling periods also were different. The monthly Antecedent Precipitation Index (API) for 1999-2000 was calculated to be 1.23 or 23 percent above normal (Ryder *et al*. 2000). For the 2000-2001 winter season the API was estimated be 0.98 or approximately normal. However it was necessary to adjust the 2000-2001 API to include a 62.2 mm early November rainfall (November 1-6, Figure 2b). The 2000-2001 API, adjusted for the November rainfall, is calculated to be 1.68 or 68% above normal (Chubak *et al*. 2001).

The monthly antecedent precipitation index for Riding Mountain National Park is calculated using the form API = SA/SB, where:

SA = the sum of the monthly precipitation (P_n) times an empirically derived constant "a"

SB = the sum of the normal monthly precipitation (1969-1999) times the same empirically derived constant "a"

"a" = 0.07, 0.08, 0.12, 0.18, 0.25 and 0.3 for May to October , respectively.

When there is a recorded November rainfall, the constant "a" is 0.5 and the API is referred to as the Adjusted API.

The heavy rainfall received in the first five days of November was followed by 21.7 millimetres water equivalent depth of wet snow on November 6 and 7 (Figure 2b). The wet snowfall continued intermittently for the next nine days, depositing an additional 12.4 millimetres water equivalent depth on the Clear Lake watershed. By the end of November approximately 45.3 millimetres (water equivalent depth) of snowfall had accumulated on the watershed as a mean 24.9 centimetres deep snowpack (Chubak *et al.* 2001). By contrast, meteorological records for the watershed (Wasagaming, Manitoba) indicate that November and December 1999 were drier than normal, recording no significant snowfalls or accumulated snow cover until late December (Figures 2a and 5).

Snow cover:

Figures 5a and 5b compare the regional extent of early seasonal snow cover for the two sampling periods. Figure 5a indicates that the southern prairies had little or no snow cover by mid-December 1999. Consequently, a large source region for airborne nutrients was exposed to the wind. By mid-December 2000, however, southeastern Saskatchewan and Manitoba were covered by at least 10 cm of snow and the nearest source region for airborne nutrients was limited to southwestern Saskatchewan, a region at least 300 km from the study area (Figure 5b).

Discussion

The difference in total ammonia and soluble phosphate ion concentrations in the snowfalls of the two study periods can be attributed to differences in antecedent rainfall and snow cover. The heavy rainfall received in the first five days of November 2000 is believed to have washed nitrogen compounds and colloidal phosphate out of the troposphere. Consequently the 21.7 millimetres water equivalent depth of wet snow that fell on November 6 and 7 contained smaller concentrations of both ammonia nitrogen and phosphate phosphorus than those measured in the November 1999 snowfalls. Furthermore, this early November wet snowfall covered the local nutrient source regions with approximately 20 cm of snow. As a consequence, there was a relative paucity of airborne nutrients following this event and it was not surprising to measure undetectable concentrations of total ammonia and significantly lower concentrations

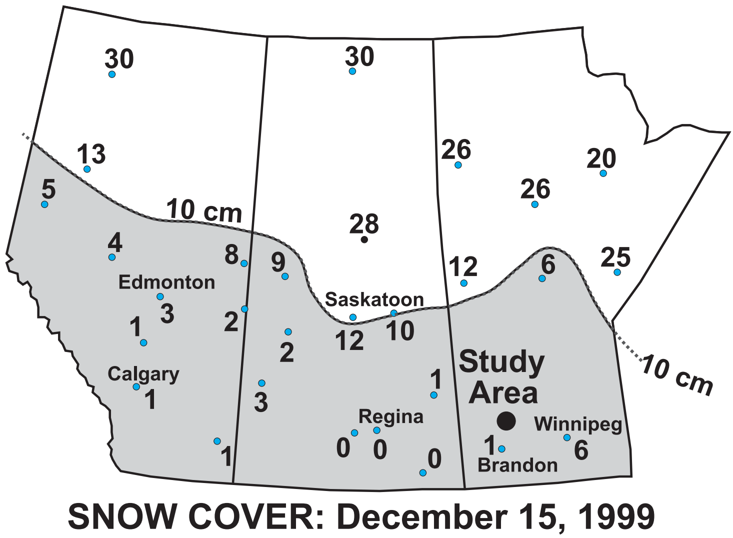

Figure 5a

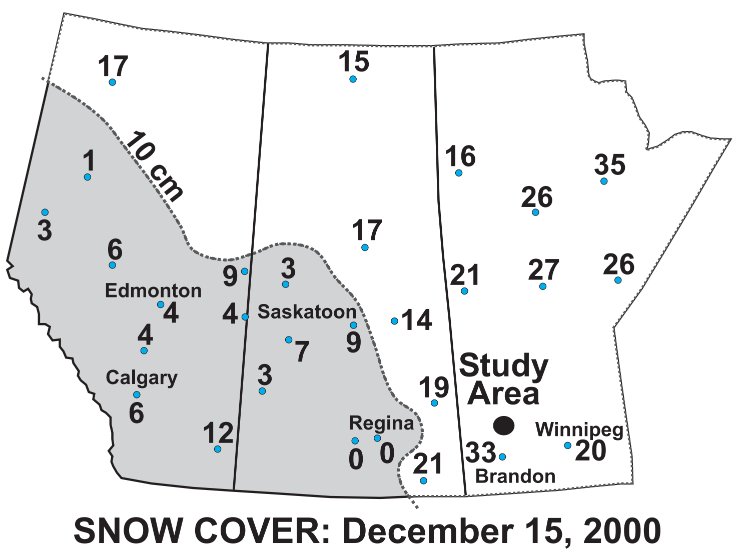

Figure 5b

Adapted from: www.msc-sme.ec.ca/ccrp/SNOW?snow_swe.html

Figure 5: *Snow cover maps.*

of soluble phosphate in the 2000-2001 mid-winter snowfalls over the Clear Lake watershed.

Conclusions

High concentrations of airborne phosphate are being deposited in early winter snowfalls on the Clear Lake watershed. Approximately 75% of this particulate phosphate is soluble and bonded to colloidal particles. The remaining 25% is insoluble particulate phosphate. While the concentrations of soluble phosphate are recorded to be significantly higher than the recommended standard, they are variable over the winter season and from winter to winter. The autumn antecedent precipitation, the winter snowfall regime and snow cover appear to account for much of this variability.

By mid-winter the accumulated snowpack has covered potential source regions for airborne nutrients and total ammonia and phosphate ion concentrations in the snowfalls are significantly reduced. As temperatures warm and the prairie snowpack melts, potential source regions for airborne nutrients become exposed to the wind and nitrogen and phosphorus concentrations are found to increase in the late winter and early spring snowfalls. The concentrations of other macronutrients (nitrate nitrogen and nitrite nitrogen) do not exceed the recommended standards. Further studies are required to evaluate the phosphate depositional loading during the winter on the lake surface. Data are required regarding airborne distribution patterns and potential source regions.

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The impacts of chloride concentrations on wetlands and amphibian distribution in the Toronto region

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Abstract: Declines in amphibian populations on global, national and local scales have been widely observed. Factors that influence amphibian decline include increased UV radiation, bacterial and fungal infections, and habitat loss. In Canada, habitat loss is the dominant factor in decline yet very few investigations have considered the effects of chloride concentrations on such habitats. In the past, it has been assumed that salts wash out of watersheds with spring runoff and have minimal impact on waterways. This paper reports on an intensive study of three wetlands in the Humber River watershed and a one-time sampling of 22 wetlands across the Don River watershed. Patterns of chloride concentration over the amphibian-calling season were assessed. Amphibian call monitoring was used to explore possible links between chloride concentrations in wetlands and the distribution of amphibians. Chloride concentrations in the Humber River wetlands increased throughout the spring and summer. Higher chloride concentrations were found with increased proximity to roads that received de-icing salts. When amphibian-monitoring results were correlated with chloride concentrations, amphibian abundance and diversity were consistently low in all wetlands where chloride levels exceeded 200 mg/l. Results indicate that chlorides may accumulate in wetlands from year to year and that the seasonal increase in chloride concentrations in wetlands may adversely affect the distribution of mid to late-breeding amphibian species.

Key words: amphibian decline, de-icing salts, metapopulations, call monitoring, wetland chloride concentrations

Introduction

Road de-icing salts are major contaminants in runoff from road surfaces. Of the pollutants found in roadway runoff, salts are the most cost-effective to monitor and, thanks to current de-icing technology, the most realistic to reduce. The diversion or collection of roadway runoff and the careful location of new highways has long been recommended (Pollock and Toler 1973), and models are available to predict the environmental effects of chemical pollution (Chandler and Luoto 1973). Although some of these recommendations have been incorporated into current de-icing practices, the cost of environmental effects are still not sufficiently considered. In the metropolitan area of Toronto alone, an annual average of 100,000 tonnes of de-icing salts are used to maintain bare pavement conditions during winter months (Howard and Haynes 1991). The majority of de-icing salts are transported by highway runoff into roadside soils and adjacent streams. This results in elevated concentrations of sodium and chloride in the Humber and Don River watersheds throughout the spring runoff season and summer months (Scott 1979). Initially, it was believed that most de-icing salts were washed out of watersheds during spring runoff. However studies by Howard and Haynes (1991) and Howard and Beck (1993) have revealed that approximately 55% of de-icing salts applied to roadways is retained within drainage basins. Moreover, salt concentrations in Toronto region waterways tend to increase with urban density (Scott 1976). Despite this knowledge, little is known about the extent of wetland contamination by road de-icing salts and the effects of salt levels on amphibian populations in the Toronto region.

Salts are released to groundwater in pulses after each rain event and fluctuations are seasonally cyclic, increasing in chloride until a balance between salt recharge and the continuous flushing and dilution by groundwater is reached (Weigle 1967). Sodium chloride de-icer is composed of 39.3% sodium and 60.7% chloride, while calcium chloride is made up of 36.1% calcium and 63.9% chloride (Schraufnagel 1967). Chloride is an essential micronutrient for plants but it is toxic in excessive amounts (Schraufnegel 1967; Prior and Berthouex 1967). Plants absorb de-icing salt elements and suffer from leaf burn, premature defoliation and terminal growth dieback (Hanes *et al.* 1970; Pedersen *et al.* 2000; Bryson and Barker 2002). In solution, the elements of de-icing salts become associated with the soil through adsorption or ion exchange (Prior and Berthouex 1967; Pollock and Toler 1973). Dissolved salt also acts as a weak electrolite and affects the conductivity of the aquatic system (Adams 1973). Excessive levels of sodium can result in reduced drainage of soils (Hutchinson and Olson 1967; Howard and Beck 1993; Lofgren 2001).

Amphibians are particularly sensitive to habitat destruction and fragmentation due to the reliance of most species on metapopulation structures. Networks of ponds and wetlands allow amphibians to migrate for breeding purposes, thus helping to maintain genetic diversity in amphibian populations, and also to survive during times of drought. Fragmented habitats, especially those near urban centres and surrounding rural areas, are often affected by contamination from rural and urban highway runoff that renders these habitats inhospitable for amphibians.

The effects of salt concentrations on the development of amphibians are reasonably understood. Anderson and Zotterman (1950) found that exposing some frog species to bathing solutions of as little as 0.05% NaCl initiated a change in osmoregulation. Exposure to high salt concentrations stresses the osmoregulatory systems of amphibians since their ability to maintain ion balance is limited. Skin resistance and concentration potential lower with the exchanges of sodium and chloride ions being independent of each other (Taylor and Barker 1965; West and Van Vlict 1992). Christy and Dickman (2002) reported significant increases in larval mortality and decreasing growth rates with increasing salt concentrations in one amphibian species. Unlike adult amphibians, larvae and embryos are incapable of active ion transport to maintain a positive ion balance. Other studies have investigated the effects of salt on embryonic development in water with low pH (Freda and Dunson 1985; Gascon and Planas 1986). There is also evidence that some amphibian species avoid breeding sites with high salt and chloride concentrations (Viertel 1999).

Despite these findings, few studies have examined the effects of de-icing salts on the distribution of amphibians (Brinkman 1999; Turtle 2000). It is possible that high salt concentrations from road salt runoff could be a factor in the absence of amphibians in some potential wetland habitats around the Toronto region. This study set two main objectives: 1) to assess patterns of chloride concentrations in Toronto region wetlands in relation to the use of road de-icing salts; and, 2) to examine the distribution of amphibians in Toronto region wetlands in relation to chloride concentrations.

Site description

The study was based primarily on intensive observation of three wetland sites (A, B and C) located north of Toronto near King City in the Humber River watershed at 43° 55' North and 79° 31' West (Figures 1 and 2). Criteria used to choose the wetlands included size, low urban density and proximity to main or secondary roads. The rationale behind the use of these criteria was as follows: larger wetlands would be more likely to support greater numbers and diversity of amphibians for study; low urban

__Figure 1:__ Location of the intensively studies wetlands in the Humber River watershed (Source: TRCA in press).

density would reduce the occurrence of other sources of chlorides such as combined storm sewer outlets; and, proximity to main roads was needed to evaluate the impact of road de-icing salts as a source of chlorides in wetlands. Physiographically, the wetlands fall within the South Slope region of the Oak Ridges Moraine at elevations that range from 246 to 308 metres. The soils are largely composed of clay covered by a thin organic layer.

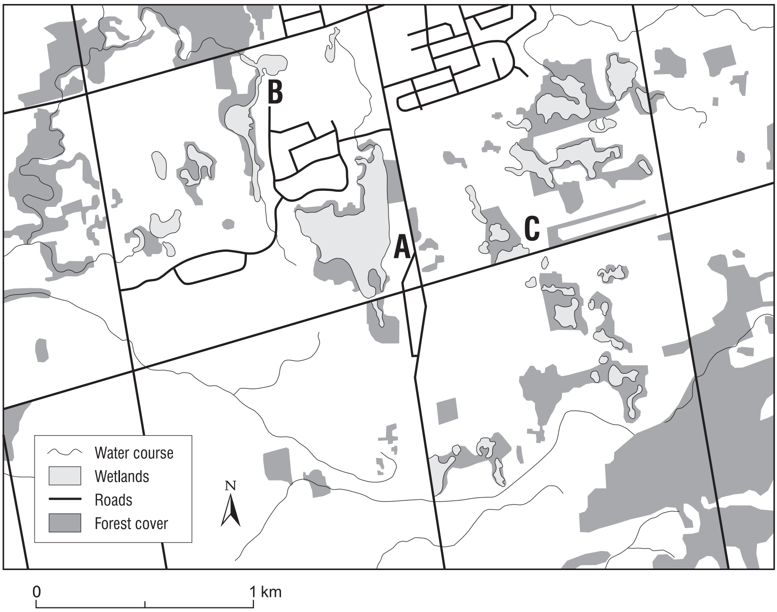


Figure 2: *Detail of the intensively studies wetlands in the Humber River watershed indicating wetlands A, B and C (Source: TRCA data base).*

Due to the high clay content in the soils, the area has a low susceptibility to groundwater contamination (Environment Canada 1979). The land-use history of the area is rural, with little residential development. A larger set of 22 wetlands located throughout the Don River watershed was also visited, but only once (Figure 3). The latter sites were consistent with those used for the Amphibian Monitoring Program of the Toronto and Region Conservation Authority (TRCA).

Methodology

The link between road salt contamination of wetlands and amphibian distribution was explored in two ways. First, thre wetlands located in the headwaters of the Humber River watershed (Figure 1), were investigated to establish seasonal patterns of salt contamination and amphibian occurrence. The second part of the study was based on a one-time sampling of wetlands in the Don River watershed. This included sites in rural areas of the greater Toronto region as well sites in the city core (Figure 3). This

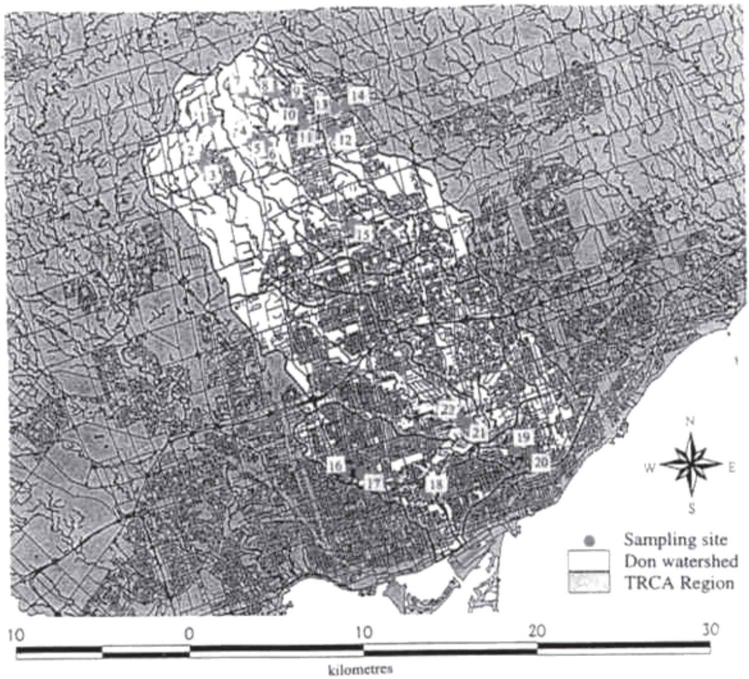
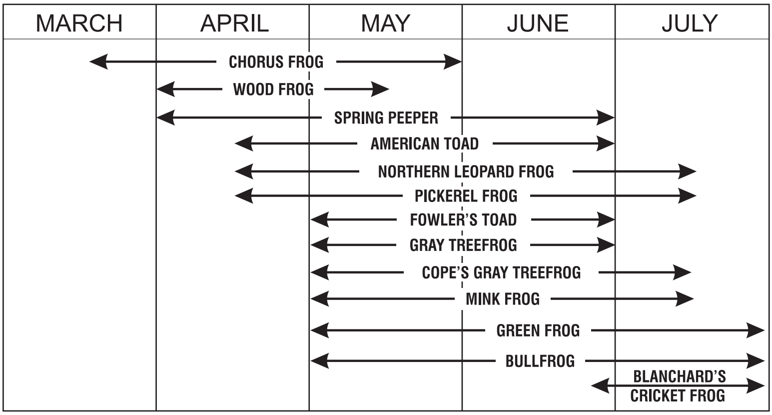


Figure 3: *Location of the 22 wetlands sampled in the Don River watershed (Source: TRCA in press).*

portion of the study examined salt contamination and amphibian distribution at the watershed level and incorporated data from TRCA's community-based Amphibian Monitoring Program.

Both components of the study used data on call monitoring of amphibians collected by TRCA from 1997 to 1999 as well as monitoring by the author during each site visit. These data were used to determine the species richness at each study site. Call monitoring by TRCA was conducted in the evenings when calling species tend to be most active. Call monitoring volunteers were encouraged by TRCA to visit their sites at least three times in a season. The first visit was made to record early breeding species and took place between mid-April and mid-May when the average daily temperature was greater than 5°C. The second visit was made between mid-May and mid-June when the temperature was above 10°C and when mid-season breeders could be monitored. The final visit



Source: Long Point Bird Observatory, 1996.

Figure 4: *Approximate breeding seasons for amphibian species of the Great Lakes Region (Source: Long Point Bird Observatory 1996).*

was made between mid-June and late-July when it was warmer than 17°C and when only late breeding species would be active. Figure 4 shows the approximate breeding periods for frogs and toads of the Great Lakes region. Weather and precipitation data for the three wetlands were purchased from Environment Canada.

The breeding calls of amphibians are very species specific. With some practise using tape-recorded calls, species can be easily identified. Following TRCA call monitoring methods, calls were assigned a rating of approximate abundance. Code 1 was used to indicate that only a few amphibians were present and that the number of calling individuals could be identified. Males will usually try not to call at the same time or call in close proximity to one another so that the females can hear them individually. Because of this, a few calling males of the same species can be located as well as accurately counted. Code 2 was used when several males were calling and their calls overlapped but the individuals could still be distinguished from each other. Usually calls can be distinguished and counted for up to 12 individuals depending on the species. Once the observer could no longer distinguish when one call began and another ended the calls were classified as a Code 3. Monitoring stations were established at each of the Humber River wetlands during each site visit. Call monitoring was conducted in the evenings at each site visit before water sampling. All non-calling frogs observed were also recorded as present to establish species presence and absence at the study sites.

During the first visits to the Humber River wetlands a water level mark was erected at each of the three sites so that changes in water level could be recorded throughout the spring and summer. At each visit, changes in water level from the previous visit were recorded and water samples were collected for chloride analysis. Samples were taken along transects so that the patterns of chloride movement over time could be established. Distances between transects were dependent on the size and shape of the wetlands. A piezometer nest was installed in each of the three wetlands to sample subsurface water. These piezometers consisted of 1.25 cm PVC pipes with a 20 cm slot zone covered with nitex mesh to prevent siltation at depths of 0.5 and 1.5 m. Shallow groundwater was sampled in August from the piezometer using a polypropylene syringe. Amphibian presence, as recorded through call monitoring and observation, was also recorded and mapped at each visit.

In mid-July 1999 a one-time sampling of the 22 wetlands in the Don River watershed was conducted from the headwaters north of the city, where urban density is very low, to the city core. Each sample site corresponded with a TRCA call monitoring station used between 1997 and 1999. Water samples were collected at one to three locations per wetland depending on the size and number of TRCA monitoring sites per wetland. The purpose of this was to determine if higher chloride levels were present in parts of the same wetland where amphibians were absent. Samples were transported to the laboratory and analyzed for chloride concentration using standard techniques on a Technicon Autoanalyser System (Environment Canada 1979). Distance from each of the 22 sampling stations to the nearest upstream road was measured on a topographical map.

Amphibian call counts, codes and the numbers of species were totalled for the monitoring period from 1997-1999 since not all wetland sites were monitored each year. The highest individual count and call code for each species during the three-year period was used to represent the amphibian abundance for each site. It was assumed that amphibian populations did not experience any severe fluctuations in population size over the time period. The highest call code is indicative of the highest potential abundance of amphibians. Where a call code was 3, the maximum number of identifiable individuals, a count of 12 was recorded. At no time was a chorus so loud as to imply that there were many more than 12 calling individuals.

The relationship between the amphibian data and chloride levels in the wetlands was analyzed using three variables, namely, amphibian abundance, the diversity of species and the sums of the call codes. For each site, the highest number of calls and sightings over the three-year period was used to represent the maximum-recorded number of individuals of each species. The highest recorded number for each species was then added in order to give the most optimistic representation of the quantity of amphibians present. The highest numbers of individuals were consistently recorded in the early breeding species *Pseudacris crucifer* and *Bufo americanus* (American toad). Four wetland sites (10, 12, 17 and 20) were found to have no amphibians.

Results and discussion

The 1999 spring and summer season was dryer and hotter than average. From March to July precipitation was 8% below average while temperatures were 1.5°C above average. Between April and July temperatures were 2.0°C above average. This resulted in the evaporation of water at many of the wetland sampling sites throughout the season and the intensified concentration of the chlorides that remained in the wetlands. Relatively dry conditions meant that rain events did little to influence the results.

Humber River watershed sites:

All three intensively studied wetlands showed spatial trends in chloride concentrations. The highest concentrations were consistently found closest to the nearest upstream road implying that road de-icing salt runoff was the main source of the chlorides. The variability of the chloride levels was high in early spring in the three wetlands with values ranging from 9.1 mg/l to 910 mg/l. Before seasonal snowmelt, the wetlands had average chloride values of 146 mg/l (wetland A), 44 mg/l (wetland B) and 32 mg/l (wetland C). By May, when surface waters were at a maximum and most of the strong seasonal runoff had occurred, the average chloride concentrations were 179 mg/l (wetland A), 108 mg/l (wetland B) and 301 mg/l (wetland C). By the end of the season the averages for wetlands A, B and C were 517 mg/l, 118 mg/l and 311 mg/l respectively. This indicated that chlorides did indeed remain in the wetlands from one season to the next and did not wash out with seasonal runoff (Figure 5).

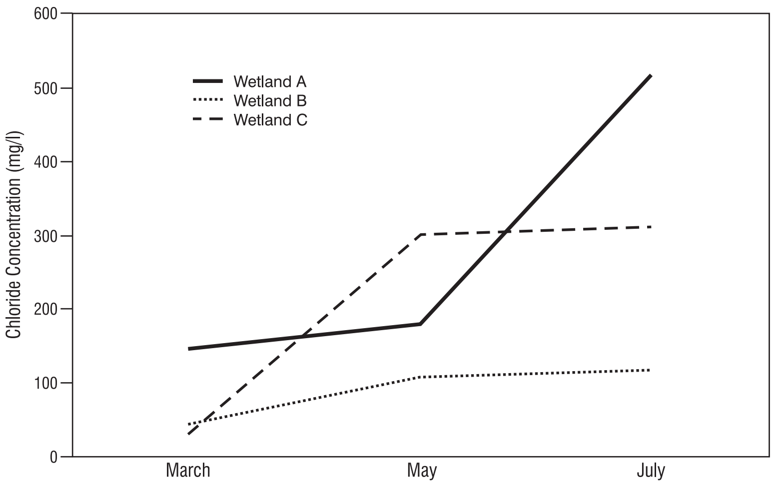


Figure 5: *Average chloride concentrations for wetlands A, B and C in the Humber River watershed for March, May and July.*

It is likely that a wetter season would result in lower chloride concentrations in the summer, however, the presence of chlorides in the wetlands in early spring and the high chloride levels after spring runoff indicate that even during a wet season, it is unlikely that the majority of the chlorides would be washed out of the wetlands. At the last sampling date in August, de-icing salt residue was still visible at the roadsides and likely continued to release chlorides into the wetlands with each rain event as elevated concentrations were observed after rain events.

Early breeding species such as *Rana sylvatica* (Wood frog) and *Pseudacris crucifer* (Spring peeper) would not be as susceptible to the increase in concentrations throughout the season since they tend to finish breeding and leave the wetlands by the end of the spring. The most abundant species heard and observed at all three wetlands were *Rana sylvatica* and *Pseudacris crucifer* with a few *Rana pipiens* (Northern leopard frog) seen across the wetlands.

Chlorides were found in high concentrations in subsurface water to a depth of 1.5 m in the Humber River wetlands in August 1999 (Table 1). The clay-rich soils underlying the wetlands inhibit the flushing of the system resulting in the prolonged retention of chlorides. The higher concentrations of chlorides at shallower depths suggest that the chlorides are entering the wetlands in surface runoff and are infiltrating downwards in the wetland

Table 1: *Chloride concentrations at groundwater sampling sites.*

	Depth = 0.5 m		Depth = 1.5 m	
	Cl concentration (mg/l)	Water level (cm)	Cl concentration (mg/l)	Water level (cm)
wetland A	194	40	132	90
wetland B	185	45	131	100
wetland C	132	45	110	90

soils. This is further supported by the fact that the water levels were consistently deeper in the 1.5 m piezometers as compared to 0.5 m piezometers. Evidence of elevated chloride levels to depths of at least 1.5 m suggests that even if the use of de-icing salts is reduced, water in these wetlands will continue to show high chloride level for many years.

TRCA call monitoring data from 1997 indicated that both *Rana sylvatica* and *Pseudacris crucifer* were present on the eastern edge of the wetland A. Monitoring results from 1999 show that both species were absent from that portion of the wetland and present only in very small numbers in the western part of the wetland. Adult *Rana sylvatica* at wetland A appeared to be tolerant to chloride concentrations as high as 171 mg/1 while the one *Pseudacris crucifer* heard was in an area where the chloride concentration was 118 mg/l.

At wetland B frog calling was very localized and only one species was heard. *Pseudacris crucifer* begins breeding early in the season and calling was most active before the occurrence of high chloride concentrations in the wetland. These chlorides may have originated from upstream. Breeding likely finished before concentrations exceeded 120 mg/l. The one leopard frog observed indicated the presence of the species at wetland B, however there was no calling evidence of breeding activity.

Rana sylvatica were heard and observed at wetland C over the spring breeding season. All calls recorded were at a Code 1 level with more adult frogs observed than heard. *Rana sylvatica* appeared to tolerate chloride concentration as high as 219 mg/l. As at wetland B, *Rana pipien*s were seen but not heard during the spring breeding season. When found, they were only on the south side of the road intersecting the wetland, where chloride concentrations were lower.

In early spring wetland areas that are still frozen inhibit water flow and contribute to variable chloride concentrations. Because of this it is possible that early breeding species are able to conduct breeding activity before higher concentrations of chlorides spread throughout the wetlands. The absence of calling evidence of breeding for mid and late-season breeding species indicates that these species possibly do not use these wetlands for breeding even though some individuals of mid and late-breeding species were observed.

Don River watershed sites:

In general, chloride concentrations were lower in the wetlands located in the northern upstream areas of the Don River watershed (Table 2). The wetland at sampling site 1 was an anomaly with a very high value of 700 mg/l. At this site only one sample was taken. The main source of chlorides at the site was likely a landfill located across the road from the wetland. Another anomaly was recorded at wetland site 16 where one sampling point indicated a chloride concentration of 505 mg/l while two other sampling points at the same wetland had chloride levels of 172 and 140

Table 2: *Don River watershed site data for riparian wetlands (RW) and ponds (P).*

Site	Wetland type	Chloride concentration	Distance upstream to nearest major road (metres)	Amphibian abundance	Species diversity	Sum of call codes
1*	P	700	5	0	0	0
2	RW	72	340	2	2	2
3	RW	72	400	1	1	1
4	RW	45	500	23	4	6
5	P	40	1,480	20	4	7
6	RW	37	2,300	26	6	9
7	RW	24	2,800	5	3	3
8	RW	25	3,600	4	3	3
9	P	51	750	3	1	1
10	RW	284	10	0	0	0
11	RW	74	810	4	1	2
12	RW	200	380	0	0	0
13	RW	262	500	1	1	1
14	RW	92	1,000	9	3	4
15	RW	91	1,150	9	5	5
16*	RW	272	1,330	4	1	2
17	RW	203	190	0	0	0
18	RW	146	350	18	3	5
19	RW	147	1,840	6	1	2
20	RW	148	840	0	0	0
21	P	134	900	24	2	5
22	RW	143	250	17	3	6

* not included in statistical analysis

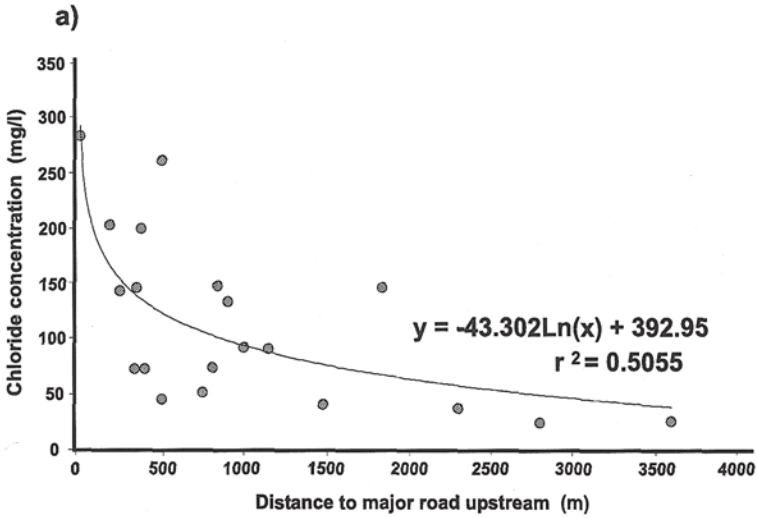
mg/l. The high value at this site was very localized and likely not the result of contamination from de-icing salt runoff.

Two wetlands sites (13 and 14) were joined by a stream that was crossed by a major roadway. One sample was taken upstream (site 14) and one downstream (site 13) of the road at equal distances from the road. The results were similar to those observed in the Humber River wetlands where the downstream side of the road had much higher chloride concentrations. One-time sampling at site 13 provided a concentration of 262 mg/l, while site 14 had a chloride concentration of 92 mg/l.

With regards to frog call monitoring, one disadvantage of the use of a community-based monitoring program is that the same sites are not monitored consistently from year to year. For this reason, species presence or absence was used to record abundance. Only long-term monitoring of urban wetland sites will determine accurate species richness of the amphibians present. Since many of the urban sites were visited only once and monitored through the TRCA Amphibian Monitoring Program for only one or two seasons, it is possible that more species were present at these sites but were not recorded.

Following log transformation of the data, a significant inverse relationship (r = -0.71, ± = 0.001) was established between chloride concentration and distance to the nearest upstream road. In related regression analysis 50.6% of the variation in chloride was accounted for by variation in distance (Figure 6a). This strong relationship may be explained by: 1) the accumulated salt residue on roadways (visible as late as August) being flushed into nearby wetlands with each rain event; or, 2) the relative lack of rain during the 1999 sampling season which would reduce the propensity of chlorides to be carried further into the wetland. Clearly distance is likely the single most important factor explaining variation in chloride concentrations. Nevertheless, since nearly 50% of the variation in chloride concentrations remains unexplained, factors other than distance should be considered in future research.

The relationship between the amphibian data and chloride levels in the wetlands was analyzed using three variables, namely, amphibian abundance, the diversity of species and the sums of the call codes. For each site, the highest number of calls and sightings over the three-year period was used to represent the maximum-recorded number of individuals of each species. The highest recorded number for each species was then added in order to give the most optimistic representation of the quantity of amphibians present. The highest numbers of individuals were consistently recorded in the early breeding species *Pseudacris crucifer*



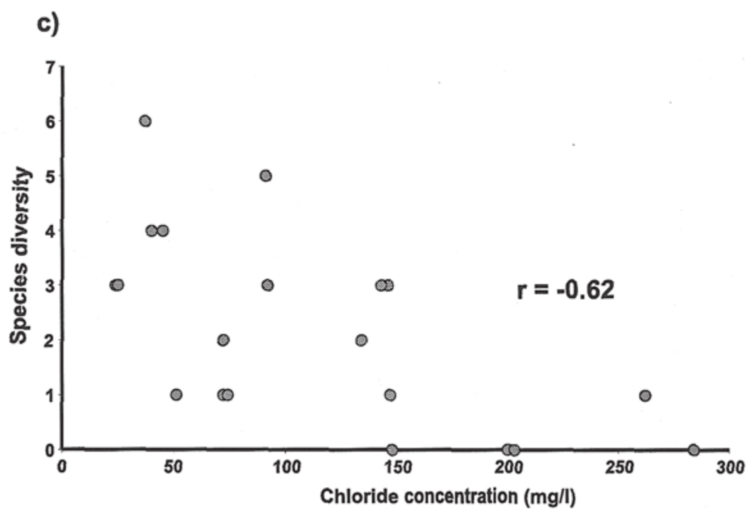


Figure 6 (a and b): *Scattergrams for relationships involving road distance, chloride concentration and amphibian distribution.*

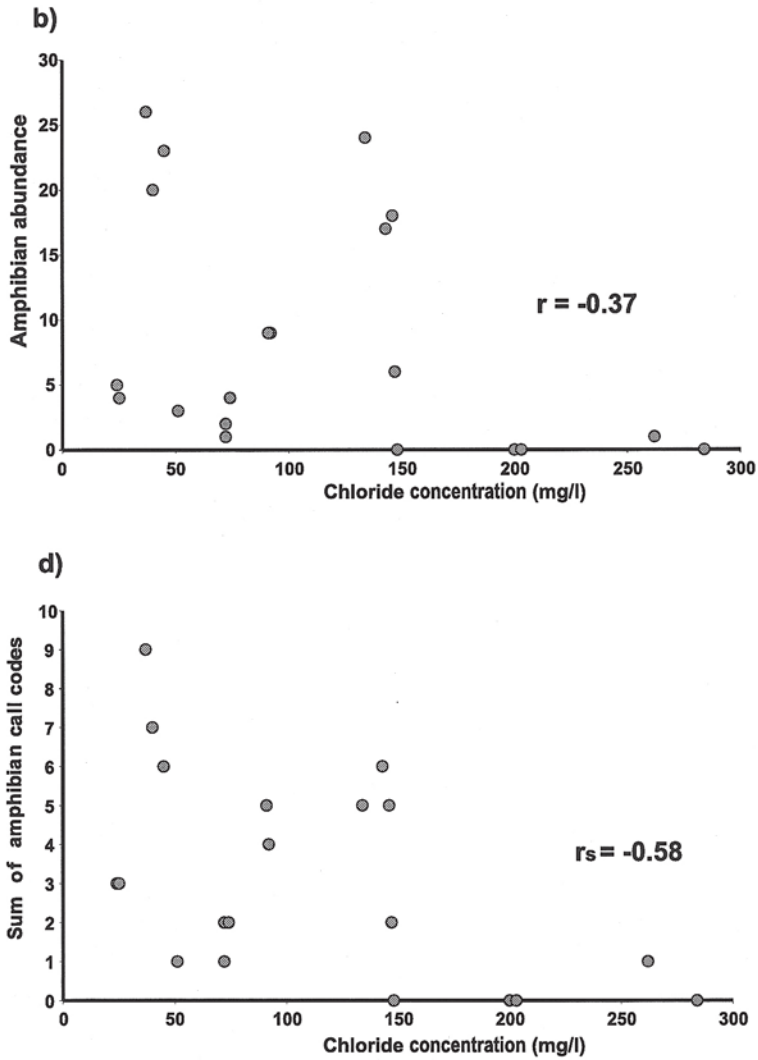


Figure 6 (c and d): *Scattergrams for relationships involving road distance, chloride concentration and amphibian distribution.*

and *Bufo americanus* (American toad). Four wetland sites were found to have no amphibians.

Regression analysis was not performed on the amphibian data as regression requires the independent variable (x) to be free from sampling error. As there was a possibility of sampling error when measuring chloride concentrations, correlation analysis alone was used. The relationships between chloride concentration and both amphibian abundance and diversity were analyzed using Pearson's product moment correlation. Due to the ordinal nature of the data on the sums of call codes, Spearman's rank correlation was used for that part of the analysis.

In general, amphibians were most abundant in wetlands located in the northern headwater areas of the Don River watershed where salt concentrations were lower. A significant negative relationship was established between amphibian abundance and chloride concentration (r = -0.38, ± = 0.05) (Figure 6b). There was no apparent link between the type of wetland and species diversity. However, a large wetland (site 5) and wetlands linked to greenway corridors (sites 6, 7, 8, 14 and 15) tended to have greatest species diversity. A strong negative relationship was established between amphibian diversity and chloride concentration (r = -0.63, ± = 0.01) (Figure 6c). In the analysis of call code sums both species abundance and diversity were incorporated into the call code classification. A significant negative relationship (r_s = -0.59, ± = 0.01) was established between call code sums and chloride concentration (Figure 6d).

Collectively the preceding results imply that road de-icing salt runoff has an impact on amphibian distribution. The linear correlation between amphibian abundance and chlorides was weaker than that between amphibian diversity and chlorides. This may be due to the highest numbers of amphibians being consistently found in early breeding species which tend to complete breeding activity before chloride levels rise. Although the numbers of amphibians heard or observed in 1999 were small, some results of individual species were consistent with trends observed at the Humber River sites. *Pseudacris crucifer* was only found in wetlands where chloride concentrations were less than 120 mg/l and *Rana sylvatica* was only found in wetlands with concentrations of less than 200 mg/l. The distribution and chloride tolerances of each species would have to be investigated in more detail before any conclusions could be made on individual species' tolerances to chlorides. All three measures of amphibians showed considerable scatter for chloride concentrations of less than 150 mg/l. However, these amphibian measures were consistently low in all wetlands where chloride levels exceeded 200 mg/l.

Many of the sites with high chloride levels were located in urbanized areas. In such settings there are numerous factors other than chloride pollution that can influence amphibian distribution via habitat fragmentation and loss. Consequently, whilst the relationships between wetland salt concentration and amphibian distribution are strong, it is possible that at least in urban areas other factors are equally important in explaining amphibian distribution.

Conclusions

Although the scope of this study was limited, some impacts of road de-icing salt runoff were apparent and were supported with statistical evidence. At the Humber River sites, water samples were found to contain higher chloride concentrations with increased proximity to roads. The patterns observed indicated that road de-icing salt runoff is a major source of chlorides in these wetlands. Groundwater chloride levels taken late in the summer indicated that chlorides do not wash out of the wetlands with spring runoff. The persistence of high chloride concentrations throughout the amphibian-breeding period appeared to affect the distribution of some amphibian species.

Results of correlation and regression analyses for the Don River sites pointed to significant relationships between road salting and chloride levels, and between chloride levels and amphibian distribution. The study indicated that some species of amphibians have higher tolerances to high chloride concentrations than other species. Specifically, *Rana sylvatica* and *Pseudacris crucifer* were found only in areas where chloride levels were below 250 mg/l. Both species are early breeding amphibians and finished using the wetlands for breeding before chloride concentrations exceeded this level. Intolerance of high chloride concentrations (over 250 mg/l) is undoubtedly one reason why other, later breeding species were rare or absent in wetlands large enough to support substantial amphibian populations.

The study represents one step in determining the full environmental impacts of road de-icing salts on the contamination of wetlands and the distribution of amphibians in the Toronto region. Results of the study suggest a need for comparative research in areas with different levels of urbanization and for assessment of salt contamination in the context of other roadway pollutants and environmental stress factors. The effect of environmental degradation on individual species and the relationship between specific environmental events (e.g., a severe rainstorm) and wetland contamination also need to be addressed. Finally, the study reveals that much still needs to be accomplished in protecting the Humber River and Don River watersheds from pollution by road de-icing salt.

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Rock-outcrop ecosystems as influenced by point-source pollution from a base-metal smelter, Flin Flon, Manitoba

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Abstract: Some impacts of atmospheric pollutants emanating from the Hudson Bay Mining and Smelting Company base metal (copper and zinc) smelter in Flin Flon were examined. Ten ridge-crest study sites were selected on PreCambrian rock outcrops along a 37.5 km southeast transect downwind to Cranberry Portage to reflect decreasing alteration of the jack pine/cryptogam cover. In addition, two control sites were selected at 33.2 and 47.3 km east-northeast of Flin Flon at locations where no detectable modifications to ridge-crest ecosystems were observed. At each study site tree and cryptogam covers were evaluated, and the thin organic layers (Folisols) and mineral soils were sampled to determine pollution impacts and Cu and Zn contents. Mean values for mineral-soil Cu were 32.8 ppm at 37.5 km from the smelter and increased exponentially to 3,683 ppm at 4.7 km. Equivalent mineral-soil Zn values were 273 ppm at 37.5 km and 6,088 ppm at 1.65 km. For organic soils Cu increased from 43 ppm at 37.5 km to 4,833 ppm at 4.7 km, while Zn values were 352 ppm at 37.5 km increasing to 11,464 ppm at 4.7 km. Paralleling this base-metal gradient are measurable impacts to the jack pine/cryptogam/Folisol ridge-crest ecosystems which range from little impact near Cranberry Portage to the almost complete loss of both the organic soil and vascular plants, and the total demise of cryptogams, close to the smelter.

Key words: pollution, cryptogams, ridge-crests, Folisols, base metals

Introduction

The impacts of point-source atmospheric pollutants from smelters operating in the boreal forest on the Canadian Shield have been the focus of numerous studies. These include, for the Sudbury, Ontario region, Gignac and Beckett (1986), Amiro and Courtin (1981), and Whitby *et al*. (1976). For Thompson, Manitoba; Hocking and Blauel (1977), and for Flin Flon; Henderson *et al*. (1998), McMartin *et al*. (1999), Henderson and McMartin (1995), Zoltai (1988), Hogan and Wotton (1984), Orlandini (1998), Scott (2000), and Wright *et al*. (1996). While these studies report evidence of damage and soil pollutant level increases, their conclusions vary as to direct impacts on soil-vegetation systems. There is, however, general agreement that cryptogams (lichens and mosses) as well as conifers are highly impacted, and that SO_2 fumigation and base metals often reach phytotoxic levels in soils close to smelters and contribute significantly to cover demise. The great majority of these studies concentrate on forested cover changes on lower elevation minerals soils and wetlands/peatlands, while few deal specifically with impacts to the upper portions of shield outcrops with their cryptogams, Folisols (thin organic soils overlying bedrock) and open pine/spruce cover (Whitby *et al*. 1976; Scott 2000). The present study addresses impacts to ridge-crest ecosystems in the vicinity of the Hudson Bay Mining and Smelting Company (HBMS) Cu-Zn smelter in Flin Flon. The three objectives are: 1) to estimate the degree to which Folisols have been altered; 2) to estimate changes in cryptogam and tree cover with distance from the smelter; and, 3) to see if ridge-crest soils show phytotoxic levels of Cu and Zn as the smelter is approached.

The Study Region

Flin Flon is located on the Saskatchewan/Manitoba boundary at 54° 45' N (Figure 1) on PreCambrian granitic and metavolcanic rocks containing sulphide ore bodies rich in non-ferrous metals. HBMS began smelting in 1930, with atmospheric emissions of gaseous and particulate pollutants being released from a single 30 m tall stack. This was replaced in 1974 by a 251 m stack. In addition to SO_2, Zn, Cu and Cd, emissions include As, Ni, Fe, Pb, Al-oxide and Hg, with dry and wet base metal fallout taking the form of metal particulate, metal oxide and metal sulfates (Franzin *et al.* 1979). Emissions levels for SO_2 have always been high, but the addition of electrostatic precipitators in 1982 has reduced particulate emissions considerably. Between 1981 and 1985 particulate pollution ranged between 11.5 and 43.4 tonnes per day, while in the 1996, 202,032 tonnes of SO_2 were released (Krawchuk 1998). The overall history of pollution has lead to tree and groundcover mortality on ridges, and to some extent on lowlands around the smelter. In addition, studies by Zoltai (1988) show an oval pattern of decreasing base metal contaminated lowland organic soils centred on Flin Flon, with a general northwest to southeast axis.

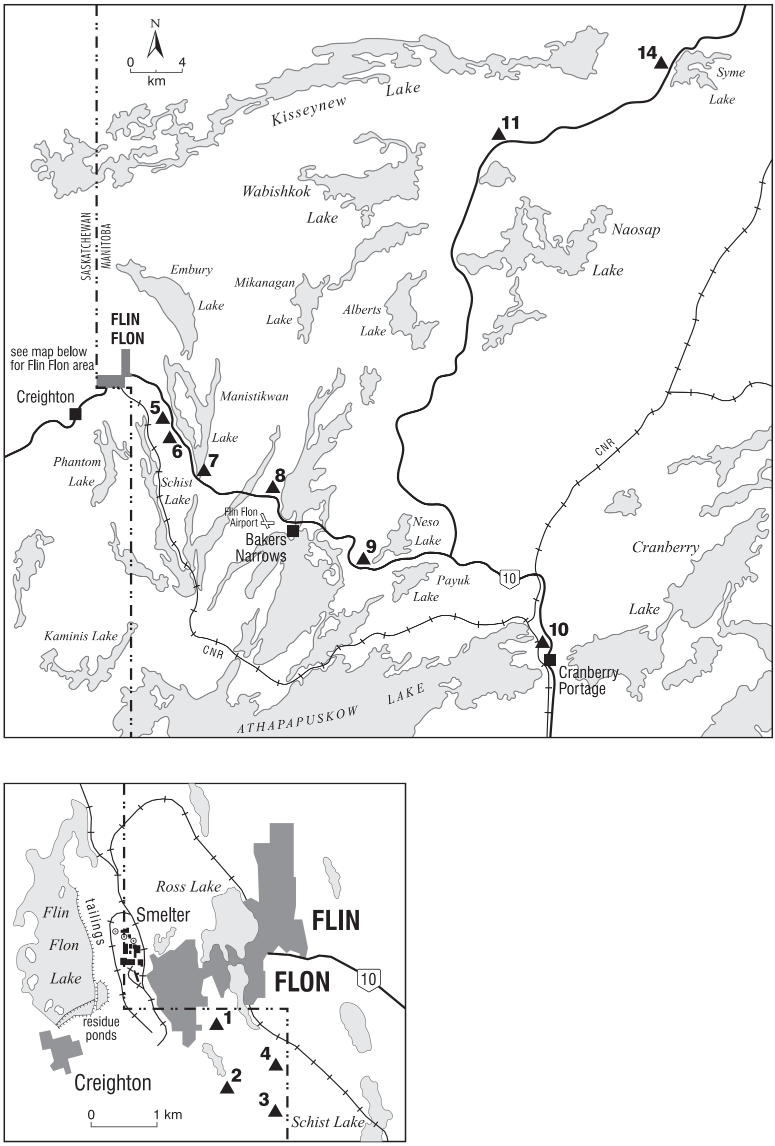

Figure 1: *Location of study sites near Flin Flon, Manitoba.*

Shield-bedrock outcrops form low rolling hills with glacially scoured crests that have been scratched relatively clean of any regolith. Intervening depressions are filled with discontinuous Quaternary tills, glaciolacustrine sediments, peats, alluvial deposits and numerous lakes. South of Cranberry Portage bedrock consists of Ordovician carbonate rocks completely buried by till and outwash. Undisturbed ridge crests include soil-free areas (with terricolous cryptogam cover) and thin Folisol-like organic profiles developed from accumulations of dead cryptogams together with some conifer and herbaceous residues. These Folisols are protected from erosion by the living cryptogam cover and provide an acidic substrate sufficient to support scattered jack pine *(Pinus banksiana*), and occasionally black spruce (*Picea mariana*). While soil acidity might be expected to increase as the smelter is approached, Hogan and Wotton (1984) found this not to be the case for lowland mineral soils and Scott (2000) found the same for ridge-crests.

Non-impacted lower slope and lowland forests are typical of the mixed-woods section of the Sub-humid Mid-Boreal Ecoclimatic Region (Scott 1995). Lowland peat cover consists of *Sphagnum* moss, tamarack (*Larix laricina*) and black spruce on Mesisols and Fibrisols. Where the landscape is gently rolling mineral soils such as Dystric Brunisols and Gleysols are found with covers of white spruce (*P. glauca*), birch (*Betula paparifera*), aspen (*Populus tremuloides*) and black poplar (*P. balsamifera*), and with a terricolous cover of lichens, especially *Cladina stellaris, C. mitis* and *C. rangiferina,* in open areas and feather mosses (*Pleurozium* spp.) under shade. In both these forest types epiphytic lichens on trunks and branches (*Usnea hirta, Evernia mesomorpha* and *Bryoria* sp.) and basal skirts of moss (*Pylaisiella polyaritha*) are the norm, while close to Flin Flon, all of these epiphytic species are missing, even in otherwise apparently healthy tree cover. Longton (1985) reports that the feathermoss *Pleurozium schreberi* is missing on shaded forest floors up to 15 km southeast of the smelter. On ridge crests not disturbed by pollution, cover consists of cryptogams overlying bedrock, and scattered jack pine, shrubs, herbaceous plants and cryptogams on thin acidic Folisols overlying bedrock. Such sites are particularly susceptible to soil moisture stress so aridity and windthrow take their toll on maturing pine. Occasionally these ridge-crest communities are burned off by lightning or human-induced fire, but immediately initiate the regeneration of a Folisol through a general crustose, foliose and fruticose lichen succession. Closer to the smelter all of these components are missing or severely damaged as the death of the cryptogams leads to the drying-out and erosion of the thin

Folisols, and regeneration of a lichen succession/Folisol is problematic. It is important to note that McMartin *et al*. (1999) have determined background soil base metal contents at >50 km from the smelter to be 21 ppm for Cu and 106 ppm for zinc. Phytotoxic levels for soil Cu and Zn were determined elsewhere by Linzon (1978) to be 100 ppm for Cu and 400 ppm for Zn.

Methods and Materials

Study site selection:

Following a preliminary reconnaissance between Flin Flon and Cranberry Portage, ten ridge-crest study sites were selected where conditions were considered similar in all respects except for pollution impacts (Figure 1). Crest-site selection was limited to five criteria: 1) conformity to the downwind pollution fallout pattern; 2) acidic bedrock; 3) past or present domination by cryptogams and open jack pine; 4) accessibility; and, 5) lack of disturbance by fire or other non-pollution anthropogenic impacts. No sites were selected southeast of Cranberry Portage due to carbonate bedrock and absence of outcrops. As the control site (# 10) at Cranberry Portage was later considered to exhibit minor pollution impacts, two additional control sites, #11 and #14, were selected 33.2 and 47.3 km respectively northeast of Flin Flon along the Sherridon Road. Here no pollution impacts were noted, and soil base metal contents approach background levels (Zoltai 1988). In addition, it was later determined that Site #4 was unsuitable due to human impacts so was not considered further. Study sites were surveyed in the summers of 1989, 1995 and 1996, with one additional visit in February, 1996.

Soil sampling:

At each ridge-crest study site the area covered by soil and non-soil was determined. While the Canadian System of Soil Classification (Soil Classification Working Group 1998) requires an organic layer (LF) overlying bedrock to be at least 10 cm thick to qualify as a Folisol, this study used a value of only one centimetre because here such a layer was not only capable of supporting fruticose lichen but often contained many living jack pine roots as well. Areas with either crustose or foliose lichen rarely were underlain by soil so were generally classified as non-soil together with truly bare rock. Often Folisols were much deeper than 1 cm and if jack pine is present these Folisols were completely permeated by a thick root mass. Some Folisols in depressions had shallow mineral regolith below them, and closer to the smelter most Folisols were missing so the only ‘soils’ available were mineral deposits in small depressions or rock fissures. At each site eight samples were collected randomly in a 10x10 m quadrat (excluding non-soil areas), however, at the almost-bare sites nearer the smelter sampling was subjective. Because of these conditions most ridge-crest soil samples close to the smelter were mineral, while at distances of over 6 km, most were organic.

Soil chemical and statistical analyses:

Soil samples were immediately air dried, and on return to the laboratory the organic samples had particles such as needles, wood and living lichen pieces removed before being ground, and then all samples were sieved through a 2 mm mesh sieve. Sub-samples were tested for organic matter content using the ‘loss on ignition’ technique (Carter 1993) and were classified as organic if they contained more than 30% organic matter. Sub-samples were leached of their base metals using EDTA-Extraction (Carter 1993) and Cu and Zn contents in ppm determined using Atomic Absorption Spectrophotometry (Model 1L151, Instrumentation Laboratory Inc., Wilmington, Mass.). Base metal data were analyzed by the Pearson Product Correlation Coefficient Analysis to determine the presence of positive or negative relationships. In addition, linear regression was used to determine the relation between Cu and Zn with distance, and an exponential regression analysis was performed using $\log_{10}$ metal concentration versus distance.

Vegetation sampling:

Each site was surveyed using three nested quadrats. Cover tree canopy, tree deadfall, shrubs and herbaceous species, were determined using the Braun-Blanquet Cover Scale in 20x20 m quadrats (Mueller-Dombois and Ellenberg 1974). For total cryptogam cover (both lichen and moss), the same 10x10 m quadrats used for soil studies were surveyed and cryptogams mapped using a grid layout, and percent cover determined from these maps. To differentiate between moss and crustose, foliose and fruticose lichen cover, five 2x2 m quadrats were selected randomly within the 10x10 m quadrat and mapped for each of these cryptogam groups.

Results

Soil and vegetation cover:

It is evident that close to the smelter there is an almost total absence of soil cover, and that the only remaining soil is regolith in rock fissures and the occasional small depression filled with eroded organic matter (Figure 2 and Table 1). At Site # 5, 6.3 km from the smelter, destruction of Folisols is less complete but >80% of outcrops are still without any soil cover. What pockets of Folisols remain support the occasional jack pine, and soil and non-soil areas have some lichen cover. By 10.4 km (Site # 7) pockets of eroded organic matter and intact Folisols cover some 30% of ridge crests, with only the occasional surface mineral layer. Here soil and non-soil areas are better covered by crustose lichens, and they share ridge-crests with some foliose and fruticose forms. By Site # 9 (23.9 km) a more typical boreal outcrop community is in place with 45% soil cover (primarily Folisols), 90% plant cover (mostly cryptogams), and a 30% tree canopy cover. The significant increase in plant cover is not due to tree canopy but to the presence of cryptogams on Folisols, and on bedrock. Differences between cover at Site # 10, and the two controls (# 11 and #

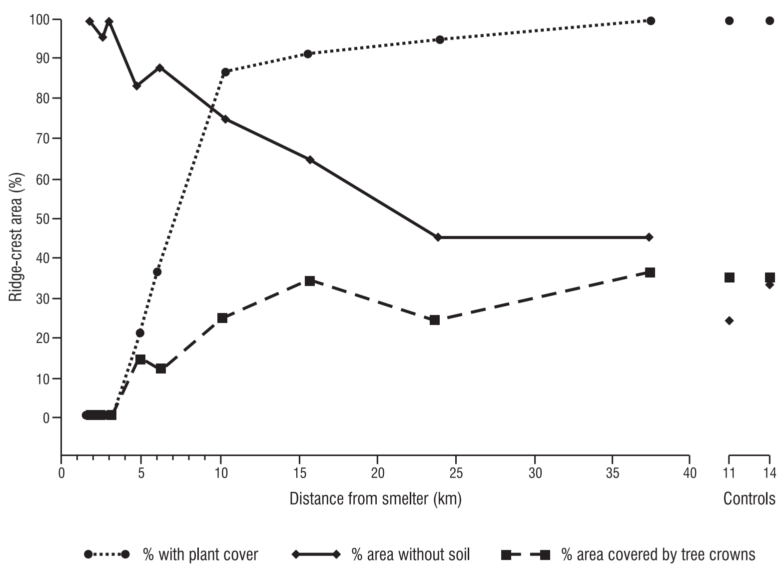

Figure 2: *Changes in soil and plant cover with distance southeast of the Flin Flon smelter.*

Table 1: *Mean values for Cu and Zn for organic and mineral ridge-crest soils.*

		Copper ppm (means)			Zinc ppm (means)		
Site #	**km to smelter**	**all samples**	**organic samples**	**mineral samples**	**all samples**	**organic samples**	**mineral samples**
1	1.65	1126 (8) [1]	- (0)	1126 (8)	6089	-	6089
2	2.45	627 (8)	724 (1)	614 (7)	770	720	777
3	3.00	833 (7)	1156 (4)	644 (4)	992	1072	637
5	4.70	1689 (8)	4833 (2)	3683 (6)	3833	11465	1290
6	6.35	1963 (8)	2145 (7)	687 (1)	6670	7157	3264
7	10.40	1172 (8)	1247 (7)	686 (1)	5808	6292	2414
8	15.70	356 (8)	462 (6)	39 (2)	1502	1939	190
9	23.90	163 (8)	162 (7)	170 (1)	1135	1139	1104
10	37.50	40 (8)	43 (6)	33 (2)	332	352	273
11	33.20	21 (8)	12 (4)	29 (4)	139	121	157
14	47.30	19 (7)	19 (8)	- (0)	130	130	-

[1] Number of soil samples used is given in parentheses

14), are modest except that Folisols cover a larger percentage of the outcrops.

Figure 3 summarizes variations in cover within the cryptogam communities on those portions of ridge-crests that have no soil cover. Mosses only become a significant component of the cover by 23 km, and even at the controls they constitute less than 10% cover and are found under partial shade. Within the lichen community a distinct trend is seen where all types are absent close to the smelter but with crustose forms taking on a significant component beyond 5 km. Of interest is that up to 10 km, only crustose lichens such as *Candelariella vitellina, Rhizocarpon geographicum* and *Aspicilia cinerea* are detected in any numbers, and they are found more frequently overlying bedrock than on Folisols. Between 10.4 and 15.7 km (Sites # 7 and # 8) the trend is for crustose lichen cover to show a modest decline as foliose, and fruticose types take on significance. On little or non-impacted ridge-crests (Sites # 9 and # 10) typical foliose species include *Peltigera aphthosa, Umbilicaria torrefacta* and *Arctoparmelia centrifuga*, while fruticose species include *Sterocaulon alpinum, Cladonia bacillaris, C. carneola, C. squamosa, Cetraria nivalis,* and the three caribou lichen, *Cladina stellaris, C. mitis* and *C. rangiferina*. The only major difference between Site #10 and the two controls, Sites # 11 and # 14, is that fruticose lichens, especially the *Cladina* spp., increase significantly in cover, primarily at the expense of crustose types.

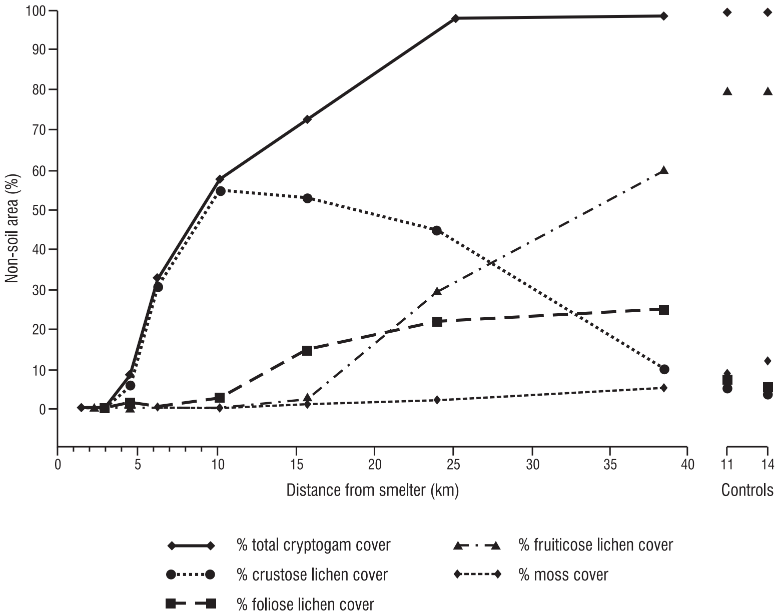

Figure 3: *Changes in cryptogam cover with distance southeast of the Flin Flon smelter.*

Soil copper and zinc levels:

Table 1 reports values for all soil-sample base metal contents from Site #10 to the smelter with maximum values being generally found at 4.7 to 6.35 km (Sites #5 and #6). The Pearson Product Correlation Coefficient Analysis for all soils between Sites #1 and #10 shows a significant correlation between Cu and distance, Zn and distance and between Cu and Zn with distance. For both Cu with distance and for Zn with distance, the relationship is shown to be negative log-linear (exponential) and significant at the 0.005 level. Analysis also showed a positive correlation between organic content and distance. Regressions were performed to determine the effects of differences in cation exchange capacity (CEC) that result from soils being either organic (higher CEC) or mineral (lower CEC). Figure 4 shows a log linear analysis for Cu from all soil samples with line of best fit for $\log_{10}$ copper (ppm) against distance (Table 2). Looking only at the organic-soil copper values against distance the Pearson Correlation Coefficient was significant at the 0.01 level, while linear analysis of Cu against distance shows a strong negative trend (at the 0.005

Table 2: *Linear regression analyses for log_{10} Cu and log_{10} Zn concentrations (ppm) against distance (km) from smelter to show exponential relationships between Sites # 1 and # 10.*

variable	base metal	r-value	r-square	t-test sample	t-value	confidence level	significant
All soil samples, sites #1 - #10	Cu	0.7375	0.5439	-9.072	-2.576	0.005	yes
	Zn	0.3976	0.1581	-3.599	-2.576	0.005	yes
Organic soils only, sites #1 - #10	Cu	0.9554	0.9128	-21.216	-2.576	0.005	yes
	Zn	0.8572	0.7348	-10.916	-2.576	0.005	yes
Mineral soils only, sites #1 - #10	Cu	0.6968	0.4855	-5.231	-2.576	0.005	yes
	Zn	0.4015	0.1612	-2.360	-2.576	0.005	no

significance level). Likewise for organic soils, Zn with distance and the association between Cu and Zu with distance were also significant. For mineral soils the Pearson Product Correlation with distance showed that the only significant relationship was between Cu and Zn.

Discussion and Conclusions

It is clear that together with the known influences of SO_2 fumigation (Longton 1985), phytotoxic levels from Cu and Zn may also play a significant role in ecosystem changes on ridge-crest sites downwind of the HBMS smelter in Flin Flon. Mean data from all soil samples at Site #10 are close to the upper background levels specified by McMartin *et al*. (1999). While Zn and Cu values are not above the phytotoxic threshold levels specified by Linzon (1978), it is possible that at Site #10 local variations in Cu and Zn, the possibility of toxicity by other pollutants, and other unknown variables, may account for the slightly lower fruticose lichen and Folisol cover here than at controls #11 and #14. At Site #9 the toxic threshold for Cu is barely exceeded while for Zn it is greatly exceeded, and for both Cu and Zn toxic levels are exceeded at all sites closer to the smelter.

Major differences are seen between the trends for Cu and Zn when organic and mineral soils are compared. For organic soils the strong correlation between distance and concentration is somewhat less dramatic than with previous lowland studies, but this is attributed to the fact that in the present study many sites were selected very close to the smelter while peak concentrations are found at approximately 5 km. Most mineral soils

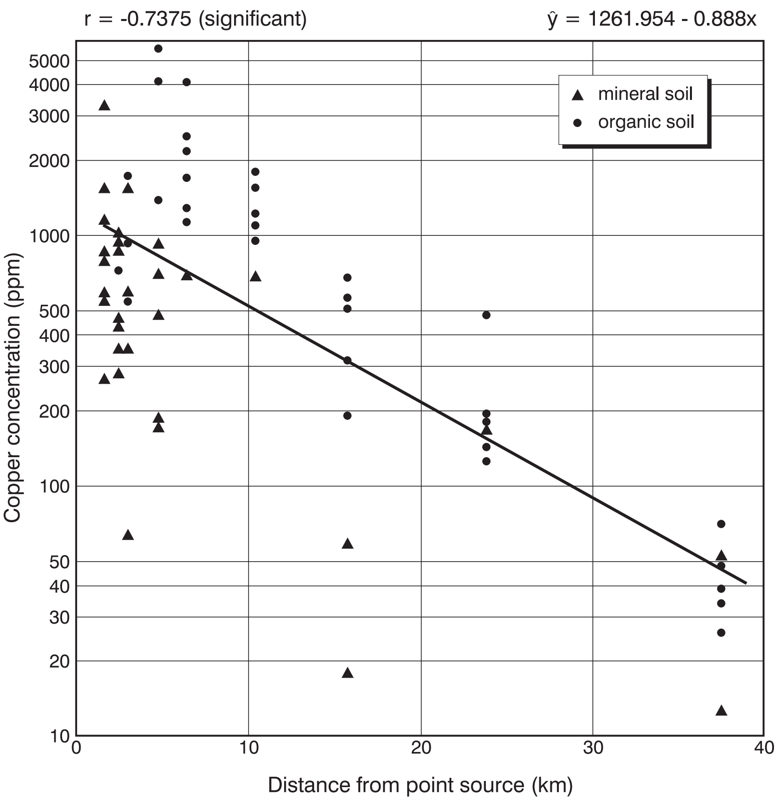

Figure 4: *Linear regressions for* log_{10} *Cu (ppm) versus distance for mineral and organic soil samples, Sites #1 to #10.*

are quite close to the smelter with only a few at greater distances, and they too show peak concentrations at about 5 km. They do not, however, show the exponential characteristics shown by Folisols.

Impacts to ridge-crest ecosystems support the conclusion that pollution has given rise to Folisol destruction as their protecting cover of living cryptogams is killed off, and that this is followed by their desiccation and removal by erosion. It is probable that much of the jack pine death between the smelter and Site #1 results from SO_2 fumigation, and direct heavy metal toxicity to trees and their symbiotic root mycorrhizae. However, occasional pine are still found in remnant pockets of organic material as close as Site # 5, and even closer to the smelter near Sites #3 and #2. Therefore, pine death beyond Site #1 is more likely the result of desiccation as they lose their water and nutrient-supplying Folisol. The fact that surviving pines have established extremely dense rooting systems to maximize use of the shrinking Folisol patches lends support to this conclusion. One intriguing observation is that following the loss of ridge Folisols some of the denuded rock at distances greater than 6 km regains some crustose lichen cover. While being speculative, it is possible that pollutant levels in the high CEC Folisols under well-developed fruticose lichens become very phytotoxic and can no longer support cryptogams, while levels from rainfall on bare rock are insufficient to prevent colonization by crustose lichens. Alterations to fallout patterns following stack elevation in 1974 would complicate this interpretation.

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Discrimination of Saskatchewan prairie ecoregions using multitemporal 10-day composite NDVI data

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Abstract: Ecosystems processes include the exchange of water, energy, and greenhouse gases between the soil, vegetation, and the atmosphere. Seasonal characteristics of plants are closely related to characteristics of the annual cycle of weather patterns, therefore, changes in plant phenological events may signal important year-to-year climatic variations or even global environmental change that should be reflected in the differentiation of ecosystems. Monitoring ecosystems that are sensitive to climate change can improve our understanding of the relationships between climate and ecosystem dynamics. This improved understanding is critical for future land-use planning purposes. The objectives of this paper were to characterize the temporal Normalized Difference Vegetation Index (NDVI) values of the four prairie ecoregions and to test the possibility of discriminating these ecoregions using NDVI data. Ten-day composite Advanced Very High Resolution Radiometer (AVHRR) data for Saskatchewan were downloaded from Natural Resources Canada Geogratis website for 1993 to 1998. NDVI channels were subset from each image. Results showed that the NDVI values were unique for different ecoregions as well as different times of year. The NDVI differences among these ecoregions were significant. The results indicated discriminating ecoregions using NDVI data with an overall accuracy of up to 73.5%.

Key words: Saskatchewan, prairie ecosystems, AVHRR, NDVI, MANOVA, discriminant analysis

Introduction

Ecosystems processes include the exchange of water, energy, and greenhouse gases between the soil, vegetation, and the atmosphere. The ability to detect changes in ecosystem processes such as carbon fixation, nutrient cycling, net primary production, and litter decomposition is an important part of defining global biogeochemical cycles. Seasonal characteristics of plants are closely related to characteristics of the annual cycle of weather patterns, therefore changes in plant phenological events may signal important year-to-year climatic variations or even global environmental change. Researchers have been focusing on large-scale changes in terrestrial ecosystems (*e.g*., Dixon *et al*. 1994; Ojima *et al*. 1994; Lambin and Ehrlich 1997). It is accepted that at the global scale rapid environmental changes are mainly a result of climatic variations and anthropogenic activities. Environmental degradation is also associated with declines in primary productivity that alter biogeochemical exchanges between the earth and atmosphere (Running *et al*. 1994). Monitoring ecosystems that are sensitive to climate change can improve our understanding of the relationships between climate and ecosystem dynamics. This improved understanding is critical for future land-use planning purposes.

Recent advances in remote sensing technology and theory have expanded opportunities to characterize the seasonal and inter-annual dynamics of vegetation communities. Time series analysis of the National Oceanic and Atmospheric Administration's (NOAA) Advanced Very High Resolution Radiometer (AVHRR) 1-km multispectral imagery has allowed scientists to examine larger-scale phenological phenomena such as greenup, duration of green period, and onset of senescence (Reed *et al*. 1994), as well as change in seasonally-dependent biophysical variables such as leaf area index (LAI), biomass, and net primary productivity (Roller and Colwell 1986; Gallo and Eidenshink 1988; Achard and Brisco 1990; Teng 1990). Using time-integrated normalized difference vegetation index (NDVI) data, Yang *et al*. (1998) revealed that spatial and temporal variability in growing season precipitation, potential evapotranspiration, and growing degree days are the most important controls on grassland performance and productivity in the central and northern Great Plains.

Temperature increases over the last century within the mixed prairie ecosystem have been among the most dramatic in the world and have resulted in the droughts of the 1930s, 1961, the 1980s, and several others (Wheaton 2000). In southern Saskatchewan, 2001 was one of the driest years in decades, causing severe crop damage (Hayward 2002). Anderson *et al*. (2001) concluded that the temperature in the prairie ecozone of Saskatchewan is expected to increase 3.5^0C to 4.0^0C in the next 50 years. Water availability will decrease because of increasing potential evapotranspiration even with increasing precipitation. Climate change will markedly alter the vegetation regime. Global warming may result in an advance of the northern boundary of C^4 species (Davidson and Csillag 2001) in the mixed prairie ecosystem. From a study conducted by Mitchell and Csillag (2001), precipitation is the primary control factor for vegetation annual productivity in the mixed prairie ecosystem.

However, research into the relationship between vegetation phenology and climate variability has not been fully investigated. This paper set three objectives: 1) to identify the NDVI changes of prairie ecoregions over the growing seasons of six consecutive years; 2) to test the NDVI differences among different ecoregions; and, 3) to investigate the overall accuracy for discriminating ecoregions using time series NDVI data. The paper represents the first part in a series of studies aimed at more fully identifying the relationships between vegetation phenology and climate variables.

Study Area

The study area is southern Saskatchewan. This is bounded by 49^0N latitude in the south, the Boreal forest ecozone in the north, and extends between longitudes 101.5^0 to 110^0W (Fung 1999). The area falls within the prairie ecozone according to the ecological land classification developed in 1991 by the Ecological Stratification Working Group of the federal, provincial and territorial governments. The framework, primarily based on soil, climate and vegetation, comprises three levels of stratification, namely ecozone, ecoregion, and ecodistrict. Ecozone "lies at the top of the ecological hierarchy, and as such, it defines, on a subcontinental scale, the major physiographic features of the country", while ecoregion is defined as "subdivisions of the ecozone, characterized by distinctive climatic zones or regional landforms, and constitute the major bridge between the subcontinental scale ecozones and the more localized ecodistricts" (Acton *et al*. 1998, 3).

The prairie ecozone encompasses four ecoregions extending from the southwest corner of Cypress Upland northward to Mixed Grassland, Moist Mixed Grassland, and Aspen Parkland (Figure 1). The region is dominated by a temperate climate with 1,800 growing degree-days and annual precipitation of less than 300 mm. These dry conditions subside moving northward and eastward to the Aspen Parkland. Prior to European settlement, southern Saskatchewan was covered with natural vegetation, mixed prairie ecosystem. The natural grasslands are fragmented by settlement and agriculture. However, even in the most altered areas, there are pockets of native vegetation which allow visualization of the landscape as it was. Recently, human settlement and, in particular, agricultural development have been the predominant forces in the evolution of the Saskatchewan landscape (Fung 1999).

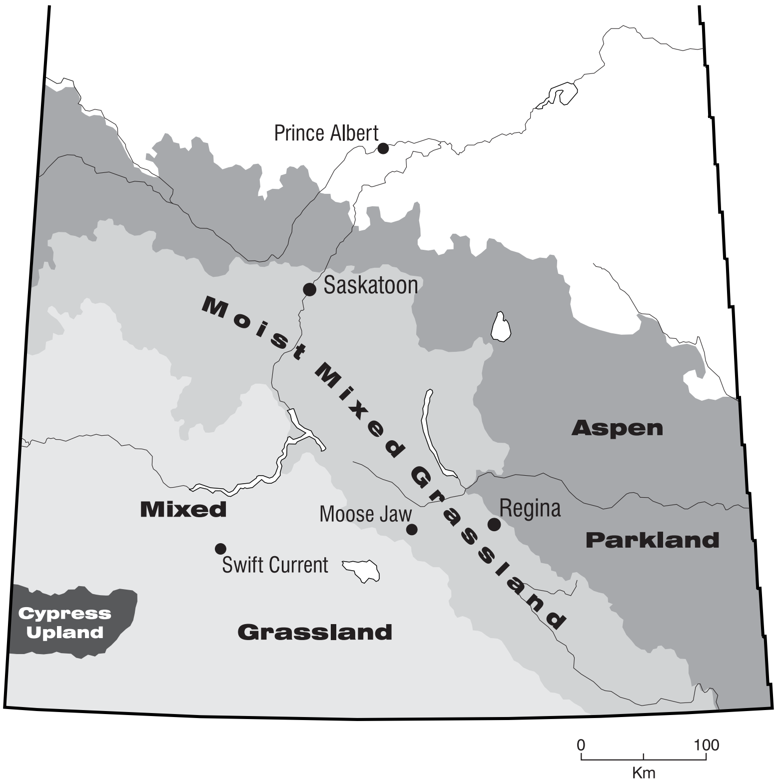

Figure 1: *Study area: the prairie ecozone of Saskatchewan showing its four ecoregions.*

Methodology

Canada-wide 1-km AVHRR 10-day composite maps were derived from NOAA AVHRR data by the Canadian Centre of Remote Sensing (CCRS) for the CCRS Northern Biosphere Observation and Modelling Experiment (NBIOME) project. The original AVHRR data are available each day. The main idea for 10-day composite maps is that after replacing noisy lines using a simple heuristic algorithm, the cloud detection algorithm was used and one image with cloud free or the least cloud cover was selected to represent each 10-day period (Adair *et al*. 2002). Based on the image processing procedure mentioned in the metadata associated with the data downloading, the NDVI layers were computed from the bidirectional reflectance distribution function (BRDF)-corrected surface reflectance for channels 1 and 2. After contaminated pixels were replaced by temporal interpolation of seasonal data, a 5-point smoothing filter was applied to the seasonal NDVI curve. NDVI values from -1 to 1 were scaled to a range between 0 and 20,000.

NDVI, as a vegetation index, is a ratio of the difference between channel 2 (near-infrared wavelength region) and 1 (red wavelength region) to the sum of these two channels. It has the advantages of enhancing vegetation signals, reducing the effects of soil and other non-vegetation features, and standardizing the values. NDVI has been used as a greenness index for vegetation. Thus, the higher the NDVI value, the greater is the greenness of vegetation and the amount of green cover on the ground. This is because green vegetation has higher near-infrared reflectance and lower red reflectance. Bare soil or areas with low vegetation cover have low or negative NDVI values. During the vegetation growing cycle the NDVI value acts as an indicator of the density of chlorophyll on the ground, increases as the vegetation starts to green up, reaches the maximum number at the highest productivity level, and starts to decrease as vegetation becomes senescent. According to Acton *et al*. (1998), ecoregions were classified based on vegetation, climate, and soil, NDVI has the potential ability to signal the vegetation features of different ecoregions and provides valuable information as a remote sensing tool in studying vegetation phenology cycles at a regional scale.

The multitemporal 10-day composite AVHRR data cover the growing seasons (April 11 to October 21) of six years from 1993 to 1998. After downloading the dataset from Geogratis (*http://www.geogratis.gc.ca/*) of Natural Resources Canada (Canadian Centre for Remote Sensing), NDVI layers were subset to the Saskatchewan boundary. Among 2,225 weather stations in Saskatchewan, 141 active weather stations in the prairie ecozone during the 1993 to 1998 period were selected for analysis. Due to the uneven distribution of weather stations, only two were available for Cypress Upland, so an additional six points were selected randomly in this ecoregion to make a total of 147 points for the study area. Pixel values for each date for a 5x5 window surrounding each weather station were extracted from the NDVI image for the four ecoregions using PCI Geomatica V8.1. Points belonging to the same ecoregion were then combined. NDVI values were rescaled back to between -1 and 1.

The median and standard deviation were calculated for each point. Some point locations were observed to be close to water bodies and subsequently were adjusted (shifted away from the water body). This adjustment was made because of the significantly different spectral characteristics of vegetation and water. Clear water has no near-infrared reflectance and higher red reflectance. The purpose of this study was to investigate the vegetation phenology. This process was aided by overlaying the water body coverage for Saskatchewan and visually inspecting each point site. The mean and standard deviation were also calculated for each ecoregion. NDVI curves were plotted for all ecoregions for these six consecutive years. The NDVI layer from April 11 of 1997 was excluded from the dataset due to a georeferencing problem of the downloaded file. Multivariate analysis of variance (MANOVA) was performed to test the NDVI differences among the ecoregions. The best time period(s) to acquire images for separating different ecoregions was/were estimated from the MANOVA test results.

Discriminant analysis was also performed to predict the classification accuracy for different ecoregions. The user and producer classification accuracies were calculated using the methods described by Congalton and Green (1998). Classification accuracy using a *Jack-Knife Cross Validation* (JCV) approach was also performed. This approach was implemented by withholding the spectral data for one point, and building the discriminant functions using the data from the remaining points. The prediction accuracy of the discriminant functions was tested by comparing the predicted ecoregion against the actual ecoregion for the one point that was withheld from the analysis. The process of removing one point from the dataset was repeated 146 times until all points had been withheld and the accuracy of the 146 discriminant functions was tested.

Results

NDVI Variations among Ecoregions and Time of Year:

The NDVI values were plotted along time series for each ecoregion (Figure 2). The graph visually showed that the maximum NDVI values changed from one year to another. The lowest maximum NDVI values were found in 1993 and 1995 and the highest maximum NDVI value occurred in 1996. Among the four ecoregions, Mixed Grassland had the lowest maximum NDVI values throughout the six years. From a geographic perspective, Cypress Upland is at the same latitude with Mixed Grassland but is at a higher elevation, so the vegetation type is more closely related to the Moist Mixed Grassland, which is northward of the Mixed Grassland (Figure 1). The NDVI curves for Cypress Upland and Moist Mixed Grassland were close to each other. Aspen Parkland, an area of mixed

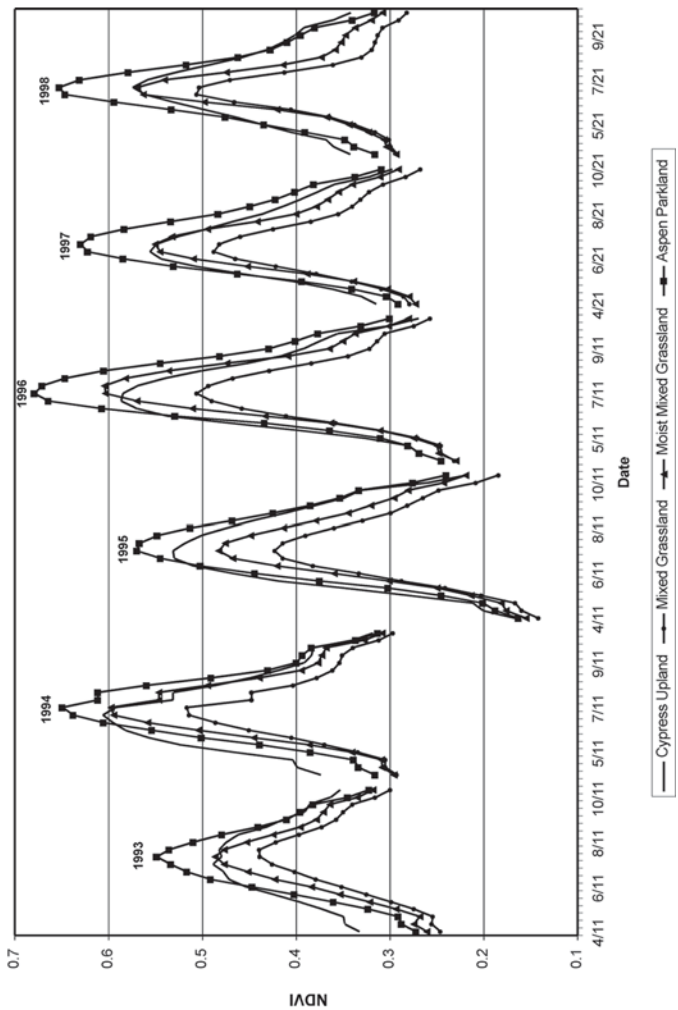

***Figure 2:** NDVI values of the four ecoregions for each growing season from 1993 to 1998.*

grasses and trees, is located in the northern part of the region. The spectral near-infrared reflectance of trees is higher than that of grasses. NDVI is the difference between reflectance of near-infrared and red wavelengths over the sum of these two values; therefore, it was not surprising that the NDVI values for Aspen Parkland were the highest. It should be noted that the majority of the prairie ecozone has been converted to cropland. The NDVI values are normally higher in cropland than that in grassland. However, the NDVI value for each pixel is the result of mixed features in that pixel. Based on the lower spatial resolution dataset (1 km x 1 km), each NDVI value might include both cropland and grassland features. Furthermore, the regional climate affects crops in the same way as it affects native grasses.

MANOVA test results:

Overall, the MANOVA test showed the difference among these ecoregions was significant. Subsequently, NDVI differences of each pair of ecoregions were compared using the Tukey Post Hoc test. Results revealed that different pairs of ecoregions had different optimal time periods to be separated. For pairs of Cypress Upland versus Mixed Grassland, Mixed Grassland versus Aspen Parkland, and Moist Mixed Grassland versus Aspen Parkland, the NDVI differences were significant from May to October. To separate Cypress Upland from Moist Mixed Grassland using NDVI data, images from May to middle June were the best. Hot summer (July-August) is the best for separating Cypress Upland and Aspen Parkland. Fall (July-October) images best capture the significant differences between Mixed Grassland and Moist Mixed Grassland. If the Cypress Upland ecoregion was excluded because of its small area and different habitat, the optimal imagery acquisition period to distinguish between the remaining three ecoregions would be hot summer and fall (July-early October). To reduce the length of the table, only the MANOVA test results from 1997 (a normal year) are listed in Table 1.

Discriminant analysis and classification accuracy:

The ability to discriminate among the four ecoregions was tested using NDVI values from these six years. The in-sample validation results indicated that it could discriminate among these ecoregions with 100% accuracy. When validated using the JCV approach, the accuracy level dropped to 73.5%. Table 2 lists classification accuracy results based on the in-sample and JVC approach. From these results, it is clear that the Canonical Discriminant Functions were successful in identifying 108 out

Table 1: *Subset (1997) of MANOVA Tukey Post Hoc test results showing the differences between each pair of ecoregions.*

		pairs of ecoregions					
Month	Day	1 with 2	1 with 3	1 with 4	2 with 3	2 with 4	3 with 4
April	21	**0.008**	**0.001**	0.128	0.808	0.220	**0.020**
May	1	**0.002**	**0**	0.138	0.890	**0.039**	**0.003**
	11	**0.003**	**0.001**	0.465	0.908	**0.001**	**0**
	21	**0.003**	**0.002**	0.955	0.999	**0**	**0**
June	1	**0**	**0.002**	0.993	0.823	**0**	**0**
	11	**0**	**0.001**	0.508	**0.025**	**0**	**0**
	21	**0**	0.131	0.054	**0**	**0**	**0**
July	1	**0**	0.897	**0**	**0**	**0**	**0**
	11	**0**	1	**0**	**0**	**0**	**0**
	21	**0**	0.982	**0**	**0**	**0**	**0**
August	1	**0**	1	**0**	**0**	**0**	**0**
	11	**0**	0.451	**0**	**0**	**0**	**0**
	21	**0**	0.177	**0.027**	**0**	**0**	**0**
September	1	**0**	0.140	0.119	**0.001**	**0**	**0**
	11	**0**	0.184	0.238	**0**	**0**	**0**
	21	**0**	0.311	0.212	**0**	**0**	**0**
October	1	**0**	0.431	0.271	**0**	**0**	**0**
	11	**0.001**	0.667	0.457	**0**	**0**	**0**
	21	**0.012**	0.910	0.626	**0.001**	**0**	**0.006**

Notes: Ecoregions are 1-Cypress Upland; 2-Mixed Grassland; 3-Moist Mixed Grassland; 4-Aspen Parkland
Differences significant at 0.05-level are in bold faces and shaded.

of 147 sites for a total of 73.5% overall accuracy. Both user's accuracy and producer's accuracy showed that the Moist Mixed Grassland was the ecoregion with the lowest discrimination accuracies (Table 2). Figure 3 shows the classification scatter plot for the four ecoregions. The Canonial Discriminant Function 1 adequately separated Mixed Grassland, Moist Mixed Grassland, and Aspen Parkland, while the second function discriminated Cypress Upland from the other ecoregions.

Table 2: *An error matrix showing the classification results according to ecoregion.*

Groups count and %	Predicted Group Membership 1	2	3	4	Total	User's accuracy (%)
Original						
1	**9/*100***	0	0	0	9	*100*
2	0	**39/*100***	0	0	39	*100*
3	0	0	**38/*100***	0	38	*100*
4	0	0	0	**61/*100***	61	*100*
Producer's accuracy (%)	***100***	***100***	***100***	***100***		***100***
Cross-Validated						
1	**7/*77.8***	1/*11.1*	0	1/*11.1*	9	*77.8*
2	0	**31/*79.5***	4/*10.3*	3/*7.7*	39	*79.5*
3	0	5/*13.2*	**24/*63.2***	9/*23.7*	38	*63.2*
4	0	2/*3.3*	13/21.3	**46/*75.4***	61	*75.4*
Producer's accuracy (%)	***87.5***	***79.5***	***58.5***	***78***		***73.5***

Notes: Ecoregions are 1-Cypress Upland; 2-Mixed Grassland; 3-Moist Mixed Grassland; 4-Aspen Parkland
Cells highlighted running diagonally through the table show the number of points correctly and their corrresponding percent accuracy.

Discussion and Conclusion

The study has shown that the NDVI values of vegetation varied among ecoregions and time of year. This may be caused by climate variations but was not tested in this study. The NDVI differences between ecoregions were significant. To capture the maximum NDVI differences among Mixed Grassland, Moist Mixed Grassland, and Aspen Parkland ecoregions, the imagery acquisition date should be between hot summer and fall (July-early October). To spectrally separate Cypress Upland from the other ecoregions an acquisition date in spring (April-early June) or summer (July-August) would be more appropriate. Ecoregions could potentially be classified at 73.5% accuracy overall. Accuracy levels varied depending upon the ecoregions. Moist Mixed Grassland was the one most difficult to discriminate.

There are several limitations in the analysis. First, climate data were not integrated into the analysis, limiting the explanation of the results. Second, the comparison was based on ecoregions, which was too broad a spatial scale to investigate the relationships between plants' temporal characteristics and climate variability. Further analysis is planned that will

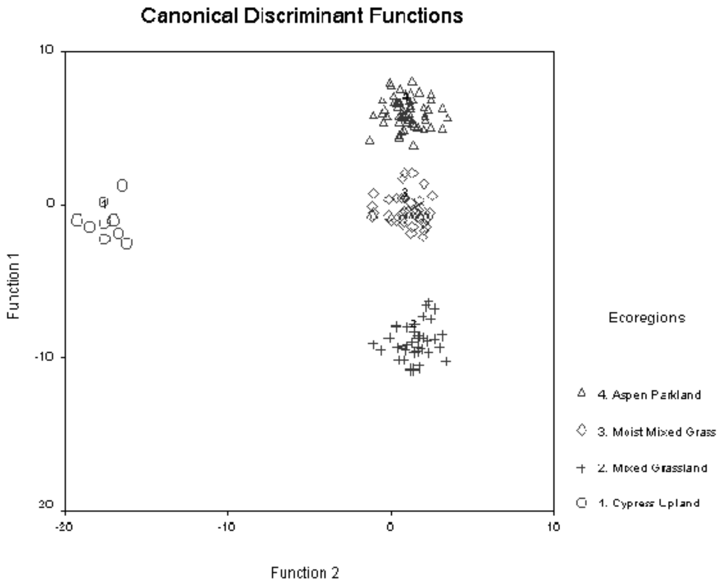

Figure 3: *Canonical discriminant classification scatter plot showing the separability of the four ecoregions using two discriminant functions.*

focus on different land cover types. Third, a six-year time frame is not long enough to conduct climate change analysis, therefore additional NDVI data are needed. These limitations aside, the results provide the basis for conducting further examination of the relationships between vegetation phenology and climate variables. Future research will investigate the relationships between NDVI data that are derived from each weather station and climate variables (e.g., temperature and precipitation). The next step will focus on how climate variables influence vegetation phonological cycles, such as the onset of greenness, the offset of greenness, the maximum NDVI, as well as what climate variable will be most important, and how long the lag will be between vegetation phenology and climate conditions.

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Definitions and boundaries of community: the case of rural health focus group analysis in southwestern Manitoba

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Abstract: Rural areas - like urban areas - are sources of community. However, communities and community life in rural areas such as southwestern Manitoba face many unique challenges, including agricultural restructuring, rural depopulation, and the resultant loss of local services (e.g., health, education, business). This paper reports on two exercises undertaken in a series of focus groups held in communities throughout southwestern Manitoba in the winter and early spring of 2001. First, the paper highlights some of the descriptions and definitions of 'rural' and 'community' that were discussed by focus group participants. Second, the results of a mapping exercise, which had participants draw the boundary of their respective communities on topographic map copies, are described. These results indicate a variety of definitions and boundary structures. In particular, there is a recognition that a range of communities exists within which respondents interact. The paper concludes that regardless of definition or perceived boundary, rural residents in southwestern Manitoba appear resilient in the face of change, adjusting their expectations and desires in order to face the new realities of the twenty-first century.

Key words: rural, prairies, community, community-definition, mental maps

Introduction

Defining notions of 'rural' and 'community' has dominated both the conceptual and empirical dimensions of the social sciences for decades. In fact, the very relevance of 'rural' has been challenged in recent years (Hoggart 1990; Halfacree 1993). Goldschmidt (1946), in his classic study of the differences in community quality of life in Arvin and Dinuba, California based on the structure of agriculture, made the distinction between 'communities of interest' and the 'geographic community'. Hillery (1955) noted more than 90 definitions of community, before settling on a distinction similar to Goldschmidt's description of 'social ties' and 'geographic area'. More recently, geographers have explored the notions of spatial and qualitative dimensions to rural and community (Leckie 1989; Kearns and Joseph 1995; Ramsey and Smit 2001, 2002 in press). They have also concluded that communities are essentially made up of people with some common identity or character, who are located in such a way that they can communicate. This communication can take a variety of forms, including face-to-face or telephone conversations, and increasingly, e-mail and chat lines via the Internet. The affordability and ease of access of the latter two have influenced perceptual constructions of community.

Traditionally, it was believed that most communities were locality-based, with social interactions limited primarily to the immediate local areas in which people lived. For example, Hillery's (1955) review showed an almost one-for-one congruence between social ties and geographic area. Others have suggested that this situation has changed, and that people increasingly operate within non-local communities, or what McClenahan (1929, 1946) has termed 'communalities', and Webber (1964a, 1964b) has called 'communities without propinquity'. Thus the individual, it is suggested, is no longer restricted to the boundaries of the 'traditional' community but can choose, or is impelled by changing social and economic conditions to choose, from a much wider range and area of opportunities. Both Webber and McClenahan, and their disciples, however, were working in large-urban contexts where the 'range' and 'intensity' of contacts changed at an earlier date, with consequent effects upon community (Wilson and Wilson 1945). Although spatial studies of rural communities are not legion, interpretation of the literature suggests that, in the past, most people viewed their communities as more-or-less contiguous spatial units that enclosed 'communities with propinquity' (Everitt 1980). The exceptions to this rule were, by definition, remarkable. The amount of investment in the local area has always, of course, varied from person to person and from group to group. An individual or group does tend to belong to a community or communities of 'limited liability' from which individuals may demand more than they invest — although they will demand and invest something (Janowitz 1952).

People have a variety of rural experiences - including those associated with 'community'. This paper sought to investigate the spatial ('geographical') extent of the communities that people lived and worked in within their activity spaces. It has been demonstrated elsewhere that activity spaces of people can give interesting insights into their spatial communities, and that these activity spaces can be mapped (Everitt 1976, 1980; Everitt and Cadwallader 1981). It has also, however, been clearly demonstrated that a person's mapping abilities are, at times, less than perfect, and that working with the end results of their efforts has to include some interpretive work on the part of the researcher (Everitt 1998). That is, there are distinctions between the 'official' and 'perceptual' communities - or, as argued by many others (e.g., Hillery 1955; Kearns and Joseph 1995), the 'geographic' (official) community and the 'community of interest' (perceptual). As noted by Ramsey and Smit (2002, in press), community is viewed by many as "an aggregation of people, usually in an area where the residents have some common ties and or interactions". Interactions within communities are based on important sets of functions (e.g. production and exchange) and structures (e.g., institutional and social) that are dynamic and interrelated.

For the focus group research reported on in this paper, it was felt to be particularly useful to try to capture people's mental images of their communities on maps, and to interpret these maps with a series of follow-up questions. To use the terminology pioneered by Rushton (1969), an attempt was made to gain insight into both 'behaviour in space' (the actual choices made) and 'spatial behaviour' (the rules that govern the evaluation and choice of location). These images and perceptions were sought to balance the Statistics Canada definitions of urban and rural within the study area of southwestern Manitoba. Urban is officially defined as geographic areas that "have attained a population concentration of at least 1,000, and a population density of at least 400 people per square kilometre" (Statistics Canada 1991, 278). All else is "considered rural" (Statistics Canada 1991, 278). One of the purposes of the focus group research was to examine how people's perceptions of urban and rural compared to the 'official' definitions.

Given the changes taking place in the 'official' rural Canada, particularly with respect to those regions facing depopulation, concerns about service delivery (e.g., health, education, elder care) have been raised (e.g., Chappell *et al.* 1996; Smithers and Joseph 2000). The purpose of a multi-year study at Brandon University was to identify determinants of the health of rural populations and communities in southwestern Manitoba (hereafter referred to as Westman). The notion of 'determinants' of health refers to the identification of appropriate indicators for assessing levels of health of rural populations and communities. The study is structured on a number of premises and stages:

1. to examine determinants of health frameworks as they relate to the rural population of Canada;

2. to develop a comprehensive framework for the determinants of health of rural populations;
3. to analyze secondary data in order to examine the determinants of health as they relate to the rural populations of Canada;
4. to conduct focus group sessions with residents of rural communities; and,
5. to compile and pilot an assessment workbook with selected rural communities.

This paper reports on the fourth section of that project, namely sessions of 15 focus groups that were held throughout Westman between January and April 2001. While the ultimate purpose of the focus groups was to ascertain measurable determinants of rural health, in order to provide context to such indicators, participants were first asked to describe their views and perceptions of what ‘rural’ and ‘community’ entailed. This involved two steps: 1) group discussion; and, 2) a ‘mental mapping’ exercise whereby participants were asked to draw the boundaries of their particular communities.

Methodology

Qualitative research methodologies and techniques are gaining favour in the social sciences (Berg 1998; Kitchin and Tate 2000). Focus group analysis, defined simply as “an interview style designed for small groups” (Berg 1998, 100), is one of many qualitative techniques which can be employed to obtain detailed descriptions of a range of phenomena in small group settings, particularly at the exploratory stage of research projects (Stewart and Shamdasani 1990). The history of focus group analysis, originally referred to as ‘focused interviews’ dates back to the early 1940s. It was originally used to obtain views on military morale, and then in the post-World War II era it functioned as a marketing tool. However, social scientists began employing the methodology much later (Berg 1998). Given the acceptance of focus groups as an analytical technique and the uncertainty about what constitutes ‘rural’, ‘community’ and ‘health’, focus groups were deemed an appropriate first step to ascertaining determinants of the rural health of populations and communities.

In the literature, the suggested size range for the number of participants varies from fewer than 7 (Berg 1998), to between 6 and 10 (Morgan 1997) or 12 (Stewart and Shamdasani 1990). While it is argued that too few

Table 1: *Rural health focus groups, Manitoba, 2001.*

Community Name	Date Held	Number of Participants	RM Population 1996	Settlement Population 1996
Strathclair	Jan. 23	4	1,030	377[1]
Miniota	Jan. 29	6	1,025	217[1]
Minnedosa	Feb. 5	15	665	2,440
Virden	Feb. 7	10	1,840	2,955
Russell	Feb. 15	16	550	1,605
Carberry	Feb. 27	12	1,900	1,490
Hutterite Colony	Feb. 28	16	na	100[2]
Rivers	March 1	13	895	1,120
Deloraine	March 5	11	620	1,040
Treherne	March 7	9	1,275	670
Glenella	March 12	15	555	130[1]
Souris	March 14	8	710	1,615
Killarney	March 20	10	1,175	2,210
Melita	April 17	5	530	1,155
Glenboro	April 19	9	860	665

[1] 1991 data

[2] estimate for each colony

Source: Focus Groups, 2001

(under 6) makes sustained discussion difficult, and more than 10 or 12 makes discussion difficult to manage, Morgan makes the case that successful discussion can be facilitated with groups of 15 to 20 if they are managed in an orderly manner. As noted in Table 1, the size of the focus groups held in Westman in 2001 ranged from 4 to 16. Consistent with concerns expressed by others (Berg 1998; Stewart and Shamdasani 1990), the focus groups with 4, 5, and 6 participants were more difficult to sustain discussion within than those of between 8 and 15. Similarly, it was more difficult to ensure all voices were adequately heard in the larger groups of 15 and 16. Nevertheless, all meetings met the stated goal of having the participants define and describe what rural, community, and health meant to them. Each focus group was facilitated by at least two researchers, one of whom asked questions and guided discussion, while the other wrote comments on 'flip charts' that were displayed in the meeting rooms. A research assistant was also present to record discussion. As Figure 1 illustrates, the focus groups were conducted in locations to provide coverage across the Westman region of Manitoba.

Participants were identified through a local public health nurse in each community. This proved to be a crucial element of the methodology as it led to a higher participation rate than has been found elsewhere. Attempts were made to include health professionals, clergy, farmers, seniors, youth, and business people; a gender balance was also sought. Each focus group was structured based on seven questions:

1. How would you, as a rural resident, describe community?
2. What do you consider to be your community?
3. What is unique about your rural community?
4. How would you, as a rural resident, describe rural?
5. How would you describe health?
6. How would you describe a healthy rural community?
7. How do you know when you live in a healthy rural community and how do we measure that?

After participants in each group had the opportunity to describe their own community and how it was unique, participants were handed a letter-sized photocopy taken from a 1:50,000 topographic map that included their region. They were then asked to draw the boundary (or boundaries) of their community. The only prompt given to them was that they did not have to use administrative boundaries to draw their boundary.

Descriptive Definitions of Rural and Community

As noted in Table 2, focus group discussion regarding what constitutes both rural and community was wide-ranging. In terms of community, the rural structure and agricultural nature of the study area are evidenced by the mention of ‘connection to land’ and ‘lower population density’. More germane to the spatial nature of community were such notions as “patterns of interaction’, ‘population diversity’, ‘trading area’, and ‘layered communities’. Nevertheless, throughout the focus group sessions, it was evident that the spatial community was much larger than the municipal entity (e.g., Strathclair proper). The community of interest is much more complex to describe as it transcends all aspects of social networks as defined by individuals. Much of the discussion was consistent with the sociological literature of community representing a sense of belonging,

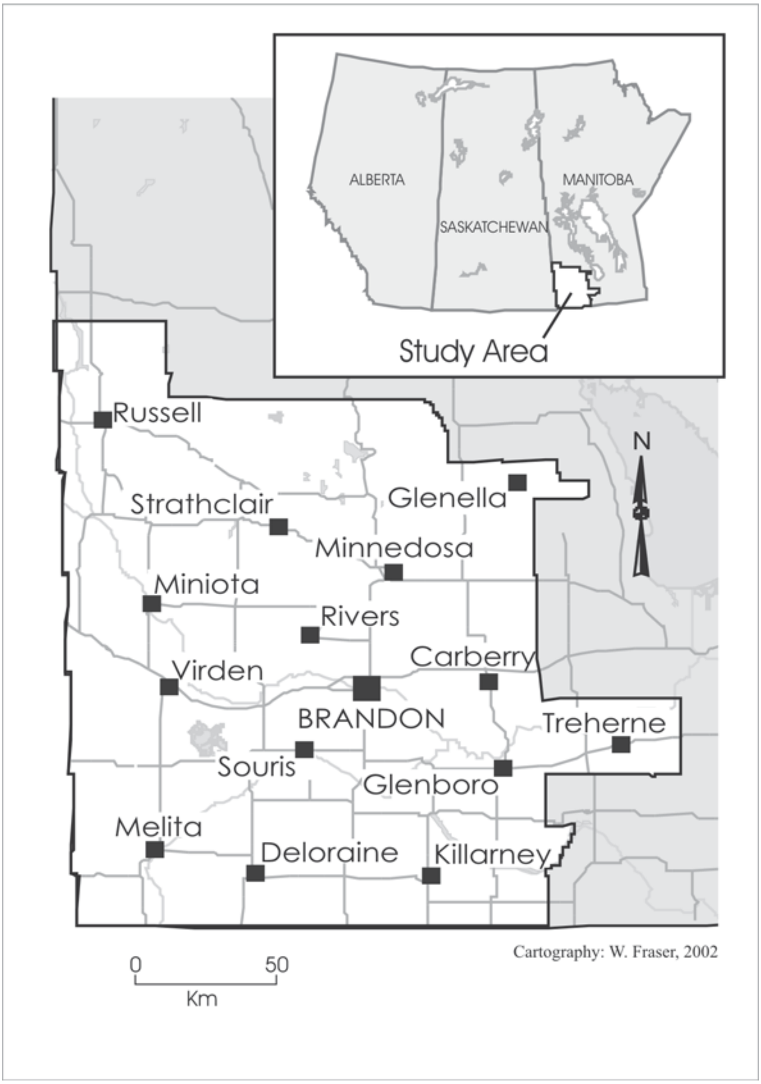

Figure 1: *Focus group study regions in southwestern Manitoba.*

Table 2: *Focus group descriptions of rural and community.*

Term	Geographic/Spatial	Interest
Rural	• Anything outside of the city • "rural is country to me, kinda small town" • "Brandon is like a rural city" • Farm life; agriculture • Less population density • Open space • Anything outside the perimeter • "people who are scattered are more rural" • Measured based on distance to obtain services • Low population over a large land mass	• "other people know your business before you do" • Being isolated • People are friendly • Higher quality of life • People volunteering their time freely • Slower pace of life • You don't have to lock your doors
Community	• Some connection to land • Based on pattern of interactions • Less population diversity • Trading area • Area of people with similar interests • Layers of overlapping communities • "geographic closeness" • "it doesn't have to be geographically small"	• Sense of belonging, common beliefs, and security • People experiencing things together • Place to raise a family • "working, living, and sharing together" • "it's what you make it" (work, play, communications) • Based on relationships • "a place I feel commitment to" • "it's the social fabric of the area" • "community is really, mostly people" • People living in close proximity • People know each other (and each other's business) • Loyalty and roots • Lack of privacy • People coming together in crisis (and good times)

Source: Focus Groups, 2001

common beliefs, and based on relationships (e.g., Hillery 1955). Furthermore, notions of loyalty and roots, as well as closeness to those with similar values were mentioned. It is important to note that definitions of community included both positive (e.g., people knowing each other) and negative (e.g., people knowing each other's business) aspects.

In addition, much of the discussion seemed to illustrate that boundaries of people's communities (both 'activity' and 'perceptual' spaces) were expanding as rural populations and communities declined. That is, as population numbers decline, individuals, families, farmers, and business people need to travel farther to obtain services and to network socially and economically. This dynamic results in both a larger activity space and perceptual community. For example, in the Strathclair area, schools have joined together to field a common sports team. In other communities, local newspapers have become more regional. As small grain elevators close, and are replaced by inland terminals, farmers must travel farther to sell their products. Additionally, participants who were either in school or who had children or grandchildren in school noted the importance of the local school and the school board in defining and redefining their community. A recent announcement by the provincial government concerning the amalgamation of school boards in the province, the first such change since the 1950s, could signal even more expanded boundaries of rural citizens' communities of interest (Dalla-Vicenza 2001).

In terms of rural (Table 2), similar discussion prevailed in that differences between space- and place-based descriptions of rural were revealed. In terms of the spatial community, participants noted generic (anywhere outside of cities and lower population density) and socio-economic (farming and rural) descriptions. Others provided comments linking rural to their context in southern Manitoba, specifically mentioning Winnipeg and Brandon. While there was no disagreement that Winnipeg was urban, there were divisions within and between group meetings regarding the classification of Brandon. Some classified Brandon as a 'rural city', others felt it was urban, and still others felt it had both urban and rural qualities, particularly as they related to Brandon's role as an agricultural service centre. Brandon also serves as a point for higher order health services (e.g., surgery).

A number of points, albeit fewer than those related to geographic community, were made regarding the social construct of rural. While some of these comments were similar to those for community (e.g., "other people know your business before you do"), others were unique, including feelings of isolation, a higher quality of life, a slower pace of life, and a feeling that one need not lock one's home or vehicle doors. With reference to the last point, others noted that such feelings are changing. Still others indicated that rural "was a state of mind" in that if one "feels rural", they are. Related to these types of descriptions were a number of statements that were difficult to classify. Because they are neither directly geographic/ spatial or based on some type or level of interest, these comments were not included in Table 2. These comments included such statements as "rural is rural", "it's a state of mind", and it is "quiet and dark at night". Taken together, 159 participants in 15 focus groups illustrate the need to recognize broader definitions of rural and community than those that are utilized by official agencies such as Statistics Canada.

Spatial Descriptions of Rural Community

Although some of the results obtained from the mental mapping exercise can only be said to have offered self-evident responses, most, when coupled with follow-up questions, did give insights into how people now view ‘rural community’. In general, the respondents indicated that to some extent they live in different ‘psycho-communities’, with the differences being a direct result of their different life spaces, particularly in terms of mobility, workplace, and leisure-time activities, and with these variations exhibiting ‘site recalcitrance’ (Orleans 1973, 126). Site recalcitrance is a result of physical and sociocultural factors acting together to restrict an individual’s image of their surroundings, and thus their behaviour within it. This restriction is demonstrated both by the shape of the area designated and by the distances involved, where role variations result in different levels of environmental apprehension, despite the fact that the same basic opportunity sets are open to everybody. Site recalcitrance may be strongly related to the physical and socioeconomic patterns of the area, but distance is influential identifying those places that are frequented most often.

Of the 159 focus group participants, 138 provided a completed map. Five chose not to participate, and maps were not distributed to the Hutterite focus group (n=16), as individuals came from three different colonies to attend. The structure of the delineations of the focus group maps varied in size and shape. In order to classify these depictions, the maps were first categorized based on percentage cover. As indicated in Table 3, most respondents drew boundaries that included less than half of the map area, indicating that they were taking a considered approach to this question. The total number of map types listed in Table 3 is 132. The remaining six maps did not include spatial delineations, but rather written comments that their particular community was larger than the map area or represented an area not included on the sheet provided. Of particular note is the role of technology and communications in this regard. One individual, for example, commented that he was closer to people overseas through electronic communications than the area in which he resided.

The maps were then classified by shape. Six general shapes were identified: extended, amoeba, nodal, multi-nodal, linear, and wagon wheel (Figure 2). First, many of the respondents mapped what appear to be ‘traditional’ representations of community. For some small town dwellers this amounted to the area of the settlement in which they lived (nodal). For farm-dwellers this constituted a larger area that surrounded and enclosed the local central place (extended). These respondents designated

Table 3: *Focus group participants' community boundary delineations.*

	Percent Coverage of Total Map				
Community	**0-24**	**25-49**	**50-74**	**75+**	**Total[1]**
Strathclair	2	2	-	-	4
Miniota	6	-	-	-	6
Minnedosa	7	3	2	3	15
Virden	6	3	1	-	10
Russell	3	4	3	3	13
Carberry	4	7	-	-	11
Hutterites[2]	na	na	na	na	na
Rivers	3	10	-	-	13
Deloraine	3	6	2	-	11
Treherne	3	3	-	3	9
Glenella[3]	5	5	5	0	15
Souris	-	4	3	-	7
Killarney	2	5	3	-	10
Melita	-	1	-	4	5
Glenboro	3	6	-	-	9
Total	47	59	19	13	138

[1] 5 participants did not complete the mapping exercise
[2] Maps not distributed at these meetings
[3] Maps were copied on 11"x17" stock
Source: Focus Groups, 2001

areas similar to those found for rural dwellers a quarter century ago (Everitt 1980), which were less propinquitous than those of the small town dwellers, but at the same time still exhibited evidence of site recalcitrance.

Second, some respondents mapped untraditional representations of community, with many being significantly larger than expected (extended). One person even mapped a large area as his/her "immediate community" with a footnote that referred to a huge "extended community" that included most of Westman. One extreme included people who mapped a series of unconnected community nodes (multi-nodal). Interestingly, these maps were similar to those of Hutterites who mapped their social spaces in the mid-1970s (Everitt 1980). The Hutterites' spaces were restricted by a philosophy that discouraged contact with the 'outside world'. The spaces of respondents in the current study appear to be limited more by individual

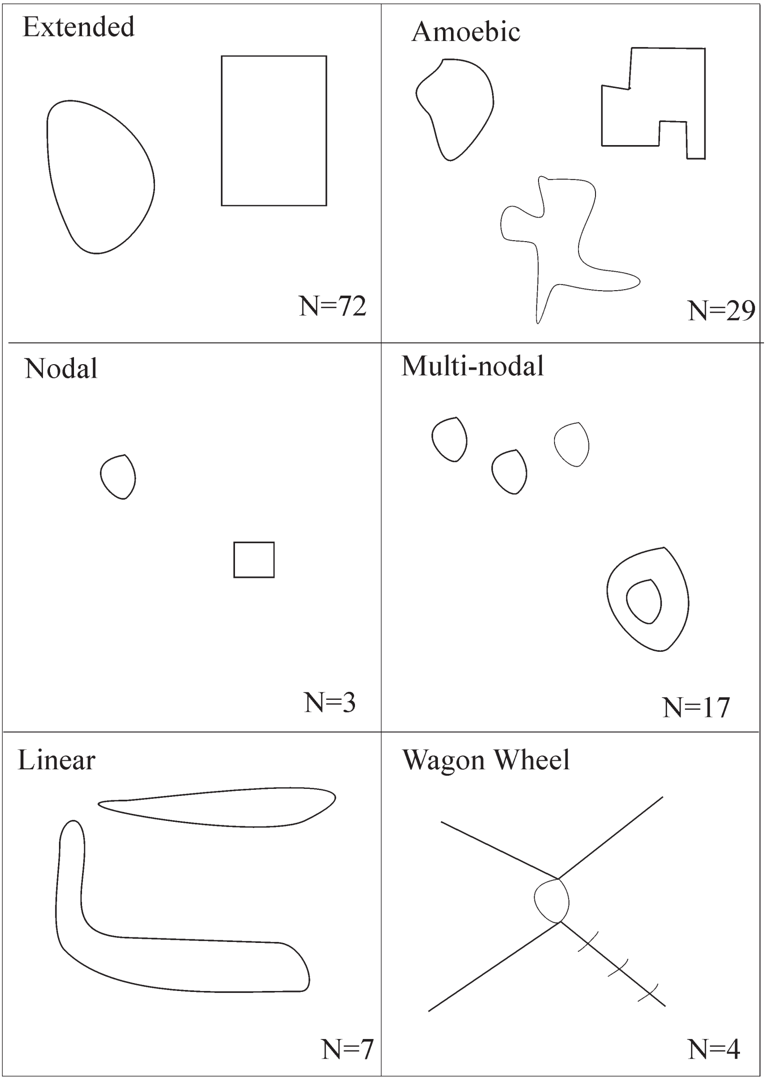

Figure 2: *Composites of community boundaries by focus group participants.*

choice and circumstance than by group ideology. There are suggestions, however, that different-sized areas may be found in different parts of Westman, perhaps reflecting population density and socioeconomic opportunities. As such, they reflect the changing range and intensity of social and economic interactions within rural communities in Westman over the past few decades.

Third, there were numerous examples of site recalcitrance. One of the typical examples includes participants who indicated 'shapes' that were clearly drawn to include nodes (e.g., villages and towns) that were joined together by wide pathways (linear and wagon wheel). These pathways were based upon roads and/or railways — although in some instances the rail line was no longer operational. In a number of instances, the pathways extended beyond the map area.

Fourth, the boundaries of many areas mapped included social, political, and physical boundaries. Thus, traditional social barriers between competing/conflicting communities can be determined, but municipal or provincial boundaries can also be isolated, as can the effects of rivers, lakes and other environmental features (amoeba, extended, wagon wheel). The right-angled depictions of some of the extended, nodal, and amoebic shapes were bounded along road and township lines (Figure 2). Similarly, the level of detail in the amoebic shaped delineations varied.

Conclusions

While the results of the focus group analysis are illustrative of changes that have taken place within Westman communities in recent years, they are, if anything, probably understating the extent of the change that has taken place. In part, this reflected the concentration on 'local actions' within the focus group sessions; in part, it reflects the fact that when individuals were supplied maps upon which it was hoped the respondents could draw their communities, in some cases the size of these areas was underestimated. Consequently these respondents simply indicated the whole of the area supplied (extended), while others indicated that their communities extended a significant distance off of these maps. As often is the case, the results have proven to be both intriguing summaries of what is there, as well as providing clear indications of how the methodology could be adjusted in order to obtain a more accurate picture of this 'reality'. This is particularly true as rural depopulation continues, school boards amalgamate, grain elevators are replaced with in-land terminals, and rumours of rural health service restructuring abound. As Christaller noted more than 30 years ago, as nodes disappear, areal districts expand (in Johnston 1994). Having a better understanding of the spatial and perceptual definitions of rural and community ensures that response to restructuring is both appropriate and relevant.

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Geographic antecedents of discontent: power and western Canadian regions 1870 to 1935

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Abstract: Regions are the manifestation of power in the landscape. This study maintains that changes in the allocation and exercise of state power are both reflected and actively advanced by Western Canada's regional geography. This power has resulted in discontent among Westerners that has been expressed politically and socially. Traditional approaches to human geography neglect this socio-political aspect of region. To that end, a focus on landscape patterns of incoming immigrants, land allocation and population characteristics will emphasize an alternative approach, one that stresses the creation and the character of the new regions that undermined – even destroyed – the indigenous regions that predated them. Western discontent resulted and has continued to influence Canadian politics, social life, economics and culture.

Key words: state power, regional geography, regional consciousness, landscape, Western Canadian discontent

Introduction

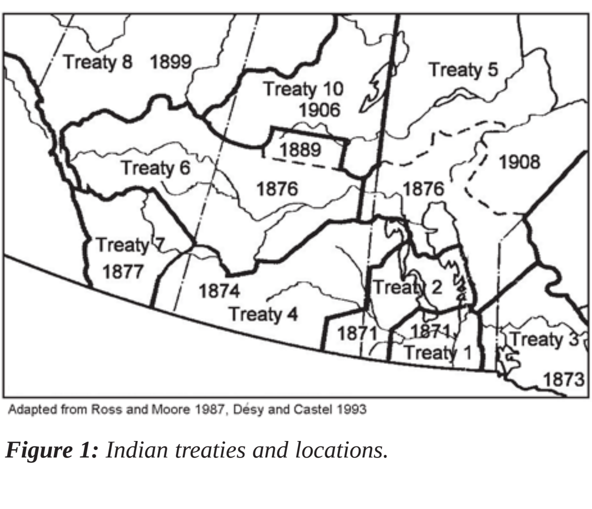
In the early years of the 20th Century the Government of Canada carved the North-West Territories into two provinces. In 1905, provincehood arrived but in a form that did not lead to immediate tangible benefits for the North-West. However, it did mark the formal integration (co-option?) of the North-West into Confederation. In absorbing the west, and expanding its ecumene Ottawa exerted economic, political, and social power. Western landscapes were thereby indelibly marked by the force and power of Canadian ideology.[1]

A power-oriented regional geography, one that emphasizes processes of land division, land distribution, provincial boundary creation and the dissemination of power to provincial governments contributes a great deal to understanding the discourse that continues to influence much of the political discontent in contemporary Western Canada. It clarifies how access to and control of natural resources has come to influence and direct Western Canada's perceived position in Confederation.

Canadian Territorial Expansion and Treaties

Rupert's Land, an enormous area of more than 10% of Canada was granted to "The Governor and Company of Adventurers of England trading into Hudson's Bay" by Charles II of England on May 2, 1670. Despite the Hudson Bay Company's (HBC) subsequent dominance of Western Canada, it was not until scientific expeditions of the mid 1800s that most Canadian (and British) attitudes towards the southern plains of the west began to develop. Reports written by the members of the Palliser and Hind-Dawson expeditions may have laid the basic conceptual framework for contemporary views of some physiographic aspects Western Canada. These beliefs ensured that arid areas of the west were avoided while others, especially the Parklands, were considered sites for agricultural communities.

Territorial expansion, scientific research and the fur trade were not the only means whereby Canadians began to impose their vision of the west. The 1870s saw the onset of the imposition of many treaties that relegated Native people to reserves, sometimes far away from traditional areas of life and, at times, against the peoples' will. Through treaties and the provisions that the government had in enforcing them (Harris 1992), the political and cultural boundaries of the west were redrawn (Figure 1).



Adapted from Ross and Moore 1987, Désy and Castel 1993

Figure 1: *Indian treaties and locations.*

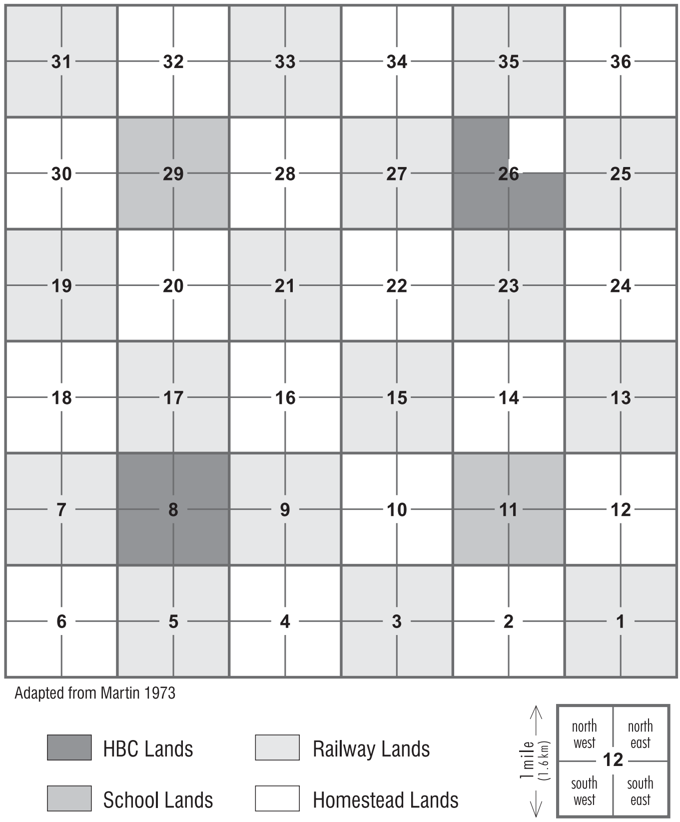


Figure 2: *The township and range system.*

By the time of Canadian Confederation in 1867, the North-West Territories were known, land was claimed through contemporary international legal means and the 'Indian problem' was in process of being solved. The west had become, in the eyes of the European world, Canadian. It remained for Ottawa to exert complete control over the shape, dissemination and regulation of land. Through the drawing of non-existent, yet powerful lines, Canada would exert its power over this vast area.

The Land Survey

By 1874, surveyors had completed their survey of the 49th parallel. Canadians were thereby enabled to begin the process of surveying western lands as a precondition of distributing them to agricultural immigrants. The township and range system, much like that of the U.S.A., was applied. It enabled the division of western lands among the HBC, the Canadian Pacific Railway (CPR) and homesteaders, and set aside two sections in each township for the future of local education (Figure 2).

By 1881, many parts of the North-West Territories well-suited to settlement had already been surveyed (Figure 3). Even so, one particular group, the Métis of St. Laurent, felt insecure in their tenure. Their insecurities were undoubtedly linked to previous experiences in Red River. Requests of both Qu'Appelle and St. Laurent groups to have their long lots surveyed in their original, traditional shape fell on the deaf ears of the federal government. Such grievances became one focal point of the Northwest Rebellion. Obviously, land, especially its manner of division and ownership, was a powerful motivator in the actions of the Métis leadership and people in 1885.

Lands near settlements like Prince Albert, Edmonton, Battleford, and Qu'Appelle had been divided and primed for settlement. All that was needed to make this 'settled' were immigrants; however, people did not arrive in the numbers that had been optimistically forecast (Table 1). Rail construction delays, scandals, world-wide economic problems, European

Table 1: *Immigration to North-West Territories, 1866-1905.*

period	Saskatchewan	Alberta
before 1866	1,146	594
1866-70	369	313
1871-75	1,147	519
1876-80	981	559
1881-85	3,060	1,550
1886-90	4,756	2,980
1891-95	6,093	5,747
1896-00	18,099	15,930
1901-05	71,150	55,883

Source: Canada 1912

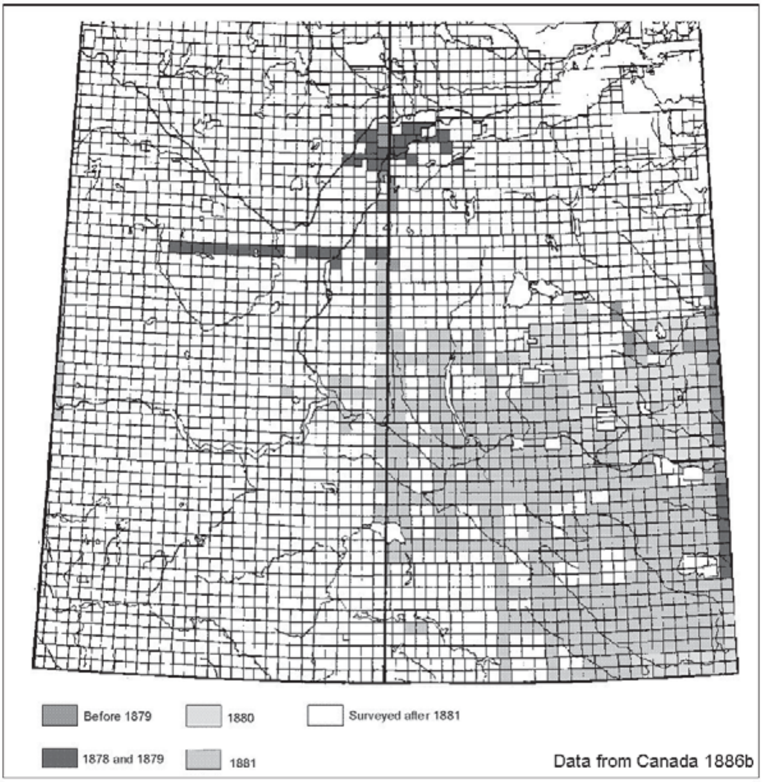


Figure 3: *Lands surveyed by 1881.*

political troubles, the aftermath of the American Civil War (and subsequent Indian Wars of the U.S. west) and the Rebellion of 1885 in the North-West Territories all prevented large numbers of homesteaders from coming to the newly opened regions of Canada.

Simply drawing imaginary lines did not create a land rush. But the legacy of the surveyors' influence, both in directly readable landscape manifestations (e.g., road patterns, town distances and field sizes) and in indirect social influences (e.g., self-sufficiency, isolation, and even mental illness attributed to isolation) helped lay the foundations of Western political discontent. The imposition of a strict, true grid system on any landscape can be seen as the overlay of a human-constructed and scaled model. Straight lines, intersecting at right angles, ending at particular graticule points and jogging at correction lines are not part of the natural environment. That they then guide agricultural settlement, an activity whereby people try to earn a living working on and with the land, can only be seen as ironic. By trying to force the grasslands, wetlands, lakes, rivers, boreal forests and coulees of the west into a conveniently distributed and divided map, Canada tried to impose rationalist ideas of order and organization onto the landscape. Simply by drawing lines on maps, surveyors and land agents alike made their attempts to subjugate and impose order on the land. Humans could conquer nature[2].

Domestic Boundaries and the Rise of Regional Consciousness

While the 1870s saw the delineation of the international boundary and the onset of surveying of property lines, internal division of the North-West Territories into land registration districts and other regional units took place throughout the 1880s.

By 1880, the North-West Territories' population warranted the creation of three Electoral Districts. These met the Canadian standard for representation in the Territorial Assembly. The standard declared:

> As soon as districts of one thousand square miles contain a population of one thousand, exclusive of aliens and Indians, they are to be constituted Electoral Districts and return a member (quoted in Robertson 1887, 97)

However, within a year, the Province of Manitoba was enlarged by Ottawa to include significant portions of what were once the Electoral Districts of Wallace and Moosimin. As a result, the odd situation resulted where the North-West was left with only one representative in the Territorial Assembly. However, by 1883, there were six Electoral Districts and as settlers arrived, the number of elected representatives increased.

In 1881, the *Census of Canada* divided the North-West Territories into eighteen separate census districts. Unfortunately, the boundaries of these regions cannot be established[3]. However, the names and presumed locations show that up to 1881 a northerly population distribution, one that still reflected the settlement pattern of the fur trade, was found on the prairies (Table 2). When compared to the *Special Census* districts of 1885 and the districts of the *Canada Census 1891*, it becomes clear that

Table 2: *Canada census of 1881: Populations.*

Census Districts	Total	Families	Males	Females	Married
Cumberland(s)	1,255	278	596	659	506
Qu'Appelle	5,241	959	2,670	2,571	1,953
Wood Mountain	4,552	901	2,350	2,202	1,843
Prince Albert	3,236	667	1,705	1,531	1,170
Battleford	4,830	926	2,400	2,430	1,884
Edmonton	3,126	602	1,602	1,524	1,109
Bow River	3,275	667	1,662	1,613	1,340
Totals	25,515	5,000	12,985	12,530	9,805

Source: Canada 1882a

the south, especially areas along the mainline of the CPR, was where the majority of new census districts were located.

According to the 1881 Census in Canada, the southern part of the North-West Territories was a region of about 26,000 people. There was a near balance between males and females. People were rather evenly distributed between the census districts, with a slight emphasis on more northern, parkland zones.

Birthplaces and origins of the people reveals the dominance of 'country-born' folk, with every district showing a clear majority of its population as born in the North-West or of Indian origin (Table 3). Prince Albert, Qu'Appelle, Battleford and Wood Mountain have a number of people born in Manitoba which, along with significant numbers of persons of Québec origin, reflects a measure of the Métis diaspora of the 1870s. All

Table 3: *Canada census of 1881: Birthplaces.*

	Cumberland(s)	Qu'Appelle	Wood Mountain	Prince Albert	Battleford
England	9	7	11	46	13
Ireland	0	8	15	25	10
Scotland	12	10	5	51	6
Prince Edward Island	0	0	1	2	3
Nova Scotia	1	2	4	4	5
New Brunswick	0	4	1	1	0
Québec	6	18	16	23	26
Ontario	24	58	98	274	44
Manitoba	34	182	143	924	151
British Columbia	0	0	0	1	4
North-West Territories	1,168	4,919	4,234	1,813	4,550

Source: Canada 1882a

Table 4: *Canada census of 1881: Religions.*

	Cumberland(s)	Qu'Appelle	Wood Mountain	Prince Albert	Battleford	Edmonton	Bow River	Totals
Baptist	0	1	1	10	0	0	0	12
Freewill	0	0	0	8	0	0	0	8
Roman Catholic	34	514	290	899	801	500	120	3,158
Church of England	30	104	129	903	270	0	0	1,436
Lutheran	0	0	0	2	0	0	0	2
Canadian Methodist	10	2	11	103	287	0	0	413
Episcopal	0	0	0	3	0	0	0	3
Pagan	0	0	0	0	115	0	0	115
Canadian Presbyterian	23	6	21	363	17	0	0	430
Scottish Presbyterian	31	2	0	0	0	0	0	33
Reformed Presbyterian	0	22	0	0	0	0	0	22
Protestant	9	0	0	21	200	250	200	680
Quaker	0	1	0	0	0	0	0	1
Unitarian	0	0	0	0	1	0	0	1
other	0	0	1	0	0	0	0	1
no religion	0	0	0	1	0	0	0	1
not given	1,118	4,589	4,099	923	3,139	2,376	2,955	19,199

Source: Canada 1882a

other groups have only minor representation although Ontario as a birthplace and English and Scottish as places of origin are in evidence.

The *Census of 1881* categorized the religions of the North-West Territories. 'Not Given' is the dominant group. Presumably, given the dominance of 'country-born', this reflects the preconceptions of contemporary census takers. Roman Catholic, Church of England, Methodist and Presbyterian are also quite numerous in some locations (Table 4).

Major crops grown show that wheat and other small grains had not yet become the most important agricultural products. Oats and barley dominate, especially in the two areas with the most acres in crop, Prince Albert and Bow River (Table 5). All reporting districts (excluding Cumberland) had barley, oats and hay, but Wood Mountain and Qu'Appelle did not report any wheat growing. The foothills areas of Bow River had yet to develop as a predominant livestock region which the relatively few acres in hay would suggest.

This census shows that the North-West Territories was not yet integrated into methods of land use that would later characterize the region. Wheat, as a crop, and ranching, as an activity, did not yet dominate. Large numbers of agricultural immigrants and stockmen had yet to transform the land. The region was not a 'wild frontier' either – a balanced sex ratio, even population distribution among the census districts, a locally born and bred population and an emphasis on mixed agriculture all attest to this.

In May of 1882, four Provisional Districts were created. Later, in 1886, Assiniboia was split into East and West districts. Provisional Districts were not legally defined Canadian provinces, nor were they legal territories,

Table 5: *Crops grown in 1881.*

	spring wheat	barley	oats	hay
Cumberland(s)	0	10	10	0
Qu'Appelle	153	2,202	4,600	1,474
Wood Mountain	20	50	253	482
Prince Albert	2,949	17,260	18,269	3,998
Battleford	154	4,219	3,108	0
Edmonton	1,000	2,500	12,000	300
Bow River	481	3,798	18,034	735
Totals	4,757	30,039	56,274	6,989

Source: Canada 1882a

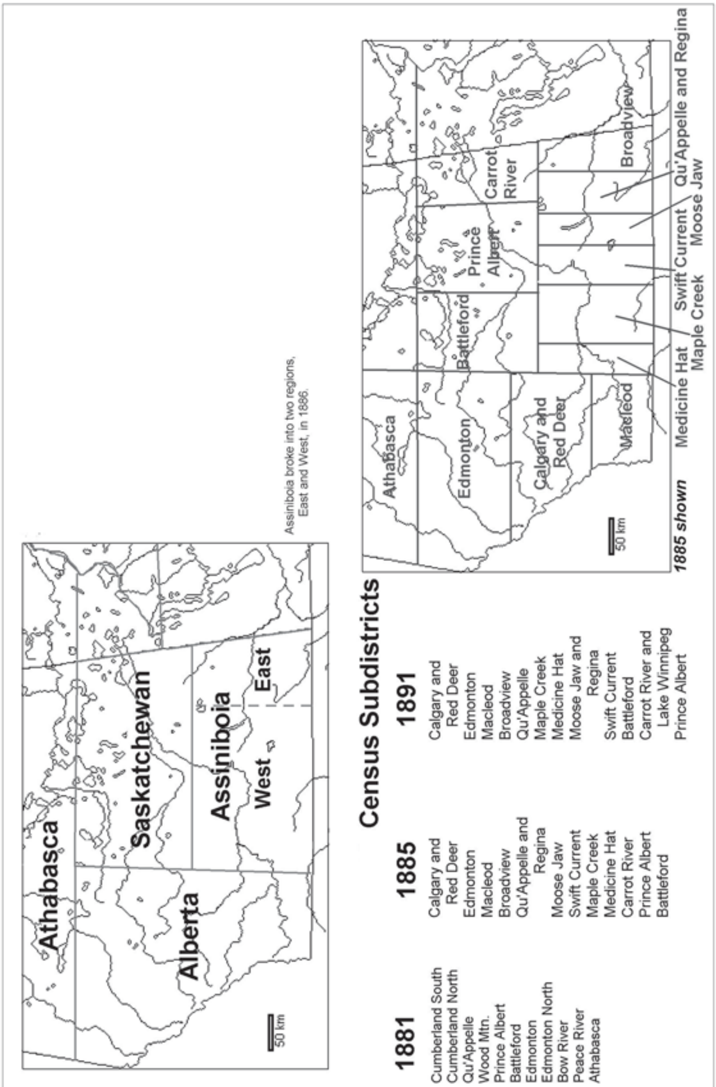


Figure 4: *The provincial districts 1882 and 1886.*

Table 6: *Canada census of 1885: Populations.*

	total population	male	female	families
Alberta	15,533	8,342	7,191	
Calgary and Red Deer	5,467	3,030	2,437	1,527
Edmonton	5,616	2,890	2,726	1,285
Mcleod	4,450	2,422	2,028	1,153
Assiniboia	22,083	13,324	8,759	
Broadview	8,367	4,971	3,396	3,028
Qu'Appelle and Regina	9,540	5,575	3,965	2,768
Moose Jaw	2,616	1,745	871	854
Swift Current	363	237	126	124
Maple Creek	465	301	164	145
Medicine Hat	732	495	237	239
Saskatchewan	10,746	5,447	5,299	
Battleford	3,603	1,728	1,875	967
Carrot River	1,770	888	882	446
Prince Albert	5,373	2,831	2,542	1,160

Source: Canada 1886a

but before 1905, and the creation of Alberta and Saskatchewan, they were the North-West's clearest internal boundaries. They had the potential to become western provinces. They were strong vernacular regions for the local inhabitants since they had existed for more than 20 years before provincial status arrived on the prairies (Figure 4).

By 1885, the population character of Canada's North-West had changed. The population had increased, the sex ratio had changed and new areas were being settled. Growing numbers of people in the south and west are shown by the large number of new census districts in these areas (Table 6). While the populations of Edmonton, Broadview, Qu'Appelle and Regina, Battleford and Prince Albert grew, their share of western people clearly declined. Most regions show a majority of men. Northern districts, however, do display less of a clear majority.

The *Special Census* of 1885 did not assess birthplaces (or major crops) but much can be inferred from the origins and religion of the people (Table 7). While Indian and "Pagan" were evident, neither constituted a majority of the population, as had been the case in 1881. English, Scottish, Irish and, to a lesser degree, French origins were there in much greater

Table 7: *Canada census of 1885: Origins.*

	Calgary and Red Deer	Edmonton	Mcleod	Broadview	Qu'Appelle and Regina	Moose Jaw	Swift Current	Maple Creek	Medicine Hat	Battleford	Carrot River	Prince Albert	Total
African	2	0	4	1	0	1	1	0	2	0	0	0	11
Chinese	6	0	2	0	2	0	0	0	0	0	0	0	10
Dutch	1	0	11	33	17	10	0	1	3	0	0	1	77
English	813	310	438	2,439	2,426	970	87	107	285	41	37	444	8,397
French	94	582	155	104	266	67	4	12	26	95	30	85	1,520
German	53	13	43	61	135	50	2	4	19	9	0	38	427
Indian	3,191	3,017	3,210	1,523	2,650	48	118	78	75	2,942	1,573	1,745	20,170
Métis English	22	12	9	7	6	2	0	0	0	10	20	489	577
Métis French	173	940	12	30	467	211	48	68	0	226	49	1,163	3,387
Métis Scotttish	3	20	3	36	64	1	0	23	0	133	0	479	762
Métis Irish	3	32	1	0	0	9	0	0	0	0	0	20	65
Métis Undefined	6	0	1	11	33	1	0	0	0	0	0	5	57
Iceland	1	0	0	0	1	0	0	0	2	0	0	0	4
Irish	433	217	274	1,537	1,684	550	47	80	136	43	0	284	5,285
Italian	31	0	0	284	0	1	0	0	0	0	0	0	316
Jewish	0	0	0	103	1	0	0	0	2	0	0	0	106
Russian and Polish	0	0	1	0	2	1	0	2	1	0	0	10	17
Scandinavian	16	5	9	13	20	6	3	25	33	0	0	6	136
Scottish	567	462	237	2,123	1,710	673	49	63	144	103	61	596	6,788
Spanish and Portugese	1	0	0	0	0	1	0	0	0	0	0	0	2
Swiss	1	1	3	2	2	0	0	0	0	1	0	0	10
Welsh	11	3	14	19	22	4	2	1	4	0	0	6	86
various	4	1	2	5	16	0	2	1	0	0	0	0	31
other	35	1	21	36	16	10	0	0	0	0	0	2	121

Source: Canada 1886a

Table 8: *Canada census of 1885: Religions.*

	Calgary and Red Deer	Edmonton	Mcleod	Broadview	Qu'Appelle and Regina	Moose Jaw	Swift Current	Maple Creek	Medicine Hat	Battleford	Carrot River	Prince Albert	Total
Adventist	0	0	0	0	0	0	0	0	1	0	0	0	1
Baptist	32	4	12	249	242	153	3	4	25	0	0	38	762
Free Baptist	12	0	0	0	0	0	0	0	0	0	0	0	12
Tunker Baptist	0	0	0	0	4	0	0	0	0	0	0	0	4
Baptist Bretheren	0	0	1	19	10	7	0	0	0	0	0	0	37
Catholic	514	2,978	319	819	1,376	366	97	186	105	926	34	1,581	9,301
Church of England	70	480	427	2,332	2,267	766	77	136	244	663	1,356	1,258	10,076
Congregational	9	7	5	60	43	9	2	2	3	0	0	5	145
Disciples	0	0	0	7	42	8	0	0	0	0	0	0	57
Jewish	0	0	0	103	1	0	0	0	2	0	0	0	106
Lutheran	25	6	14	22	65	24	2	22	28	0	0	1	209
Canadian Methodist	906	692	152	1,294	1,469	492	20	46	74	23	10	227	5,405
Episcopalian Methodist	714	0	0	9	0	0	0	0	0	10	0	758	1,491
Bible Methodist	0	0	0	7	0	0	0	0	0	0	0	0	7
Other Methodist	0	0	0	7	0	0	0	0	0	0	0	0	7
pagan	2,600	14	3,200	671	1,408	0	0	0	0	0	0	0	7,893
Canadian Presbyterian	535	291	247	2,548	2,016	727	64	68	168	65	23	906	7,658
Scottish Presbyterian	0	0	20	0	0	0	0	0	0	0	31	0	51
Other Presbyterian	2	0	0	0	0	0	1	0	0	0	0	0	3
Protestant	0	6	0	6	0	1	0	0	0	0	9	0	22
Quaker	1	0	2	7	22	2	0	0	0	0	0	2	36
Unitarian	4	8	1	2	10	1	0	0	1	0	0	1	28
universalist	15	1	0	1	3	0	0	0	0	0	0	0	20
other	0	7	6	3	6	0	0	1	3	0	0	0	26
no religion	3	0	22	3	536	0	0	0	76	0	0	1	641
not given	25	1,122	22	298	20	60	97	0	2	1,916	307	595	4,464

Source: Canada 1886a

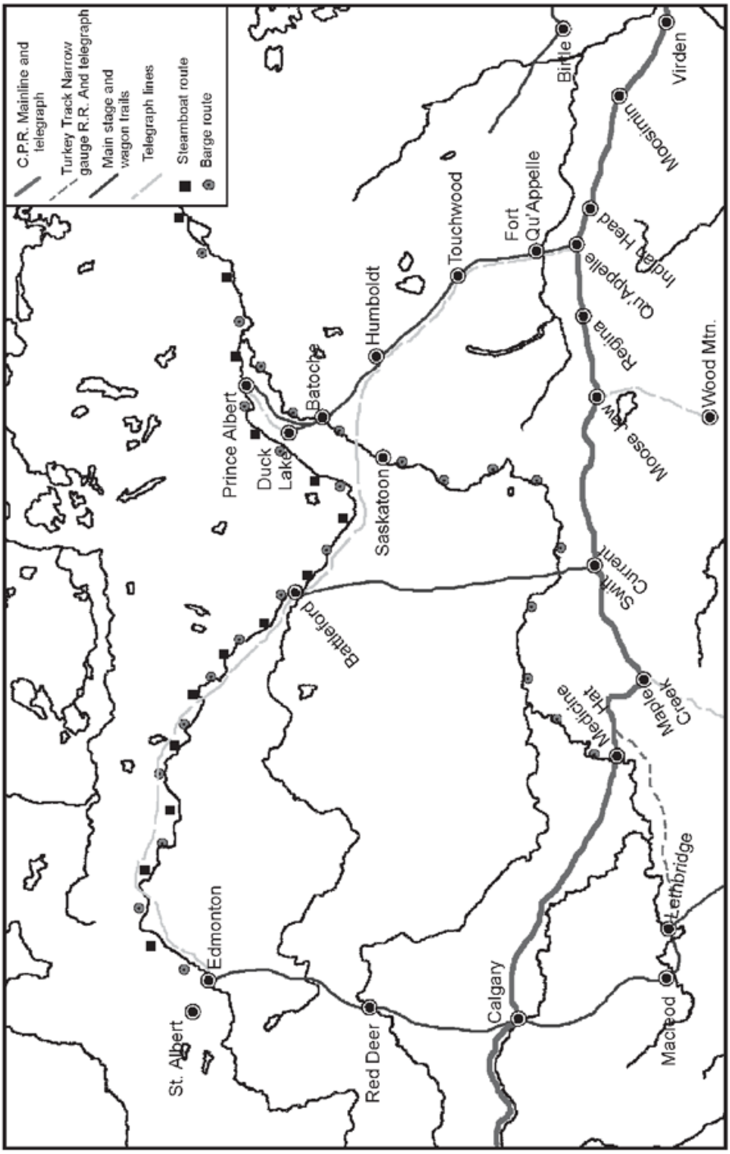
proportions (and numbers), especially across the south. Religions became more varied and evenly spread (Table 8). Districts where origins were shown as Indian showed large proportions of “Pagans”, but other religions were evenly divided among Roman Catholic, Church of England, Presbyterian and Methodist.

The once dominant fur trade had declined in importance in the parklands and the boreal forest. Census information shows the importance of the Provisional Districts as statistical regions and illustrates the rise of agriculture as a way of life. The CPR is clearly an important influence on many facets of day-to-day living (Figure 5). Southern towns were rising in both population and in political power much more quickly than those areas further north. Populations were growing around Red Deer, Edmonton and Calgary. The railway had influenced, perhaps forced, homesteaders to locate in southern areas, opening lands adjacent to their mainline and thereby making settlers farm the drylands that had once been thought too arid for agriculture.

The North-West, especially the railway dominated south, seemed on the verge of a boom in population and economic growth. One reason was bountiful crops. Large grain harvests were reaped because both climate and technology allowed wheat to become the crop-of-choice. As the decade neared its end, Canadian, American, British and continental Europeans began to arrive; the cosmopolitan migration had begun.

Regional consciousness is formed in many different ways. Formation may occur through processes of communication or through resource use and employment patterns. In the North-West Territories aspects of communication and economy were beginning to draw many seemingly disparate groups together into regional entities. For example, the late 1870s and 1880s saw the creation of no less than fourteen local newspapers. Another manifestation of the increased interaction among westerners was their shared experience with the CPR.

Spanning the south rather than the parklands of the North-West, the CPR played an essential role in the existence of many new towns. Within these communities, the railway was also a major landowner, meaning that the manner in which they grew was influenced by the interests of the CPR. By the time the CPR was completed, the railway was many things to the west: urban developer, communications ‘provider’, land and immigration agent, transportation system and employer. It was the major means whereby goods, services, people and ideas diffused to the North-West. The railway allowed for the communication so essential to the creation of a regional consciousness. Despite this positive feature, the railway became



Adapted from Warkentin 1967, 57

Figure 5: *Communication and transportation* circa *1886.*

Table 9: *Canada census of 1901: Populations.*

	males	females	total
Alberta	36,886	28,990	65,876
Assiniboia East	27,682	22,611	50,293
Assiniboia West	10,220	7,472	17,692
Saskatchewan	13,250	12,429	25,679
North-west Territories	87,438	71,502	158,940

Source: Canada 1902

a focal point for western discontent. Its creation, maintenance and continuing growth at the expense of farmers was one manner in which a western regional consciousness was formed.

The long-anticipated immigration boom period eventually arrived. From 1881 to 1891, the population of the southern regions of the North-West Territories increased 25,815 to 66,799 (Table 9). By 1901, it had grown to 158,940, a 138% increase from 1891 and a 516% increase from 1881. People streamed in.

Homesteaders lived within the square land survey grid. On their cultivated lands, they were more likely to grow wheat than ever before. The number of acres planted in wheat had expanded rapidly as methods, means and transportation faculties devoted to its production were developed. Barley and oats declined in importance as subsistence agriculture waned and was replaced by grain as a cash crop. Not only had immigrants arrived on the CPR, they now, as a group, depended on its existence to transport their produce to markets outside the North-West Territories. They were united as users of the rail line. More and more, these different people had begun to live like one another as citizens of the North-West. While they were still a heterogeneous *émigré* population (Table 10), representing many nationalities and religions (Table 11), common interests in North-West development were creating more local pride and cohesiveness.

The 1901 *Census of Canada* shows how the west's population increased tremendously. Towns and cities had begun to develop and grow while branch lines of the CPR and other railways reached into developing areas. On the brink of provincehood, the North-West Territories had matured into a populated region capable of taking its place in Canadian Confederation, but the political and economic powers associated with

Table 10: *Canada census of 1901: Birthplaces.*

	Alberta	Assiniboia East	Assiniboia West	Saskatchewan
Manitoba	1,097	1,536	540	2,653
Ontario	11,420	9,928	5,313	1,568
Québec	2,506	916	331	322
North-west Territories	18,683	13,908	5,134	12,713
England	4,479	4,154	1,728	391
Scotland	1,532	1,800	642	252
Ireland	998	708	324	128

Source: Canada 1902

Table 11: *Canada census of 1901: Religions.*

	Roman Catholic	Church of England	Presbyterian	Methodist	Baptist	Pagan	No religion
Alberta	12,957	8,888	10,655	9,623	2,722	2,488	132
Assiniboia	10,663	10,086	15,015	11,559	2,506	1,696	58
Saskatchewan	6,453	6,392	2,136	969	112	1,091	12

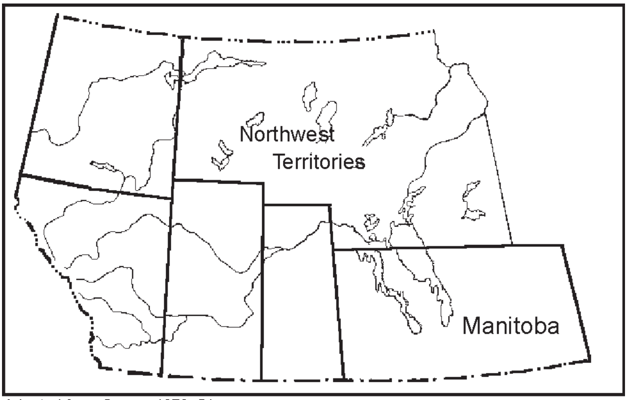
Source: Canada 1902

that place remained to be negotiated between the Canadian Parliament and the Territorial Legislature.

The Drive to Provincehood

The idea that the North-West would eventually join Canada *ad mare usqua ad mare* had been germinating at least as far back as 1864. At that time the purchase of the Hudson's Bay Company's lands became the focal point of discussion at conferences in both Charlottetown and Québec City as well as in London, England that eventually led to Confederation in 1867. The new Dominion of Canada bought Rupert's Land and the Northwestern Territory from the British government in 1870. Later, in 1870, the Province of Manitoba was created and, in 1871, the Province of British Columbia joined Confederation. By the 1890s, the politicians of the North-West Territories, most of whom had been born in Ontario, reasoned that the time had finally come for provincehood to be realized.

As early as 1872, J.S. Dennis, then Minister of the Interior, had advanced proposals that would have divided the west into provincial areas (Figure 6; Owram 1979, 51). Such plans were reiterated in 1882 and thereafter



Adapted from Owram 1979, 51

Figure 6: *The J.S. Dennis proposal of 1872.*

regularly put forward to the government in Ottawa. The Dominion government felt that the west was past due for full responsible, representative government and a place in Confederation. Thomas (1978, 96) states:

> By 1895 the federal government finally accepted the need to negotiate western demands. In one sense the ensuing decade may be seen as a time of territorial and legal wrangling, but, in addition, many issues of region, place, and self-determination were also at the core of decision-making processes.

People of the west wanted to control their destiny, especially their purse strings. With provincehood looming, many of the feelings, ideas and visions of the future held in the west would become apparent. What followed was a process fraught with frustration. For while the west had been colonized by the East, local initiative and vision would not die.

The west seemed caught between two distinct visions of what it should and could be. As Morton (1985, 25) notes:

> The settlement of the West by the Ontario migration, then, had brought the institutions of civilization to the prairies, law, police, agriculture, commerce, and education. It had incorporated the West into the political

> structure of Canada. Yet it had failed either to people the plains or to create a civilization adapted to the character of the plains.

Part of the maturation of local character was the development of regional identity. This maturity was reflected in the emotions and feelings for the three districts of Assiniboia, Saskatchewan and Alberta. Thomas (1978, 98) observes that [these] “became centres of sectional feeling or what may be termed ‘district consciousness’”.

Assiniboia, Saskatchewan and Alberta became focal points of both regional consciousness and agitation for provincial status. Their existence provided a focus for western solidarity and consciousness. They gave legitimacy to feelings of self-definition and provided justification for the drive toward recognition by eastern power brokers. However, western agitation for provincial status was not simply an idealistic desire to join in Canadian Confederation. Of more immediate necessity was the need for tax revenues. Money was needed to build the transportation and economic infrastructure and to operate the day-to-day processes of government. While a local, elected Territorial government was established in 1888 and many elements of quasi-provincial status had been attained, budgetary shortfalls were the rule. Typically the Canadian government passed annual grants to the Territorial Council but these too “proved insufficient to meet the Territorial requirement” (Brennan 1985, 365). Nicholson (1979, 129) observes that this shortage of revenue, coupled with increases in population, created problems for the government of the North-West Territories:

> [in the early 1880s] population began to spread westward at an unprecedented rate. Immigration was under the control of the federal government, but the task of providing for the immigrants by the construction of local works and improvements was the responsibility of the territorial government. The problems (mainly financial) created as a result of this gradually became almost insurmountable and, consequently, the territories began to look forward to provincial status.

Several scenarios were evident by the time western provincehood was being seriously considered. Schemes to divide the Territories included the creation of four provinces, three provinces (one northern; one southern:

one eastern; one western), two provinces, and one province (Figure 7). But the Dominion government only considered those which would result in one or two provinces.

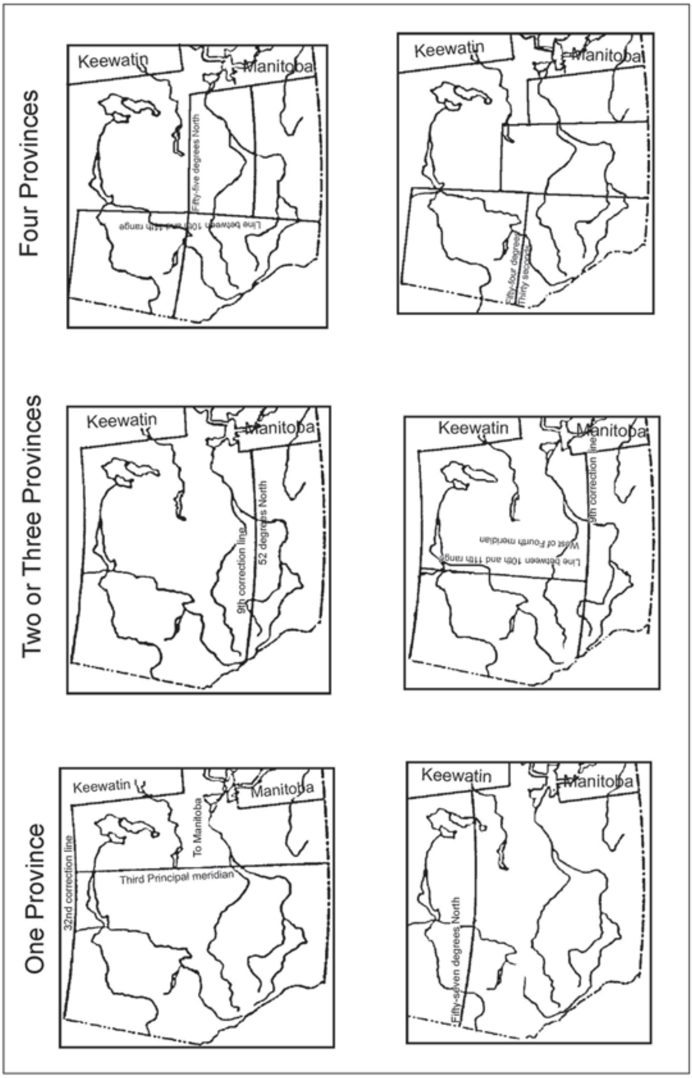
As the 20th century opened, debate over western provincehood crystallized between the two levels of government and around two powerful, charismatic political leaders; Laurier, Prime Minister of Canada and Haultain, Premier of the North-West Territories. Haultain would submit:

> a draft bill creating a single province which would comprise all territory between Manitoba and B.C. and between the 49th and 57th parallels of north latitude. This province was to have full provincial rights, including control of all public lands and natural resources. Laurier rejected these proposals...claiming that the demand for provincial autonomy was premature and that there was no general agreement in the Territories or elsewhere on the number of provinces to be created (Brennan 1985, 365).

As Lingard (1946, 203) notes, Haultain believed that the North-West Territories should not be divided

> because the people of the Territories have acquired a political individuality and identity as distinct as that of the people of any Province...There does not seem to be any reason...they should be suddenly divided in two, separated by a purely arbitrary line and obliged to do with two sets of machinery and institutions what they to a great extent have been doing quite satisfactorily and efficiently with one.

Despite the popularity of the proposal for one government for the entire North-West Territories, there were dissenting voices over Haultain's proposals. Notable among these were a *Calgary Herald* editorialist who was a strong advocate for capital status for Calgary's new province (whatever that may have been), Edmonton's city fathers (strong advocates for capital status for Edmonton's new province), and the few Liberal



Adapted from Nicholson 1979, Nicholson *et al.* 1990

Figure 7: *Proposals for provincehood.*

members (both Senate, House and Legislature) of government serving the west who saw fit to obey Laurier's Liberal party line (Owram 1979).

Contrary to Haultain's stance, Laurier would side with those who believed the North-West Territories should be divided. Eventually two provinces were created. The Liberal government (and most vociferously Laurier) publicly cited two reasons for dividing the North-West Territories. The first involved the relative sizes of then contemporary provinces (Table 12). To Laurier, it was obvious that a North-West Territories of 1,112,527 square miles (as advocated by Haultain) was much too large compared to other provinces. Second, Laurier argued there was a certain economic *raison d'être* for separateness: Alberta was ranching country; Saskatchewan was farming. Provinces would thereby simply be based on land-use patterns and similarities in life-styles. Each, in retrospect, seems rather spurious, if not willfully misleading.

Laurier's concerns about provincial size were dashed in 1912 when Québec was enlarged to 594,534 square miles. That year Ontario grew to 412,582 square miles as land claimed by Manitoba became part of it. Clearly for the Laurier government, or the Borden regime that followed, there were no firm guidelines on provincial size (at least for central Canadian provinces). Similar to Laurier's concerns regarding provincial size were the 'misconceptions' about productivity of the land, land use and the character of western regions.

The Foothills and Cypress Hills regions of the North-West, had, since the 1870s, been the site of cattle ranches. In the two areas, grazing and riparian rights had already been established before homesteaders arrived in any great numbers (Evans 1976; Breen 1983). By the mid 1880s, it was evident that some parts of western Assiniboia and Alberta had become different from eastern Assiniboia, Saskatchewan and Athabasca.

Table 12: *The sizes of the provinces, 1871-1931.*

	1871	1881	1891	1901	1911	1921	1931
Ontario	101,715	101,733	219,650	260,862	260,862	365,880	363,282
Québec	187,530	188,688	227,500	351,873	351,873	690,865	523,534
New Brunswick	27,177	27,174	28,100	27,985	27,985	27,911	27,710
Nova Scotia	20,909	20,907	20,550	21,428	21,427	21,068	20,743
Prince Edward Island		2,133	2,000	2,184	2,184	2,184	2,184
British Columbia		341,305	382,300	372,630	355,855	353,416	359,279
Manitoba		123,200	64,066	73,732	73,731	231,926	219,723
Northwest Territory		2,665,252	2,371,481	2,437,904	1,921,685	1,207,926	1,258,217
Saskatchewan					251,700	243,381	237,975
Alberta					255,285	252,925	248,800
Yukon Territory					207,076	206,427	205,346

All figures in square miles

Data from Laurier's Department of the Interior repudiated the view that Saskatchewan was 'farming' and Alberta 'ranching' country. Evidence suggests that Laurier was well informed of the reality of western life (Lingard 1946, 205) but he "played upon" what was thought to be "common knowledge" of the west. Department of the Interior records show that during 1901, Alberta had 80,000 acres of potential grain-growing lands, Saskatchewan 86,000; Alberta had 113,559 acres of ranching land, Saskatchewan 106,887; and Alberta contained 41,000 acres of potentially irrigated lands while Saskatchewan only had 32,000. Were these differences great enough to create an internal provincial boundary comparable to that which existed along the Ottawa River? Given the fallacious nature of Laurier's public arguments, the subsequent enlargement of central Canadian provinces after the fact, and the seeming lack of concern regarding the decision, there must have been other motives in estranging Haultain who was a popular, albeit Conservative, elected leader of the west.

Ottawa rejected Haultain's one province. The Laurier government preferred two smaller provinces. Perhaps Laurier was concerned that a single North-West province could, in time, disrupt the delicate balance between Ottawa and the powerful provinces of Ontario and Québec. To that end, the creation of two relatively low population, politically weak provinces rather than a single potentially powerful entity that could not (and would never?) force its view of Confederation onto central Canadians, or Ottawa, satisfied the agenda of the Laurier government.

Other reasons for division of the North-West Territories include overt 'party politics' and personality clashes. Lingard (1946, 205), for example, saw a number of different purposes served by the division.

> That the territories were divided may be attributed to the unfortunate development of local personal ambitions centred in two or three communities, the willingness of the federal authorities to give more weight to the representations of the North-West Liberal members than to those of the Territorial government, who alone were elected on the autonomy platform, and the fear in the older provinces that the one large province would assert a preponderant influence in the Dominion Parliament. The dividing line was purely an arbitrary one. No natural division existed along which the boundary between the two provinces could be drawn.

The actions of Laurier's government to create two provinces were entirely consistent with those of John A. Macdonald, who wrote "Canada...is the paramount power and has a distinct interest in the size, population and limits of every Province within her bounds." (Thomas 1978, 96). This centralist view suggests that Ottawa preferred a divided, peripheral North-West Territories. From this failure to create a place suited to its local cultural ecology would rise frustration, anger, mistrust, and antagonism. In short, all those attributes that have typified western federal-provincial relations to this day.

In 1905, Alberta and Saskatchewan were created. Having ensured that these provinces would not challenge eastern dominance through mere size, the federal government also ensured that they could not challenge through economic success. To further hamstring their development, all relevant aspects of provincehood were granted the new provinces but one: control of natural resources, hence land. These would remain in the Dominion's control until 1930:

> [for] the federal government...had no wish to create another large, strong province which might well challenge its policies. Hence two provinces were created...neither of which was given control of its natural resources...a serious departure from the principle of federalism as then understood (Thomas 1978, 265).

This manipulation was, perhaps, an even greater abuse of power relationships in a geographical sense than that perpetrated by boundary manipulation. The inhabitants of the old North-West Territories were deprived by the federal government of control of their region for another 25 years.

Conclusion

The geography of the North-West was transformed as surveyors and settlers made their way west. Through the process of territorial expansion and the rigorous application of a geometric land division pattern, the Dominion of Canada exerted both its power to colonize and its power to impose a modernistic landscape on the west.

Canada, the nation, was made by political deeds. Confederation was achieved by central Canada convincing Maritimers, British Columbians, and, later, Newfoundlanders to join in their vision. On the other hand, Ottawa did not have to convince westerners of the merits of their state; they bought them. Because the North-Western Territory was purchased (and renamed the North-West Territories in 1870), Ottawa's power was seen as total. Ottawa exercised this power, in a rather firm manner well into the 20th century.

A regional geography focused on issues of power and the creation of two, western Canadian provinces in the late 19th century is one that shows Saskatchewaners and Albertans were admitted to Confederation under different conditions from other provinces. Both lands and resources were controlled by Ottawa until 1930. The two new provinces, therefore, could not realize the potentials of their environment and the natural wealth within their boundaries.

Through the application of a newly formulated regional geography, relationships of power between different levels of government, between indigenous westerners and incoming Eastern Canadians, between ranchers and farmers, between urbanites and country folk and between Albertans and Saskatchewaners can be seen. By emphasizing procedures and patterns of land division and processes of provincial creation, evidence of the effects of power on the landscape becomes clear.

Notes

1 Local allegiances and emotions are strong in Canada and continue to challenge the existence of the nation. Québec separatism, western alienation, northern land claims, and the movement to create Cascadia are all contemporary issues. However, the dominance of Canada by its populous 'heartland' continues as a national trait.

2 As Gregory (1996) and Blaut (1993), among others, have discussed, modernism can be seen as the ideology that was a push toward colonization of 'new' worlds for Europeans. Modernism directs an agenda of organization and determines aspects of economies and politics. Modernism created systems of trade, dominance and patterns of minority marginalization. It is inexorably linked to capitalism and created a European realm that has dominated the earth. Gregory (1996) cites four important aspects of the modernist agenda. The first of these is the intellectual "abstract spaces of rationality" that "absolutize time and space". In Canada, the Dominion Land Survey system and the imposition of human derived rationality on nature exemplify these. The second aspect refers to "exhibiting the world" where European social elements are compared to foreign elements and usually found superior. In western North America, the famed portrait photographer Edward Curtis may be seen as exemplary. The third aspect visualizes "normalizing the subject" by creating poles of differences between the above-mentioned societies, the

imposition of a "continuum of development". The existence of concepts such as "orient" and "occident" are results or, in the Canadian example, 'west' and 'east'. The fourth aspect refers to the exclusive and non-integrated aspect of humans and nature. Through modernism comes the "environmental otherness" and detached view of nature that many contemporary societies apply.

3 Boundaries of the Canada Census of 1881 cannot be established. Maps outlining the census districts were lost in a Parliamentary Library fire of 1916 (personal correspondence 12/16/92).

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Francophone land settlement in southwestern Saskatchewan: homestead choices of French speaking settlers in the Gravelbourg-Meyronne area

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Abstract: During the late 1800s and early 1900s, several thousand Francophones migrated to Western Canada. While there are several studies on the history of this migration, few have considered their land settlement pattern, especially the settlement choices of individual homesteaders. This paper presents some preliminary results in a study of Francophone land settlement in southwestern Saskatchewan. While early French speaking homesteaders in the Gravelbourg-Meyronne area frequently chose the best available land, several factors influenced homestead selection including proximity to water, access to a limited amount of bush, proximity to relatives, friends, acquaintances, countrymen and previous neighbours. The land chosen and the factors considered varied for each settler. The role of the priest, Father Gravel, complicated any evaluation of land selection. He advised and reserved land for an unknown number of settlers, and suggested that others file 'blind'.

Key words: Saskatchewan, Francophone, Gravelbourg, land settlement, homesteaders

Introduction

Several thousand Francophones migrated to western Canada during the late 1800s and early 1900s. Most settled together, in rural areas, where they established Catholic parishes. Schlichtmann (1977) has argued that ethnic groups often displayed characteristics which distinguished them from their neighbours and which contributed to spatial differentiation of the earth's surface. This uniqueness was expressed in locational behaviour such as preference for specific types of settlement areas, or in individual and group distributions. Schlichtmann (1977, 10) further remarked that "Geographic research seeks to show why, to what extent, and how spatial concentrations of people of shared ethnicity developed just where they did, ...research is concerned with location at the individual and group levels." Others have researched the land settlement decisions of members of various ethnic groups on the Canadian prairies including Anglophones (Richtik 1985), Icelanders (Richtik 1986), Germans and Scandinavians (Boyd 1989), Scots (Lewry 1986) and Ukrainians (Lehr 1985). By contrast, Francophone land settlement has not been considered. One objective of this paper is to determine if Francophone settlers within the Gravelbourg-Meyronne bloc settlement displayed unique locational behaviour and to suggest some factors that contributed to any unique settlement patterns.

Literature Review

Many have researched the history of Francophone migration to western Canada; fewer have investigated this group's pattern of land settlement. At a continental scale Trudel (1961) mapped the expansion and contraction of French Canadians in North America until Confederation in 1867. Frémont (1959), Bédard (1979) and Old (1980) mapped the location of historical French towns and villages in Saskatchewan. Fung's (1999) maps outlined the location of Francophone and other ethnic bloc settlements in the province, but did not show the distribution of members of this group with in these settlements. Morisette (1970) mapped the locations of individual French-origin settlers who had patent land in colonies established by Monsignor Jean Gaire in southeastern Saskatchewan. He focused on the efforts of Monsignor Gaire to establish the settlements and on the surrounding of the colonies by those of other backgrounds, rather than on factors influencing the locations of individual homesteads. In contrast, this paper presents some preliminary findings in a study of Francophone land settlement in southwestern Saskatchewan and focuses on settlement in the Gravelbourg, Lafleche and Meyronne area.

Study Area

The chosen area (Figure 1) approximates that of the Gravelbourg-Meyronne settlement bloc identified in the *Atlas of Saskatchewan* (Fung 1999). Four Francophone settlements were planned within this bloc. Gravelbourg was initially to cover townships ten and eleven, ranges four and five, Lafleche, townships eight and nine, ranges four and five. West Gravelbourg was located on township nine, range six. Le Pinto, later named Meyronne, was originally planned for township eight ranges six, seven

Figure 1: *Location of the Gravelbourg-Meyronne area.*

and eight, but was soon reduced to township eight, range seven, all west of the third meridian (NAC 1908, 1909). A few townships surrounding the bloc settlement were included if there was a significant number of French-speaking homesteaders, and if the township was not better included in another Francophone bloc settlement[1] .

Sources and Method

Homesteaders were identified using the Department of the Interior's Township Registers and Homestead files[2] . Several sources were used to identify Francophone settlers. Family names served as a guideline[3] , but they proved insufficient for mapping individual settlers. Some settlers whose last names appeared to be French in fact had other backgrounds, such as George Marquis, the son of an Englishman, John Marquis (SAS Homestead files 1772232 and 1782862). A few lists were available: one compiled by Father Gravel, another of Francophones at Lafleche. Both were incomplete and inaccuracies were found in Father Gravel's list (SHSB c.1910; Anonymous n.d., 14-15). Birthplaces of settlers, determined from homestead files and local histories also served as a guide. However, several non-Francophones were born in French areas, such as Québec-born John McDonald who settled south of Lafleche, or Harvey Gibson who homesteaded southwest of Gravelbourg (SAS Homestead files 1772628, 1778300, 2240007 and 3021447). At the same time, many Francophones were born outside of French areas in the United States, Ontario or Manitoba. However, they were often sons of Québec-born homesteaders who also took up land in the settlement. This allowed their origins to be traced back to Québec. A few settlers of non-French origin and with family names reflecting other ethnic backgrounds were identified as Francophone by secondary sources. Like the Ross family that settled at Gravelbourg, Arthur Smith's family had likely been in Québec for so long that it had assimilated into French Canadian culture[4]. Additional problems arose in identifying French-origin settlers from the United States as Francophone. Taped interviews and letters demonstrated that there had been different degrees of assimilation, especially among those born in the United States[5]. Furthermore, some Francophones in the United States anglicised their names, making it difficult to identify them[6].

Birthplaces and last residences of Francophone settlers were determined using homestead files and local histories[7]. Taped interviews, genealogies, church papers and letters sent to Father Gravel provided additional information on the pre-settlement locations of a limited number and added information about the context of this settlement.

Physical Geography

The Gravelbourg-Meyronne area lies within the Old Wives Plain. Soils in this region are among the best in southwestern Saskatchewan. The heavy clay loam of the Sceptre Association, found near Gravelbourg, is the most productive soil type in the brown soil zone. Topography changes from relatively flat at Gravelbourg, to rolling heading south to Lafleche. Haverhill soils predominate in the northern part of the Lafleche settlement. Although inferior on rolling land, when found on level land, such as that south of Lafleche, Haverhill soils are second to Sceptre soils in productivity.

However, they lack the moisture holding capacity of Sceptre soils, are susceptible to leaching, and are often stony. Sandy loam of the Hatton Association is found further west in the Meyronne area, especially south of the town. This soil's sandy nature limits its moisture holding capacity, resulting in little resistance to drought and drifting. It is possible to obtain good crops on such soils in years with above average precipitation; however poor crops or even total failures occur when precipitation is insufficient (Loveridge and Potyondi 1983, 42; Mitchell *et al.*1987, 54-58, 67-71, 73-76).

Using Köppen's classification, climate in southwestern Saskatchewan is classified as moist mid-latitude steppe. Moisture, rather than temperature, limits agriculture. Mean monthly temperatures peak in July at 18° to 19 °C, and drop to their minimum in January at -13° to -15°C. Although precipitation is greatest during the summer, high temperatures and frequent winds from the southwest result in excessive potential evapotranspiration compared to precipitation, and large water deficits (Longley 1972, 24, 72; Fung 1999, 18, 99-100).

The natural vegetation of southwestern Saskatchewan has been described as mixed grass prairie. Wheatgrass and speargrass are the most common species found. Blue grama grass is less common except on very droughty soil. Sages and common cacti are also frequently found (Watts 1959, 34-35; Padbury and Acton 1994). Surveyors' field notes indicate that prior to settlement prairie dominated in all townships in the Gravelbourg-Meyronne area. A very limited amount of bush, including willow, maple, cherry and thorn was found along the Wood River. Although insufficient for building, this provided fuel for settlers in the Gravelbourg area. Elsewhere, they had to travel to Wood Mountain for coal (ISCR Surveyors' Field Notebooks). Surveyors also mentioned the presence of antelope, jackrabbits, ducks, chickens and deer within the study area. However, some of them stated that game was not plentiful (ISCR Surveyors' Field Notebooks).

Historical Background: Francophone Settlement in Southwestern Saskatchewan

Early Francophone settlers in southwestern Saskatchewan were French and Michif-speaking Métis, mostly from the Red River area in Manitoba (Lalonde and Lapointe 2000, 16). They came, beginning in 1856, because of a decline in the bi-annual Red River buffalo hunt coincident with increased trade for buffalo robes. Many more arrived in 1869-1870 pushed by near annual drought, declining crop yields, failure of the Red River hunt and concern with repercussions from the Red River Resistance (Rondeau 1923, 29; Ens 1989, 107-108, 220). Temporary wintering settlements were established at Wood Mountain/Willow Bunch, and later at Cypress Hills, Lac Pelletier and along the Frenchman River, near what is now Val Marie (Lalonde and Lapointe 2000, 16).

At this time, still clouded by its negative image as the northern extension of the Great American Desert, southwestern Saskatchewan remained largely uninhabited by those of European descent (Ennis 1977, 17). However, by the late 1870s, ranchers were attracted to the area as they participated in the expansion of the 'ranching empire' from Texas across the American plains and into the southern prairies of Alberta and Saskatchewan (Breen 1983, 4). Severe winters in 1903-1904 and in 1906-1907, declining cattle prices, a world-wide recession, a final end to closed leases in 1896, and an amendment to the Dominion Lands Act in 1908 allowing a 160 acre pre-emption in addition to a homestead led to a decline in ranching (Lambrecht 1991, 39; Potyondi 1995, 56-57). A wet cycle persisting through most of the first decade of the twentieth century promoted grain farming in areas which were previously considered marginal for agriculture and led to a southwesterly direction in the expansion of settlement (McCormick 1977, 163).

Until this time, few had chosen to homestead in southwestern Saskatchewan. There were few positive references to the region and most intending settlers headed to other, apparently more fertile areas (Ennis 1977, 22). Yet, for the French Catholic clergy in western Canada, the limited settlement was ideal. Although initially preferring bloc settlements, by the early 1900s they were attempting to form a chain of smaller, though solid, group settlements. They hoped that with high birth rates, further immigration and subsequent acquisition of land owned by other groups, the small settlements would eventually be linked (Painchaud 1976, 3; Lalonde 1983, 493).

However, fewer came than the clergy had hoped. Although farms were small in Quebec, France and Belgium, many opted for opportunities in urban centres within their own, or in nearby countries, or chose migration to the United States rather than to western Canada. Those promoting immigration to the prairies faced opposition from the government, various societies and local Catholic clergy, particularly in France and in Québec. Also, they had to counteract the image of western Canada as a cold place of hardship where one would not likely succeed[8].

The Gravelbourg-Meyronne Area

In September 1906, Archbishop Adelard Langevin authorised Father Louis Pierre Gravel to establish a parish at a location of his choosing, though he recommended the Gravelbourg area (SAR 1906; Hébert 1965, 17). Earlier, a few colonists had followed the advice of Willow Bunch priest, Alphonse Lemieux, and Métis living in the area, that they would find fertile, flat land, and some bush, at 'La Vieille' rather than hilly land like at Willow Bunch. They soon squatted at what would become Gravelbourg. When Father Gravel first came to the area, he found these colonists settled and Monsignor Marie Albert Royer recruiting for a colony. The wealthy Gravel family's influence and instructions from Archbishop Adelard Langevin forced Albert Royer to relocate. He eventually founded Notre Dame d'Auvergne, today Ponteix, while Gravel began sending colonists to 'La Vieille', for land in four townships reserved for Francophone settlers (Royer c. 1918/1919, 8; 'Un Ancien' 1920, 36-37; Auclair n.d., 45, 51; Lapointe 1987, 38-39; Wilhelm 1990, 129).

In 1907, Father Louis Pierre Gravel was appointed repatriation agent for the federal government. He was to encourage French Canadians living in the United States to return to Canada (NAC 1907). To this end he advertised in newspapers in Québec and in the New England States: *Le Canada*, *La Presse*, *La Patrie*, *L'Étoile*, *Le Witness*, *L'Avenir de Manchester*, and *Le Record* (NAC Parks Canada; SAR 1909a). He gave speeches in Québec and in Franco-American centres, (NAC n.d., Weekly Reports) and published two brochures promoting colonisation: *Le Pays des Bles d'Or* (The Land of Golden Wheat) and *La Saskatchewan* (Saskatchewan) (Tessier 1974, 18). Although his numbers may be questioned, Reverend Gravel claimed to have attracted over 10,000 French Canadians, many from the United States, to southwestern Saskatchewan[9].

Two other colonies were established in the Gravelbourg-Meyronne bloc settlement[10]. After leaving Gravelbourg, Albert Royer explored the area around the confluence of Pinto Horse Creek and Wood River. He noted that while the land was rolling, hills were only steep near the river, and the land was cultivable. Monsignor Royer directed a group of settlers who were not satisfied at Gravelbourg to this area where they formed a settlement known as 'Buffalo Head', the precursor of Lafleche (Royer 1908, 6).

In 1908, pioneers Benjamin Soury-Lavergne and Marcel Dugas left Gravelbourg to look for homesteads adjacent to a projected railway. They searched for two weeks but saw nothing to their liking until they found good land two to three miles north of Pinto Horse Creek. The new residents of the area later attracted Reverend Jules Bois from France; he became their parish priest at Meyronne (SAR 1934, 57-59; Soury Lavergne n.d., n.p.).

Land Settlement

Other homesteaders soon followed the initial settlers at Gravelbourg, Lafleche and Meyronne. Many Francophones squatted before the land was surveyed, at Gravelbourg, and to a lesser extent at Lafleche (Figure 2). Chi-square tests (Table 1) show that Francophone squatters at Gravelbourg chose the best quality, class 2[11] land, more frequently than expected, while they avoided class 3 and class 4 land. Squatters at Gravelbourg, especially those from France, clustered around the group initially brought by Reverend Albert Royer. This group gathered near his proposed church on section 14-10-5-3. Another group formed near the initial settlement in the area known as Gauthierville on section NE32-10-4-3[12]. Others settled throughout the four townships of the Gravelbourg colony, although they avoided the rolling land in the southwest corner of the settlement.

Although too few quarters were claimed by Francophone squatters at Lafleche to conduct chi-square analysis, early Francophone settlers here too displayed a preference for the best land: 85.71% of the quarters chosen were class 3 land, 7.14% class 4 land and 4.14% class 6 land; no class 5 land was selected. They avoided rolling land north of Lafleche and class 5 land east of the town. Francophone squatters did not specifically locate near the proposed railway[13]. On the contrary, there was a tendency to

Table 1: *Land claimed by Francophone settlers at Gravelbourg.*

Soil class	Observed number of quarters claimed	Expected number of quarters clamed	Deviaition %
2	90	48.1	+53.44
3	64	87.7	-27.01
4	0	5.2	-100.00

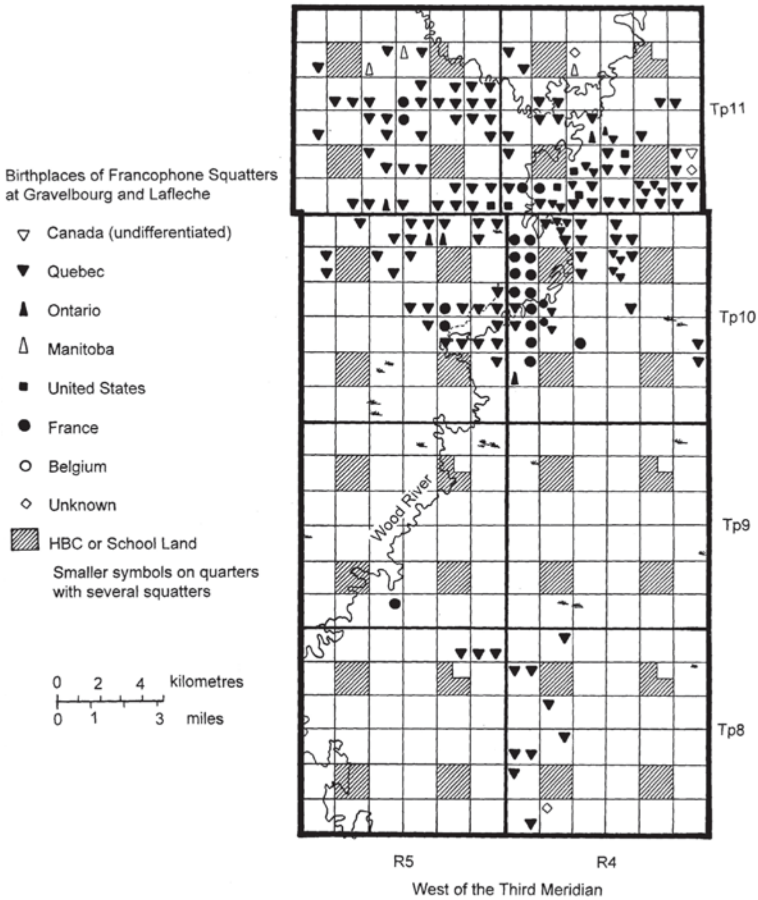

Figure 2: *Francophone squatters at Lafleche and Gravelbourg.*

settle near family members, acquaintances or those who had previously resided in a common location.

Land in the area was surveyed in 1908. Most squatters filed for their claimed homestead quarter, though many selected a new pre-emption. Like those who had squatted, and as shown in Table 2, Francophone settlers frequently selected the best available land. Rolling land in the southwest corner of the Gravelbourg settlement and North of Lafleche, as well as sandy land south of Meyronne was avoided. Clustering was most

Table 2: *Land entered by Francophone settlers in 1908:*

Settlement	Soil class	Observed number of quarters claimed	Expected number of quarters claimed	Deviation %
Gravelbourg	2	135	95.2	+41.84
	3	144	173.5	-17.00
	4	1	10.3	-90.32
Lafleche	3	51	38.5	+32.51
	4	2	17.6	-88.61
	5 or 6	7	4.0	+77.06
Meyronne	3	12	6.2	+93.50
	4	1	1.9	-46.25
	5	7	11.9	-41.36

evident at Gravelbourg; non-Francophone settlers took only a few quarters around the edge of the settlement. Smaller groups were present at Lafleche and Meyronne.

Difference in the size of the settlements may be partially explained by the reservation of the four townships, yet specifics relating to this reserve are unknown and a few non-Francophones filed as early as 1908. Also, requests to Father Gravel for information about settling in southwestern Saskatchewan suggest that Gravelbourg soon acquired a reputation: many asked about settling in Gravelbourg rather than elsewhere (SAR 1908b, 1908c). As an immigration officer at Moose Jaw, Alphonse Gravel directed Francophones to Mortlach, then south to French colonies (SAR 1909b). Letters in the Fonds Famille Gravel tell of some settlers who were attracted by advertising, while others followed friends, acquaintances and relatives.

It is also difficult to assess how well the results of the chi-square test reflect any ability of these settlers to select good land. The earliest homesteaders in all three settlements chose homesteads generally surrounded by good land: others may have simply settled near them. Written evidence suggests that other physical features, especially access to the limited amount of wood and water were desired, and influenced the choices of some settlers. For example, Mr. Beaubien selected land by the river to have wood and water (SAR c.1966). J.B. Delbrouck wrote to Father Gravel requesting assistance in finding land that was near wood and water; being near a railway apparently did not matter so long as he could hope that one would soon be built:

> *Je vous serais infiniment reconnaissant de bien vouloir me dire ou je pourrais trouver un bon homestead ainsi qu'une préemption; cela ne me ferait pas trop d'être quelque peu éloigné des lignes de chemin de fer actuelles, si je pouvais espérer qu'il s'en constuirait de nouvelles assez proches des terres à prendre. J'aimerais assez ne pas être trop éloigné du bois et que l'eau ne soit pas trop difficile a trouver. Si possible* (SAR 1909c, 910).
>
> I would be infinitely thankful if you would tell me where I could find a good homestead and pre-emption; it is fine with me if I am somewhat away from current railways, if I can hope that new ones will be built close to the available land. I would like to be not far from wood, and would like it if water were not difficult to find. If possible.

Surprisingly, land near the river, and land with some bush was not always the first to be taken. Families and acquaintances often chose land within the same colony and at times settled on adjacent quarters (Figure 3). For example, Zenon Desrosiers asked Father Gravel to reserve adjacent quarters for himself and a friend (SAR 1908d). Raoul Bourgeois later wrote that his uncle, Ulric Bourgeois, had arrived at Gravelbourg with a group of friends. They subsequently chose land within the same region. Raoul's brother followed the next year and also selected a nearby quarter:

> *Quelques-uns de ses amis étaient Hormidas Boutin, Alex Samoisette, Amedée Lorrain, Sylva Bourgeois et Hector Pinsonneault qui étaient arrivés avec lui. Tous ses amis prenaient du terrain dans les mêmes environs et sont toujours demeurés bons amis. Son frère, Aimé, arrivait en 1909 pour se situer sur une terre près d'Ulric* (Gravelbourg Historical Society 1987, 262).
>
> Hormidas Boutin, Alex Samoisette, Amedee Lorrain, Sylva Bourgeois and Hector Pinsonneault were among the friends who arrived with him. All of his friends took land in the

> same area and always remained good friends. His brother, Aime, arrived in 1909 and took land near Ulric's.

Some settled adjacent to their countrymen or near those who had previously resided in the same location (Figures 4 and 5). In both cases, proximity to family, friends or countrymen at times outweighed land quality, provided poor quality land was recognised. However, the mobility of the Francophones meant that maps of settlement by birthplace or by last residence sometimes obscured links between family members and acquaintances.

The unknown number of Francophones who had requested Father Gravel's assistance in choosing land further complicated analysis of land selection[14]. For example, Joseph Cormier wrote to Father Gravel on August 7th, 1907:

> *J'ai appris par plusieurs que vous aviez du terrain en main pour former un settlement canadien je m'adresse à vous pour m'en garder un morceau soit que vous choississez vous-même le terrain ou que vous faites visiter quelqu'un je vous paierez ce que ça vaudra. Veuillez m'écrire aussitôt que possible j'irai moi même voir cela* (SAR 1907a).
>
> I've heard from many that you have land to form a *Canadien* settlement I'm writing you to have land saved for me, either that you choose the land or that you have someone visit it I will pay what it is worth. Please write as soon as possible I will go and see it.

Another prospective colonist, Louis Tessier, wrote on September 30th, 1907:

> *voudrier vous avoir la bonté de voir me prendre une homestead. je vien de voyage et j'ai entendu parler que vous en arrier an main voyez s'il vous plair enprendre un pour moi sur le rang 4 et je consen a payer votre commision comme les autres faite moi reponse au plustot possible* (SAR 1907b).
>
> would you be good enough to take a homestead for me. i returned from a trip and I heard that you had some in hand would you take one for me on range 4 I will pay you commission as the others are please respond as soon as possible.

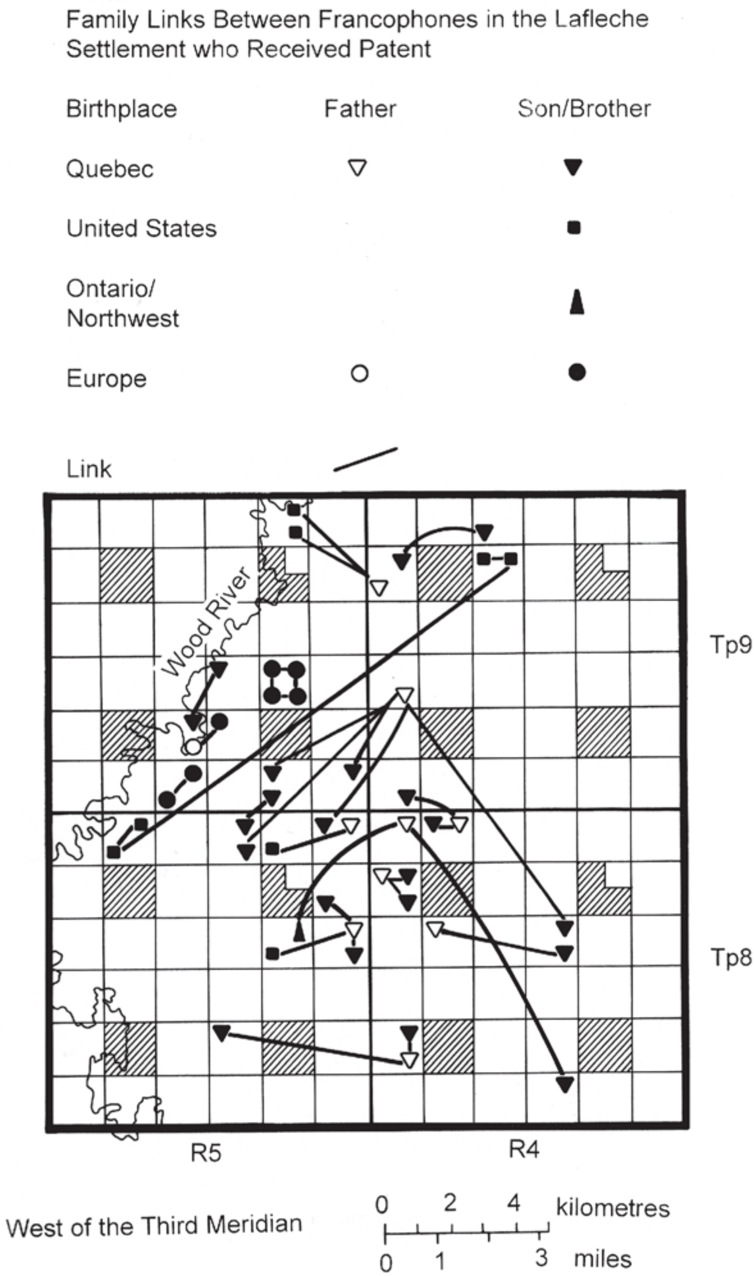

Figure 3: *Family links between Francophone homesteaders in the Lafleche Settlement.*

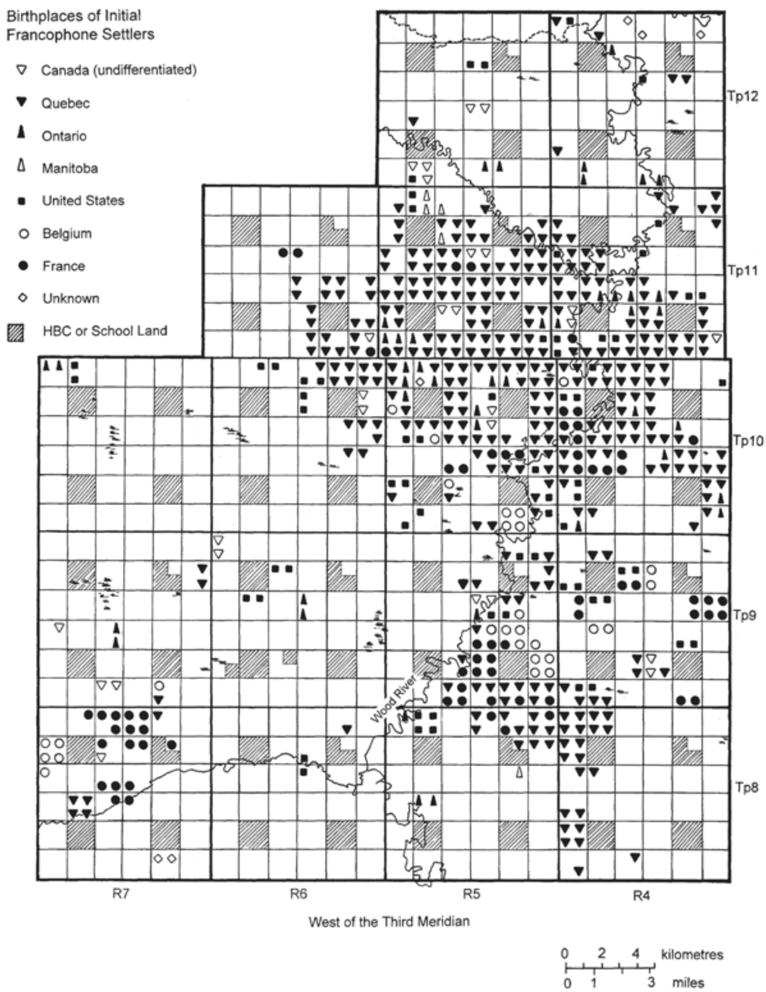

Figure 4: *Birth places of initial Francophone settlers.*

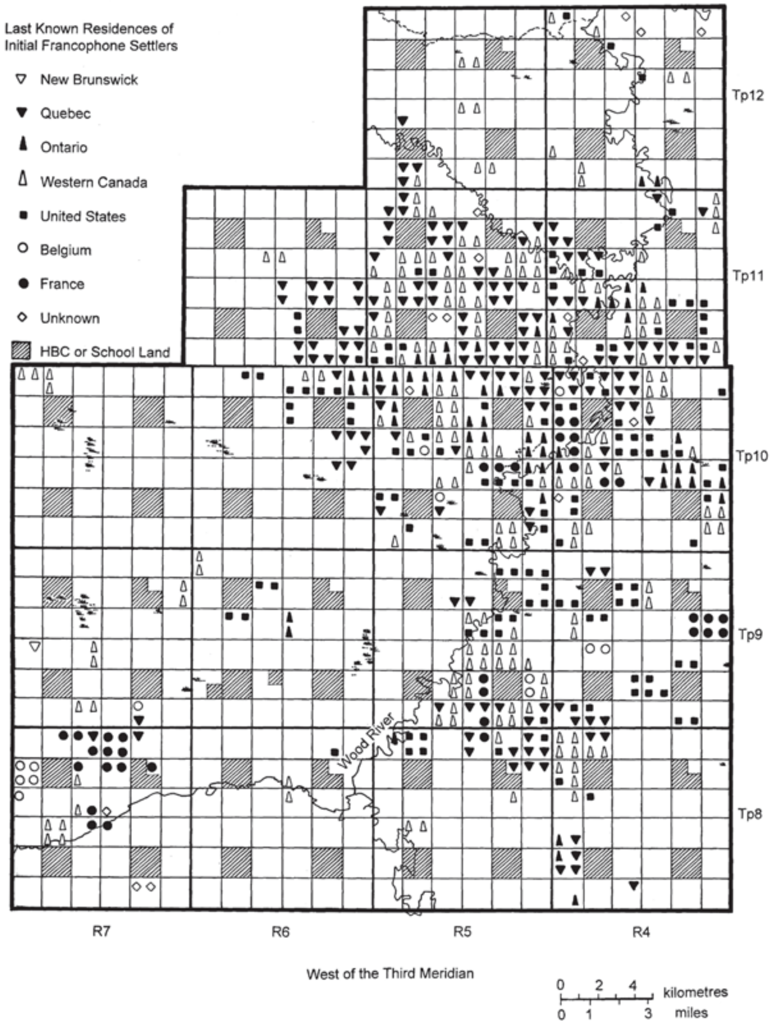

Figure 5: *Last residences of initial Francophone settlers.*

Later accounts also indicate that Father Gravel was involved in selecting land with the colonists. For example, Raymond Bourgeois wrote that Louis Pierre Gravel had assisted his father, Tancrede,

> *En 1906, papa se rendit à Moose Jaw, où avec l'aide du bon Père Gravel, il choisit une bonne terre tout près du site de la future ville de Gravelbourg* (Gravelbourg Historical Society 1987, 261).
>
> In 1906, father went to Moose Jaw, where, aided by the good Father Gravel, he chose good land close to the future site of the town of Gravelbourg.

Father Gravel was involved in selecting land for another group. In 1909 Arsene Bouvier, his brother, Alcime, his father Pierre, a friend Moise Douville and his sister Marie Rose investigated settlement possibilities in the Meyronne area, then,

> The following year, 1910, Arsene returned to Saskatchewan with his father, Alcime and Honore and Moise Douville. On Father Gravel's recommendation, they homesteaded each a quarter section together eight miles north of Meyronne in a part of the country later known as 'Bouvierville' (Gravelbourg Historical Society 1987, 268).

Other Francophones filed 'blind'. Choosing good land in this situation may have been luck as much as anything. For instance, Irene Himbeault later wrote that her father, Joseph Chouinard, arrived at Moose Jaw and selected a quarter on a large map in the Dominion Lands office. After a trip to this sandy quarter section south of Lafleche, he returned to Moose Jaw intending to exchange it. En route, he met Mr. Ross who directed him to file for an available quarter two to three miles south of his own place (Gravelbourg Historical Society 1987, 307). In fact, Father Gravel counselled some Francophones to file 'blind' with little information about the land. For example, J.B. Delbrouck wrote Father Gravel that he was concerned about Gravel's suggestion of filing without first seeing the land. However, he trusted Gravel to select good land for him:

> *J'ai bien reçu votre lettre du 21 janvier dernier ainsi que la carte que vous avez bien voulu m'envoyer. Vous me conseillez de faire application de suite sans aller voir les terres, mais c'est que déja une fois je l'ai fait et j'ai eu a m'en repentir:*

> *un individu avait pris une grande quantité de homesteads - on pouvait faire application pour d'autres en ce temps - et sur sa parole je suis parti avec tout un stock et j'avais une terre inhabitable; resultat cinq cents dollars perdus. Vous ne me dites pas quelles espèces de terres sont ces homesteads. Sont-ce des terres à blé? Y a-t-il du foin? Je suppose puisque vous m'envoyez là que vous devez connaitre celà. Comme j'ai déja eu un homestead et que j'ai un permi d'entreprendre un, ne pensez vous pas que vous pourriez faire application sur deux quarts pour moi? Cela m'exempterais le voyage à Moose Jaw; Je vous enverrais ce permis et tous les renseignements voulus ainsi que l'argent* (SAR 1909d, 902-903).
>
> I received the letter and the map you sent on January 21st. You advised me to apply immediately without going to see the land, but I have already done this once and lived to regret it: someone took a large number of homesteads - we could apply for others at that time - and on his word I left with much stock and I had uninhabitable land; result the loss of five hundred dollars. You do not tell me what kind of land these homesteads are. Is it wheat land? Is there hay? I assume that since you are sending me there you know this. As I've already had a homestead and have a permit to take another, do you not think that you could apply for two quarters for me? This would save me the trip to Moose Jaw; I will send you the permit and all information needed as well as the money.

Finally, not all could apply for the land they desired; for example Zenon Desrosiers was likely told that he would have to apply in a township adjacent to that which he preferred. On July 9th, 1908, he wrote,

> *Je désire de prendre un homestead à la rivière la vieille s'il vous plait je vous demande de entrer mon nom sur le Town 10, r4 sec. 24 3ième méridien la ½ sec. du Sud Ouest et Sud Est, veille s'il vous plait de mettre mon nom pour le quart Sud Ouest, et le Sud Est pour mon ami Rudolphe Hardor [?] et si par lors cette demi section est demandé avant nous bien je vous prie de me réserve deux quarts sur la section la plus proche et naturellement on désire que vous nous réserve du bon terrain ... nous désirons beaucoup de nous établir ici dans [?] dans une Colonie Canadiens et Catholique, et autrement si nous reussissons pas à prendre du terrain dans*

> *votre colonie à la rivière la vieille que vous être à l'oeuvre de fonder, et bien nous nous retourneront dans la P Quebec notre place natale* (SAR 1908d).
>
> I would like to take a homestead at Old Wives River I ask you to please enter my name on the south half of township 10, range 4, section 24 west of the 3rd meridian, would you please enter my name for the southwest quarter and the southeast is for my friend Rudolphe Hardor [?] and if by chance this half section has already been requested I ask you to reserve two quarters for me on the closest section and naturally we ask you to reserve good land ... we would really like to establish ourselves here in a *Canadien*, Catholic Colony, and otherwise if we do not manage to take land in your colony, the one which you are founding, at Old Wives River, then we will return to Quebec, our birthplace.

A note scribbled on this letter indicated that land was to be reserved in township 11, range 5, rather than in township 10, range 4, as requested. However, homestead records indicate that Zenon Desrosiers never patented land in western Canada (SAR Township Registers; http://www.archives.ca).

Conclusions

Several intertwined factors influenced Francophone land settlement decisions. French-speaking, Catholic priests sought to establish solid, stable bloc settlements where the French language, culture, and the Catholic religion might be preserved. They selected areas with few other settlers, where they believed the land was good (Royer 1908, 6). They recognized the importance of locating where farmers might prosper in order to build stable settlements and preserve culture. However, they avoided good farming areas if others were already there. As a result, colonies were not always optimally located. In contrast, individual settlers who chose homesteads at locations where colonies later developed made decisions on economic bases: they attempted to select good farmland, relatively close to existing or projected railways. Presence of other settlers was not influential.

Colonising missionary priests recruited in Québec, in the United States and in French speaking areas in Europe. They were challenged by the decisions of those who saw better opportunities in urban centres or in the United States. Also, particularly in Québec and in France, governments, the church, newspapers and other members of the elite discouraged migration. Frequently, they promoted a negative image of western Canada. Also, concern over a treeless environment, and the limited amount of water available deterred potential migrants, particularly those who were considering southwestern Saskatchewan. Some Catholic clergy in Québec, such as curé Labelle, suggested that Québecois who wanted to move to the United States, because of the difficulty involved in clearing land to start farming in Québec, consider migrating to the western prairies where trees would not be an obstacle (Lalonde 1979, 168). Nevertheless, priests in southwestern Saskatchewan had to promote the idea of farming in a treeless area. In particular, they mentioned that the land, although treeless, was fertile and that other sources of fuel were available (Anonymous 1903, 269-270). Areas with some bush, like Gravelbourg, were attractive.

The numerous letters written to Father Louis Pierre Gravel requesting information about homesteading in western Canada are indicative of the influence of this priest in attracting settlers. However, like several other groups, processes of chain migration influenced Gravelbourg's development[15]. Examples such as that of Ulric Bourgeois demonstrate how communication between those settled and others still in the homeland led to chain migration and growth of Francophone colonies. Many were attracted to these colonies where they understood that institutions had been developed that would enable them to retain their culture, and settle alongside other Francophones, friends and family.

Many factors influenced individual homestead selection within the colonies. Letters to Father Gravel, such as those by J.B. Delbrouck and by Zenon Desrosiers, demonstrated interest in obtaining good land. Most Francophone homesteaders chose good land. Often, homesteads were selected near others born or last resident in similar areas, or near family or acquaintances. However, family members did not always choose adjacent quarter sections. Groups based on common origins and last residence remained small. The role of Father Gravel in reserving land and advising settlers in homestead selection, especially in the Gravelbourg area, complicates evaluation of homestead choices. The extent of his influence in land selection is unknown, particularly outside the Gravelbourg settlement, though evidence suggests that he did play a role in establishing several other Francophone colonies in southwestern Saskatchewan.

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Notes

[1] This method for establishing boundaries for an ethnic block settlement has been used by Wonders (1980).

[2] Township registers and homestead files have frequently been used in studies of land settlement on the Canadian prairies (e.g., Lewry 1986 or Boyd 1989).

[3] French family names were identified using Dauzat and Marlet (1987) and Dionne (1914). Family names have been used before for identifying Francophone migrants and settlers (Vicero 1968).

[4] The English-origin Ross family had settled at Rimouski after William Ross was granted land for service in the 78th regiment during the taking of Louisbourg and Quebec in 1759 and in the American Revolution (Gravelbourg Historical Society 1987, 593-594). Both Joseph and Pierre Ross appeared on a list of Francophones whom Father Gravel claimed to have enticed to settle in Saskatchewan (SHSB c.1910). Father Royer later described Mr. Ross as a good Francophone in spite of his name (Royer c.1918/1919, n.p.). In a taped interview with Rene Smith, Arthur Smith is described as Francophone (SAR 1973a). He also appears as ‘French’ on a list of Meyronne settlers classified according to nationality (Therens 1955, n.p.).

[5] Most prospective settlers living in the United States but of French origin who requested information from Reverend Louis Pierre Gravel wrote in French. But, a Mr. Beauchamp in Devil’s Lake, North Dakota wrote that while Father Gravel had sent his father, Emile Beauchamp information on settling in southwestern Saskatchewan, he, Emile’s son, needed information in English since he did not read French (SAR 1908a). A Mr. Bourassa who settled at Lafleche told of speaking mainly English in St John, North Dakota (SAR 1973b).

[6] Francophone names were sometimes changed by record-keepers in the United States (Poteet 1987, 318). In other, but less frequent, cases, Francophones in the United States anglicised their own names in an attempt to integrate into American society. These voluntary name changes may be viewed as evidence of assimilation (Lambert 1987, 319; Poteet 1987, 318). For example,

"Durocher" was changed to "Stone", while "Lamontagne" was sometimes changed to "Lamountain", "Longtagne" or "Mountaine" (Forget 1987).

[7] Homestead files and local histories have been used to identify previous residences of English Canadians who settled in Saskatchewan (Widdis 1992).

[8] Ennis (1977) for example, summarises various factors influencing Francophone migration to western Canada. Silver (1969) and Lalonde (1979) have researched attitudes of the Québecois elite regarding migration to western Canada.

[9] A list of settlers whom Reverend Louis Pierre Gravel claimed to have attracted to southwestern Saskatchewan was found in the Fonds Langevin. However, a letter from Archbishop Langevin indicated that other priests, Reverends Lemieux, Magnan, Bois, Royer, Dufresne, Jayet and Woodcutter claimed to have attracted the same settlers. Further verification of this list showed that some settlers were not of French origin, while later accounts by some of the settlers suggested that they had come independently, and had never been in contact with Louis Pierre Gravel (SHSB c.1910, 1911a, 1911b).

[10] The colony at West Gravelbourg would remain small and was eventually known as Woodrow (Barry 1998, 394).

[11] Land classes are based on the Canada Land Inventory Soil Capability for Agriculture maps (1967).

[12] Both of these sites were proposed for the centre and church in the colony. The decision to locate the church and the town on NE36-10-5-3 and SE1-11-5-3 was controversial and influenced by the Gravel family: Father Gravel's brother, Emile owned SE1-11-5-3. As a result, the town was unusually located: away from the river and on marshy land. Later accounts suggest that in the early years at times there were two to three foot deep sloughs in the town during the spring (Royer c.1918/1919, n.p.; Auclair n.d., 63; SAR 1977, 1980).

[13] There is no indication that a railway was planned at Gravelbourg. Father Gravel made great efforts to attract both the CNR and the CPR to the town, appearing before the Railways Commission in 1910, writing to William White of the CPR and to Mr. Burns, locating engineer of the CNR on several occasions, and touring Mr. Burns through the area. In spite of his efforts, only the Canadian National built through Gravelbourg; the Canadian Pacific followed its previously planned route arriving in both Lafleche and Meyronne in 1913. However, Father Gravel was credited with bringing the CNR to Gravelbourg (SHSB 1910, 1911c; NAC 1911; Drake 1950; Anonymous 1979, n.p.).

[14] One later account suggests that all land within the French colony at Gravelbourg had to be taken through Father Gravel, rather than the Department of the Interior. Although this was not confirmed, some prospective settlers wrote Gravel requesting, and at times offering payment, for his assistance in selecting land (SAR 1980). Also, several quarters were listed in the Township Register as claimed and there was some regularity in the distribution of homesteads and pre-emptions suggesting the possibility of planning: four homesteads were frequently all located on the same section, while all pre-emptions were on the adjacent and alternating sections.

[15] Others have shown the influence of chain migration in the development of various ethnic communities, for example, Lehr (1985), Ostergren (1998) and Richtik (1985, 1986).

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A spatial analysis of crime in Brandon, Manitoba

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Abstract: Crime analysis has become a prominent subject within social geography. This study involves the analysis of crime data as well as socioeconomic data gathered for Brandon, Manitoba. Crime is broken down into personal crimes and property crimes. It was hypothesized that there is a significant correlation between the socioeconomic indicators of education and income levels with crime levels. Crime statistics were received from the Brandon Police Service for 1996 in order to allow comparison with the 1996 census data, the most recent data available at the time of the study. Through the use of a correlation analysis it was determined that correlations did in fact exist between education levels, income levels and personal and property crime levels. In addition, surveys of respondents' perceptions of crime within Brandon were shown to closely parallel those of the actual crime occurrences in the city. As a result of this research it is hoped to raise awareness and understanding among those interested in Brandon and in crime in small cities.

Key words: GIS, geography of crime, cognitive mapping, small cities, Brandon

Introduction

Crime analysis studies are not new to geography (Albaum 1973; Evans 1980; Georges 1978; Harries and Brunn 1978). In the mid-1960s Keith Harries used mapping techniques to determine that there were large spatial variations in the rates of crime committed in the United States, thereby establishing the foundation for modern geographic crime analysis (Harries 1974). Crime analysis has since become a common field of study within social geography, in both Canada and the USA, reflecting the significance of crime analysis and crime reduction in contemporary society (Getis *et al*. 2000; Sharpe 2000).

Crime analysis involves an analysis of past and present crimes, and the deduction of possible future trends based on detailed reports compiled by police departments. However, only in the past decade or so have these reports been available in digital format. This technical development, coupled with the improvement of specialized crime databases has meant that very specific and detailed information has been kept on criminal incidents and offenders. These databases include information on the type of crime committed, the location of the crime, persons involved, time of day and day of week. Also associated with each incident reported is a unique identifier or incident number. The incident number allows for the easy retrieval of all information relevant to a specific crime and, along with its associated address, allows the police incident database to be linked to a map. Although there are still problems with the data sources, the ability to digitally record the geographic location of a crime and the associated attributes of that same incident has lead to a shift from traditional methods of crime analysis toward the application of geographical information systems (GIS).

Despite the fact that law enforcement agencies are very diligent in their data collection, historically they have had little, if any, training in geography or GIS to aid in performing crime analysis. Traditionally, crime analysis by law enforcement officials involved the time consuming activity of plotting the location of crimes with pins on paper maps. It was then the task of detectives to determine possible patterns or trouble areas based upon their ability to visually interpret patterns produced by the pins. As such, crime analysis was a potentially biased and subjective process that relied heavily on the intuition of the detectives involved. Although useful results could be obtained, they typically varied with the personnel involved in each case.

Since the introduction and implementation of GIS, crime analysis has become an increasingly objective and analytical science. This more scientific approach has resulted in police forces becoming more proactive in their methods of community policing. With the coupling of current and historical data, police forces are able to forecast the contexts of criminal activity and react accordingly. Thus, computerized GIS provide increased efficiency and allow law enforcement agencies to address previously unanswered questions.

The following crime analysis study focuses on Brandon, Manitoba (Figure 1). Urban areas typically have higher rates of crimes than rural areas (Carter and Hill 1979; Sharpe 2000, 422). In addition, urban areas have demonstrated a significant spatial variation in the occurrences of crimes (Macionis and Spates 1982). Brandon is a small city with a population of approximately 40,000 people. Its small size means that the number of crimes committed, the volume of data collected by the Brandon Police Service, and the number of enumeration areas are manageable for purposes of this study. A number of problems do, of course, exist with

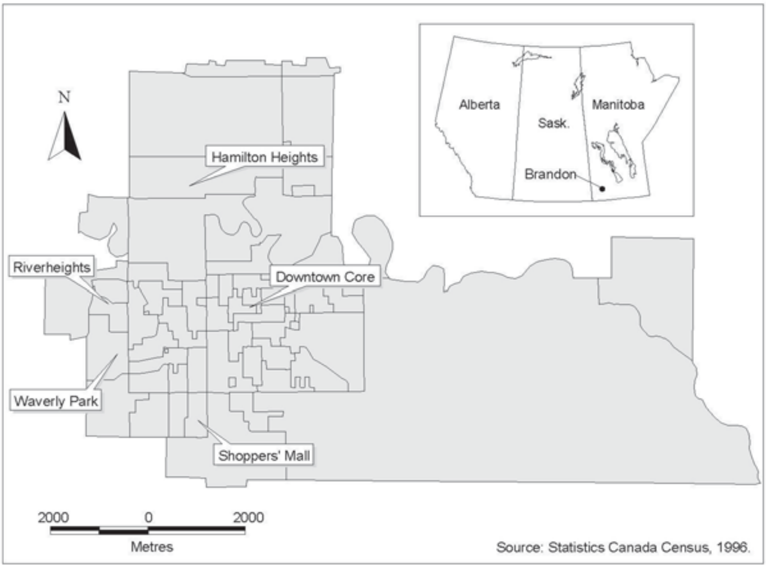

Figure 1: *Enumeration areas and neighbourhoods in Brandon.*

police data that can limit the analysis and even mask important patterns – as Harries pointed out many years ago "crime statistics are at best an approximation of the true crime situation" (1974, 4). For example unreported crimes, repeat victimization, multiple crimes and policing variations can cause distortions in the information available, and mean that the utmost caution is necessary in interpreting and explaining the resulting spatial patterns.

This study addresses two aspects of crime in Brandon. The first involves a comparison of 1996 census data, and crime data collected for the same period by the Brandon Police Service. Two hypotheses were formulated. The first was suggested by the work of Stahura and Huff (1979) who found that the higher the low-income population of a suburb, the greater the incidence of both violent and property crimes. This led to the generation of a hypothesis that "*crime rates of Brandon will have a negative correlation with income levels*"**.** That is, as the income level of an area decreases the corresponding crime rate for that area will increase.

The second hypothesis is related to levels of education, which Macionis and Spates (1982) have related to occurrence of crime. They suggest that many poor or near-poor people, having restricted educational backgrounds and thus more limited job-training opportunities, may seek to supplement their incomes by turning to crime. Following this line of reasoning it was hypothesized that "*crime rates of Brandon will have a negative correlation with education levels*". That is, the crime rate will increase as the level of education decreases. Although these hypotheses were based upon literature that refers to large metropolitan areas, prior knowledge of the urban geography of Brandon, as well as discussions with members of the Brandon Police Service suggested that they would also be applicable to the smaller urban context of Brandon.

The second aspect of this study involves an evaluation of the way that people perceive the occurrence of crime in Brandon and compares it to the actual occurrence of criminal activity. Perceptions of crime, as obtained from survey results, were used to develop cognitive maps that might aid in the understanding of crime and how it relates to other forms of spatial behaviour in Brandon. One hypothesis was formulated, namely, that the "*residents of Brandon will indicate the downtown core area of the city as having the highest rates of crime*".

A survey was used to collect data on respondents' perceptions of areas of high and low rates of crime, as well as background socio-economic data including income levels, and education levels. Perceived areas of high and low rates of crime, as indicated by the survey results, were digitized in order to allow their incorporation into a GIS. From these maps 'hot areas', or areas of perceived high crime rates, and 'cool areas', or areas of perceived low rates of crime were indicated.

Methodology

Five main areas of the research are discussed. First, the study area of Brandon and the enumeration areas that constitute the study area, are examined. The second section is concerned with the process of developing socio-economic maps based upon income and education levels, using data taken from the 1996 Canada Census data (Statistics Canada 1997). The third section discusses the design of crime maps and the construction of an appropriate crime index. The fourth section examines the processes involved in the production of cognitive maps of crime based on the survey responses. Lastly, a correlation analysis comparing average income, education levels, and property and personal crimes is presented.

Study Area

Brandon consists of sixty-two enumeration areas [EAs] (Figure 1) that constitute one Census Area (CA). However, not all EAs are equal in size, shape or socio-economic composition. An evaluation of the EAs enabled four categories to be developed based upon the relationship between each EA, and the neighbourhood-type that it was hoped to depict. The categories that were constructed included: 1) EAs consisting of institutions such as Brandon University, the Brandon Regional Health Authority hospital, and elderly persons' housing (EPH) complexes; 2) EAs that cross the boundaries of at least two of the traditional neighbourhoods; 3) EAs that have very irregular boundaries resulting in the inclusion of pieces of several neighbourhoods; and, 4) EAs that include sections of only one neighbourhood. The final category includes areas that are likely to be more homogeneous in terms of income and education levels — the two socio-economic variables used in this study. Consequently, only category four EAs were used for the sampling frame of this study.

The Development of Socio-economic Maps

One of the primary objectives of this study was to determine the validity of a hypothesized relationship between income and education levels, and the corresponding rates of crime at the EA level in Brandon. To facilitate this analysis, income and education levels, and the occurrence of crime were reduced to standardized indices. Once these indices had been determined it was possible to make an unbiased comparison between enumeration areas. The need for a comparison between enumeration areas resulted in maps of average income and education levels and the associated crime indices for each enumeration area. Figure 2 shows average household income in Brandon, and Figure 3 shows the percentage of people with post-secondary education. Although these two maps show largely similar distributions, there are some differences. For example, the lower household incomes are concentrated to a greater extent in Brandon's core area than are the lower educational levels. It was thus expected that the correlations between these variables and the crime data would differ to some degree. These two sets of data were derived from the 1996 census (Statistics Canada 1997).

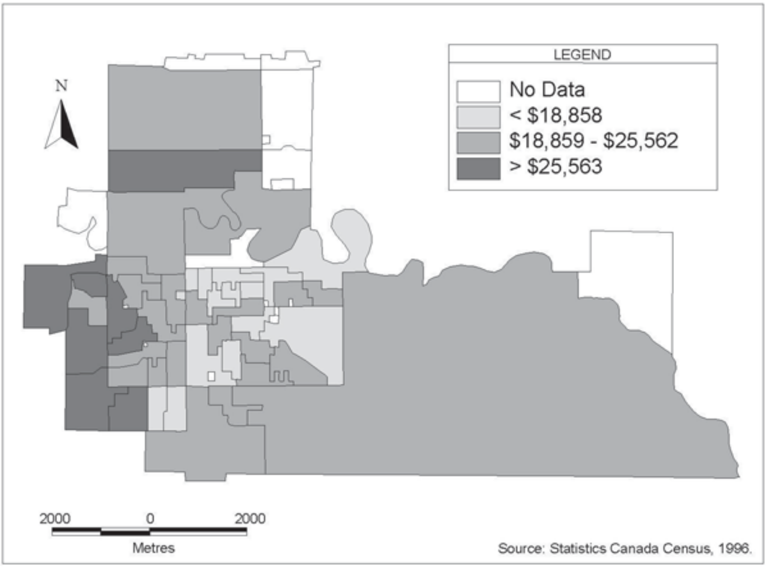

Figure 2: *Average 1995 household income.*

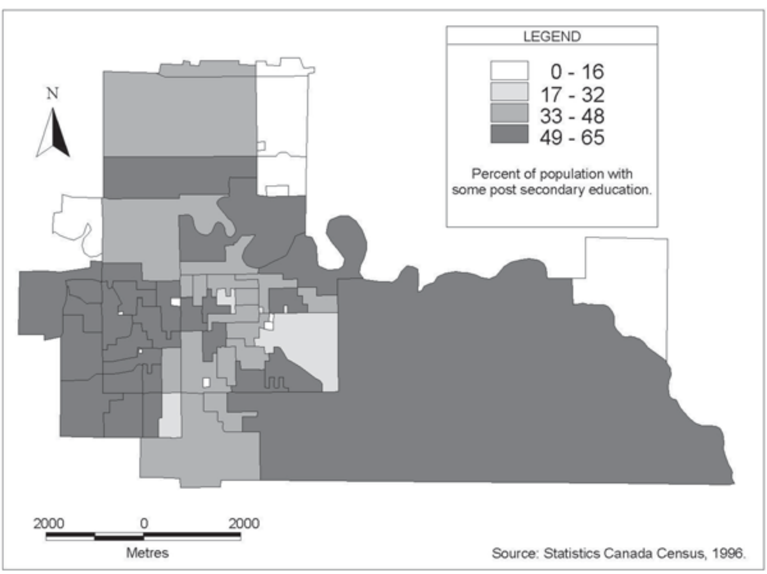

Figure 3: *Post secondary education levels.*

The Development of Crime Maps

In order to compare the income and education levels across Brandon with the crime rate, a crime index was determined. The crime index used was designed to take into account the number of crimes committed as a function of the population of the enumeration area. As it was not practical to compare every category of crime with income and education levels, two broad categories of crime were used that reflected traditional usage in the literature (Carter and Hill 1979), and within the Brandon Police Service.

The first of these broad categories was termed 'personal crimes', and included assaults, sexual assaults and robberies. The second category used was called 'property crimes' and included arson, business and residential break and enter, fraud, theft of motor vehicles, theft under and over $5,000, theft from vehicles, possession of stolen goods and mischief under $5,000 (Brandon Police Service 2000). Data problems could, of course, result from the use of such broad categories of crime where the severity of crimes within these categories can be seen to vary considerably. However, it was felt that for this preliminary study of the geography of crime in Brandon, where comparisons with other jurisdictions were not critical to conclusions of the study, and where within-category distinctions were not being made, that the use of the traditional categories was appropriate for the type of analysis undertaken.

In the development of the crime index, two key components were used, namely the number of crimes committed, and the total population of the enumeration area. A crude comparison of the total number of crimes for each enumeration area would have led to results, particularly in the correlation analysis, that would have been difficult to interpret. Therefore, it was determined that a standardized crime index was more appropriate, even though this might exaggerate the incidence of crime in the core area, and understate the crime situation in the suburbs. This crime index **(Ci)** was defined as the total number of crimes per 100 of the population. Two unique crime indices, one for personal crimes ($\mathbf{Ci}_{\mathbf{(personal)}}$) and one for property crimes ($\mathbf{Ci}_{\mathbf{(property)}}$), were then calculated for each enumeration area, producing two maps (Figures 4 and 5).

The Development of Cognitive Maps

Within the survey there were two questions that specifically pertained to peoples' perception of crime in Brandon. First, respondents were asked to "outline the one area that you feel has the highest rate of crime in

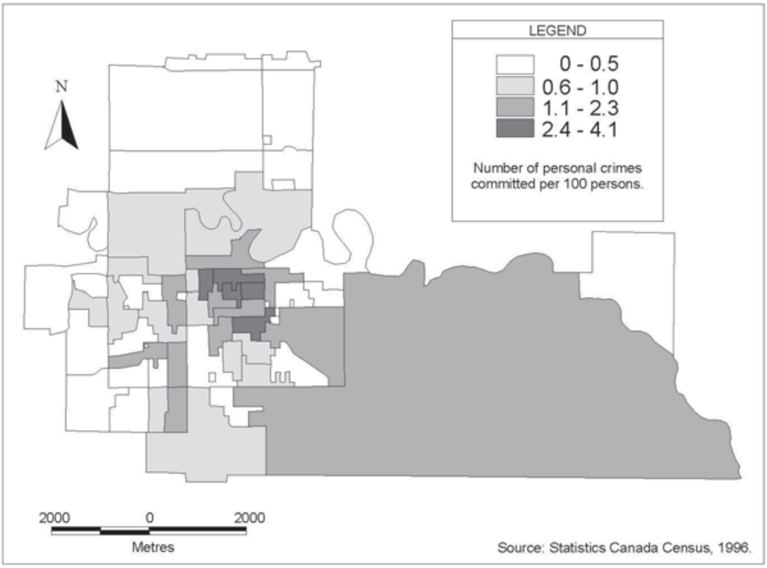

Figure 4: *Personal crime index.*

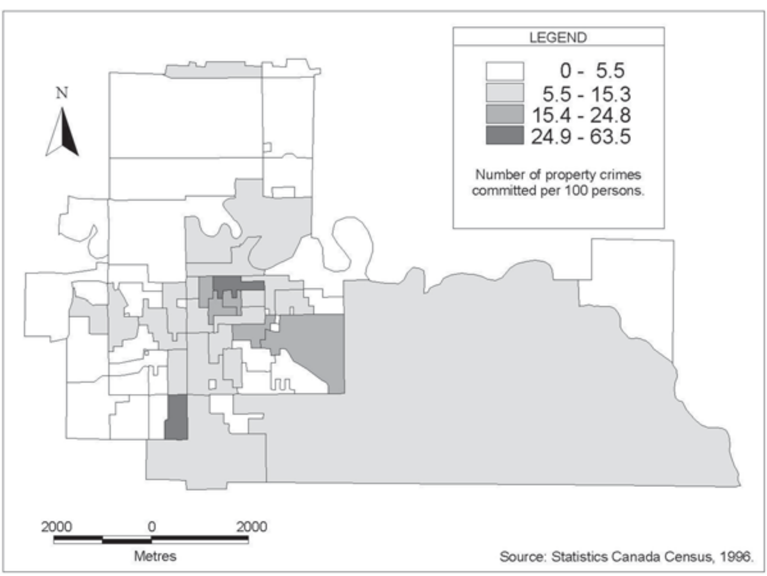

Figure 5: *Property crime index.*

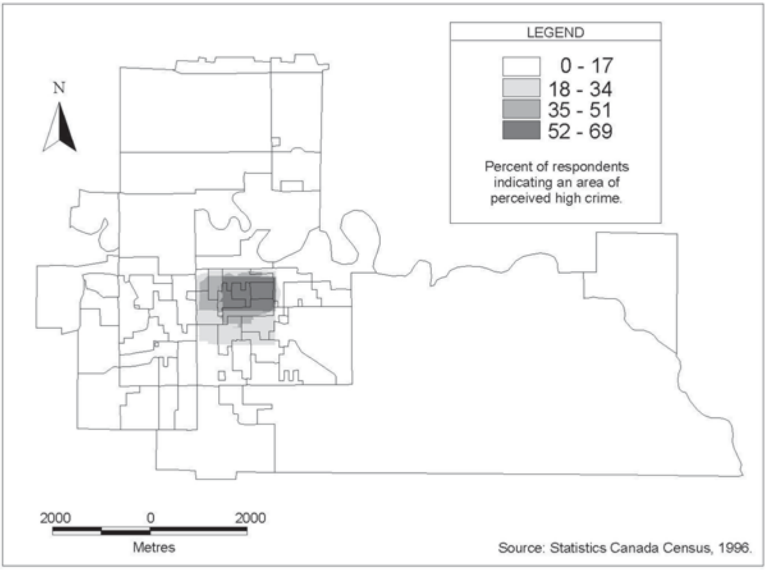

Figure 6: *Perceptual areas of high crime rates.*

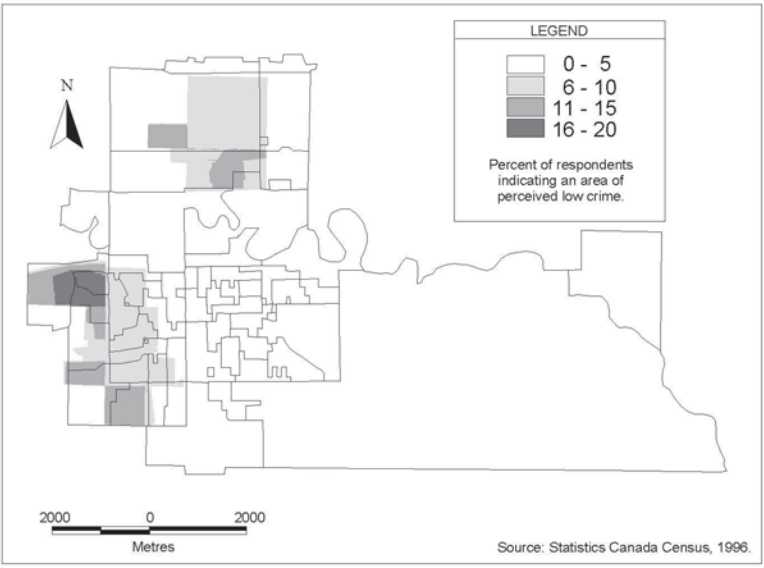

Figure 7: *Perceptual areas of low crime rates.*

Brandon", and second, to "outline the area which you feel has the lowest rate of crime". Once all the surveys had been compiled they were entered into a GIS to develop cognitive crime maps for Brandon (Figures 6 and 7)

Correlation Analysis

Once the survey data had been collected and evaluated, four Pearson's Product Moment correlation coefficients were calculated using the derived crime index. The first two correlation analyses incorporated forty-six observations (N), and compared average household income with the property crime index (**Ci** $_{\textbf{(property)}}$), and average household income with the personal crime index (**Ci** $_{\textbf{(personal)}}$). The other two correlation coefficients incorporated forty-eight observations, and compared the percentage of the population with post-secondary education and the property crime index (**Ci** $_{\textbf{(property)}}$), and the percentage of the population with post-secondary education and the personal crime index (**Ci** $_{\textbf{(personal)}}$).

Results

The results section is divided into three major parts. The first section documents the responses of the surveys sent to 200 residents of Brandon. The second section deals with the correlation analyses, which analyzed the four major variables included in this study. The final section discusses the results that led to the construction of the cognitive crime maps.

Survey Responses:

A survey was mailed to 200 residents of Brandon chosen at random from across the city. Of the 200 surveys that were sent, 100 were returned. In addition to identifying hot and cold areas, respondents provided additional information through two additional questions, concerning their opinions about crime in Brandon. The first of these questions was "Do you feel that personal crimes or property crimes are the most prevalent crimes in Brandon?" It was included in order to assess the respondents' knowledge of crime in Brandon. Of the 100 respondents to this question, 86% correctly judged that property crimes were the most prevalent, 12% felt that personal crimes were most common, and 2% did not respond. The second question was, "Do you feel that most criminals commit crimes in their own neighbourhoods or others?" It was included in order to further assess the perceptions of respondents. Of the 100 respondents to this question, 36% felt that criminals committed crimes in their own neighbourhoods, 47% felt the majority of crimes were committed in others' neighbourhoods and 17% failed to respond. These results will be discussed later in the paper.

Correlation Analysis Results:

It should be noted that the identification of a relationship through correlation analysis does not necessarily mean that a causal relationship exists. That is to say, one variable is not necessarily dependent on the other variable. Any relationship identified by the correlation analysis simply indicates that the two variables react in the same fashion and determines whether the relationship is positive (an increase in one variable is associated with in an increase in the second variable), or negative (an increase in one variable is associated with in a decrease in the second variable).

The first two variables analyzed were the average household income and the property crime index. The calculated correlation coefficient for these variables was found to be -0.541**,** significant at the 0.01 level. This indicates that there is a strong inverse relationship between income levels and the derived property crime index. The next correlation evaluated the relationship between average household income and the personal crime index. A stronger inverse correlation was found with the resulting coefficient being -0.691**,** also significant at the 0.01 level. Thus, both the personal and property crime indices were found to have an inverse relationship with average household income. This supports the first hypothesis that "*crime rates of Brandon will have a negative correlation with income levels*".

The third correlation analysis evaluated the relationship between the percentage of the population with post-secondary education and the property crime index. Once more, an inverse correlation was found, with a correlation coefficient of -0.481. The last correlation evaluated the relationship between the percentage of the population with post-secondary education and the personal crime index. Again, an inverse correlation was found (-0.442). The latter two correlation coefficients were significant at the 0.01 level. This confirmed the second hypothesis of this study that "*crime rates of Brandon will have a negative correlation with education levels*". The weaker relationships involving education level are no doubt related to the differences in the distributions of income and educational levels within the city, and in particular, the more concentrated nature of the low income households in the core area.

Cognitive maps of crime rates:

It had been hypothesized that the "*residents of Brandon will indicate the downtown core area of the city as having the highest rates of crime*". A qualitative analysis of the resulting cognitive maps appears to support this assertion. As can be seen in Figure 6, respondents identified the downtown core as having the highest rate of crime, with over two thirds of the respondents selecting this area. In addition, the second highest area indicated, with 42% to 55% response rates, was also found in the downtown core.

As Figure 7 shows, there are three major areas with perceived low crime rates in Brandon. The first can be found within the neighbourhood known as Riverheights in the west end of Brandon; the other two are found in the neighbourhoods of Hamilton Heights, on the north hill, and the Waverly Park subdivision in the west end. The larger number of cool areas identified accounts for the lower frequency of responses (with a high of about 17% compared to 55% for hot areas).

Cool areas were more widely distributed across the city, and some explanatory characteristics can be found when comparing them with the two socio-economic factors identified earlier. All of the cool areas are located in more affluent areas, with average annual incomes of $24,597 and over, and high rates of post-secondary education. Conversely, the area identified as having the highest rate of crime, fell into both the lowest categories of income ($17,573 or less) and post-secondary education (less than 42% of the population). Thus, the expected relationships between income and education levels, and crime rates, were observed in the cognitive maps of crime.

Conclusion

This study determined that there are statistically significant negative correlations between crime rates and both income and education levels. It was also demonstrated that the majority of Brandon residents identified the downtown core as the area with the highest rates of crime. Although this is a correct perception, the results of the survey indicated that the Brandon Shoppers (sic) Mall (Figure 1), also an area of high (property) crime, is not perceived as such by Brandon residents. This conclusion warrants further investigation, but it is likely a reflection of information received by the respondents — crime at the mall receives less 'press' than crime downtown. It may also reflect the fact that the mall is located in an area with a higher socio-economic status, and such areas are, as the research found, not usually associated in the public mind with high levels of crime.

A more varied response was given to the question regarding areas of Brandon that have the lowest rates of crime. In this case, a number of areas were identified. All were affluent, suburban areas where crime rates might be low, but where the number of crimes might be much higher. Once again this response deserves further research, but also reflects the information available to the respondents from the press. It might also reflect the desire of some respondents to visualize their own neighbourhoods as safer and more crime free than other areas of the city.

Lastly, doubts remain concerning the validity of the results of such a preliminary study, and thus the insights that can be derived from these findings. For example, what exactly does a correlation between the crime rate and the socio-economic status of an area mean? It could mean that the areas of lower status harbour more criminals – and this would appear to be the belief of many of respondents in this study. On the other hand, *it could mean* that the residents of (for instance) the central area of the city are more easily victimized - by people who might live in (for instance) the suburbs of the city.

Consequently, this first geography of crime in Brandon must be seen for what it is — an attempt to begin to identify the challenges and prospects associated with the spatial analysis of crime data collected by the Brandon Police Service. The results indicate that from a crime perspective Brandon is similar to other Canadian and Anglo-American urban areas, and that generalizations made elsewhere can be used to interpret the general situation in the 'Wheat City'. At the same time it is clear that further research has to take place at a finer scale in order to distinguish the characteristics that are particular to Brandon and to begin to provide solutions to the challenges of crime in the twenty-first century. It is hoped that studies such as this will encourage the use of geographical information systems in the recording and analysis of crime, and will contribute to improved crime detection and management practices within the Brandon Police Service.

Acknowledgements

We would like to thank the people who responded to our survey, and the City of Brandon and the Brandon Police Service for their help in data production and analysis.

Notes

1. Using data provided from the Uniform Crime Reports of the F.B.I., Harries produced crude maps to show the rates of eight common crimes committed throughout the United States.

2. It is interesting to note that a relatively new crime series on CBS TV, "The District" uses the ability to combine crime data with a GIS as a centre point of the shows.

3. Brandon has always been treated as one Census Area by Statistics Canada, even though its population of some 40,000 might justify its subdivision into a number of census tracts.

4. Enumeration Areas were designed to "be as compact as possible to minimize travel and optimize census representative work. EAs are delineated so that the census representative may locate them with as little difficulty as possible. Therefore, wherever possible, EAs follow easily recognizable physical features (such as the road network and rivers)" (Statistics Canada 1992, 191). That is to say, EAs were not defined with neighbourhood boundaries or socio-economic divisions in mind.

5. These neighbourhoods are based upon the socio-economic development and physical growth of Brandon over time. They are generally recognised by the long-term residents of Brandon, and were once mapped by the Real Estate Board. This map has since been updated by the Department of Geography at Brandon University as urban growth has extended Brandon's built up area, and the latest version of this figure was used as a base map in this study.

6. Although this process of selection eliminated some problems from the sampling frame, it may have introduced others. For example, the exclusion of EPHs left out concentrations of elderly people who might experience, and perceive, crime differently to other age groups. However, the authors are confident that the sampling process that was used eliminated more problems than it created.

7. Although it is recognized that a map showing the absolute number of crimes might be quite different from one of crime rates - reflecting the different populations of the enumeration areas – the data available for this study was not in a form that could provide an accurate dot density map of crime counts. For this reason, as well as others discussed in the text, crime rates were mapped using a choropleth mapping technique.

8. Although there are sixty-two enumeration areas in Brandon, usable data are not available for all of these. Some areas have no permanent population, and others have numbers that are small enough to cause difficulties with respect to

confidentiality regulations. Forty-six or forty-eight EAs yielded usable data, depending upon the variable in question.

9. A 50% response rate was felt to be good for this kind of survey. The rate was probably improved by a story about the study that appeared in the local newspaper the Brandon Sun concurrently with the implementation of the survey.

10. Significant issues with this kind of analysis can arise from scale effects and the modifiable areal unit problem. These are not issues in this paper as both scale and areal units are constant in the present research design. It would, however, become an issue if comparisons to other studies and cases were to be made.

11. This conclusion is based upon the personal experiences and judgments of the authors. It was confirmed in conversations with media reporters.

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Approving intensive livestock operations: conflict in the countryside in southwestern Manitoba

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Abstract: Confinement agriculture is fast becoming the dominant livestock raising system in North American agriculture. In southwestern Manitoba, this transition is partially led by the recent construction of a large-scale Maple Leaf Pork Processing Plant in Brandon, Manitoba. The current production capacity of the Brandon operation is 2.5 million hogs per year. This capacity will rise to 5 million hogs per year when the plant adds a second shift in 2003. One of the more alarming results of this production facility has been the contentious nature of locating intensive livestock operations (ILOs)[1] in the rural municipalities adjacent to, and beyond the boundaries of Brandon. These local conflicts are reminiscent of the 'Not In My Back Yard Syndrome' (NIMBY) notion that became household language in the 1980s in, and adjacent to, larger cities in North America. This paper examines the existing decision-making process as well as recommendations of two studies of the industry, one independent of government and the other commissioned by the Government of Manitoba. The issues of locating ILOs are further described through content analysis of local media coverage of municipal decision-making. This is followed by an analysis of governance issues that have arisen with respect to hog production and processing in Manitoba. The findings are discussed based upon a force-impact-response model. The paper concludes with recommendations for further research.

Key words: intensive livestock operations, governance, land-use conflicts, agricultural restructuring

Introduction

In recent years there has been a shift in the meat packing industry from locations in urban centres to rural communities. Corresponding with this shift is a movement toward large-scale producer operations, referred to in the literature as confinement agriculture. Most often cited examples include hog production in North Carolina (Furuseth 1997) and the meat packing industries in Iowa (Leistritz 1997) and Alberta (Broadway 1998, 1999, 2000, 2001). More recently, the subject of both hog production and processing has been criticized in Alberta and elsewhere (Epp and Whitson 2001). Furuseth (1997) describes the concentration of hog production on fewer operations and the contraction of these operations into a smaller number of confinement agriculture friendly counties. The work of Broadway (1998, 1999, 2000) and Leistritz (1997) examines the socioeconomic impacts of large meat packing plants in rural communities. Work such as this provides a framework for examining the changes currently taking place in southwestern Manitoba.

The province of Manitoba is experiencing intensification in the hog sector. Since 1995, hog production has increased faster than at any other time (Figure 1). In addition to a proposal from Schneider's in Winnipeg to add a second shift, the 1999 opening of the Maple Leaf hog processing plant in Brandon, Manitoba has created a demand for hogs to be produced locally. As a result, the construction of ILOs has both proliferated across southern Manitoba[2] and become a contentious issue within municipalities where ILO proposals are being brought forward. The provincial government recognizes both the economic importance of the hog sector to agricultural communities in financial crisis and the potential negative impacts of such operations on the environment, the health of citizens and the communities in the vicinity of hog barns.

The purpose of this paper is to analyze the impacts of restructuring the hog industry in Manitoba on farms and in communities, and the responses of farmers and communities to these impacts. First, a conceptual framework, based on political economy, is presented for the analysis. Second, the context of the hog-raising and processing sectors is outlined

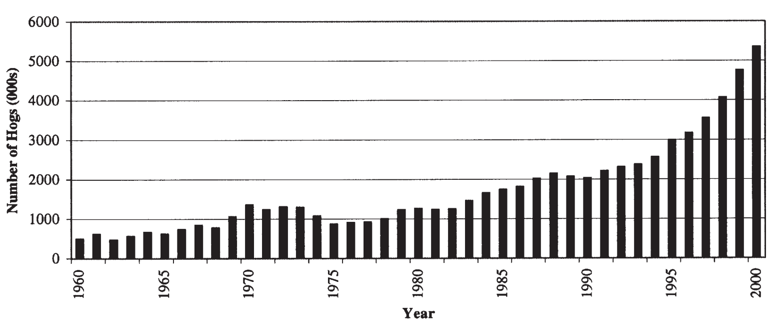

Figure 1: *Hog production in Manitoba, 1960-2000 (Source: Manitoba Agriculture and Food 2001a).*

beginning with a description of the Maple Leaf operation in Brandon. This leads to the main focus of the paper, namely assessing the impacts of, and responses to, ILOs in southern Manitoba. Four sources of information are examined for this assessment, namely: two reports on public hearings; content analysis of local media coverage on the issue; and, the recent provincial convention debate on resolutions put forward regarding the hog industry in Manitoba. The implementation of large-scale, confined modes of hog production and processing and the restructuring of the hog sale system were the domain of a Conservative government in Manitoba, particularly between 1988 and 1999. However, a change in government to the New Democratic Party (NDP) in 1999 left the party with difficult questions about the raising, selling, and processing of hogs in Manitoba, particularly given the uncertainties facing farmers in the post-Crow Rate era (Ramsey and Everitt 2001).

Conceptual Framework

Troughton and Leckie (2000) have explored the nature and impacts of confinement agriculture, and in doing so, offered it as subject matter ripe for study in contemporary agricultural geography. Among the seven concluding points Troughton and Leckie made about confinement agriculture was the suggestion that models of political economy need to be adopted in a more central way if modern agriculture is to be described and explained in any substantive way. One potential model, not uncommon in agricultural geography, is the force-impact-response model (Ramsey and Smit 2002; Bradshaw and Smit 1997; Smit *et al*. 1996)

The model applied in this study (Figure 2) has been modified from past force-impact-response models. It adopts the force-impact framework put forth by Ramsey and Smit (2002) by recognizing a range of external forces (economic conditions, policies, and three environments—production, biophysical, and social), as well as impacts on both farmers (individual and family condition) and communities (economic functions, institutional and informal structures, conditions). The model also includes responses in a similar fashion to that developed by Ramsey *et al*. (2002). That is, faced with changes and the impacts brought on by these changes, farmers can respond by continuing as is, modifying existing operations, re-specializing to another agricultural product, diversifying into other agricultural products, or exiting agriculture altogether. Likewise, a community's response is a matter of degree as it is driven by the impact

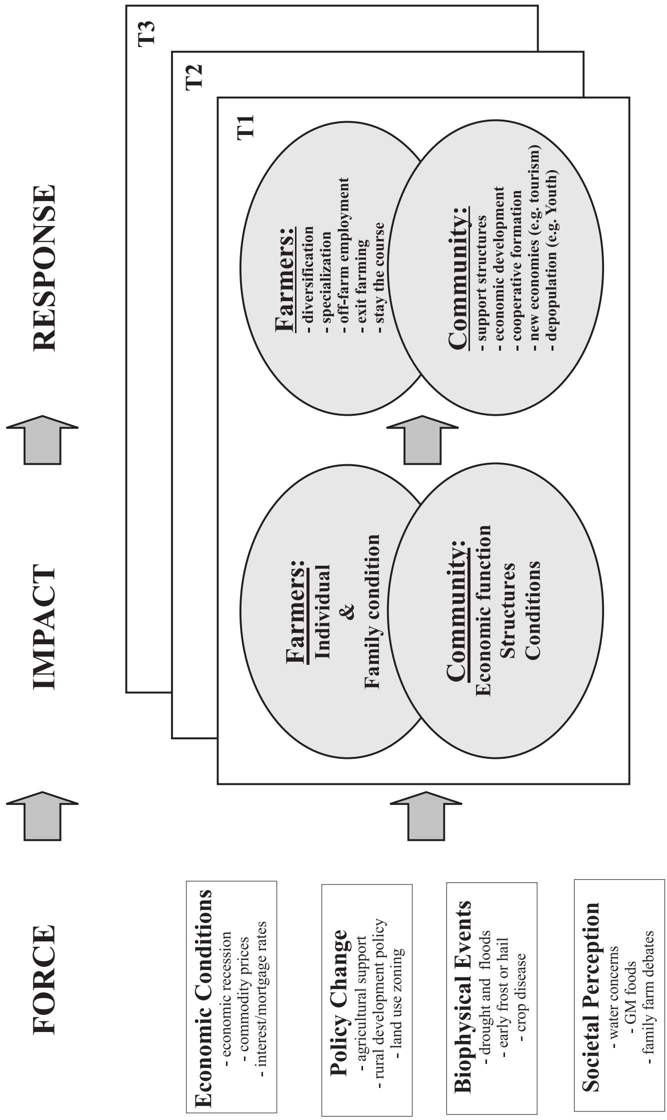

Figure 2: *Force-impact-response model for hog production in Manitoba.*

the forces have on the community. This paper adopts this force-impact-response approach to theorize about confinement hog production.

Analysis of the Hog Industry in Manitoba

Background:

Manitoba is the latest Canadian province to develop its hog industry. Its contribution to the national hog production is growing rapidly. While accounting for only about 3 percent of the total human population in 2000, Manitoba accounted for 22.7% of the total hog production in Canada making it the third largest producer behind Québec (28.8%) and Ontario (24.0%) (Manitoba Agriculture and Food 2001b). In 1990, total hog production in Manitoba was 2 million—a decade later that figure was 5.35 million. Over the same period the number of hog farms declined by 55% from 3,150 to 1,430. Whereas hog production was once the domain of the family farm, the decade of the 1990s saw hog production accelerate along with the number of large-scale operations and in particular, confinement raising systems. The average number of hogs per farm has more than tripled over 1990 levels.

Prior to mid-1999, hog processing in Manitoba took place in Schneider's plants in Winnipeg and the Springhill plant in Neepawa. In July 1999, the first shift at the Maple Leaf hog processing plant began. Soon after, an average of 45,000 hogs were being processed each week. This is similar to the processing rates at Schneider's hog processing plant (Springhill processed 20,000 hogs per week under contract from Maple Leaf Foods). Both plants are proposing a doubling with additions of second shifts.[3] Maple Leaf is expecting to introduce its second shift in either 2002 or 2003 with an expected production average of 90,000 hogs processed at the Brandon plant each week.

The demand created by the Maple Leaf processing plant also created opportunities for local producers to increase their hog production. The developing relationship between processor and local producers notwithstanding, Table 1 lists additional reasons why hog production and processing is on the rise in Manitoba (Fallding 2001).[4]

While many of these conditions have existed long before the recent spike in hog production, it could be that the unique combination of these factors at this point in the history of the hog industry has produced the spike. Furthermore, a case could be made that some of the reasons are not reasons but rather the *consequences* of the growth in hog production.

Table 1: Reasons for the increase in hog production and processing in Manitoba.

Factor	Reasoning
Availability of feed grains	• Southern Manitoba is primarily agricultural land used to grow grains for market. • The feed grain market provides the opportunity for farmers to diversify. • Local markets also mean reduced transportation costs for farmers.
Diversification of risk	• Commodity prices have been fluctuating at or below current levels limiting farm net income. • By diversifying activities farmers can, in theory, reduce the fluctuations in their net income by being less reliant on one commodity.
Increasing world demand for agricultural products	• An agricultural economy is in a prime position to meet this growing world demand and in particular pork products.
Crow Benefit	• The Crow Rate for grain was eliminated in 1996. • As a result farmers need to seek new economic opportunities.
Technology	• Improvements in environmental controls, management systems, computerized feeding, climate control, animal husbandry and genetics have improved efficiency and productivity regardless of location.
Investment and profit potential	• Input costs are low and the return on investment is between 10 and 15 percent. Rural areas are a source of cheaper labour than urban centres. • As it takes few people to run a a high tech ILO, concerns of farm labourers organizing is reduced.
Synergy	• Large-scale hog processing provides economies of scale, corporate ownership, and control over inputs throughout the production chain (vertical integration). • Production and processing grow in concert.
Government policy	• The Government of Manitoba and the City of Brandon provided huge incentives to Maple Leaf in exchange for them locating in Manitoba and in particular, Brandon. • For example, incentives included relaxing environmental laws - Clean Environment Commission hearings were never held despite public requests for hearings - and a promise to Maple Leaf not to return to single-desk selling.

Source: Fallding 2001

Finally, with the exception of the availability of feed grains and the willingness of the provincial government to make concessions, these factors are not unique to Manitoba, yet it is Manitoba's hog industry that is growing; or perhaps circumstances in other jurisdictions play a role in the Manitoba situation. All of these points are outside the scope of this paper and would best be addressed by further research.

One last background factor needs to be mentioned, namely the manner in which decisions regarding the location of ILOs are made. In Manitoba the decision-making process can proceed along one of two paths, depending upon whether or not the proposed site of the ILO is in an area where a land-use plan exists. If a land-use plan does not exist then the local government has no direct involvement in the decision-making process. Their role is restricted to making presentations to senior government. It is the province that makes the decisions at each step. Alternatively, with a land-use plan in place the project proponent consults with staff from the Rural Municipality (RM) office, Manitoba departments of Agriculture and Food, Intergovernmental Affairs, and Conservation. Application for a development permit is made to the RM/Planning District which then consults a provincial Technical Review committee. Where livestock production is a permitted use (subject to zoning by-laws) a development permit is issued. At this point the provincial government (Manitoba Conservation) grants permits for manure storage and water rights. The RM/Planning District works alongside the government throughout the project. It is worth noting that despite the decision-making powers of the province's Planning Districts, the province retains the right, under the Planning Act, to approve or disapprove of land use.

Citizens' hearing on hog production and the environment:

Once the announcement was made that Brandon was being considered as a site for a large-scale hog processing plant concerned citizens began talking about the potential negative impact it would have on the environmental, economic, social, and public health aspects of the region. When Maple Leaf Meats (MLM) was granted the appropriate permits and licences without holding Clean Environment Commission hearings, these local citizens held their own hearing (Canadian Centre for Policy Alternatives-Manitoba 2000). In addition, the hearing commissioners examined articles describing large-scale meatpacking operations in other jurisdictions. The subsequent report is organized around the five major categories that emerged from the hearings—public health, general demographic aspects, social aspects, economic aspects, and environmental aspects. Table 1 identifies the scope of each category and highlights the conclusions drawn by the commissioners. No single category was identified as being more important than the others. On the contrary, the categories are described as mutually interdependent. This characteristic is evident in Table 1.

The Government of Manitoba endorses the concept of 'population health' the foundations of which are nine determinants of health (Manitoba Health 1997). The information received during the hearings was relevant to three of these determinants—income and social status, employment

Table 2: *Summary of potential impacts identified at the public hearing in Brandon.*

Category	Scope	Highlights/Conclusions
Public health	Applicable determinants of health: income and social status; employment and working conditions; safe and clean physical environments.	"Human health, as defined by the World Health Organization and the governments of Canada and Manitoba, is also clearly compromized..." (Canadian Centre for Policy Alternatives-Manitoba 2000, 13).
General demographic aspects	Hog production; processing plants.	A decrease in the number of stable family units and an increase in transient, single workers resulting in a change in age composition, family structure and ethnic composition.
Social aspects	Large-sacle hog production; large-scale meat processing.	• Associated problems include: homelessness, crime, domestic violence, child abuse, employee turnover, reduced wages, lack of adequate low-cost housing, health problems (associated with high-speed worker lines), and stress on the education, social services and communication infrastructure. • Corporation becomes more powerful than local government
Economic aspects	Private benefit and public cost; public good; sustaining individual producers and rural communities; economics of regulation; future of agriculture; future costs: who should pay? Who will pay?	• Unclear who is liable for the costs of future remedial work and liability - fear is that the public will bear the costs. • Vertical integration forces individual producers out of business and contributes to a decrease in rural population.
Environmental aspects	*Production* - emissions, waste and waste disposal, water consumption. *Processing* - water demand, odour, liquid waste, solid waste, downstream concerns.	• Reduced volume of water available for other uses. • Health problems related to emissions. • Odour a problem for people living downwind. • Contamination and pollution of ground and water.

Source: Canadian Centre for Policy Alternatives-Manitoba 2000

and working conditions, and safe and clean physical environments. While it was recognized that new jobs would be created by the growth in the hog industry, wages are known to be consistently lower than average per capita income and there is a high rate of employee turnover (averages 100% annually). Under these income and social conditions the health of the population is compromised with increases in homelessness, crime, domestic violence and demands for social assistance. There is a high rate of injuries and illness, especially chronic respiratory illnesses such as asthma and bronchitis resulting from an unsafe and dirty working environment.

The rural landscape changes as family operations are forced out in favour of corporate owned, industrial production. High turnover rates and a depleted local labour force changes the age-composition, family structure and ethnic composition of communities. Small communities are particularly affected.

Overlapping the shift in demographics is a series of additional social changes identified at the hearings. These include a loss of local control over decisions affecting the community resulting in local strife among residents and a decrease in public confidence as large corporations negotiate incentives with senior governments. Large-scale corporations tend to integrate all functions of the hog industry forcing smaller suppliers, usually locally owned, out of business in favour of cheaper inputs. Loss of local business results in a decrease in a community's population. Furthermore the increased demand on the health, social, and justice systems requires a shift in the corresponding infrastructure.

The report recognizes the fact that the industry brings the promise of new jobs, increases in population, increases in the tax base, and the establishment of new businesses; however, the report also points out there are significant public costs, too. In addition to having a social impact, there would be an economic impact. First, the social infrastructure would need to be increased. Second, money that would normally multiply by staying in a community would now leave the community and go to corporate headquarters. Finally, concern was raised about who would end up paying the future costs of upgrading the water treatment facility, liability for downstream damage, decommissioning and clean-up costs and monitoring costs for compliance with licence and secondary environmental impacts. The general fear was that because of gaps in federal and provincial legislation it would become a public cost.

Concern over the environmental impact included air quality, contamination and pollution of surface and ground water as well as the ground itself, and the increased demand for water. All of these aspects were feared to affect human health and the surrounding ecosystems. Again, government legislation was seen as being inadequate.

The report made eleven recommendations with four themes emerging. Four recommendations targeted legislative changes at both the federal and provincial levels including provisions to help governments resist the temptation to provide large subsidies for corporations to locate in certain areas. The recommendations point out the need for greater public participation and access to documents. Finally, the role of government in areas such as cooperating with municipalities and reviewing and supporting research into the impact if ILOs on water and human health is described in four of the recommendations.

Livestock stewardship panel:

Four months after the Citizens' Hearing on Hog Production and the Environment the Government of Manitoba formally announced its Livestock Stewardship Initiative with the aim of "ensuring the sustainable development of Manitoba's livestock industry" (Tyrchniewcz *et al*. 2000, 1). The public hearing process began with the release of a discussion paper in June 2000, followed one month later by ten days of hearings before the Stewardship Panel in six southern communities—two urban (Winnipeg and Brandon) and four rural (Morden, Arborg, Dauphin and Steinbach). To clarify points raised in the submissions the Panel also met with key industry, government, and public interest stakeholders.

Table 3 indicates that environmental monitoring and evaluating proposals were the topics most often raised at the hearings. The other popular issues were property values and property taxes and the overall economic impact. These four items represent 82% of the total. Further analysis of the topics reveals that presentations were predominantly in favour of expanding the hog industry and were more inclined to make suggestions for improvements rather than condemning the initiative. For example, most presentations indicated that current regulations (i.e., assessment and environmental) were acceptable; however, monitoring and enforcement of these regulations was inadequate.

Lack of enforcement of environmental regulations was raised at each hearing. Presentations on the topic of the environment repeatedly identified concerns about air and water quality and manure management. Performance bonds and educating producers were often cited as being necessary. Common themes within the evaluating proposal topic included

Table 3: *Summary of topics livestock stewardship public meetings.*

Topic	Morden	Arborg	Brandon	Dauphin	Winnipeg	Steinbach	Total
Environmental monitoring	8	16	12	3	14	8	61
Evaluating proposals	5	7	9	3	9	6	39
Property values and property taxes	3	2	4	1	4	5	19
Overall economic impact		3	4	2	3	3	15
Other issues	3	2			3	2	10
Labour			2	1	2	2	7
Farm ownership		2	1	1	1		5
Public health			1		2	2	5
Animal welfare					2	1	3
Totals	19	32	33	11	40	29	164

Source: Tyrchniewcz *et al*. 2000, 14-21 (in no particular order): (1) encouraging public input; (2) decisions based on science; (3) providing written reasons for rejection; (4) the AU (animal units) limit; and, (5) making available an appeal process.

Presentations were more likely to cite the tax base advantages than any disadvantages. However, to put it into context there were just as many voices recommending further studies of the impact of ILOs on property values. Urbanization of farmland and zoning by-laws were frequently mentioned as areas of concern with respect to property. A positive outlook about the overall economic impact was ubiquitous. Only in Brandon was concern raised about large barns creating few jobs and the fact that they do not buy locally. The concept of new generation cooperatives[5] versus vertically integrated operations was mentioned a number of times under the topic of farm ownership. Overall, research was mentioned as necessary in order to better evaluate proposals and monitor environmental impacts. Research was also recommended to better understand the effects of the location of ILOs on property values and to compare the illness and injury rate in the hog industry to other industries.

The Panel concluded that a number of key issues required further analysis. Four research roundtables were convened to further explore issues of water quality, air quality, manure management, and monitoring and information systems. Scientists and practitioners knowledgeable in these matters were invited. The final report, released in December 2000, included 40 or so recommendations in four key areas. First, the role of the provincial government in sustainable livestock development was the focus of about two-thirds of the recommendations. The overarching recommendation called for a commitment of human and financial resources to: (a) examine the hog industry in the overall context of agriculture in Manitoba; and, (b) provide a regulatory framework and a monitoring and enforcement effort. The second recommendation called for reliable information to be made available to the concerned public. The role of ILOs in sustainable rural development was the focus of the third recommendation. Intensive livestock operations were viewed as only an option. Farmers not wishing to go the ILO route should be assisted. The final recommendation supported provincial and municipal participation in the decision process for siting ILOs, with the province responsible for the environmental impact before construction begins. As of September 2001 the province has yet to respond to these recommendations.

Media coverage:

The rate at which the media covers an issue can be considered an indication of its public interest, at least in the mind of the media—the greater the public interest the greater the coverage. A total of 40 articles on the hog industry appeared in the six newspapers surveyed.[6] It should be noted that the high number of articles found in the *Brandon Sun* may be explained in part because of its regional coverage, that is, articles would be written about other communities as well as the Brandon situation. The Panel included two public meetings in Winnipeg as part of the consultation process. In spite of this fact, the urban media - *Winnipeg Sun* and *Winnipeg Free Press* - reported little on the issues.

Most of the articles relating to the hog sector focused on the debate in and around municipal council meetings over the location of ILOs, and the effects such debates have had on families and communities. For example, Arbor Mayor Bert Kindzierski told the Panel "previous mega-livestock projects have created internal family conflicts as well as made enemies out of neighbours" (Spring 2000, 1). However, collectively, the issues that were raised were not mutually exclusive. For example, the debate over the cost of ILOs as a form of economic development was discussed in terms of air quality, water quality (especially drinking water), and manure management to name a few.

Governance:

The Sustainable Livestock in Manitoba report and the NDP government's continued support for both the hog processing and industrial hog production sectors warrants a discussion of 'party' versus 'government' policy. The provincial party has longstanding policies that support the family farm, single-desk selling and labour rights. However, the agricultural resolutions debated at the provincial convention in Winnipeg in February 2001 raise questions about whether implementing such policies will take place. Only three of the nine hog-related resolutions submitted to convention were debated (Manitoba New Democratic Party 2001). The first motion, which was distributed to Convention delegates as an emergency resolution, called on the federal government to recognize the farm crisis (Turtle Mountain NDP Riding Association 2001). The delegates gave unanimous consent to this resolution. The provincial government followed up this consent with a motion in the legislature calling upon Ottawa to recognize the scale of the agricultural crisis in Manitoba, and to provide $500 million in immediate emergency assistance. Following unanimous consent in the Legislature, an all-party standing committee on agriculture conducted public meetings across the province to hear the voices of concerned citizens. The results of these meetings and the unanimous resolution have been presented to the federal government. As of September

2001 the Federal Government had not responded. However, it should be noted that in the fall of 2001, a Liberal Caucus Committee held a number of meetings across Canada allowing citizens to voice their concerns about the future of farming in Canada. These meetings included two Manitoba stops, in Winnipeg.

A second motion called for a return to single-desk selling[7]of hogs and was also distributed to Convention delegates as an emergency resolution (Interlake NDP Riding Association 2001). The Conservative Government eliminated single-desk selling in 1996. While not receiving unanimous support, this motion was also supported by a large majority. This motion, however, sparked the longest debate of the convention (Fallding 2001) including a shouting match that resulted in one delegate being called upon to apologize to another. While the amended motion passed, it appears it is moot for two reasons. First, Rosann Wowchuk, Minister of Agriculture, supports the motion only if the farmers want it, although it remains to be seen whether those hog farmers displaced by the elimination of single-desk selling and the move toward confinement production systems will be included in such a discussion. Second, media reports have quoted the Premier as promising Maple Leaf Meats that there will be no return to single-desk selling. In a media interview following the debated motion, the Premier stated, “the majority of producers don’t want to return to [single-desk selling]” (Fallding 2001, A1). A key informant interview conducted with an individual within the agricultural ministry stated that the comments by the agricultural ministry and the Premier could be based on discussions with both agricultural representatives and discussions with farmers that took place during a series of ‘rural tours’. It appears that this outreach is an attempt of a largely urban and northern based governing party to better understand the issues facing Manitoba farmers.

The third motion called for an immediate moratorium on further construction of ILOs until the issue could be assessed. The debate included contributions by two cabinet ministers, including the agricultural minister, expressing concerns that such a moratorium would have negative impacts on farmers and hog industry. A vote was called by the moderator, while delegates were still lined up at both the ‘pro’ and ‘con’ microphones. The motion was defeated. Based on participant observation it was clear that those voting for the motion represented primarily the two Brandon riding associations and southern agro-Manitoba riding associations. While this may not reflect a formal ‘split’ in the party between the northern and urban centres (less Brandon) and agro-Manitoba, there did appear be a lack of understanding of the impacts ILOs could have on the rural landscape and in rural communities. The complexities of the issues regarding ILOs in rural Manitoba have been illustrated in the media prior to and following the NDP convention. Examples include a fire chief in Lowe Farm, Manitoba resigning over concerns related to ILOs not having to follow the same building code requirements (e.g., sprinkler systems) as other commercial operations (Friesen 2001), and more recently resident concerns about water quality issues (Dalla-Vicenza 2002).

Discussion

Force:

Forces affecting, or causing the movement towards confinement hog production are complex and interrelated. Economic conditions include the demand for hogs established by the location of the Maple Leaf hog processing plant in Brandon. This has followed with the proliferation of corporate interests (e.g., Elite Swine, a subsidiary of Maple Leaf) who are aggressively seeking out locations and interested individuals willing to enter into an ILO contract. Also, the crisis in the grain sector has resulted in farmers seeking alternative farming ventures in which to engage. The policy environment affects the hog sector in two ways. First, the provincial government is supportive of the hog industry as it is perceived to provide skilled labour both in processing and hog raising and thereby scores political points in addressing the farm crisis in southern Manitoba. In fact, Assiniboine Community College in Brandon recently began offering programs designed to provide skills to ILO workers. Second, while municipal governments facing declining populations are often concerned with negative impacts, they equally welcome the economic development ILOs provide through increasing the tax base and maintaining the population base.

While the growth in the hog industry may be viewed as an economic blessing for rural and small towns, there are also environmental, public health and social issues related to the production and processing of hogs that impact farmers and communities. Restructuring of hog production and processing are relatively new to Manitoba, but their reputations precede them (Broadway 1998; Qualman 2001). In other jurisdictions there have been serious environmental, public health and social impacts wherever ILOs or large-scale processing plants have located.

Impact:

The impact on Brandon could be seen shortly after it was announced that Brandon was to be the site of a new and modern hog processing plant.

Supported by the experiences of other jurisdictions in a similar situation, area residents began expressing concerns about the environmental, public health and social impacts of the Maple Leaf operation. Concerned citizens demanded their government hold Clean Environment Commission hearings, but the government refused. Under a cloud of suspicion, Maple Leaf Meats was eventually granted the necessary development permits by the Brandon and Area Planning District and the provincial government. Opening of the business then set the stage for a series of debates in municipal chambers in southern Manitoba regarding ILO location and development.

The less than open communication surrounding the granting of the development permits to MLM fueled speculation concerning the secrecy. Why, for example, would the government not hold public hearings on the issue when the public clearly sought such hearings? It is possible that the government firmly believed that there was no basis for concern, that is, the public was overreacting and therefore there was no need to waste taxpayers' dollars on Clean Environment Commission hearings.

If this were the case then why would the provincial government be so reluctant to make public the government-MLM agreement? Refusing to hold public hearings combined with secrecy around the agreement with MLM leads one to come to at least three possible conclusions. First, making information public either through public hearings or documents, would, in the eyes of the government, jeopardize MLM settling in Manitoba. After all, Manitoba was only one of many players vying for MLM's business. Without disclosing the terms of the agreement the public will never know how much MLM was offered in incentives to choose Manitoba for their operation

The second possible conclusion feeds off of this last point. With different jurisdictions bidding for their business, MLM is in a clear position of power. They are certainly more powerful than local governments, and some would argue even more powerful than the provincial government (Qualman 2001). The lack of clear federal and provincial government responsibilities leaves the public, not the industry, vulnerable for future costs associated with everything from monitoring the environmental impact to cleaning up if MLM decides to leave. In fact, following this argument a step further, MLM, or any other industry that pits one jurisdiction against another, is committed to their present location only to the extent that the current location begins to turn a profit and a better incentive package comes their way.[8] While these conclusions are speculative, they are consistent with the recommendations of the government's own Livestock

Stewardship Panel (LSP) which calls for greater public access to information and participation in the decision-making process in the future.

A third conclusion could have to do with nothing more than political timing. The Progressive Conservative Government was in power in Manitoba from 1988 to 1999. With a stronghold in southern, agro-Manitoba, this government eliminated single-desk selling in the hog sector and constructed the deal to develop the Maple Leaf plant in Brandon. As the plant opened the political landscape changed. Not only did the NDP return to power, they did so by electing Members of the Legislative Assembly (MLAs) in two agricultural ridings and in both Brandon ridings. Given the agricultural crisis and the perception that the Manitoba NDP is urban and northern based, the new government faced a great deal of pressure to not only honour existing agreements but also to endorse and further develop the hog sector.

Both the Citizens' Hearings on Hog Production and the Environment and the Livestock Stewardship Panel agreed that the growth in the hog industry poses serious environmental, public health and social risks to Manitobans with the effects on the quality of air, water and land being the areas of most concern. The fact that changes in the hog industry in Manitoba can stimulate both government and non-government debate and attract the media coverage that it did is testament to the impact this issue has had on the citizens of Manitoba for whatever reason. Perhaps it is the shock of the shear magnitude and swiftness of the changes, or the reputation of the industry that people are reacting to. It is an issue worthy of further research as the government considers the Panel's recommendations. This point is discussed below under 'Response'.

While the two public hearings agreed on many issues there was one clear difference. Public opinion in the Panel hearings tended to view the growth in the hog industry as supplying new jobs, reversing the decreasing population trend in small towns thereby increasing the local tax base, and attracting new businesses. That is, the Panel viewed properly managed ILOs as having a positive economic impact. This could be construed as a ray of light in an otherwise dark and gloomy picture (i.e., environmental damage, lack of public participation, threats to the family farm and threats to public health). However, while job creation is a given, there was no mention of the *quality* of the jobs created.

Industrialization of the hog industry has been around since the mid-nineteenth century, but recent restructuring has meant even more specialized assembly line operations and subsequently a greater division of labour. The work is repetitive, requires little skill, and is boring for the workers. This is evident in high turnover rates at non-unionized plants where wages have been reduced (Broadway 1999; Novek 1992). While more jobs are created, there was no mention in either of the reports of other jobs that would be threatened or even lost as a result of this restructuring. For example, meat cutters at one time were a highly regarded and valued trade because of their skill in cutting the whole animal. Today, modern meat processing facilities have reduced the demand for this trade and replaced it with value-added processing and a series of single tasks requiring less overall skill.[9] Furthermore, the vertical integration of the industry means the industry controls the majority of the inputs. By virtue of economies of scale, large corporations purchase their inputs more centrally thus putting local suppliers out of business.

This raises the further question of how much of the corporate profits stay in the community and how much leaves? For example, owners of family farms residing in the area would normally buy locally. In contrast, the corporate owners of MLM do not live in Brandon and are likely to spend very little in the city. As hog production also goes the way of the corporation it is safe to assume their owners do not live and spend money in the community where the ILO is located. Presently, one can only speculate on the overall economic impact. Some shift in the local economy is definite. The question is, when the 'new' economy stabilizes will there be more, or less, money in the community? It is a complex question that can only be answered with further research.

Before leaving this last point there is one more detail brought out in the analysis worth discussing in this context. The sudden and massive increase in demand for hog production appears to have put added pressure on the family farm and the families themselves. The trend amongst hog farmers is not unlike the trend in agriculture in general towards fewer, but larger farms. When the demand is for over 5 million hogs per year farmers with small operations are faced with questions that are not easily resolved, for example: do I join the trend and diversify into livestock? and, can I afford to grow that much, that fast? Economies of scale favour the largest operators while smaller ones may succumb to working under contract for larger operations, or be squeezed out of farming altogether. This situation is likely to result in fewer family owned farms and more corporate owned farms. Stories reported in the news cite how this decision is dividing families (Spring 2000).

After two years of operating with one shift, a number of socio-economic issues have surfaced: absenteeism (particularly the day after payday), alcoholism, and high turnover rates. Brandon faces housing shortages that will be exacerbated by the addition of the second shift and the expansion of the Shilo military base just west of the city. Based on a survey of first shift employees at MLM, Rounds (2000) predicted the impact of MLM on transportation, housing, daycare, education, and employment in Brandon. Rounds predicted that each of these areas would impact the city in the future irrespective of a second shift being added.

A number of environmental mishaps have occurred with respect to effluent from the plant. Of particular concern were two occasions in the summer of 2000 when breakdowns in the ultraviolet system for disinfecting waste water occurred and resulted in a breach of the agreement Maple Leaf has with the City of Brandon. On the subject of water, the City and Province provided the $12 million for the plant that is exclusively used by Maple Leaf Meats, thus all results relate directly to the operation. City engineers operate the water treatment plant and the City plans to convert its chlorine system to the ultraviolet system in question (Nickel 2000).

While it is the purpose of this paper to examine the impacts and responses of large-scale meat packing and ILOs on rural life, it is worth stepping back, if only for a moment, and look at the bigger picture. Decisions to locate ILOs have been controversial mainly because of the negative impacts they could have on the quality of life in communities and on the pristine countryside (even urban dwellers, wishing to escape the stress and pollution of the city, will retreat to the countryside from time to time). In the larger context there seems to be a growing trend for rural communities to be faced with decisions that threaten their quality of life. In addition to decisions about locating ILOs, rural municipalities have recently been faced with big decisions regarding the intake of solid or hazardous waste from urban centres whose landfill sites have reached capacity or are unsuitable. Historically, rural residents did not have to face such ‘unpleasant’ decisions.

Response:

Data suggest that farmers are responding by getting out of hog farming (i.e., the decrease in the number of hog farms from 3,150 to 1,430) or trying to compete by diversifying their farm operation to include ILOs (i.e., increase in the average size of hog farms). This conclusion is based on secondary data. A more accurate picture would come from interviewing farmers to see how much effect the change in the hog industry had on their decisions, especially those that chose to leave hog farming or even farming altogether. Furthermore, as the force-impact-response model indicates it would be necessary to examine farmers’ responses over time. The amount of time would depend on how long it would take the hog industry to 'normalize' in the province and thereby give farmers adequate time to respond.

Similarly, it is too early to get a full picture of how communities are responding. The immediate impact appears to have divided communities, but it is too soon to examine how communities will change as a result. The work of Rounds (2000) suggests that many of the formal structures in Brandon will have to adjust in order to accommodate the impact of the first shift of MLM workers (i.e., transportation, housing, education and daycare). Informal conversations indicate that MLM has forced lower-end wages upward. This would be logical since the Brandon and area labour market has been exhausted and MLM is beginning to import labour from other parts of Canada. Recently, they returned from a recruiting mission to eastern Canada were they reported recruited 100 new employees (Nickel 2001a). More recently, MLM has recruited workers from Mexico (Nickel 2001b; Bird 2001).

A logical time to do primary research on the impacts and responses of the hog industry on southern Manitoba, and in particular Brandon, would be just before MLM introduces their second shift, currently projected to be 2002. This would establish a benchmark to compare the responses and impacts of the second shift.

Finally a broader analysis of the newspapers could enhance understanding of the impacts and responses of the hog industry by providing more data to draw from. This paper analyzed only newspapers within the same timeframe as the hearings and within the readership of the local papers. A wider, longer timeframe of analysis would yield more data because in reality such impacts and responses reach beyond a one-month time period and the six communities. In addition, newspaper coverage of the hog issue could be compared to other issues (e.g., Minnesota's water diversion project and its implications for Manitoba) for frequency, amount and scope of coverage as indicators of the public's concerns. This would put the hog issue into perspective relative to other major issues facing Manitobans.

Conclusion

With the support of the provincial government, both Progressive Conservative and New Democrat, Manitoba has become a major producer of hogs in Canada. From 1990 to 2000 the number of hogs produced in

Manitoba increased from 2 million to more than 5 million and that number could increase still further if local production can match demand when the Maple Leaf hog processing plant adds a second shift in 2002.

This paper analyzed secondary data within the context of a force-impact-response model to ascertain the impact of large-scale corporate owned hog processing in Manitoba on farmers and communities and their subsequent responses. The impact was felt immediately after it became known that Brandon would be the site of a new, state-of the-art hog processing plant owned by Maple Leaf Meats. After being denied Clean Environment Commission hearings local citizens organized their own hearings. Subsequent to those hearings, but after Maple Leaf Meats was granted a development permit, the provincial government initiated a Livestock Stewardship Panel. These two documents formed the basis of the analysis in the paper. Local newspaper coverage and pertinent resolutions at the NDP convention rounded out the data for analysis.

It would appear that the province limited public access to information as well as public involvement in the initial decision. The direct impact of this unilateral decision has forced local municipalities to make decisions about the location of ILOs when ILOs are neither clearly desirable, nor undesirable. The ensuing debates have divided community members and communities, pitting proponents of economic development against proponents of protecting the environment and their quality of life as expressed in property values, labour issues, farm ownership and public health. Thus far it appears that proponents of economic development are prevailing.

Documented responses are few at this point. Discussion with community members and continued monitoring of the hog sector, both production and processing, is needed to establish a full picture of how farmers will react and communities change. There are implications for the smaller farm operations and community infrastructure such as transportation, schools, daycare, and social network. Early indications suggest that hog farming is mirroring the agriculture industry in general insofar as it is exhibiting a trend towards fewer but larger farms.

The topic of restructuring of the hog industry is not new but continues to be a controversial one (Hart and Mayda 1997). As the hog industry continues to grow rapidly in Manitoba it is important to continue researching the impacts on farmers and communities and their responses.

Notes

[1] Intensive Livestock Operations, or ILOs is a term used in Manitoba and Saskatchewan. In Alberta they are referred to as Confined Feeding Operations, or CFOs. Both terms refer to an indoor, confined mode of production as compared to the age-old method of raising hogs outdoors where the animals can roam freely.

[2] "Between 1990 and 2000…the average number of hogs per farm has more than tripled—increasing from 388 head to 1,290 head" (Manitoba Agriculture and Food 2000, 7). Coinciding with ILOs is fewer hog farms with more capital investment per farm. This point is discussed below under 'Analysis of the Hog Industry in Manitoba'.

[3] Since completing the research for this paper Maple Leaf Foods purchased Schneider's. The future expansion of the Winnipeg plant is in doubt.

[4] The full extent of the incentives has never been established. Repeated efforts to have access to the agreement with Maple Leaf Meats by interested parties was denied; and, when information was forthcoming, it was edited with large sections blacked out casting further suspicion as to whether they acted within the boundaries of their own legislation.

[5] In a New Generation Cooperative, or NGC, selected or closed membership gives the holder the right to vote and the right to purchase equity shares, which are attached to delivery rights. NGCs are organized to add value to an agricultural commodity. In the traditional cooperative membership is open and members receive patronage payments that are unconditional.

[6] Because the inventory was conducted long after the hearings were completed surveying electronic media would be difficult and not as accurate as newspaper.

[7] A single agency markets the hogs on behalf of all producers assuring equitable payment for comparable hogs. Without single-desk selling, companies such as Maple Leaf Meats dictate the price producers receive for their hogs.

[8] Two examples are worthy of note. First, the Carnation plant threatened to leave Carberry, Manitoba when the parent company did not like the workers' demands and threat of strike. A second example would be MLM closing their aging Edmonton plant prior to opening the Brandon plant using a labour dispute as a reason. The latter warrants further discussion in analyzing future linkages between the hog raising and processing industries in Manitoba, particularly the role of MLM in both sectors.

[9] Additional support for this point is the fact that Safeway has recently eliminated its meat cutters in favour of buying their meats already packaged.

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Western Australian sandalwood and Winnipeg's mosquito wars: a secret weapon?

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Abstract: During the summer of 2001 Winnipeg was hit by one of the worst invasions of mosquitoes in recent years, capturing news headlines on several occasions. Proposals for fighting back the mosquito onslaught varied widely. One possible deterrent is the use of sandalwood mosquito sticks, a new product now being manufactured in Western Australia in response to global trends in product specialization, agricultural diversification, niche marketing and other influences. Western Australia is now the world's largest exporter of sandalwood, with the industry actively pursuing research into production and management of the resource and undertaking inventive ways of developing new products and markets. The mosquito stick is just one of these initiatives: oils, balms, unguents and other health spa related items are also promising therapeutic benefits. This paper examines Western Australia's sandalwood industry in the light of these trends.

Key words: sandalwood, mosquito repellent, agricultural diversification, tree products, health products, regional tourism

Introduction

During the summer of 2001 Winnipeg experienced one of its worst mosquito outbreaks for many years. Indeed, so bad was this invasion that local newspapers carried numerous articles on the extent of the problem and what should be done about it. These 'solutions' ranged from pretending that the pests did not exist for fear of discouraging tourists, to alarmist calls for wholesale chemical warfare to prevent the threatened spread of the dreaded West Nile disease, now being carried northwards by birds and mosquito vectors from the southern United States. While there appear to be a range of chemical solutions to the problem, it is probably fair to say that most residents would prefer a more 'clean and green' approach to the problem. According to a number of entrepreneurs in Western Australia, there is a natural product available that may help to deal with Winnipeg's mosquito invasion – sandalwood – which in a powdered form is used to manufacture mosquito sticks (Figure 1). Sandalwood grows naturally in Western Australia, and while the state has a long history of exporting the unprocessed timber to Southeast Asia, it is now being used to manufacture a range of pharmaceutical and medical products, flavoured boutique wines and, of particular relevance to Winnipeg, mosquito repellents.

While the capacity of sandalwood to solve Winnipeg's mosquito plague is highly contestable, the resurgence of interest in the species provides a valuable case study through which to consider a number of themes that are of interest to geographers. Indeed, sandalwood provides opportunities to examine far reaching adjustments being made in the world economy as a result of globalization, post-Fordism, the emergence of a 'post-productivist countryside', and a host of new attitudes, values and approaches being pursued in the industrialized world, such as ecological sustainability, the search for alternative medicines and natural products, and a growing demand for 'exotica' on the part of consumers. Rather than dwelling on the prospects of the sandalwood mosquito stick becoming the final solution to Winnipeg's mosquito plagues, this paper will examine Western Australia's sandalwood industry in the light of these much wider trends.

About Sandalwood

Humans for millennia have exploited aromatic sandalwood (*Santalum spp.*), which is a small, slow growing hemi-parasitic tree requiring a host plant for its survival (Figure 2). There are sixteen different species of the genus of which only two: *Santalum album* and *Santalum spicatum* are of major commercial importance. These species are highly valued in Southeast Asia for their aromatic wood, which is burnt as incense in Buddhist and Hindu religious ceremonies. The wood is also carved into jewellery boxes, fans and fan handles, letter openers, card cases, pen holders and a host of other items. In addition to these uses, sandalwood is prized for its santalol oil, which is distilled from the heartwood of the plant and has traditionally been used as a fixative in soaps and perfumes. Its medicinal properties are valued as well. The oil is used in embrocations and, before the discovery of penicillin, it was a treatment for venereal disease. The northern Australian Aborigines have also long valued the wood and its aroma as elements in their 'sex magic' (Statham 1988).

Figure 1: *The mosquito stick – Australia's secret weapon .(Photo courtesy Westcorp Inc.)*

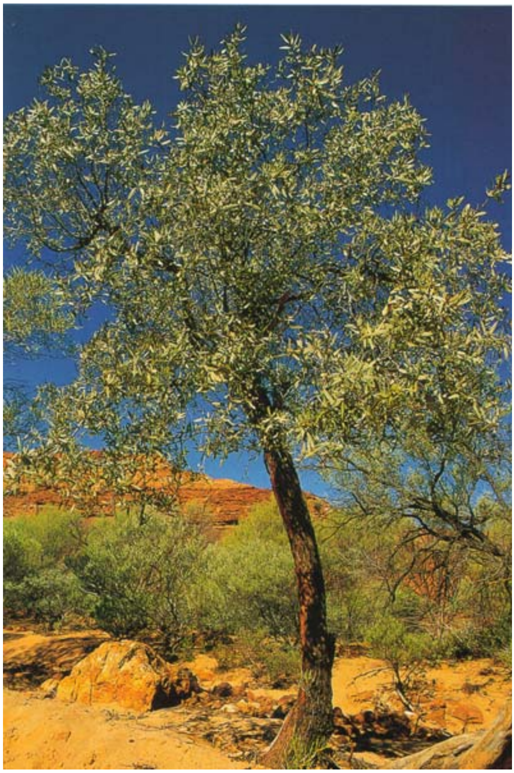

Figure 2: *A mature example of* Santalum spicatum*.*
(Photo courtesy CALM)

Santalum album is widely distributed through tropical Southeast Asia and, in a commercial sense, is far superior to *S. spicatum*. It is faster growing and produces a higher yielding oil product. *S. spicatum* is a native of Australia and is distributed over 42 million hectares of which the majority is in the state of Western Australia (Shea *et al.* 1998) (Figure 3). Although it is slower growing and less productive than *S. album*, it is now estimated to be the largest reserve of sandalwood in the world, with an approximate resource of 200,000 tonnes (CALM 2001). While the species occurs in a range of climatic zones, the optimum conditions for growth are within the 300-600mm rainfall isohyets (Brand 2000). Extensive clearing of this region for agriculture from the 1820s reduced the sandalwood's range considerably, and it is now concentrated in the lower rainfall parts of the state. It grows on a variety of soil types, preferably loamy soils, but the tree will produce in relatively infertile environments. More important is the

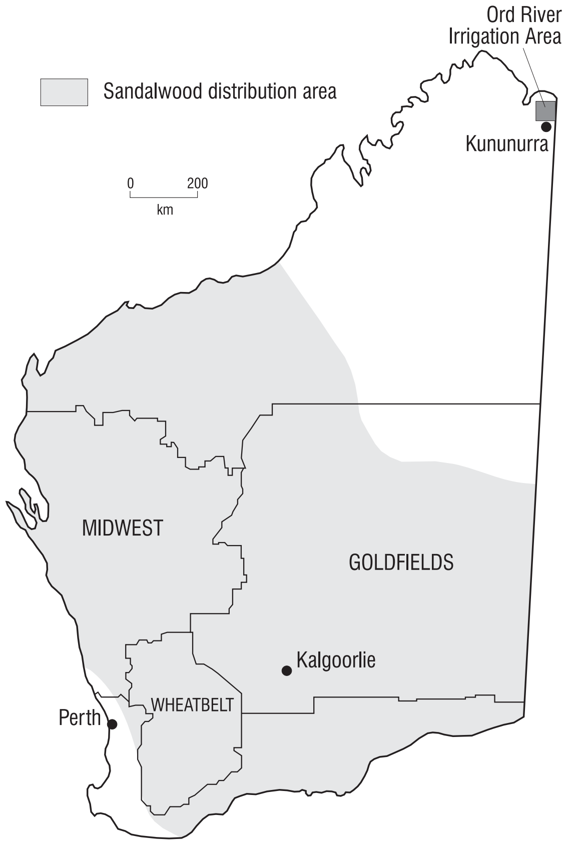

Figure 3: *The distribution of* Santalum spicatum. *(Source: Shea* et al. *1998, 11)*

presence of host plants (particularly *Acacia spp.*, *Allocasurina spp.* and *Ermophila spp.*), which supply the parasitic sandalwood with its essential nutrients (Brand *et al*. 2000). However, even in optimum conditions *S. spicatum* matures very slowly, taking several decades to reach harvestable size. Sandalwood's value lies in the woody parts of the plant's superstructure and roots, especially the heartwood, which contains the sandalwood oil. Both green and deadwood are harvested. Older trees tend to have a much higher oil content than younger plants (Loneragan 1990).

Background to the Western Australian Sandalwood Industry

Commercial exploitation of Western Australian sandalwood dates back almost to the first days of European settlement in 1829. For a short while it was almost the infant state's most valuable export product, second only to wool (Statham 1988). The wood was exported to China, Singapore, and other Asian ports, and sold to Chinese merchants for manufacture into incense. Even in the mid-1800s, demand for the product in the Orient exceeded that region's local supplies, providing a growing market for Australian sandalwood. This caused a boom in Western Australia where there were bountiful supplies of the wood within relatively easy access to the coast. Despite a volatile market, the demand for sandalwood continued well into the twentieth century, resulting in a severe reduction in supplies of wood available from the more productive portions of the southwest area of the state. Stocks were further reduced by agricultural land clearing, demand for firewood and fence posts, and grazing by introduced animals, such as goats, sheep and rabbits. As a result, the state government introduced measures to conserve stocks as early as the 1880s. However, these efforts were largely unsuccessful because of an inability to police the regulations.

The discovery of gold near Kalgoorlie in the early 1890s, and the subsequent opening of the Eastern Railway in 1896, led to another boom as new supplies became accessible. However, the bubble eventually burst when widespread recession in farming and the mining industry encouraged many to turn their hand to sandalwood gathering. This generated a huge over-supply of sandalwood, especially in 1920 when in excess of 14,000 tons were cut, the largest annual harvest ever produced (Statham 1988). Over-harvesting continued over the next few years, creating massive stockpiles of sandalwood that littered railway sidings and the wharves at Fremantle, the state's major port (Figure 4). Consequently, in 1923, more stringent regulations were implemented that effectively put control of the sandalwood industry almost entirely into the state government's hands. Total output was limited to 9,000 tons annually, sandalwood pullers had to obtain a license, strict quotas were introduced, and prices fixed (Kealley 1989). In 1929 the state government passed the Sandalwood Control Act, which closed a number of loopholes in the earlier legislation and, in the following year, established the Australian Sandalwood Company, an amalgam of four pre-existing companies, to be the sole agent for Western Australian sandalwood. Most of this was exported as unprocessed logs merely stripped of their bark, with only about 20 per cent of output being

Figure 4: *Sandalwood stockpiles at Fremantle harbour c1920. (Photo courtesy CALM)*

absorbed by local oil distilleries. However, the last of these ceased operations in 1971, since far higher prices could be obtained for the raw logs overseas than the distillers could afford to pay for the low yielding *S. spicatum*. For example, in 1968 raw logs for the export market were worth A$731 per ton, while local distillers were paying A$76 per ton (Statham 1988).

Despite Western Australia being the world's largest exporter of sandalwood, production has been limited to collection of the plant growing naturally in the wild. Virtually no trees were planted to replace those that were ripped out. Any replenishment of the resource was therefore limited to natural regeneration – and that, in turn, was minimized by disease and, more importantly, by overgrazing by mostly feral animals, especially goats (Brand 1999). Although overseas demand was reasonably steady, the industry was small and not a particularly important contributor to the Western Australian economy. Its participants were limited in numbers, generally part-timers who frequently lived on the periphery of the mainstream economy and on the geographic margins of settlement. Sandalwood collection provided a useful supplement to farm income and helped support a few fossickers or prospectors in their search for minerals. For the most part, the collectors' lifestyle was seen to be colourful and romantic in the eyes of the larger population, but of little consequence. These conditions still prevail, although there are now interesting new developments in the industry.

Current Production in Western Australia

As in many other parts of the world, Western Australia has undergone quite massive economic restructuring over the past few years, particularly in rural regions (Haslam-McKenzie 2000; Tonts 2000; Curry *et al*. 2001). Farmers have become increasingly exposed to international competition as commodity markets have been freed from domestic support prices, import restrictions and various statutory marketing arrangements. For some commentators these trends can be conceptualized as a shift from a Fordist to a post-Fordist agriculture (Lawrence 1996). This perspective holds that there has been a general shift away from Fordist mass production and consumption in favour of specialized 'flexible' production methods and niche markets. According to Harvey (1989), Fordist standardization and modernism have given way to consumption patterns that celebrate difference, ephemerality, fashion and the commodification of culture (see also Lash and Urry 1994). For Australian farmers engaged in the mass production of commodities such as wheat and wool, this has necessitated a shift towards more diverse and flexible production that meets the needs of these new consumption patterns. Initiatives include farm diversification, the identification and exploitation of niche markets and the search for new 'value added' products that bring in higher returns than the more traditional sales of raw materials. Indeed, many Australian farmers have been only too willing to diversify their operations and move away from the narrow 'factory farming' model, and are now engaged in growing organic foods, hemp, seafood, essential oils, timber, goats, emus and kangaroos (Hyde 1998). There is also a growing interest in planting sandalwood as a form of farm diversification.

Despite the potential for the production of sandalwood on farms as part of an integrated form of agroforestry, much of Western Australia's sandalwood is harvested from natural reserves. There are, however, concerns about the sustainability of this resource. Although some conservation and research measures were initiated in the 1920s and 1930s, it was not until the 1980s that the Department of Conservation and Land Management (CALM) began a thorough assessment of the sandalwood resource (Loneragan 1990). Serious efforts were made to establish how much remained and where it was located. More detailed management plans were put into place and experimental plantations established. The agency has also established share-farming arrangements with farmers. This involves CALM providing financial assistance and expertise to farmers interested in establishing sandalwood plantations. In effect, this is a land rental agreement, with CALM taking the majority of the risk and the farmer receiving a return on investment upon harvest. CALM has estimated that most farmers can expect to receive around 30 per cent of net revenue. For example, one farmer in the southwest of the state has planted 20 hectares of his 4,000-hectare property with 16,000 sandalwood seedlings. Since CALM have provided the seed, expertise and will market the product, the farmer's estimated return will be around A$100,000, or A$5,000 per hectare (Henschke 2000).

In addition to providing a valuable economic return, planting sandalwood and the associated host species has the capacity to provide farmers with important environmental benefits. In many parts of Western Australia agricultural regions are suffering severe land degradation in the form of soil salinization, erosion, soil structure decline and diminishing levels of biodiversity (Conacher and Conacher 2000). One of the strategies of farmers in response to these problems has been to engage in various forms of revegetation. A benefit of planting sandalwood is that it not only helps to arrest environmental degradation, but also provides the prospect of a financial return from otherwise unproductive land. In addition to planting degraded agricultural land to sandalwood, farmers can also utilize remnant bushland to grow the tree. Since sandalwood is a native of the region, it is well adapted to the climatic and soil types, as well as the range of potential host species indigenous to the southern parts of Western Australia. In a number of agricultural regions, remnant bushland is a non-commercial resource. That is, it does not generate income, despite providing some environmental services, such as soil salinity and erosion control. Planting sandalwood in stands of remnant vegetation provides an opportunity to derive a financial return from what might otherwise have been a resource that did not generate income. As such, it has the potential to increase farmers' financial security by providing a source of future income as well as adding to both economic and biological diversity.

Another important initiative has been the establishment of faster growing Indian Sandalwood (*S. album*) plantations in the Ord River Irrigation Area (ORIA), in the far north of Western Australia. The ORIA was established in the late 1960s and early 1970s following the construction of two dams on the Ord River. Initially, the ORIA was planned as an extensive agricultural region for the production of crops such as cotton and sugar. However, problems with insecticide resistant pests undermined the establishment of these crops, and for a number of years the project was viewed as a failure. More recently, however, experiments with alternative crops, particularly in horticulture, have helped to revitalize the region. Similarly, growing certain species of trees under irrigation is seen as an important future industry. Experiments by CALM suggest that the growing conditions in the ORIA are particularly well suited to *S. album*. In addition, there appears to be some potential to grow S. album with other commercially valuable species as hosts, such as East African ebony (*Dalbergia melanoxylon*). The production of these trees has the added benefit of ameliorating the imminent problem of a rising groundwater table and the associated process of soil salinization. This will help to ensure the longer-term sustainability of the region's horticultural and other agricultural industries. Thus, sandalwood not only has the potential to diversify the economy of the Ord River region, but to also provide important environmental benefits (Radomiljac and Clews 1996).

The Changing Use of Sandalwood

Until the mid-1990s, the Australian Sandalwood Company held a contract with the state government to export all sandalwood harvested in Western Australia. While the company provided a degree of stability in the industry, it was widely criticized for simply exporting raw sandalwood rather than adding any value to the product. In 1995, however, the state government abolished the monopoly held by the company and, through a competitive tendering process, awarded the contract to export the sandalwood quota derived from natural supplies to a new player, Westcorp Sandalwood Inc.. This new entrant has brought considerable changes to the industry. Unlike the Australian Sandalwood Company, Westcorp has attempted to diversify sandalwood exports through a series of value-adding ventures. While the main export is still raw logs, the firm is marketing increasing quantities of sandalwood as chips and powder for the manufacture of joss sticks. In 1999, Westcorp established a sister firm, The New Mountain Company, which produces 15,000 joss sticks a day. In 2001 the sticks are expected to generate A$2.5 million in revenue and A$10 million in 2002. This is a significant contribution to the export economy, with potential for massive expansion throughout Southeast Asia. The company also markets the sticks in Australia as New Mountain Mosquito Sticks, and has plans to export the product to North America and Europe. This product, like other fumigants that rapidly disperse in the air, has questionable value as a deterrent. However, it is nevertheless finding a market among those searching for something more 'natural' because it is presumed to be healthier than the synthetic, chemical-based mosquito repellents. So successful has the New Mountain venture been that the workforce will increase from 11 to 25 during 2002 with numbers expected to reach 50 in 2003 (Trott 2001).

Westcorp are also investigating other marketing opportunities for sandalwood based products. For example, the seeds or nuts from *S. spicatum* presently command premium prices of around A$75 per kilogram from those looking to establish plantations. Although stockmen once used the nuts to control diarrhoea (Statham 1990, 27), they are now being promoted as a specialty food, similar to 'pine nuts'. With 'bush foods' becoming an increasingly profitable niche market in Australia and, to a lesser extent, overseas, sandalwood seeds have the potential to generate income from a part of the tree that had previously been a waste product. In some respects, the expansion of this market in bush foods reflects changing consumer tastes in favour of specialized and often exotic commodities (Fox 1997).

Another recent development, which also reflects these trends, was the establishment of Mt Romance Australia in 1999. Mt Romance is a new sandalwood oil distillery and factory located near Albany, a small port and service town in the southwest of Western Australia. The company has a contract with CALM to take up to 1,000 tonnes of sandalwood a year, estimated to be worth at least A$40 million over the contract's ten year term (CALM 1999). One tonne of sandalwood produces around 50 litres of sandalwood oil, worth around A$500 per litre on the world market (Henschke 2000). In addition to extracting the oil for export, Mt Romance is producing a wide range of "…bodycare and therapeutic products; specially created to lift your spirits, heighten your senses, pamper your body and appeal to all that is masculine and feminine within us" (Mt Romance 2001). While sandalwood products have not been approved for ingestion, the oil's supposed curative powers when employed externally are being enthusiastically propagandized. Table 1 provides some examples of Mt Romance sandalwood based products and their claimed benefits.

Quite obviously, the company is seeking to capitalize on the huge and lucrative cosmetics industry market. However, there is also an active and high profile program of research into new uses for the product, especially by the pharmaceutical industry. There is, for example, widespread research into the capacity of sandalwood oil (and its components) to treat skin and other cancers, *Herpes simplex, Candida spp*, and the highly antibiotic resistant Golden Staph (*Staphylococcus aureus*) (e.g., Dwivedi and Zhang 1999; Benencia and Courrèges 1999; Hammer *et al*. 1998). The oil is also being tested for its antiseptic properties and as a base for hospital cleaning products.

Table 1: *Examples of Mt Romance sandalwood products.*

Product	Claim
Body Splash	"...refresh[es] your soul and touch[es] your heart ...This superbly fragranced, versatile splash has unisex appeal..."
Slick Shave	"...creates a rich, lasting lather to promote smooth, irritation-free shaving."
Bath Oil	"...oil bathing, an ancient, sensual practice reputed to focus the spirit and provide healthy vitality."
Massage Oil	"…a sensual balm with a rich aromatic base to relax muscles, delight the senses and promote a feeling of well being."
Deodorant	"...Sandalwood oil, Farnesol and Irgasan will inhibit the growth of odour-causing bacteria while preserving natural body flora."

In addition to its production of sandalwood oil and a range of exotic products for niche markets, the Mt Romance factory is being promoted as a tourist attraction in the southwest of the state, already a major tourist destination for domestic and, to a lesser extent, international tourists. While the district's major attractions include the beaches, forests, historic towns, vineyards and a range of craft industries, the sandalwood factory adds to these resources, and its products are seen as an important form of 'regional marketing'. The factory is quite lavishly appointed, with a garden restaurant and a spacious retailing outlet featuring its output. These include those products described above, as well as some more unusual items, such as a sandalwood flavoured 'boutique' wine selection. These initiatives are strongly endorsed by the state government, whose Environment Minister, Cheryl Edwardes sees the operation as bringing "long-term benefits not only for the State's sandalwood industry, but also for regional economies such as Albany" (CALM 1999). Certainly the factory has added to the diversity of the Albany economy. In an era when many regional cities and towns are facing considerable hardship in the face of economic restructuring, such niche industries have the capacity to make a small, though valuable, contribution to local and regional economies.

Conclusion

The sandalwood industry is just one example of the kinds of recent changes and adjustments observed in rural Western Australia. In many respects, the industry represents a shift towards the post-industrial ideals of economic diversity, flexible production, niche marketing and changing consumer habits in favour of natural products and, to some degree, exotica. This is evident not only in the diversification strategies of those farmers investing in sandalwood plantations, but also in the products and marketing of companies such as Westcorp and Mt Romance. However, the current promotion of sandalwood needs to be set against its much longer history as an important contributor to Western Australia's export income, particularly during the nineteenth century. Indeed, sandalwood was a key element in the integration of the state's economy with the global economy. Sandalwood also has a long history as an income supplement when mining and agricultural production has fallen on hard times. Adaptability is not so recent an innovation as is sometimes claimed. Nevertheless, the expansion of plantations, rather than the use of native resources, together with the diversity of sandalwood products are clearly new trends. While the industry may not be able to single-handedly solve Winnipeg's mosquito problem, it is contributing to the rehabilitation of Western Australia's degraded rural landscapes. Furthermore, it provides a useful model showing how a natural resource can be exploited to provide farmers and regions with a source of economic diversity and stability.

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GIS for the people: cognitive errors and data restrictions

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Abstract: Public Participation GIS (PPGIS) has become a popular tool for integrating diverse groups of people into complex decision-making processes. Not only do PPGIS scenarios provide under-represented groups the opportunity to participate in a component of decision making and planning from which they might have traditionally been excluded, they broaden the experience and knowledge base from which decisions can be made. Traditionally PPGIS has involved giving new groups access to the technology traditionally available to institutional, governmental, and other administrative decision-making bodies. While these strategies are not new, innovation is possible by changing the boundaries of GIS data to include knowledge and information that does not conform to the Euclidian rules of the world. Specifically this includes the information and knowledge held by individuals in the cognitive representations of space; representations that are often at the root of their personal decision-making. Such innovation may help define a new era of spatial decision support.

Key words: PPGIS, behavioural geography, community participation, data integration

Introduction

Humans store, represent, and process information in many ways. Geographic information systems (GIS) have been designed to complete operations on spatial information in a reliable fashion that has very little in common with how human minds complete the same tasks (Albert and Golledge 1999). Understanding the nuances of how humans process spatial information has been a topic of concern for geographers, psychologists, and cognitive scientists for quite some time. Over the past decade the relationship between human information processing and digital information processing in a GIS domain has become increasingly important (Medyckyj-Scott and Blades 1992). While others have describe the nature of human cognition and its importance to developing user friendly GIS environments, less has been done on the need to develop systematic spatial database structures that can readily accept the diverse set of inputs required for many real world problems (Mark 1988).

Geographic information systems offer an environment for the input, storage, and processing of spatial information. While the majority of decision-making problems faced at an institutional or administrative level can be solved with aggregate spatial data available from government and private data providers and vendors, there is an array of community level problems that present unique data needs that are difficult to address with currently available aggregate data. Some data are still available in aggregate form, such as census, land-use, transportation, and other forms of physical (e.g., elevation and land cover), and human data, but there are undoubtedly data needs that can only be acceptably met on a case by case basis and may be in a form that cannot be readily represented within current GIS data models. These data may take the form of externalizations of internal, cognitive representations of space, and are commonly referred to as a cognitive or mental map. The former data type (standard data) works seamlessly with existing data models while the latter (public participation or community data) is difficult to integrate with existing data models and often is left out of geographic analysis performed in a GIS environment.

In the context of participatory GIS communities can include any sub group of the population for whom GIS represents a viable decision-making tool. Within the realm of Public Participatory GIS (PPGIS), community includes both marginalized and minority groups (e.g., aboriginal peoples, developing countries, the poor) but can also include any non-institutional or non-government group that would like to participate in the decisions that affect them. While only a fraction of the world's population currently has access to geographic technology, the issues raised here will have an increasingly important impact as these groups gain access to geographic tools and data. In light of this proliferation of GIS technology it is important to consider the different ways these 'community groups' envision relevant spaces and places. This will likely require novel techniques for incorporating new data types into tradition GIS models, or changing GIS data models to accommodate a wider array of data sources (Seiber 2001a).

Systematic Cognitive Distortions

Much is known about the human cognitive map; systematic errors associated with non-Euclidean representations of space underlie many of the differences between reality and how reality is represented in a person's mind (Tversky 1992). Justifying the inclusion of information from cognitive maps in geographic analysis is critical to understanding the importance of these data to making real world decisions. Nowhere is the need for this type of information more critical than in the area of PPGIS. Gathering information from public and community participants involved in the decision-making process and giving these groups access to the tools used to catalogue and process spatial data (GIS) are hallmarks of PPGIS, and have been in use in a variety of areas around the world, including developed, developing, and less developed countries (Harris and Weiner 1998; Jordan 1998; Meredith 1997). Current implementations of PPGIS tend to use existing aggregate data sets that are not a product of the communities or populations that are being directly affected by the decision making. Such data sets include, but are not limited to, census data, data from government mapping agencies, and institutional data (Harris and Weiner 1998; Jordan 1998). As a result it has become clear that new techniques for GIS data collection and processing are necessary to accommodate the emerging needs of the community groups that are currently implementing, as well as those that might in the future introduce, GIS technology (Seiber 2001b). Much of the data collected from public input are in a form that is ill suited to the strict models of GIS data currently in use. Individual differences in the nature of cognitive maps and the potential for a wide range of responses to the environment make it difficult to fit personal perspectives and community attitudes into a GIS domain.

These issues, cognitive inputs to GIS, and removing the restrictions inherent in GIS data models, are necessary for the application of new data types to public participation GIS based research. There are real problems that GIS can help solve and in many cases the most important data will not fit into current data models; dominant data models include raster, vector and object oriented. While common problems among these models exist, there are also unique limitations of each that restrict easy co-ordination of community and standard data. Inputs cover a range of data types, including imagery, sketches, diagrams, attitudes, affective responses, and pictures, among others. While some of these data can be incorporated into standard data models, other types are limited to lists of non-spatial attributes referenced to a discrete location within the area of study, an option that ultimately limits analytical options.

Understanding the distortions inherent in how humans process and represent spatial information in their cognitive maps is a first step towards creating an understanding of how existing data models might be augmented and how new types of data for community and non-institutional decision making might drive the development of new data models. It is interesting to compare the shared conceptual and nominal characteristics of standard data models and cognitive irregularities in such a way that will benefit the larger community of GIS users. It is important to note however that while cognitive maps often distort reality, the nature of many of these distortions is that they are systematic and can be understood and modelled in a limited heuristic fashion. A prominent example is the hierarchical storage of spatial information (Toronto is in Canada, Canada is north of the continental USA, therefore Toronto is north of all locations in the continental USA), which is used to make judgements about relative spatial relationships, and has been identified at multiple scales (Hirtle and Jonides 1985; Maki 1981; Stevens and Coupe 1978). Errors resulting from this systematic bias are predicable and can be used to establish parameters for GIS databases in which such data can be stored and later analyzed. That cognitive maps are based on reality implies that individuals use information present in the environment to develop working models upon which decisions can be made, and that across cultures the shared experience with the common spatial elements of the world suggests that certain internal spatial structures are shared by all people. At the same time there is need to accept that not everyone's cognitive experience is the same and that individuals will develop unique understanding of their surroundings. That both shared and unique experiences contribute to one's representation of the world is a powerful argument for developing tools for collecting inputs from a wide range of participants and shareholders involved or affected by decisions supported by analytical GIS.

Hierarchical reasoning is just one of numerous systematic distortions that enables an individual to store large amounts of spatial and non-spatial information about the world within their cognitive map, and to operate on that information to solve simple and complex spatial problems. Others include, but are not limited to, the presence and absence of prominent landmarks and decision points producing errors in distance and angular judgements about space (Montello 1991); the alignment of newly experienced spatial information with existing knowledge at various scales which results in errors in both the position and arrangement of the new information (Tversky 1992). While each of these distortions is important, the critical question for GIScience is developing techniques and tools for accommodating these and other known, and potentially unknown, errors in how spatial information is stored and processed. Understanding that any model of human cognition is flexible and openly affected by personal experiences (past and present) means that bridging the GIS – cognitive map divide will require certain limits being placed on both the data model and the cognitive model used to integrate relevant inputs.

Data Inputs and GIS Models

Altering the expectations of what can reasonably be used in even the most ambitiously open data model will require re-thinking the potential inputs for GIS-based community decision making. While spatial inputs are necessary, the collection of these inputs should be reconsidered in light of the intended application. With non-profit and other community and citizen groups making increased use of GIS technologies the demand for systems that can adapt to new data needs is necessary (Seiber 2001a). As GIS adoption moves into new areas the limitations of current data and processing conceptualizations become more obvious. Currently community groups want to use the spatial analytic tools offered by GIS technology, but they also demand that data related to their causes be accommodated.

Modifying the GIS model is one alternative, and one that has been argued for by others. There is an equal need to consider the development of data collection tools that might normalize data inputs from human cognition (Seiber 2001a). Creating more systematic, or normalized, techniques for collecting data related to sense of place and, more generally, place based cognitive responses to the environment will allow for more systematic use of this class of data. Emotions, values, judgements and perspectives represent some of the ways in which individuals and groups respond to the environment and should be part of the decision-making process, independent of whether that decision is being supported by a GIS or an informed decision maker. Data inputs from cognitive representations for GIS-based decision making include, but are by no means limited to, sketch mapping (various methods), survey responses, diagrams, distance and direction judgements, field based imagery, and text based, or other procedural descriptions, of the environment. In the following section each of these data collection methods will be presented along with some suggestions as to how they can be adapted to produce data useful within the current structure of GIS data.

Sketch mapping:

Sketch mapping has a long history in geography has been employed in many studies of cognitive mapping (Saarinen 1999). There are numerous limitations of the sketch mapping method, some of which can be overcome by adjusting methods of data collection. While sketch mapping gives an individual the opportunity to develop a free form ‘map’ (drawing) of an environment, it is the free form nature of this opportunity that is its primary limitation. At the same time it is important to recognize the cross-cultural flexibility of the sketch mapping paradigm (Stea *et al*. 1996; Stea *et al*.

1997; Whittaker and Whittaker 1972). Determining the frame of reference, scale, orientation, and limits of a single sketch map are often difficult; doing so for sketch maps collected from a large group of individuals may be impossible. Providing limits (i.e., boundary, or set of well-known locations) to the space being sketched can provide 'sketchers' with a frame within which their own judgements can be placed. The limits or 'control points' can be used in most conventional GIS software packages to map the location indicated by the 'sketchers'. This will not only provide locations for known or important locations for a specific issue it can also be useful for determining the amount of distortion in an individual's or group's cognitive maps of the environment.

By having individuals include a set of 'control points' and providing limits or a boundary, the sketch mapping task loses much of its free form nature but can still provide very useful data that can be incorporated seamlessly into contemporary GIS environments. However, this does not remove all of the limitations of the technique. Sketch maps will still include distortions that are inherent in the cognitive map of the individual. Drawing skill, knowledge, experience, and personal values will still affect the final outcome of the map. This is a characteristic of most methods designed for collecting data from individuals and should not be ignored. In order to account for these errors, several options are available. First, the analytical nature of the GIS can be used to determine error values. These might take the shape of error ellipses or uncertainty measures (Golledge and Stimson 1997, 248). Error data in either form can be mapped to represent the accuracy of knowledge or catalogued in metadata files for future analysis. Second, an *a priori* decision can be made as to what data will be collected from the sketch map and in what form, even though other data are likely to be present. For example, this would enable the individual the opportunity to select categories or perform counts of occurrences from any type of sketch map. This can create data that are less affected by individual differences in drawing proficiency (Jacobson 1998).

Survey methods:

Survey methods offer a researcher the ability to collect data on specific components of community or group concerns. While survey responses can vary from open ended to limited choice alternatives, the themes developed in the preceding sketch mapping section continue to govern how a survey is developed. Survey responses that limit the alternatives available to an individual will be better suited to a GIS data environment than more open-ended responses. Furthermore, responses tied to a specific area of the earth's surface will have more utility in a GIS/mapping environment than responses with no links to space or place. For example, having respondents rate mapped regions on some scale for a specific variable (e.g., "How suitable would each of these regions be for locating a shopping mall?") lends itself well to various mapping techniques (e.g., choropleth mapping) and can be adapted to existing data model constraints. As GIS architecture becomes more open to variable data inputs the constraints on the types and variability of data inputs will lessen (Seiber 2001b). The result will be an opportunity to collect potentially richer data in new ways. This includes, but is not limited to, data collected via both survey methods and sketch mapping.

Diagrams:

Not unrelated to sketch maps, diagrams can provide data on spatial and non-spatial relations that may or may not include cartographic, or environmental, features. Sketch maps represent a type of diagram and contain spatial information about the geographic features experienced by an individual. Diagrams, more generally, can include hierarchical information about non-spatial structures (e.g., hierarchical nature of a storm sewer system or management charts) that are also represented in a person's cognitive representation of the world. Again, limitations associated with the drawing process present obstacles to the incorporation of knowledge from an individual's mental representation in this manner. However, by creating artificial and real limitations on the type of data collected the researcher can establish guidelines, again *a priori*, for what data will be incorporated into an existing GIS data structure. This has the additional benefit of reducing the amount of interpretation that is necessary when coding data from these types of sources.

Distance and direction estimation:

There is a long history of using distance and direction judgements to establish an individual's knowledge of different environments, including but not limited to cartographic representations of the world, virtual environments, other graphical representation of the real world, and, indeed, the real world itself (Golledge *et al*. 1995; Richardson *et al*. 1999; Thorndyke and Stasz 1980; Thorndyke and Hayes-Roth 1982). These data can be used to establish an individual's geometry of a field site or study location, as well as the potential to describe group biases or distortion in how a space is represented. These biases might be helpful in explaining group decisions or values associated with a particular place. One's judgement that a region is unsuitable for some type of development or conservation effort might be based on a representation of that space as being much smaller (and therefore inadequate) than its actual dimensions. As these data are generally collected as angle and distance measures that are consistent with GIS data models establishing the nature of these types of biases should be a reasonable expectation of most GIS software packages.

Image and text inputs:

Written descriptions of space are notoriously difficult to code and most attempts at quantifying them leave researchers wanting more from their data (Ward *et al*. 1986). While qualitative methods have been devised for coding verbal and written passages the ability to incorporate them into existing data models is restricted by inability to quantify the contents. From the perspective of the GIS software this could be stated as the GIS's inability to store, and operate on (analyze) qualitative data. This is one area for which a viable alternative to a free form data collection method is difficult to devise. While memos and tags that contain the verbal passages can be added to most spatial data sets, the ability to incorporate them into analysis is currently negligible. New conceptions of GIS data models will have to account for this type of data as the majority of the lay public prefer to respond (sketch mapping is not a universally preferred method for communicating, even for spatial information) (Seiber 2001a).

Image data, collected in free form using still cameras, video cameras, and photo selection (i.e., selecting a representative set of images for an area) present similar limitations to those offered for verbal and text passages. Image data, collected by individuals, is a novel technique for developing the 'vision' or understanding for a particular space by a group of people (Herman 1999). Creating a structure for the incorporation of these representations of space and place will open the doors to qualitative analysis and data developing within the GIS environment.

Conclusions: Qualitative versus Quantitative

Developing tools for analyzing qualitative data has, in general, lagged behind that for quantitative data. Arguably the use of qualitative methods is essential to the integration of 'sense of place', community based research, and public participation into the GIS forum. While it is essential that new data models for GIS must be pursued to allow for the incorporation of new data types, research must also examine two other critical components, namely data collection techniques and qualitative data analysis. While the preceding sections covered several community based data collection techniques, and methods for adapting them to current data model constraints, very little has been said about qualitative data analysis. Qualitative analysis has generally been pursued by social scientists, among them prominent geographers, but these techniques have historically not been part of the array of data collection or analytical techniques associated with GIS. It is time to open the doors to these methods in order to support the analysis of new problems at the community level. The creation of an open data model that will provide an environment for a wider range of data types should be a goal for the GIS community. Developing analytical and data collection tools (such as those suggested and reviewed above) that can be used by community groups as well as a wider body of social scientists will make GIS, truly, a tool for the people.

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Multispectral classification algorithms and their application to thin section imagery

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Abstract: When working with soils or glacial sediments there frequently is a need to look at their microscopic-scale features. At the same time GIS is often perceived as applicable to macro scale studies founded on remotely sensed imagery or surveying data. But there is another side to GIS. Recent research results show that GIS applications are quite capable of dealing with micro-scale features. Images obtained from thin sections of glacial sediments were fully processed and analyzed using standard GIS techniques and produced quantified descriptions of the tested sediment samples. The key to this information lies in an effective application of multispectral classification algorithms. Classifications are used to accurately identify and segment imagery prior to any quantification procedure. It was found that in the highly complex visual space of glacial sediment thin sections, unsupervised classification methods are more effective in identifying micro-features.

Key words: micromorphology, multispectral classification, glacial sediments, image analysis

Introduction

Glacial micromorphology is still a new science - constantly and rapidly changing and growing. It is based partly on the body of work originating in soil science. A number of thin section description classifications have been created (Brewer 1964, 1976; Jongerius 1964; FitzPatrick 1984) but they are generally written with soil science in mind. This limits their usefulness to glacial sedimentologists. Van der Meer (1993) modified the standard soil classification system created by Brewer (1976) to better fit the growing needs of the new science. However, current micromorphological studies of glacial sediments are very often qualitative in nature. This unavoidably leads to a degree of ambiguity in description and interpretation. There were some attempts at making thin section descriptions more objective (FitzPatrick 1984, 1993) but these were limited to soil science and even then there is little consensus among researchers on which system works best. It may indeed be that each field of study, and even individual interest areas within each field, may require their own version of a classification system.

It is not the purpose of this paper to create such a system. Neither is it meant to restate the history or the principles of image analysis. Papers of this nature have already been written on the topics of image analysis in soil science (Mermut and Norton 1992; Terribile and FitzPatrick 1992). The purpose is rather to initiate the process of objective study of micromorphological features using the technique of image analysis. The long-term goal of this process is to create a comprehensive system to objectively describe thin sections of glacial sediments - likely a complimentary system to any qualitative method of classification presently existing or to be defined in the future.

To initiate this undertaking it is necessary to create a firm basis of feature identification in thin sections. A feature could be any object or objects of interest to the researcher. Void spaces, plasma, individual mineralogies, skeleton grains, staining patterns, and microstructures - these are but few examples of features of interest. It may prove impossible to devise a single method of feature identification for all of them at the same time. The principles used however, should stay the same and the classification method employed may also remain constant while some variables change based on the main topic of research. The result of such modifications should be an increase in the accuracy of the results of feature identification.

Previous Work

The basic concepts of multispectral image analysis form an integral part of most raster based Geographical Information Systems (GIS). GIS applications are generally used in large-scale studies of landscapes, natural resources management or social geography studies. As such they appear to have very little in common with image analysis of small-scale imagery such as thin sections of glacial sediments. However, previous work by the author showed that even the simplest of GIS programs are quite capable of dealing with very small coverages - both theoretically (Zaniewski 1994) and in simple practical applications (McCarthy and Zaniewski 2001).

For any application dealing with digital imagery, be it GIS or image analysis programs, it is necessary to define the various objects and to create topology for the images tested. The topology (or the information regarding the relationships between individual objects in a coverage) can be created following a translation of what is essentially a two-dimensional set of random values into a series of classes or objects. This can be achieved with the use of 'Athreshold' values. This is a very simple way of identifying the various features in digital imagery. Multispectral image classification methods tend to be more accurate and far more sophisticated in their assessment of the digital information. The use of multispectral image classification was developed for use in remote sensing to take advantage of available satellite imagery. The techniques and methods of such classifications are numerous and vary in their specific complexities, accuracies, applications and availability. A number of remote sensing textbooks include descriptions of some of the main techniques involved (Jensen 1996; Lillesand and Kiefer 2000). The use of multispectral image classification routines in thin section studies has been tried in soil science (Protz *et al*. 1992) and in glacial sediment studies (Hiemstra *et al*. in prep.)

Methodology

Hardware and software:

The process of image classification and analysis involves a series of steps. The procedure begins with image capture. There are several methods of image acquisition. For this work images were obtained by a Leica DC200 digital camera mounted on a standard petrographic microscope (Leica Wild M420) capable of low magnifications (up to 10x). Imagery was imported and processed using a GIS program (TNT-Maps and Images Processing System) incorporating a number of multispectral classification options.

Image collection and preparation:

Each of the images captured for this project were stored as a TIFF format, 24bit RGB graphic file. This was done in order to accurately measure and record the spectral intensity of each image pixel for the three colour bands (red, green and blue). The use of 256-colour images (such as GIFs) should be avoided since the choice of values for each scanned pixel is random and the values do not reflect the intensity of colour. It is quite likely that two pixels with a slight variation in colour will be

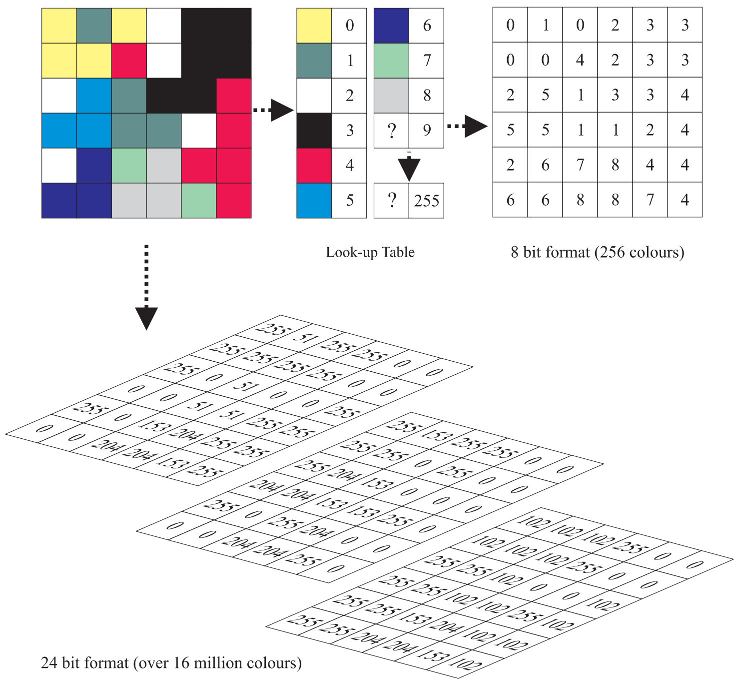

Figure 1: *Illustration of the difference between 256-colour and 24-bit colour data storage and display.*

represented as different values in a 256-colour image (Figure 1). Any analysis of such an image is likely to be impossible.

Images to be analysed were captured in sets of three. Every thin section was previewed and an area of interest was visually identified. Once the target area was selected it was photographed in plain light, under cross-polarized light and with a gypsum wedge in place - making sure that the thin section did not moved during the process. This was necessary in order to assure that the three images were showing the exact same location in the thin section. Each image was 1280 by 1024 pixels in size and was taken at the approximate magnification of x 10. Each pixel was calibrated to have the length and width of 5 microns.

The image capturing procedure was repeated four times - resulting in four sets of raw image data representing the selected coverage areas. The final result of image capturing was a series of pictures showing the same

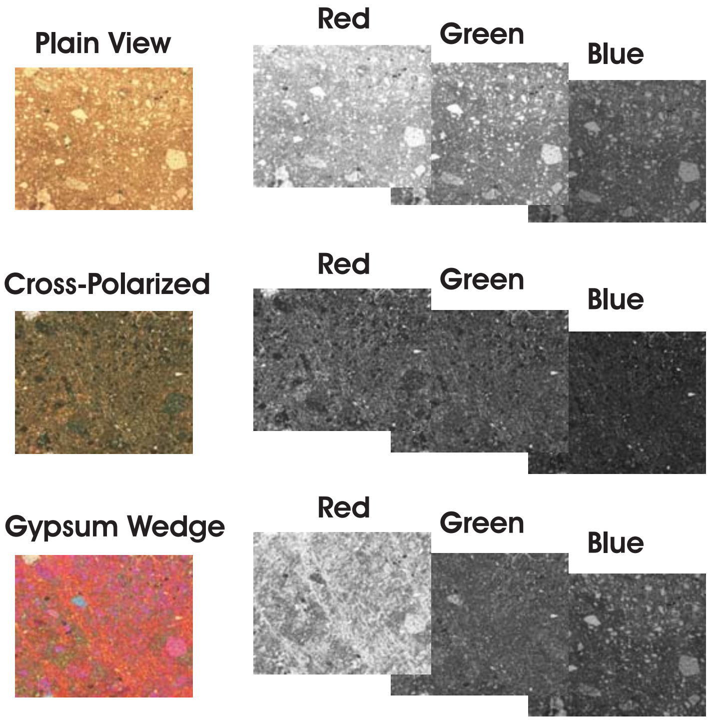

Figure 2: *Source images and their 9 colour 'bands'.*

part of a thin section under different viewing conditions. This is the micromorphology equivalent of remotely sensed images.

Importation:

The importation routine was performed by the GIS/image analysis program used in this project (TNT-MIPS). This program allows for a number of modifications to the original file as specified by the user. During the importation routine each of the three images for each coverage was divided into their colour bands (Figure 2). These were representing the red, green and blue spectrum bands of each digital image. For every one of the four coverages analysed there were now 9 individual spectral bands.

Spectral band selection:

Although the process of classification may be performed on all nine of the spectral bands (red, green and blue bands for plain, cross-polarized and gypsum wedge images) it is neither necessary nor practical. In fact it may be counterproductive and result in a longer procedural time without any substantial benefits in the form of increased accuracy. Multispectral classification algorithms are meant to identify features based on changes in their appearance (grey tone brightness) from image to image. Where differences between images are minimal (high correlation, data redundancy) the images will contribute little to the overall accuracy of the routine but will extend the time required to run the algorithm.

The number of spectral bands and their content may change from application to application. It is dependent on the spectral qualities of the material studied. This project looked at a small subset of the possible material types. This included: voids, plasma (material of colloidal size, i.e. <2¼m in diameter, which can also be referred to as sedimentary matrix) and mineral grains. A choice of 3 or 4 bands had to be made to maximize the effectiveness of the procedure. This is possible if the bands chosen represent spectral data of highest contrast between the different features of interest.

There are several criteria that could be used to select the four bands. The choice could be made based on prior knowledge or experience. If the objective of the project was to identify pore spaces (voids) then the use of UV illumination in combination with UV sensitive dye could produce an image with sufficient contrast between void and non-void pixels to satisfy the requirements of classification. This approach to band selection is however limited to the few situations where the variety of materials and the number of classes of interest are small.

An alternative approach is to use statistical correlation information. For each pair of images tested a correlation value was given, a line of best fit was calculated, and the correlation pattern was temporarily displayed on the screen. The objective of the tests was to identify 4 bands that were least alike. Once all 36 tests were performed a decision was made as to which set of image bands could be used most efficiently. The decision was based on the observed differences in correlation values with maximum variance being preferred. Table 1 shows the results of the correlation tests.

The following spectral bands were selected: the red bandwidth of the cross-polarized images (X_R), blue and red bandwidth of the plain light images (P_B and P_R) and the green bandwidth of the gypsum wedge superposition images (W_G). Even though some correlation values appear high, the correlation values for the remaining spectral bands justified their selection. For example, the correlation value for bands P_B and P_R is very high (0.80), however, the values for P_R and the remaining two bands (W_G,

Table 1: *Raster correlation values for sample R.745(1).*

	P_R	P_G	P_B	X_R	X_G	X_B	W_R	W_G	W_B
P_R									
P_G	0.89								
P_B	0.80	0.97							
X_R	0.20	0.10	0.06						
X_G	0.34	0.28	0.25	0.94					
X_B	0.40	0.39	0.37	0.82	0.92				
W_R	0.50	0.46	0.42	0.73	0.75	0.69			
W_G	0.35	0.25	0.21	0.74	0.75	0.67	0.71		
W_B	0.69	0.80	0.80	0.32	0.48	0.57	0.61	0.6	

X_R) are sufficiently low (0.20, 0.35) to justify the use of this spectral band. For some classification methods it may be necessary to limit this selection even further based on training site statistics.

Classification method testing and selection:

There are many methods of multispectral image classification. General remote sensing textbooks usually contain some explanation the most common algorithms, such as ‘Maximum Likelihood’ or ‘Parallelepiped’ (Lillesand and Kiefer 2000). These methods tend to vary in many respects. Two main types are supervised and unsupervised classification methods. These procedures can be further divided into more specific methods. Some techniques are faster but less accurate (e.g., ‘Minimum Distance to Means’ classifier which does not account for class variance) and their use tends to be limited to situations where spectral images fit a narrowly defined set of limitations – such as uniform class variances. Other methods may be more accurate but tend to require more processing time (required to calculate more comprehensive class definitions) and better quality data (higher overall signal-to-noise ratio) (e.g., ‘Minimum Distribution Angle’). The challenge is to decide which one best suits the purpose of thin section image analysis.

The variety of features and materials found in glacial sediment thin sections increase the complexity and difficulty of the multispectral classification. The requirements of an accurate supervised classification specify the need for a clearly defined set of training sites. Training sites are supposed to represent only one feature class (single material) and be spectrally homogenous. All of the different types of material should be defined or the algorithm may leave large portions of the image unclassified.

The alternative to this is to use an unsupervised classification method. This avoids the training site definition stage but includes complications unique to this group of classification techniques. To achieve accurate results with an unsupervised classification it is necessary to exaggerate the number of actual classes known to exist in each image. For example, if a known number of mineral types are 5 then in order to classify the sample field it is necessary to ask that at least 15 different classes be identified. This exaggeration allows the computer to identify new classes. These additional classes may include small areas of unique material left unobserved by the user (not an unlikely scenario when looking at thin sections of glacial sediments) or represent areas of the image where the mixing of skeleton grains, voids and plasma produced unique 'intermediate stage' 'fuzzy' classes. It is important to point out that a thin section image represents approximately 20 ¼m thickness of glacial sediment and not only its surface.

Unsupervised classification involving large numbers of classes can be a slow process. Furthermore, final classification routine does not label each spectral class, rather it is the user that has to identify the various class clusters and provide an appropriate attribute label. K-means method has been used effectively in pore studies (VandenBygaart *et al.* 1997) indicating that the unsupervised techniques have their place in sediment or soils-based studies.

To compare and evaluate effectiveness of the multispectral classification approach it was necessary to classify the same image using a variety of algorithms. Classification results were evaluated for accuracy and processing time. The image used to test the algorithms was selected to represent a typical glacial sediment thin section. It contained examples of a variety of skeleton grains, plasma, voids and plasmic fabric.

Results

Testing showed that the processing time might vary substantially. Table 2 lists the times obtained. It is important to note that the table only shows the time required to run the process. For supervised classifications actual processing time must include the creation of training sites. This tends to differ from image to image based on the variety of features contained in it. For example, when skeleton grain material consists of a large number of lithologies it becomes necessary to create a larger number

Table 2: *A summary of the classification techniques tested.*

Name	Type	Processing time	References
Simple One Pass Clustering	unsupervised	14 sec	Jensen (1996)
K Means	unsupervised	1min, 22 sec	Duda and Hart (1973); Schowengerdt (1997)
Fuzzy C Means	unsupervised	24min, 31 sec	Cannon *et al.* (1986); Schowengerdt (1997)
Minimum Distribution Angle	unsupervised	1min, 8sec	Paris and Kwong (1988)
ISODATA Classification	unsupervised	35 sec	Tou and Gonzalez (1974); Jensen (1996)
Self-organizing Neutral Network	unsupervised	1min, 55 sec	Schowengerdt (1997)
Adaptive Resonance	unsupervised	1min, 45 sec	Capenter and Grossberg (1988)
Minimum Distance to Means	supervised	13 sec	Jensen (1996); Lillesand and Keifer (2000)
Maximum Likelihood	supervised	19 sec	Lillesand and Kiefer (2000)
Stepwise Linear	supervised	10 sec	Johnston (1978)
Suits Maximum Relative	supervised	12 sec	Wagner and Suits (1980)

of training sites with an associated increase in preparation time. When using spectral signatures or spectral response patterns this preparation time may be minimized. However, the variety of material contained in glacial sediments will frequently require additional training site definition regardless of the pre-existing set of spectral definitions.

For unsupervised classification methods the additional processing time comes from post-processing of the classification results. Before the results can be evaluated for accuracy, care must be taken to reclassify the results accurately. This task must be performed every time an unsupervised algorithm is used. As can be seen from Table 2 most routines ran for less than 1 minute. Only the ‘Fuzzy C Means’ method took substantially more time.

Further evaluation was then performed visually to establish which classification methods came the closest to producing an effective rendition of the original image. This was done by comparing the characteristics of the original photo to those observed in the resultant class image. By concentrating on ‘landmark’ areas (such as boundaries between voids and plasma or plasma and skeleton grains) it was possible to note exceptional classification errors.

Overall most unsupervised classification methods produced good results. The exception was the ‘Simple One Pass Clustering’ algorithm which produced images of lesser quality. The best apparent agreement between the original photo and the classified results was obtained when the ‘Minimum Distribution Angle’ algorithm was employed.

All of the supervised classification results suffered from obvious errors where pixels were assigned into a wrong class or were left unclassified. Accuracy improved with progressive redefinition of the training sites.

However, it never achieved the quality of the unsupervised classifications results.

Discussion

Supervised classification methods should not be attempted for this type of analysis. The problem has to be traced to the inherent training site definition error encountered whenever imagery used shows a high degree of spatial variability. In transitional areas (contact zones) between voids and skeleton grains or voids and plasma the appearance of pixels will change gradually to represent the changing composition of the material. It is important to recognize that the thin section images are produced by illumination from below the sample (transmitted light). Every pixel in such an image is a product of the many different materials contained within the thickness of the section. Transitional areas will frequently exhibit a very high degree of spectral fuzziness – not fitting into any of the main material classes. Allowing a portion of the classified image to be left as unclassified will only solve some of the problems. Further problems may be encountered when training sites include areas not belonging to the right class. This can only be avoided by defining sites on pixel-to-pixel basis. This is a very slow and tedious process not practical when large numbers of thin sections are considered. The use of spectral keys (unique diagnostic spectral characteristics of a material) may be attempted but some caution is advised. Microscope settings must remain identical from sample to sample. Furthermore, spectral keys have to be redefined overtime in order to adjust for the changing brightness of the light bulb. New keys may have to be created to allow for inclusion of additional types of material not encountered previously.

Unsupervised classification algorithms showed many advantages over the supervised approach. No *a priori* knowledge is required. The computer does all the calculations necessary to identify groups of pixels similar in appearance. To complete the process it is necessary to reclassify the results so that they produce a more ordered appearance allowing for visual interpretation as well as conversion to vector based images, if necessary. Even when looking at a highly complex set of results (40 or 50 different classes) the time required to reassign pixels into voids, plasma and skeleton grains did not exceed that of the retraining procedures necessary for the supervised classifications.

A procedural time of over 20 minutes per application means that the 'Fuzzy C Means' algorithm should probably be considered too slow to be used on large numbers of images required to analyse even a single thin section. All other algorithms produced their results in less than 2 minutes leaving accuracy as the decisive factor. The problems encountered when using supervised classification methods, combined with their lower overall accuracy means that only unsupervised classification algorithms should be considered for use in thin section studies. Of all the methods tested, the 'Minimum Distribution Angle' showed best results and must therefore be recommended.

Conclusions

A classification routine, no matter how complete and accurate, should only be considered as a preliminary stage of image analysis. It is simply a first part of a longer procedure and it serves to provide rudimentary information as well as spatial definitions of some of the features contained in an image. For a micromorphologist this means that more studies are necessary if a more accurate means of data extraction are to be found. What is needed is a methodology of feature measurements better suited to micromorphology. For example, identification of all the quartz grains in an image must be followed by measurement of the grains identified. The measurements may involve simple area or diameter calculation for each grain. They may perhaps involve identification of shape characteristics or even the relationship between the grains and other material in the images. It is hoped that the use of this technique will result in a more accurate, certainly more objective, way of describing many of the micromorphological characteristics of glacial sediments. In order to reach this goal it is important to use the best available tools for obtaining the raw data. As such only some of the unsupervised classification methods appear to fulfil the basic requirements of speed and accuracy. Of these, the 'Minimum Distribution Angle' method shows most promise and is therefore recommended.

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Perceptions of Peru′s Sierra and Costa from the literature of José María Arguedas

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Abstract: The paper examines the use of mountains as metaphor in the literary work of José María Arguedas, specifically from his novel *El Zorro de Arriba y El Zorro de Abajo* (*The Fox From Up Above and The Fox From Down Below*). The paper addresses Arguedas's perceptions of the mountains of Peru and examines the contrasts drawn by Arguedas between the mountains and the coast of the country in which he lived. Arguedas used these physical geographical features and locations to represent human beings who come from such locations, and to illustrate the differences between inhabitants of these areas. Arguedas creates a parallel between differences in the geographic locations and differences in the people from such locations.

Key Words: Sierra, Costa, Foxes, crillolo, cholo, Chimbote

Literature from around the world makes use of physical geographic phenomena in order to illustrate and refer to various human conditions and emotions. This technique can be seen in novels such as Mary Shelley's (1818) *Frankenstein,* wherein she uses the Arctic to represent the cold, desolate, lonely life of the monster. It is also seen in Emily Bronte's (1847) *Wuthering Heights,* as the author uses the physical geographies of Thrushcross Grange and Wuthering Heights as representations of the families and individuals who reside in each location. Mountains, for example, are referred to often in literature and are utilized by the author as simile and as metaphor to represent an idea, belief or emotion. This may be noted in Edgar Allen Poe's (1838) *The Narrative of Arthur Gordon Pym of Nantucket* and in H.P. Lovecraft's (1936) *At the Mountains of Madness,* a novel that was an extension of Poe's *Arthur Gordon Pym*. In both of these pieces of literature mountains are used as an allegory for the human condition. Lovecraft particularly uses the mountain as a metaphor for insanity and for the ways in which humans are driven to madness. It is the primary objective of this paper to examine the use of mountains as metaphor in the literary work of José María Arguedas, specifically from his novel *El Zorro de Arriba y El Zorro de Abajo* (*The Fox From Up Above and The Fox From Down Below*) (Arguedas 1971, 2000).[1] This paper will take into account the ways in which Arguedas uses mountains to symbolize the people who come from them, and the relationships they form with those from the coastal region of Peru. The history of his life must be taken into account while completing such an examination as his personal experiences are the driving force of the novel and of his use of mountains as metaphor.

José María Arguedas, born in the small Andean city of Andahuaylas in 1911, is undisputedly one of the greatest Peruvian authors of the twentieth century (Ortega 1999). He has published such works as *Yawar Fiesta, Diamantes y Pedernales*, his most celebrated novel, *Los Ríos Profundos, and Todas Las Sangres* (Arguedas 1941, 1954, 1958, 1964). Owing to the death of his mother when he was only three years old, and to the fact that he was raised by his father and stepmother, Arguedas received little of the attention he needed from his parents, and was influenced significantly by the Indians of the southern Sierra where he grew up (Ortega 1999, 1). These Indians taught Arguedas how to communicate in Quechua, as well as how to appreciate and love the land and the country in which he was born. As a teenager, Arguedas was taken from his home in the Sierras to complete school as an acculturated young white Peruvian in the city of Ica, in the desert coastal region of Peru, and later in the city of Huancayo, where he began writing for a student magazine. This change in geographical location and cultural setting must be noted when examining Arguedas' novel *El Zorro de Arriba y El Zorro de Abajo* as his personal experiences with the Sierra and the Costa of Peru figure prominently in the novel. Arguedas continued his formal education at the University of San Marcos in Lima, where he focused on his writing and the study of anthropology (Castilla 1999). He pursued a career as a secondary school teacher in Lima, then continued on as a university professor, as well as serving on various boards and committees for the preservation of Indian culture and folklore (Ortega 1999, 1). Tortured by political injustices and the prospect of suicide for much of his adult life, Arguedas began writing *El Zorro de Arriba y El Zorro de Abajo,* his last novel, as a means of emotional purging and as an attempt to regain his will to live and to write (Ortega 2000, xi-xxxii). He was struggling at the time with the end of his marriage to Celia Bustamante, his wife since 1939, and the beginning of a new marriage with Sybila Arrendondo, which had commenced just two years earlier in 1967 (Castilla 1999, 2). However, prior to completing the novel, he shot himself twice in the head while in his office at University Agraria La Molina, and died four days later without having regained consciousness. He passed away on December 2, 1969 at the age of 58 (Ortega 1999).

José María Arguedas was a man torn apart by two conflicting segments of his very psyche. He was an educated, white Peruvian man on the outside, but a large part of him remained a Quechua speaking Indian from the Sierra, as he stated himself in his diary of *El Zorro de Arriba y El Zorro de Abajo*, when he said "…I am '*de la lana'*, as you used to tell me; that is, from the 'high country', which in Peru means an Indian, a highlander…" (Arguedas 2000, 55). All of his life, his two identities seemed to be at war, and this constant struggle of his psyche is apparent in the novel discussed in this paper. According to César Caviedes:

> This experience turned Arguedas into a man deeply split between the Indian values and world perception that he had acquired as a child and the values and cultural attitudes imprinted on him as a cultured Peruvian from the coastal lowlands…(Caviedes 1987, 59)

Complementing Caviedes on this impression is a passage by Mario Vargas Llosa from *José María Arguedas: Entre Sapos y Halcones:*

> … he found the Indian way of life to be more humanistic and less alienating than life according to Western values (Vargas Llosa 1978, 43-45).

El Zorro de Arriba y El Zorro de Abajo is a novel of great importance regarding the demise and ultimate destruction of the fishing town of Chimbote on the northern coast of Peru. Until the 1950s, Chimbote was a beautiful, pristine town of about 2,000 inhabitants. In the years that followed Chimbote was transformed into a 'boom town', bustling and growing exponentially with the arrival of the anchovy fishing industry. In only two decades, the city grew to more than 200,000 inhabitants, many of whom were from the Sierra and who had come in search of work and in hopes of becoming prosperous. The effects of the anchovy industry on the city were devastating, as seen here in an excerpt from Julio Ortega:

> The beaches were destroyed by the fishing industry, which had grown without plan or design inside the urban area and

> expelled its wastes directly into the bay, today an ecological disaster of dead waters, fenced in by a sanitary cordon of rocks, infested by rats (Ortega 2000, 1

In a period of only a few decades, Chimbote was metamorphosized from a small fishing village on the Peruvian coast into a cesspool of disease, brothels, greed, and poverty, transforming not only the physical landscape and ecological aspects of the area, but also its inhabitants, many of whom were Indians and highlanders from the Sierra. The coast was a place of pestilential environment that nevertheless continued to call to workers from the Sierra with the promise of profit. The 'fox from below' tells it best when he says to the 'fox from above':

> …here it feels like a mishmash of dying and dawning, of what seethes and spatters, of what ferments and turns sour, of being calmed down by force or by sheer effort. All that ferment is here (Arguedas 2000, 87).

In the novel, the 'foxes' are native gods that represent the world of up above (the Sierra), and the world of down below (the Costa). Their occasional dialogue in the novel gives insight into the contrast between the two geographical regions, not only physically, but more importantly on a human scale (Ortega 2000, 2). According to Columbus, the 'foxes' come from an ancient Andean legend in which they are "deities of the night and of the moonlight, mysterious cult figures,…never deities of the first rank" (Columbus 1986, 30). In Andean mythology, the meanings of the foxes shift continuously from one tale to another, and Arguedas uses this ancient myth to fit his own needs in this novel.

El Zorro de Arriba y El Zorro de Abajo is an extremely complex novel, filled with allegory, metaphor, and symbolism. It has a plethora of characters and a proliferation of voices, most of which are unusually complex in themselves, and are interconnected in one way or another. The characters consist of persons from the coast (*criollos*), the Sierra (*cholos*), and North America. They serve as illustrations and as symbols from the very regions of their origin, and may also be identified by distinct social and economic strata (Rowe 2000, 284). More central to the novel, these characters or 'voices' also serve as an illustration of the attempt at homogenization of the city of Chimbote. In the course of the novel, the reader is introduced to a veritable glut of characters, some of whom are merely presented through the conversation of other characters, and some who are met as primary persons in the novel.

What is so essential regarding these characters and their geographical origin is that although they came to Chimbote from three distinct geographical regions, within and outside of Peru, they were all brought together into one coastal community. Throughout the novel, the reader continues to see these characters intermingle with one another, and to see them communicate regardless of their differences in terms of geographic origin or socio-economic status. *El Zorro de Arriba y El Zorro de Abajo* begins with the story of the highlanders and their lives in Chimbote. Primarily, the beginning of the book focuses on Chaucato, the fish boat captain, and his crew. However, this first part is also the section in which the reader is first introduced to Maxwell, during the time that he is working for the Peace Corps. The highlanders in this chapter are portrayed as being relatively uneducated and rough, but pure of heart. They are, for the most part, honest, hard-working men who are trying their best to make better lives for themselves and for their families. These men are ruled by the anchovy fishing industry and their lives are dictated by the amount they catch at sea. They are also controlled by the parent company and its 'big fish' of the industry, in Chaucato's case, a man by the name of Braschi, who is the powerhouse of the company that owns Chaucato's boats, and virtually all of these men as well (Arguedas 2000, 30). Caviedes describes his character as: "an evil man, a reckless exploiter who at first used to mix with the humble and encourage them to work for a profit, but who later developed into a manipulator who rarely returned to Chimbote, preferring to direct his fishing empire from Lima through a hand picked *mafia*" (Caviedes 1987, 66). As the chapter unfolds, the reader comes to learn that Braschi is taking these men for all they have… he is simply using them to gain what he wants and to secure more wealth and prestige for himself. Chaucato and his men are being made victims by the company, and are getting nothing in return. They are living in filthy shantytowns because they are poor, uneducated, unskilled highlanders. The coast and its inhabitants are eating them up, taking advantage of them, and holding them down by keeping them in poverty (Arguedas 2000, 27-55). This point is illustrated in an exchange between Chaucato and one of his men on the deck of the ship:

> …how come other skippers who haven't been fishin' as long as you, whoare less deservin' – you're such a pal of Braschi's, practically his father, and you're the one who's taught almost all the trawler skippers how to find anchovies and net 'em – how come you got an old boat, a hundred tonner, when they

> gave these other guys, who don't know near as much, two hundred- and even two-hundred-and-fifty-ton trawlers, so they can earn double what you do (Arguedas 2000, 29)?

These other men, to whom Chaucato's fisherman is referring, are not highlanders, but men from the coastal regions. It is stated here that Chaucato was wronged by Braschi because he came to Chimbote from the highlands, and was not seen as worthy of the wealth and prosperity he so desired and deserved. The change in Chimbote and the importance of the anchovy fishing industry and its bosses is illustrated as well in the following excerpt from *The Andean Air Mail and Peruvian Times:*

> …by 1970, nineteen fish-processing plants operated out of Chimbote and the town had grown to 111,000 inhabitants. By 1980, the population had doubled. The four largest plants belonged to Luis Banchero (Braschi), two were owned by American companies, three were operated by Italian entrepreneurs, two were owned by Jewish merchants, another pair belonged to Spaniards, one was owned by Yugoslav-Argentines, and the rest were in the hands of powerful Peruvian capitalists, among whom the Gildemeister family occupied a conspicuous place (Andean Air Mail and Peruvian Times 1970, 57)

It is evident in this first chapter that the highlander is constantly being tested, corrupted, and polluted by the city of Chimbote and by the coastal inhabitants and their vices. After coming in from their anchovy fishing, the men go straight to the brothels for booze and prostitutes. They are lured into the filth and the moral corruption of the coast by their declining situations and shattered dreams of prosperity, as is stated by the Fox from up Above:

> Two thousand five hundred years ago Tutaykire, the warrior from up above, son of Pariacaca, was detained in Urin Allauka, a yunga valley of the world of down below; he was detained by a harlot virgin who awaited him with her bare legs widespread, her breasts uncovered, and with a large jar of corn beer. She stopped him to make him go to sleep and sidetrack him (Arguedas 2000, 54).

It is here that the reader is introduced to Paula Melchora, the prostitute from the Sierra who had settled like many others in Chimbote. This illustration of the highlander's life in Chimbote is again a reflection of Arguedas' own life, and how he was taken from his pure, unadulterated mountain home and transplanted into the life of the coast (Fernández 2000, 291). Arguedas paints a vivid geographical, cultural, and social picture for the reader in his first chapter as he describes the debilitating situation of the highlander turned coastal dweller. As stated above, Arguedas was at one time forced to leave his home in the Sierra to come to the coast to study and to become what others expected him to become: an acculturated, educated white Peruvian (Caviedes 1987, 59). His distaste for the coastal region as opposed to the Sierra is evident in the first part of the novel, as he compares the sea upon which all of these highlanders are dependent to the sexual organ of a 'great whore':

> Before it was a mirror; now it's the million-dollar sex organ of the great whore, prostituted by gringoized mobster pimps… Great big pimping sharks (the fish meal factory industrialists) – they're prostituting Chimbote from the fucking hell (Arguedas 2000, 46).

In his own struggle of life and death, Arguedas points to the conflict between elements from the coastal regions and the highland, and to the complex social and geographical distinctions between the two. There was, upon the onset of the anchovy industry, an infiltration of Indians to the coast, a mixing of two cultures that had remained separate and equal in their own rights. The novel focuses on the corruption of and effects on the mountain inhabitants as they infiltrate Chimbote, and their attempt at peaceful co-existence in the city; the possibility of unifying the country of Peru for the first time (Rowe 2000, 294).

The mountains of the Sierra are, in this case, symbolic of purity, hope, and life, based on the author's childhood and his experiences with the Indians of the region. It is a place of purity and innocence, untouched by corruption and the influence of the Western world (Castilla 1999, 1). The Sierra of Peru symbolized for Arguedas a place of peace, a place of pure, unadulterated beauty and a place in which he was truly at home. In one of his diaries, Arguedas even found this beauty of the mountains in a *nionena* (pig) he was petting in San Miguel de Obrajillo as he observes the waterfall:

> The high, extremely high waterfall that flows down off the unreachable rocky peak was singing in the deep tone of that nionena, in his stiff bristles, which softened; and the sunshine that had heated the stones, my chest, and each leaf on the

> trees and bushes, warming with plentitude and beauty even my wife's angular and forceful features – that sun was more present in the nionena's language, in his delicious slumber, than anywhere else. The waterfalls of Peru, like those of San Miguel, where water slides down into abysses hundreds of feet deep, dropping almost perpendicularly and irrigating terraces where food plants flower, will comfort my eyes moments before dying… they exist because of those sheer mountains, capriciously arranged into gorges deep as death and more fiercely alive than ever…(Arguedas 2000, 10-11).

In this passage the meaning of the waterfall may be ambivalent. At times, when Arguedas notes the abysses, the image may be seen in the gothic context. However, the waterfall also encompasses life-giving aspects, as the author paints a picture of it irrigating the terraces, feeding the plants and warming the body. At the conclusion of the passage the reader sees in the waterfall the theology of hope, as it comforts the author's eyes before he dies.

The second chapter of *The Foxes* focuses on the perceived lunatic Moncada and his only friend, Don Esteban de la Cruz a man from the Sierra (Arguedas 2000, 138). Moncada is the 'madman' from the coast who goes about the El Modelo marketplace and the city of Chimbote preaching to whoever may listen. He speaks of the corruption of the city and the corruption of the industry, all the while bearing a large wooden cross. He continuously berates the anchovy fishing industry, the foreigners who give the orders in Chimbote, and the politics surrounding the successes and failures of the town (Arguedas 2000, 57). In the following passage, Moncada laments the proliferation of 'outsiders' or foreigners who have come to Chimbote and who control the industry as well as the inhabitants of the town. The foreigners are the ones who are becoming wealthy at the expense of the *cholos* and *criollos*, by exploiting not only the resources in Chimbote but its inhabitants as well:

> Here, in Peru shall we say, since San Martín, Don José, there's been nothing but outsiders, foreigners giving the orders. We've been nothing but the servants of foreigners (Arguedas 2000, 59).

Caviedes confirms this in his assessment of the resentment and fear felt by the people of Chimbote and more specifically, the highlanders who migrated to the coast:

> …the exploitation of the resources of the sea from Chimbote had fallen, within the anticipated 'five or ten years' into the hands of foreign profiteers. This is the reason for the strong resentment that exudes from the pages of *The Foxes* each time one of Arguedas's characters refers to the Peruvian capitalists or the foreign speculators (Caviedes 1987, 66).

Esteban de la Cruz is dying from the coal dust deposited in his lungs from years of working as a miner. He is physically weak and fragile, but is accepting of Moncada and believes him to be a wise man who speaks the truth, unlike other coastal inhabitants. Although Moncada is from the coastal region of Peru, he is one of the very few who has seen and recognized the changes that have taken place. He has witnessed the continued demise of the coast and its inhabitants, and has seen the greed, corruption, prostitution, filth and dishonesty that continuously arise in the coast's industry and daily life. What makes him even more different from other coastal or highland residents of Chimbote is that he chooses to speak of these changes and disasters, as well as of his present situation and that of other coastal inhabitants in the poor neighbourhoods owned by the Corporation:

> A strip of muddy ground's your home, compadre; my home's the same and so's the home of all us thirty families who live like pestiferous parasites on the body of the Santa Corporation (Arguedas 2000, 147).

Don Esteban seeks help and condolence not only in Moncada but also in his wife's cousin, with whom he visits for some time. He is the one who speaks out about these things, the Santa Corporation in particular, and is the only coastal inhabitant who seems to recognize the pernicious effects on the region, both ecologically and culturally. Don Esteban, although from the Sierra, is also witness to this destruction through Moncada. He lives in the poverty, the filth, and the corruption, and is as much a victim and contributor to it as any other. However, unlike other highlanders who arrive in search of something better, he has not been jaded so much by the prospect of wealth by way of the anchovy, but sees in Moncada the truth of the coast and the purity of the Sierra (Arguedas 2000, 87). Both Don Esteban and Moncada draw upon the wisdom of the great *aukillu*, the omnipotent, omniscient 'Lord', priest, sorcerer who presides over all mountain cult celebrations and rites. According to the *aukillu*, Don Esteban must cough up five ounces of coal from his injured lungs in order to be saved. His wife's cousin stresses the fact that Don Esteban must follow these orders if he wants to continue to live and to escape the curse of the coast and its disease. It is in the exchange between these two ailing men that Arguedas again refers to the mountain as metaphor: "*Aukillu*, ancient mountain, grand Lord. He knows" (Arguedas 2000, 168). The comparison drawn here by Arguedas between *aukillu* and an ancient mountain is symbolic of his love and admiration for the mountains of the high Sierra. The 'Lord' is historically seen as an inherently good entity, one full of purity, hope, love, joy, and peace. By comparing this 'Lord' of the Sierra to an ancient mountain, Arguedas is putting into words his very feelings of adoration for the Sierra.

The third chapter of *The Foxes* introduces the reader to Don Angel Rincón Jaramillo, the manager of the Nautilus Fishing Company fishmeal factory, and to a 'stranger', who the reader later comes to know as Don Diego. These characters are central to the illustrations of coastal vices and the control held by the company owners over the general population of highlanders. It becomes even more obvious as the chapter and dialogue progress that the highlander is seen as no better than an animal. There is no moral dilemma when it comes to exploiting those from the Sierra, as they are naïve, uneducated, untrained, and optimistic upon arrival on the coast. The coast is a place of festering, seething, growing filth and corruption, and there is no evidence of conscience in the treatment of the highlander or his inevitable fate. During the dialogue between Don Angel and Don Diego, the reader learns that Don Angel prides himself on the makeup of his workforce, and feels that he has done a service to the highlander by allowing him to be a part of the fish-meal factory, as he implies in the following comment:

> …they don't even know how to pronounce the name of their province, some of 'em; others curse their father and mother; they all get drunk as worms, but nevertheless, when they're taught to run machinery, and what's more, when the engineers explain the workings of the most complicated key parts and tell them how the machines function as a whole, these animals learn – rather slowly…there's no agreement amongst them, nor discipline, nor real direction…out of my own pure cussedness and goodness of heart I've trained a workforce (Arguedas 2000, 124).

It is evident throughout the novel that those born and raised on the coast have a certain contempt for the immigrants from the Sierra, and that they clearly feel that those from 'up above' are truly inferior (Caviedes 1987, 70). During the conversation between Don Diego and Don Angel, it becomes clear that Don Angel has no feeling of respect or care for those from the Sierra, and that he feels they deserve no better than they are getting. He feels that he is doing them a favour by employing them in his factory, and implies during the conversation that those from the Sierra should be thankful for what they have been given on the coast. The truth of the matter, however, is that these workers and their families are living in putrescence and extreme poverty, barely surviving by their many hours of hard labour in the factories. There is one barrio mentioned by Don Angel that according to Caviedes:

> there are even worse places in Chimbote. Until the mid-1970s, for example, there was a swamp south of the city formed by the waters of seasonal creeks from the western slopes of the coastal range and the sewage from the shanties. Left vacant because of the threat of malaria, these unhealthy grounds began to be invaded by squatters who formed the lowest population stratum – late arrivals from the Sierra, those who could not find employment because of physical or mental impediments, single Indian mothers, and criminals (Caviedes 1987, 70).

Don Angel, on the other hand, shares an entirely different perspective regarding these areas with Don Diego:

> It's unbelievable, Diego, my friend. They live better there, that is to say, better than a combination of ducks and mosquitoes would. In there people – cholos and Indians – are livin'; they even have shops, little yards with pigs, guinea pigs, and ducks amidst the deceptive solidity of the clumps of sod on the shores of those very strange quagmires in this desert. There they dance on certain days, get drunk, and even put up Peruvian flags without knowin' what they stand for…He's king! On the ocean side of the highway and up on the dunes, too, there are better shantytowns, much better. But these settlements on the marshes, they're not all that sad, who knows for what mucky reasons. They're not sad (Arguedas 2000, 134).

It is here, in Don Angel's words, that the reader clearly sees how the man from the coast perceives the highlander. According to Caviedes:

> this dialogue is, indeed, indicative of the coastal inhabitant's perception of those 'from above', whom he considers inferior and deserving no better. In this passage Arguedas points, with a sharp understanding, at the 'social and ethnic differences' that separate *costeros* from *serranos*, and Peruvians in general (Caviedes 1987, 70).

It has been suggested by Caviedes that the social network cited in the novel parallels the actual social situation in contemporary Peru, as it has been for the past five centuries, since the Spaniards conquered the country five hundred years ago. Since then the country has been ruled by a Spanish 'elite' which has continued to strengthen its social, political, and economic mastery. The elite group consists of the racially pure, excluding anyone from any other area of the country or any other race. Moreover, the cultural and ethnic opposition between the coast and the Sierra existed before the Spanish came to rule, thus making the opposition in contemporary Peru even more acute (Caviedes 1987, 70). This theme is central to Arguedas's novel as he repeats it many times over throughout its course.

The second part of the novel consists of only one chapter and is concluded with Arguedas's *Last Diary?* This last official chapter of the novel focuses not on one or two central characters, as Arguedas had done in previous chapters, but pulls together all the characters in one time period. In one exchange between the characters Chaucato and Butterball, Chaucato compares Braschi to a fiery volcano:

> …he gave birth to this whole world of Chimbote, and it's true now that monkey mouth he used to have is lookin' like the mouth of a fiery volcano that swallows, swallows, swallows up the shitty banknotes of the world just to screw things up, that's all (Arguedas 2000, 196).

This use of mountains as simile by Arguedas is unusual in the novel, as he primarily uses the image of the mountain as something pleasant and innocuous, not something so violent and volatile as a volcano. However, the image of a volcano here in the context of Braschi is much different from that of his images and metaphors relating to the Sierras of the country. Arguedas's use of the volcano in the above passage is an anomaly in the novel, as in all other references to mountains, Arguedas paints them as being peaceful and pure.

Immediately after the exchange between these characters, the reader is taken back to Maxwell, the ex-Peace Corps volunteer, Don Cecilio Ramirez from the high Andes, and Bazalar, the pig raiser from San Pedro, who are all waiting for Cardozo at his residence (Arguedas 2000, 204). There is some speculation as to the motivation for Maxwell's character. Caviedes states:

> Maxwell appears to be based upon an American anthropology student who had come in contact with the Indians of Titicaca Lake in southern Peru, from whom he learned to play the charrango – a string instrument that uses the shell of an armadillo as a percussion box. Maxwell's inclination to familiarize himself with the Indian folklore and to serve as an interpreter of their music is seen by Arguedas – who had himself been a researcher of the Indian ethnology and folklore since 1947 – as evidence of a commitment to the Indian culture very similar to his own (Caviedes 1987, 66).

It is with these comments by Caviedes that the reader must examine the last section of the novel, as it focuses in large part on Maxwell, and tells the story of how he came to leave the Peace Corps and become a mason's partner, living in the La Esperanza shantytown as did so many others who came to Chimbote from the Sierra. Arguedas points out, in his last chapter, that Maxwell himself is not immune to the temptations and corruptions of the coastal region:

> On the first night of his official withdrawal from the Peace Corps, Maxwell set out to walk to the port. … Consciously, 'stupidly', rather than heading straight for the port, Maxwell swerved off onto the brothel footpath, made by men who had just the right amount of money or were simply going to look. He arrived; he heard the rock and roll music in the enormous pink hall and invited China to dance. Never before had a Peace Corps worker been seen in the brothel (Arguedas 2000, 206).

Conclusion

Arguedas's *El Zorro de Arriba y El Zorro de Abajo* is an extremely complex and difficult novel, at times even frustratingly so. It is, however, a novel worthy of tremendous consideration - socially, economically, culturally and geographically. As the reader examines the author's life it is evident that his personal experiences had an undying effect on his perceptions of place and space. These perceptions are clearly evident in his descriptions of the mountain and coastal regions of Peru. To Arguedas the mountains are symbolic of simple good. They represent all that is true, pure, joyful, peaceful and innocent in the world, as well as the hope that so often drives humankind. Arguedas refers to this time and again in the novel, both geographically in his descriptions and in the story line itself. Every mention of the mountains and its population is a celebration. The inhabitants of the coast who came from the mountains did so in search of improvement in their lives. They had hope, and it drove them to seek out and pursue the lives of their dreams. Virtually all references Arguedas makes to the mountains are ones with a positive connotation, and their symbolism becomes even more apparent when compared with references to the coast. The coast is symbolic of filth, corruption, sadness, poverty, greed, desperation and violence. Every mention of coast and its people is an indictment. Arguedas obviously had no love of the coast, although he spent much of his life there and continued to visit Chimbote on numerous occasions throughout his life. His true heart lived in the Sierra with the indigenous people for it was here that he grew up and learned to love the land.

Note

[1] The original text of Arguedas' novel was published in 1971 but is not generally available. In 2000 Fred Fornoff wrote an English language translation of the novel with the title *The Fox from Up Above and the Fox from Down Below*. The quotations presented in this paper are drawn from the translated work.

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