TALKING TO TREES: A DENDROCHRONOLOGICAL ASSESSMENT OF THE ATMOSPHERIC POLLUTION EFFECTS OF ATHABASCA BITUMEN MINING DOWNWIND FROM THE INDUSTRY

by

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The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled "TALKING TO TREES: A DENDROCHRONOLOGICAL ASSESSMENT OF THE ATMOSPHERIC POLLUTION EFFECTS OF ATHABASCA BITUMEN MINING DOWNWIND FROM THE INDUSTRY" by Geoffrey G.L. Kershaw in partial fulfilment of the requirements for the degree of Master of Environmental Studies.

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For all living beings and the sun that feeds us.

One love.

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ABSTRACT

Bitumen mining in Alberta is considered one of the largest economic vehicles in Canada, but the assessment of this industry's environmental impacts is incomplete. The region downwind of this pollution source is occupied by an Indigenous population concerned for the health and viability of their territory. This thesis presents dendrochronology results of principal component and regression analysis documenting white spruce (*Picea glauca*) growth suppression associated with bitumen mining activity. The growth suppression is most pronounced close to the disturbance and in the most recent rings. With a desire to share these results with the Indigenous peoples whose traditional territory overlaps this study's transect, I engaged in relationship building and knowledge sharing activities beyond the scope of my scientific analysis. This thesis presents both dendrochronology results documenting tree growth suppression associated with bitumen mining activity and reflections on the relational ethics of conducting research-relevant activity on Indigenous lands in Canada.

LIST OF ABBREVIATIONS USED

AAG	American Association of Geographers
ACUNS	Association of Canadian Universities for Northern Studies
AEMP	Alberta Environmental Monitoring Panel
CAG	Canadian Association of Geographers
CBC	Canadian Broadcasting Corporation
CBPR	Community-Based Participatory Research
CEMA	Cumulative Environmental Management Association
CIHR	Canadian Institutes of Health Research
CLS	Canadian Light Source Inc.
CNRL	Canadian Natural Resources Limited
CNOOC	China National Offshore Oil Corporation
ERCB	Energy Resources Conservation Board
FGS	Faculty of Graduate Studies
GIS	Geographic Information System
LTRR	Laboratory of Tree-Ring Research
MLR	Multiple Linear Regression
NSERC	Natural Sciences and Engineering Research Council of Canada
NSTP	Northern Scientific Training Program
PC	Principal Component
PCA	Principal Component Analysis
PNAS	Proceedings of the National Academy of Sciences
PAHs	Polycyclic Aromatic Hydrocarbons
RAMP	Regional Aquatics Monitoring Program
REB	Research Ethics Boards
SRES	School for Resource and Environmental Studies
SHE	Society for Human Ecology
SSHRC	Social Sciences and Humanities Research Council of Canada
TCPS2	Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans
WBEA	Wood Buffalo Environmental Association

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CHAPTER 1 - INTRODUCTION

1.1 Introduction

Bitumen mining[1] in northern Alberta is a multi-billion dollar industry. The industry is enormous in magnitude whether one is concerned with its economic value (Atkins and MacFadyen 2008; Plourde 2009; Alberta Government 2012) or environmental costs (Timoney and Lee 2009; Kelly et al. 2010; GIS Services (JS) 2012). Due to the extensive environmental degradation caused by the mining process (Timoney and Less 2009; Kelly et al. 2010; GIS Services (JS) 2012), the industry has become a highly contentious political issue with no one wanting to be viewed as exacerbating climate change or sacrificing an otherwise ecologically intact boreal landscape (CBC News 2012; Broder et al. 2013; The Canadian Press 2013). While these far reaching and highly charged disputes occur on regional, national and international stages, the local Indigenous[2] stake (including Aboriginal rights, title, treaty) is often ignored in the debate over the industry's impacts and assets (Passelac-Ross and Potes 2007; Assembly of Treaty Chiefs 2012).

This thesis is intended to contribute to the dialogue surrounding bitumen mining by helping resolve one of the larger unknowns – that of ecosystem degradation due to atmospheric pollution from the industry. Through the application of dendrochronological analysis, the research conducted for this thesis seeks to identify the severity of tree-growth suppression in response to bitumen mining

[1] In this thesis, the term bitumen is used when describing the Athabasca region's hydrocarbon resources rather than oil sands or tar sands. This was decided based on 1) accuracy, as the raw reserves mined are bitumen and not tar or oil (Hertzel 1979), and 2) the desire to avoid political affiliations assumed when using either term (Demdicki 2011).

[2] In this thesis, Indigenous refers to First Nations, Métis, and Inuit peoples in Canada; the federal government has designated these peoples as "Aboriginal" in the Canadian Constitution, but I have chosen the term Indigenous because of its more inclusive usage based on the United Nations recognition of Indigenous rights (United Nations 2008).

activity along both temporal and spatial gradients. In considering *who* to engage in the discussion surrounding the downwind impacts of bitumen mining, it was my prerogative to begin with the Clearwater River Dene Nation (Figure 1.1), an Indigenous community member of the Meadow Lake Tribal Council which voiced concerns to the media as well as my supervisor and his colleagues over the atmospheric impacts of the industry on their traditional territory[3].

This Chapter presents different layers of northern Alberta's bitumen mining geography. In the following section, I discuss the history of the industry's development, what is known and debated about the resulting environmental impacts, the political realities of bitumen mining, and the ever present Indigenous context. After this, an exploration of the ethical challenges and relational considerations associated with the research is provided. I conclude with an overview of the project including specifics of the research goals and objectives, a short summation of the project design, and an outline of the thesis itself.

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[3] In this thesis, Indigenous lands or traditional territory is meant to include all lands occupied and used historically by an Indigenous group (Bill 2006). Traditional territory often extends beyond lands which Indigenous groups have title to in contemporary times, be they reserve lands, "a tract of land, the legal title to which is vested in Her Majesty, that has been set apart by Her Majesty for the use and benefit of a band" (Indian Act 2011), or treaty lands that are part of larger co-governance structures.

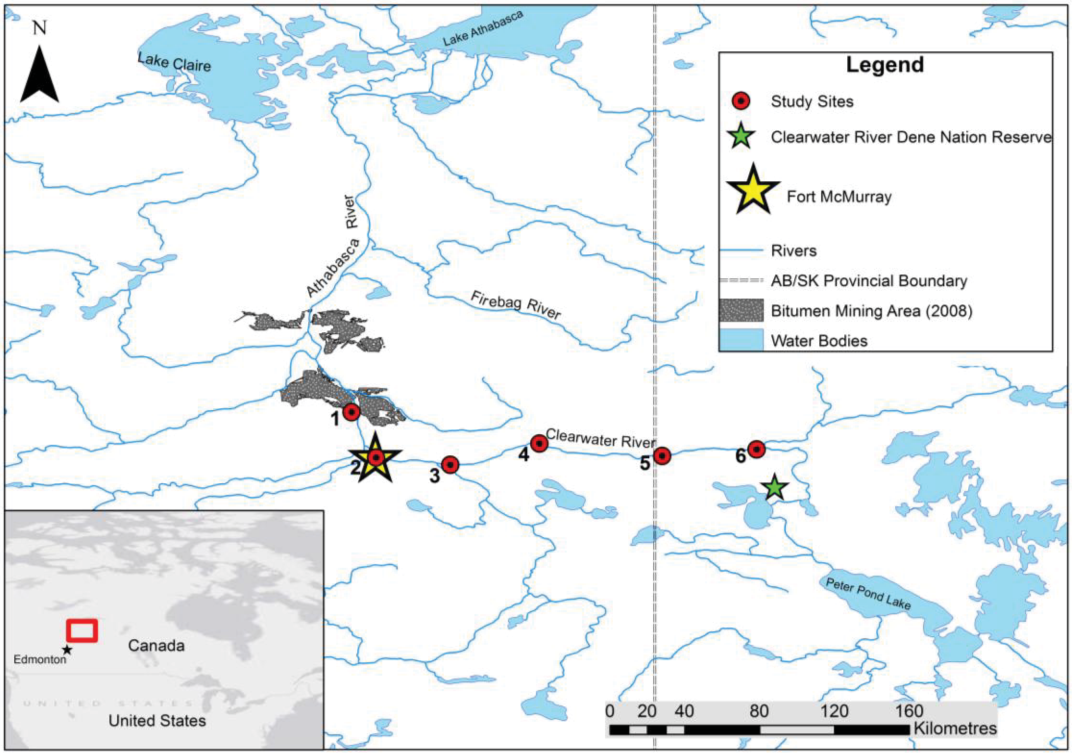

Figure 1.1 - Map of bitumen sands mining activity in the Athabasca region. Locations of study sites, major water bodies, the Clearwater River Dene Nation reserve, and other large settlements are also included.

1.2 Geography of the Athabasca Bitumen Sands

1.2.1 A SHORT HISTORY OF THE INDUSTRY

Along the banks of the Athabasca River in northern Alberta, there are multiple areas where bitumen seeps out into the water. It was at these places that the Indigenous peoples of the region first discovered the usefulness of the substance in patching and sealing their canoes (Chastko 2004). With the 1882 Canadian Geological Survey led by Robert Bell, colonial expeditions looking to develop the resource began. Most of these early expeditions applied conventional well drilling techniques and were unable to effectively tap the resource trapped in the sand (Hein 2000; Chastko 2004). In 1929, Dr. Karl Clark, a professor at the University of Alberta, built a bitumen sands processing plant on the banks of the Clearwater River (Chastko 2004). This marked the first of a series of university and government scientists' initiatives to develop the technologies required for separating and refining the Alberta bitumen reserves.

In 1967, industrial scale development of Alberta's bitumen reserves began in earnest with the first private processing plant operated by Great Canadian Oil Sands Limited coming on line (Hein 2000). The facility was called Tar Island and today resides in the centre of Suncor's mining activities, which applies the same open pit mining and hot water separation process that has remained the industry standard for surficial deposits. In 1979, following Suncor's example, Syncrude opened its Mildred Lake facility. Since 2000, many more companies have joined in with Williams Energy Inc., Albian Sands, Shell, Fort Hills, Petro-Canada, Canadian Natural Resources Limited (CNRL), and China National Offshore Oil Corporation (CNOOC), not to mention extensive expansions of Suncor and Syncrude's operations (Figure 1.1). This increase in activity (Figure 1.2) is expected to continue as bitumen sands production is forecast to rise from 1.6 million barrels per day of Canada's 3.0 million in 2011 to a projected 5.0 million barrels per day of Canada's 6.2 million by 2030 (Canadian Association of Petroleum Producers 2012).

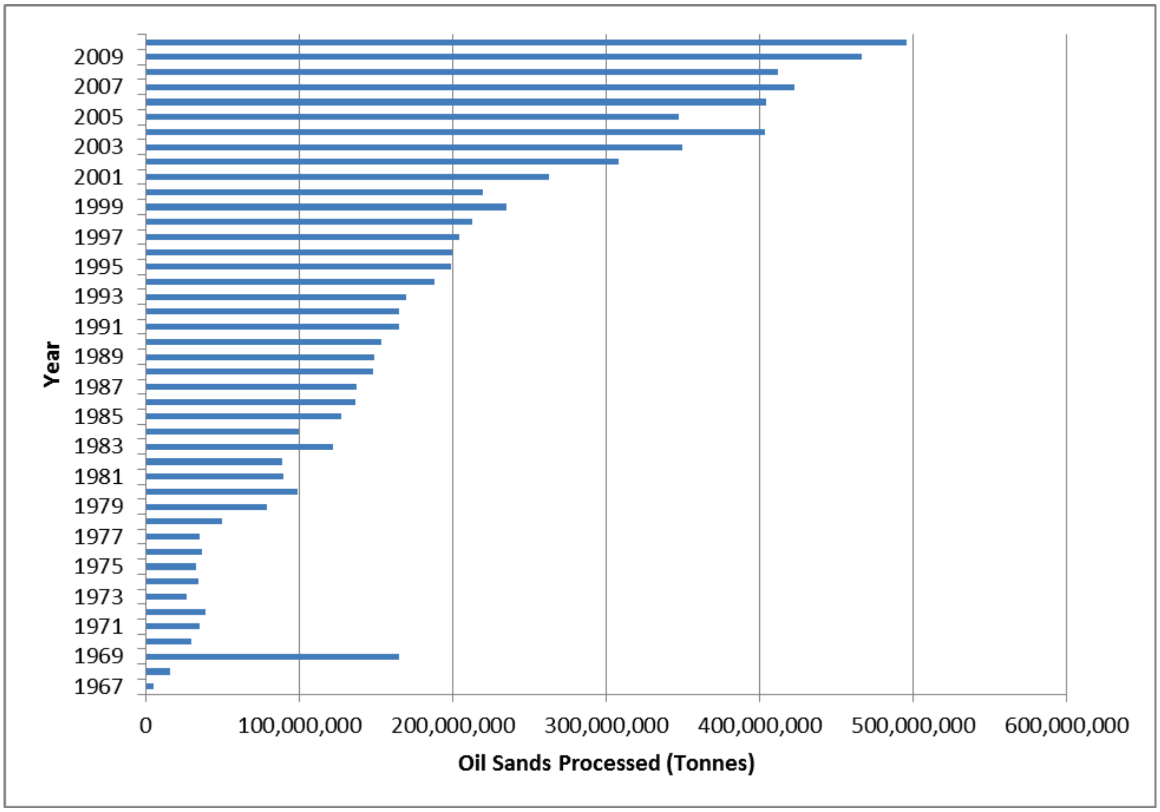

Figure 1.2 - Cumulative amount of oil sands processed[4] reported from mining operations from 1967-2010 (Adapted from ERCB 2012).

1.2.2 BIOGEOGRAPHICAL EFFECTS

Currently, 602 km^2 are directly impacted by open pit bitumen sand mining in the Athabasca region (Figure 1.1) and a further 4750 km^2 is leased for development (GIS Services (JS) 2012). Paralleling the expansion of bitumen mining, seismic activity, new technologies for exploiting non-surficial deposits (GIS Services (JS) 2012) and the influx of workers and their living needs[5] have also contributed to the human

[4]'Oil sands processed' is a term used throughout this thesis. While bitumen is a preferable term for the resource, oil sands processed has been retained where it refers to a specific category of industry data reported to the ERCB (ERCB 2012). This category was essential in this thesis' analysis.

[5] Fort McMurray currently has 72,944 residents. An additional 39,271 people live in work camps in the region. The Regional municipality of Wood Buffalo, of which Fort McMurray is part, increased 9% in 2012 (Regional Municipality of Wood Buffalo 2012).

impacts across the Athabasca region. The environmental impacts of the present bitumen mining industry and its part in the cumulative human impact in the region have yet to be assessed thoroughly as a precautionary approach before launching additional development (Timoney and Lee 2009; Kelly et al. 2010). The industry has largely been self-monitored, with mining companies contracting consulting firms directly to monitor their environmental impacts. The methods and findings of many of these studies have often been lacking in scientific rigor; produced without baseline data, reference site data, and often poorly designed sampling regimes resulting in data unfit for confident statistical analysis (Dowdeswell et al. 2010; Gosselin et al. 2010; Kelly et al. 2010). The efficacy of the data collection methods industry applies have been challenged by independent studies with results contrary to the government and industry position that negligible to minimal impacts result from mining activity (Timoney and Lee 2009; Kelly et al. 2010; Kurek et al. 2013). This situation makes current assessments claiming negligible bitumen mining impacts (e.g. RAMP, WBEA, and CEMA 2008) suspect (Timoney 2007). The frequent claim that there is no deviation from baseline environmental conditions in the region (Gosselin et al. 2010) is just as often met with scepticism, including from Indigenous peoples living on the landscape under threat (Poitras et al. n.d.).

Funding for independent, regional projects assessing the cumulative environmental impacts of bitumen sands development have recently been established (Stikeman Elliot 2011), but it will take some time before conclusions can be drawn from such a large and complex task. Regardless of what vested interests are involved in such research, a robust assessment of the full range of bitumen mining impacts requires a complex and data intense meta-analysis that cannot be attained given the current state of knowledge (Gosselin et al. 2010; AEMP 2011; Environment Canada 2011). The various vectors of output (air, water, biotic), timescales of impact (short-term aerosols, long-term heavy metals), and ecological niches at risk (including those that humans inhabit) make current assessments of bitumen sands mining impacts seem elementary, yet elementary is where the work must begin if a more comprehensive cumulative analysis is to be possible in the future (Timoney and Lee 2009; Gosselin et al. 2010; Dillon et al. 2011).

Atmospheric emissions from bitumen mining are one of the major pathways of pollution in the region. CO_2, sulphur, nitrogen, particulate matter, volatile organic compounds, PAHs and heavy metals are some of the known potentially harmful emissions of the industry (Gosselin et al. 2010). Current emissions are considered by some to “pose an ecosystem or human health risk” (Timoney and Lee 2009, 65), though others claim that the concern is unsubstantiated given the current data (Gosselin et al. 2010).

Atmospheric emissions in the region are largely distributed according to the prevailing winds in the area, which blow from the west to east (Appendix A). The local topography is also important, as river valleys channel the movement of the airborne pollutants (Miller and McBride 1975). This channelling effect has been documented in the Athabasca river valley (Berryman et al. 2004). The Birch Mountains to the west of the mining activity are the highest point of relief in the area, while the landscape east of the mines is quite low and flat with less than a 300m change in magnitude of relief above the Athabasca and Clearwater Rivers (Government of Alberta 2009).

Dendrochronology, the analysis of tree rings to document changes in the environment affecting tree growth (Speer 2010), could potentially contribute to an assessment of historical bitumen mining environmental impacts in the region. Dendrochronology was first established in North America by A.E. Douglass, who founded the Laboratory of Tree-Ring Research at the University of Arizona in 1937 (LTRR 2012). Since the methodology’s inception, tree-ring analysis has been applied to many research purposes of historical and contemporary importance; from aging historical buildings and Stradivari violins to documenting climate change and fire cycles (Speer 2010). Dendrochronology has also been used to document pollution impacts on a regional scale (Mclaughlin 1998; Savva and Berninger 2010; Speer 2010). Some researchers suggest that research focusing on bitumen mining impacts needs to limit itself to specific spatial, temporal, and biological targets (Timoney and Lee 2009; Gosselin et al. 2010; Dillon et al. 2011), and the utility of dendrochronology's temporal resolution and extensive spatial distribution makes the methodology an ideal candidate in this assessment.

1.2.3 Political dimensions

As noted in the Introduction (1.1), the Alberta bitumen sands are arguably the most significant economic vehicle in Canada today. The industry has direct benefits for both provincial and federal governments with billions of dollars in royalty payments, forecast to amount to $444 billion dollars over the next 25 years (Alberta Government 2012). In the Canadian context, government(s) have a responsibility to manage these reserves for the public good, and in choosing to lease to private companies, government regulation of the private sector and the use of royalties they generate is of great importance (Gosselin et al. 2010).

Alberta's bitumen mining industry has received a lot of attention in civil society due to the extent of environmental degradation and greenhouse gas emissions it causes. The resistance from some segments of civil society has been international, with an estimated twenty thousand protestors congregating in Washington against a pipeline to transport bitumen earlier this year (Marsden 2013). Public pressure has created a range of political responses, with the European Union debating if and how to identify Alberta bitumen derived oil as more polluting than conventional oil (CBC News 2012), and American President Barak Obama's administration deliberating if they should allow for pipeline infrastructure expansion to carry more bitumen to American refineries (Broder et al. 2013). Public debate and resistance (including civil disobedience) has also been very active within Canada. The campaign against the proposed Northern Gateway Pipeline, for example, which would transport the bitumen to tankers on the British Columbian coast, is one of the more recent examples of this tension (Meissner 2012).

Both provincial and federal governments have responded to the public outcry with a political position on the matter. The conservative Alberta government has developed an advertisement campaign supporting bitumen mining as environmentally responsible[6], and the conservative federal government is set to follow suit with a nine million dollar campaign of their own (The Canadian Press 2013). With the general public's confidence in the effectiveness of environmental regulation of bitumen mining so heavily eroded, both federal and provincial governments have commissioned research groups to develop plans for independent, credible, and effective monitoring systems (AEMP 2011; Environment Canada 2011).

When considering the political dimensions of bitumen mining in northern Alberta, it is important to acknowledge the context of Indigenous peoples' relationships to the land and government's role in this issue. There are specific responsibilities the federal and provincial governments have when regulating the development of this (and any) industry as it potentially affects Indigenous peoples in Canada who hold constitutionally protected treaty rights. The next section will explore the historical and contemporary state of Indigenous peoples' involvement in the Athabasca bitumen-mining region.

1.2.4 An Indigenous context

The Athabasca area has a long, rich history of Indigenous peoples on the landscape. Cree, Chipewyan, Dene and Métis communities have and continue to exist throughout the region (Hein 2000). The Athabasca bitumen sands largely lie within the boundaries of Treaty 8, which was signed by Cree and Chipewyan bands at Fort McMurray on August 4th 1899 (Duhamel 1899). Treaty 8 was unique compared to previous treaties signed with the Canadian government as it recognized Aboriginal title for both First Nations and Métis peoples (Library and Archives Canada 2008). For all Indigenous groups who signed the Treaty (officially 7 Chiefs and 23 Headmen

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[6] The 'Tell It Like It Is' campaign, a sample of which can be found at http://www.oilsands.alberta.ca/documents/Ad-TILIS.pdf

representing 2217 people), concerns were raised over education, respect for their religion, aversion to being placed on reserves and dispossessed of their lands, and aid in times of disease and famine (Duhamel 1899). The fundamental issue though was the right to hunt and fish as they always had:

> "we had to solemnly assure them that only such laws as to hunting and fishing as were in the interest of the Indians and were found necessary in order to protect the fish and fur-bearing animals would be made, and that they would be as free to hunt and fish after the treaty as they would be if they never entered into it… It does not appear likely that the conditions of the country on either side of the Athabasca and Slave Rivers or about Athabasca Lake will be so changed as to affect hunting or trapping" (Duhamel 1899)

Since Treaty 8 has been in effect, a long and complicated history of undermining Indigenous rights in the Athabasca region has followed (Assembly of Treaty Chiefs 2012). This history largely aligns with the rest of Canada, where religious freedoms, freedom of movement, support in times of sickness and famine and the integrity of hunting and trapping territories have all been severely compromised (Paul 2007). The continuation of these oppressions is often based on oil and gas resource development, such as the Lubicon Cree who are experiencing great hardships due to extensive pipeline and gas well installations in their traditional territory (Ominayak and Thomas 2009; Amnesty International 2011).

Resistance to these environmental injustices has been as constant as the attacks on cultural and individual wellbeing (Agyeman et al. 2009). Legal challenges in the Treaty 8 area have met some success, such as in the Mikisew Cree First Nation v. Canada (Minister of Canadian Heritage) case (2005) where the construction of a winter road neighbouring reserve land was put on hold as Sheila Copps, the Minister of Canadian Heritage, failed to consult the Mikisew Cree before approving construction. As recently as January 2013, the neglect of Indigenous peoples' rights in the area has been legally challenged with the Mikisew Cree First Nation filing a legal case against the Government of Canada for changes in legislation made in Bills

C-38 and C-45 (also known as Omnibus Bills), which they view as violations of Treaty obligations to protect their traditional territories from environmental degradation (Galloway 2013). In short, settler (white) relations with Indigenous peoples have a long and contentious history in the Athabasca region and it is reasonable to expect that these struggles will continue to play out in the courts and on the ground as the bitumen sands industry expands and intensifies.

Moving east from the bitumen sands mining in Alberta, Saskatchewan is downwind of this pollution source and occupied by an Indigenous community, The Clearwater River Dene Nation (Figure 1.1), many of whose members are concerned about the impacts of the industry in terms of the health of their territory and the future viability of their land-based lifestyle. The Clearwater River Dene Nation is within Treaty 8 and part of the Meadow Lake Tribal Council in northern Saskatchewan (Meadow Lake Tribal Council n.d.) and their membership have erected roadblocks to forestall exploration of bitumen deposits in their traditional territory in the past (CBC News 2007). Environmental concerns were one of the main reasons behind this action (Ingram 2011). Plans to expand the road network to link Fort McMurray and northern Saskatchewan would bring benefits to the isolated community, but the band leadership also foresee additional stresses on the sustainability of land-use management in the area (Meadow Lake Progress, 2005). Given these circumstances and my own interests in ethical/moral spaces of natural science research involving Indigenous peoples, attempts were made in this research project to engage with the Clearwater River Dene Nation. In the next section, an overview of the ethical considerations for such engagement is explored.

1.3 Ethical Considerations

1.3.1 *Research as part of the colonial enterprise*

Research has played a key role in the disempowerment of Indigenous peoples in Canada (Ermine et al. 2004), but there is a contemporary attempt to reverse this trend by using research to extend the political autonomy and self-determination efforts of Indigenous peoples (Fletcher 2003). Attempts to decolonize academic institutional culture have largely been developed through research involving Indigenous peoples as partners in community-based participatory research (CBPR)[7](Fletcher 2003; Ermine et al. 2004; Ball and Janyst 2008). Another much needed, but seldom enacted, change is to extend acknowledgement of Indigenous authority to all research occurring within a traditional territory, even when not explicitly involving Indigenous peoples themselves as subjects (Ermine et al. 2004).

1.3.2 *The challenge to natural scientists*

The Tri-Council research agencies in Canada (Canadian Institutes of Health Research (CIHR), Natural Sciences and Engineering Research Council of Canada (NSERC), and Social Sciences and Humanities Research Council of Canada (SSHRC)), which fund a significant amount of research undertaken at Canadian universities, have developed ethical guidelines specific to research involving Indigenous peoples (CIHR, NSERC, and SSHRC 2010). While this has resulted in a more thorough ethical review process at the university level, natural science and engineering research (funded by NSERC) continues to largely circumvent this area of the ethics review process. This segment of the researcher population is often considered exempt from ethics review as they are not typically collecting data from human participants, but I would assert that does not mean the knowledge they generate is without potential effect on the people interspersed with the animals, plants and minerals these scientists target in their

[7] While CBPR has largely been applied by non-Indigenous researchers using western research methods in a community-based and participatory way, the number of scholars applying Indigenous methodologies, be they Indigenous or not, are also on the rise (Wilson 2008; Kovach 2009).

studies[8]. It is the scientist's responsibility to respect the privilege they hold and the power they wield by considering the social and political context in which their results exist (Anderson et al. 2008).

Research findings should be communicated outside of the academic spheres that produce them (Williams et al. 2007). If academics in publicly funded institutions do not take on the task of engaging potential knowledge users, private sector experts will act as the main informants influencing general public perceptions and government policies to suit their own ends (Foote et al. 2009). The challenge for natural scientists is to modify the classic scientific procedure with the addition of a step requiring the ethical context be considered. There has been some progress in adapting scientific procedures, as northern Canada currently has a movement among natural scientists committed to more community involvement in research occurring in Indigenous spaces and places (Korsmo and Graham 2002; Gearheard and Shirley 2007). Hopefully the future will have more fully integrated research engaging Indigenous partners in the process earlier than dissemination and adapting methodologies to reflect the advantages inherent in Indigenous ways of knowing (Wilson 2008; Coombes 2012; King 2012).

1.3.3 Personal positionality

As an academic-in-training in the 21st century, I feel it is important to be forward about my personal history and values as these factors will affect my research. I was born in Edmonton, Alberta and grew up in a rural area east of the city. With a botanist for a mother and a geography professor interested in climate change and post-oil spill ecology for a father, I have been immensely privileged with life-long experiences of scientific principles in practice.

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[8] This is something that is also articulated in the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (TCPS2) Arctile 9.1: "Where the research is likely to affect the welfare of an Aboriginal community, or communities, to which prospective participants belong, researchers shall seek engagement with the relevant community" (CIHR, NSERC, and SSHRC 2010, 110).

My own research interests are two-fold. One portion focuses on a particular area of the Mackenzie and Selwyn mountain ranges in the Yukon and North West Territories. This area is the traditional territory of Kaska Dena and Mountain Slavey peoples. My work there has focused on landscape features sensitive to climate change, as well as ecological recuperation following disturbances beginning in the 1940s associated with a pipeline built to support the American war effort. The other branch of my research has focused on the Alberta bitumen sands industry's environmental impacts and what information gaps exist in monitoring the industry. In both places, I seek to assure my work is guided by the ethical/moral issues concerning the impacts of the oil and gas industry and how Indigenous interests are considered and accommodated in the process. It is this place of awareness and understanding that my thesis takes as its point of departure for the project outlined below.

1.4 Project Overview

1.4.1 Research goals and objectives

1.4.1.1 Research goals

The goals of this thesis were to document tree growth responses associated with bitumen mining activity and discuss these findings with local Indigenous peoples. Given these goals, my research addresses the following question: How can the Clearwater River Dene's information needs concerning atmospheric bitumen sands pollution be met through dendrochronological analysis?

1.4.1.2 Research objectives

The research goals and question generated two interconnected research objectives. The first objective was to develop meaningful, culturally appropriate engagement processes with members of the Clearwater River Dene Nation. By engaging in relationship building and knowledge sharing activities beyond the scope of furthering my own dendrochronological analysis, I hoped that trust, respect and reciprocity would be established with the Clearwater River Dene community. Such a process of relationship building and knowledge sharing has the potential to help develop the appropriate terms and context for framing the study's results so they are applicable to and valued by community members and leaders.

The second objective was to explore the potential of dendrochronology in identifying the presence and effect of atmospheric pollutants from bitumen sands mining activities. I hypothesized that a long-term reconstruction of the detrimental effects on ecosystems downwind of Alberta bitumen sands operations can be quantified as suppressed growth of trees in response to pollutant inputs. Both temporal and spatial trends are expected to be evidenced as greater growth suppression in the trees closest to the mining and within their most recent rings, grown when mining activity has been most intense.

1.4.2 Study area

My study sites are within the boreal plains ecozone (Ecological Stratification Working Group 1995). This region's climate is characterized by long cold winters (-17.5°C to -11°C on average) and moderately warm summers (13°C to 15°C). The forest along the study's transect was predominantly mixed-wood, with trembling aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*) and white birch (*Betula papyrifera*) hardwoods; jack pine (*Pinus banksiana*), white spruce (*Picea glauca),* and black spruce (*Picea mariana*) softwoods. Hardwood understories had an array of shrubby and herbaceous plants, while softwood understories often developed more feather mosses (Ecological Stratification Working Group 1995). All study sites were selected within homogeneous, old growth, white spruce stands.

1.5 Research Approach and Design

1.5.1 Community involvement

In 2009, the research team I am involved with became aware of local Indigenous concerns amongst members of the Meadow Lake Tribal Council over downwind pollution risks and began a dialogue on potential research to explore the extent and impacts of bitumen mining pollution in Saskatchewan. As natural scientists with limited training and experience in engaging Indigenous peoples in such a dialogue, this process was largely limited to conversations between academic experts and Meadow Lake Tribal Council experts, such as forestry managers and community health coordinators. In research engaging Indigenous peoples, there are cultural gaps that need to be bridged for effective communication that do not exist when attempting to engage other scientists or even the general public (CIHR 2009). Attempting culturally appropriate engagement with members of the Clearwater River Dene community developed through three phases: A preliminary phase where beginning relationships were formed, a second phase where time was spent in the community and field trips were arranged to involve Dene youth in the research process, and a final phase providing updates as research progressed and final results were established[9]. A detailed account of measures taken to maximize the opportunity for community involvement and enhance inter-cultural communication and teaching/learning between the Clearwater River Dene community and myself as well as other members of the research team is discussed in Chapter Two.

1.5.2 Dendrochronology study design

As noted in the Introduction to this chapter (1.1), tree-ring analysis has the potential to help in understanding the environmental impacts of bitumen sands pollution in

[9] It is my hope that while this project has come to an end, this will be the beginning of a career of relevant, responsive research in collaboration with the Clearwater River Dene Nation and other Indigenous communities with similar concerns regarding industrial development.

the region. In this study, tree samples were collected at six sites following the Athabasca and Clearwater Rivers downwind (east) of mining activity (Figure 1.1). After samples were mounted and sanded in preparation for measurement, a 63x microscope was used to accurately measure each core's annual changes in growth as per standard dendrochronological analyses (Speer 2010). A series of statistical tests and data transformations followed to remove physiological growth trends associated with age (Cook and Holmes 1986; Speer 2010) and isolate components of the growth signal that could be related to potential growth affecting factors (Fekedulegn et al. 2002). The final stage of analysis applied multiple linear regressions to test the strength of association between the isolated principal components of growth and specific climate and industry activity variables. A detailed account of the dendrochronology study design is presented in Chapter Three.

1.5.2 Organization of Thesis

This thesis is organized into four chapters. Chapter One introduces readers to the context of my research by exploring multiple layers of the social, environmental, and industrial geography of the Athabasca bitumen sands region. This chapter is also intended to establish the ethical imperative of my research question and process.

Chapter Two is an independent manuscript prepared as a journal submission exploring the ethical/moral imperatives that natural scientists face when developing research programs occurring on Indigenous landscapes in Canada and reflecting on my attempt to share this space with Indigenous peoples. Chapter Three is an independent manuscript prepared for journal submission detailing the design, execution and outcomes of a white spruce dendrochronology study following a transect extending from bitumen mining operations in Alberta into Clearwater River Dene territory in Saskatchewan. As both Chapter Two and Three were designed to be self-contained manuscripts, there is some repetition in the content of their introductions and the material found in Chapter One. Each Chapter is with its own reference section.

Chapter Four offers final conclusions for the thesis, revisiting the original purpose and objectives stated in Chapter One and reflecting critically on the study's ability to fulfill them. Content of both Chapter Two and Three will be synthesized in Chapter Four and thoughts concerning the strengths and limitations of my project will be discussed so future research and policy on these subjects may benefit from this thesis.

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CHAPTER 2 - PHYSICAL GEOGRAPHY KNOWLEDGE MOBILIZATION ON INDIGENOUS LANDSCAPES IN CANADA: IDLE NO MORE? A SPECIAL CALL TO EARLY CAREER SCIENTISTS

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2.1 Statement of Student Contribution

G. Kershaw was responsible for the original draft of this manuscript. All interaction with Clearwater River Dene community members and preparation for engagement described in this chapter involved G. Kershaw. Revision based on feedback from co-authors was also completed by G. Kershaw.

2.2 Introduction

2.2.1 The ethics of physical geography in Indigenous spaces

The Idle No More movement, which is an Indigenous peoples' led resistance to recent federal omnibus legislation affecting Indigenous treaty rights and environmental integrity (The Canadian Press 2013), has precipitated a lively, if not heated, national dialogue concerning the relationship between Indigenous-settler peoples in Canada. Given the legacy of unethical research involving Indigenous peoples to date and the current calls for change coming from the Idle No More movement, it is incumbent on us as physical geographers to critically reassess how our research engages Indigenous peoples, spaces and places in Canada.

The three research funding councils of Canada (Canadian Institutes of Health Research (CIHR), the Social Sciences and Humanities Research Council of Canada (SSHRC), and the Natural Sciences and Engineering Research Council of Canada (NSERC)) have established a "Tri-Council" policy statement concerning the ethical conduct of researchers receiving their grants. The 1998 statement was in need of revision to maintain its currency with the evolving nuances of what constitutes "ethical" research, and so in 2010 a revised joint policy statement was released*: The Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans* (CIHR et al. 2010), or TCPS2 for short.

A substantial change from TCPS to TCPS2 was the addition of Chapter 9, which is specifically dedicated to the ethics of research involving Indigenous peoples in Canada (CIHR et al. 2010). Chapter 9 was a constant reference in last year's (2012) Summer Issue of *The Canadian Geographer* (56:2) (Castleden et al. 2012a; Castleden et al. 2012b; Grimwood et al. 2012; Koster et al. 2012), which focused on Indigenous community-based participatory research in Canadian geography. The special issue included accounts of the progress made and challenges faced by geographers responding to the ethical requirements of research with Indigenous peoples in Canada.

The current structure of the TCPS2 does not give direct consideration to non-human research subjects: "[r]esearch that involves the collection and analysis of tissue samples from animals or plants, and not involving human research participants, is not covered within the scope of this policy and does not require institutional REB review" (CIHR et al. 2010, 113). But, while physical geography research does not typically involve human participants, the resulting knowledge produced often has impacts on human populations. After examining the TCPS2 chapter 9, we found it surprising how little direction is given concerning how physical geographers might apply ethical principles in their research projects when occurring on Indigenous lands.

Some guidance for ethical considerations concerning non-human subjects is given tangentially through association with Indigenous peoples as their "ethical obligations often extend to respectful relations with plant, animal and marine life" (CIHR et al. 2010, 108). This consideration is limited to First Nations, Inuit and Métis lands, which include "Indian reserves, Métis settlements, and lands governed under a self-government agreement or an Inuit or First Nations land claim agreement" (CIHR et al. 2010, 108).

Currently the ethical responsibility for physical geography research is limited, but there is space to expand within the guidelines of the TCPS2. University-based research ethics boards (REBs) in Canada could assert the need for ethical review of physical geography research regardless of its location relative to indigenous lands by instead emphasizing that where "research is likely to affect the welfare of an Indigenous community, or communities…researchers shall seek engagement with the relevant community" (CIHR et al. 2010, 110). This stipulation applies a broader understanding of Indigenous well-being which considers the environment's state of wellbeing as linked to human health (Parkes 2010). This concept is often referred to as EcoHealth (Rapport and Singh 2006). As NSERC is responsible for assuring the TCPS2's full and fair application in NSERC-funded research, and is "committed to the continued evolution of this Policy" (CIHR et al. 2010, 105), the Idle No More movement should be viewed as an opportunity to reassess the TCPS2's application in physical geography.

2.2.2 (Un)learning to collaborate

The importance of Indigenous community involvement in physical geography research is heightened when one considers how Indigenous peoples often emphasize "[o]ne essential aspect of their relationship to nature [being that] humans are formed of the same essence as other life forms and may transform from one to the other (Kew and Griggs 1991)" (Ayers et al. 2012, 265). As the TCPS2 policy does acknowledge "the role of community in shaping the conduct of research that affects First Nations, Inuit and Métis communities" (CIHR et al. 2010, 107), non-human subjects should be treated with such respect as the community deems fitting. Following from Ayers et al.'s above quote (2012, 265); this could result in ethical considerations for non-human subjects' having parity with humans. In this light, physical geographers should at least ask Indigenous peoples associated with the landscape under study what ethical and/or relational sensitivities they have towards non-human subjects and how we, as researchers, can accommodate them.

Physical geographers do not (typically) receive training in participatory research, which is not requisite for their projects and is even actively discouraged by the dominant discourse based on the values of scientific objectivity (Daston 1992). This lack of skill is in part responsible for the limited buy-in from local residents of externally developed conservation projects (Mulrennan et al. 2012). The expectation for separation between researchers and potential Indigenous community partners is reinforced in the TCPS2: "a community may, for example, support a research project carried out independent of community influence, or without any further collaboration of the community in the actual implementation of the research in order to use *scientifically defensible results* to validate a negotiating position [emphasis added]" (CIHR et al. 2010, 122).

Much of NSERC funded research is undertaken with industrial partnerships and holds economic implications. It is stated in the TCPS2 that if "research has explicit commercial objectives, or direct or indirect links to the commercial sector, researchers and communities may want to include provisions related to anticipated commercial use in research agreements" (CIHR et al. 2010, 129). Given the legacy of unethical research resulting in economic gain (e.g., misappropriating Indigenous Knowledge concerning the medicinal properties of herbal plants; geological surveys for future resource extraction (Hein 2000; Mgbeoji 2006)) and the current time and space of Indigenous-settler cultural relations (e.g., the Idle No More movement in response to the federal government's omnibus bill changes to environmental protections and Indigenous governance structures (Ecojustice 2012; The Canadian Press 2013)), it is incumbent on natural scientists and engineers to fulfill, in good faith, their side of the reciprocity exchange. This means that when access to reserve lands/traditional territories is granted and the research involves potential economic gain, researchers need to share—at a minimum—the results and, ideally, economic gains with the Indigenous community/communities affected.

2.3 Our Attempt To Be Idle No More

As a team of natural and social scientists, we have attempted to respond to the ethical dimension of our research on potential Alberta bitumen mining pollution impacts registered in tree growth downwind. This research project occurs in traditional Dene territory in northern Saskatchewan, and while not a community-based participatory research (CBPR) project (CBPR being much more rigorous and extensive in the measures it uses to assure inclusion and an equitable distribution of influence and benefits between the research team and the partnering community (Castleden et al. 2012b)), the following account reflects the best ethical response we could manage given the limited time and resources associated with a self-contained masters thesis project.

2.3.1 Phase I – Establishing first relations

In the summer of 2011, our tree sampling began. Some of the sampling sites selected were within a Dene community's traditional territory. Leading up to the fieldwork, extensive e-mail and telephone conversations were had with the Band's management concerning how to arrange a trip to the community to discuss the project with the Chief and Council. Logistically this was difficult to achieve due to scheduling incompatibilities and the physical distance between the community and the researchers (~5000 kilometres). After several failed attempts to coordinate schedules, I embarked on an eight-hour drive to the community, hoping the Chief and Council would be available.

The plan, on arrival, was to simply ask for an opportunity to speak at a Council meeting: this was granted and a brief introduction to the research project (already underway[10]) was delivered. Additional discussions with the Chief, Band manager, and health coordinator took place immediately afterward. At the conclusion of this first trip, it was agreed that an ongoing dialogue with Band management as well as

[10] Dialogue involving the Meadow Lake Tribal Council, of which the First Nation was a member, had occurred prior to data collection and permission for the study was granted at this level.

local teachers would follow. The involvement of teachers specifically was based on the demonstrated interest of some of the students and the expressed need for showcasing future science career options to the youth.

With this trip, three key objectives were met: 1) we created an awareness of our project in the community and attained permission to continue with our research; 2) we demonstrated a commitment to the leadership to communicate openly throughout the research process; and 3) we established an expectation in the community for follow-up and an investment on the part of the research team to make the project relevant to the community's needs.

2.3.2 Phase II – Community engagement

2.3.2.1 Preparation

An experiential learning module for high school science students was designed with input from community teachers and university educators. It remained difficult to develop full commitment and mutual understanding with the teachers and Band management given the physical distance between the community and our universities, but enough conversation occurred to allow us to prepare for two weeks in the community involving class presentations and field trips for the students. The field school was implemented in April-May 2012.

2.3.2.2 Classroom delivery

Before in-class activities began, a week of time was reserved for re-introductions to Band management, school administration, and other interested community members. Instruction style and content was discussed with the teachers and other school support staff. Presentations were then made to Grade 10 students in two subject areas: energy and mining, and geography. Approximately 25 students were involved.

2.3.2.3. Field school

The week after class presentations, 14 students, two Elders, one teacher, another school staff member and G. Kershaw went to collect tree samples. Before our demonstration was complete, students were using the corers to sample trees, suggesting strong interest on their part. The planned schedule was quickly abandoned to put everyone (else) at ease and allow for unforeseen mutual learning opportunities; in retrospect, this was key to the field trip's success. For example, an Elder taught how to break a log by leveraging it between two tree trunks. Also, a student translated a conversation between an Elder and I, which led to further discussion about tree selection for the purposes of my thesis and what factors influence tree growth.

2.3.2.4. The Canadian Light Source (CLS)

Nine students elected to participate in an overnight trip to visit the CLS at the University of Saskatchewan. Dr. Colin Laroque, himself Métis and originally from Saskatchewan, was present at the university to talk about science as a career motivated by personal connections to the land. Some of the most engaging learning took place over meals or on the road and while these moments often did not focus on the research project, they were opportunities to explore each other's understandings of ecology and culture more broadly. One student expressed interest in going to university and all students appreciated the learning opportunity that the trip provided. In short, there was a sense of satisfaction (relational ethics) for me concerning the level of interest among the students involved.

2.3.3 Phase III – Continuing relationships

Short jargon-free updates on research progress have been submitted to the Band management over the life of the project. Final results will be shared in the community in the coming year. This will hopefully take the form of in-class visits, a discussion with Chief and Council, and a multimedia presentation followed by discussion open to all community members. Having developed this community-university relationship, we desire to maintain it and continue to share our passion for physical geography with the Clearwater River Dene Nation.

2.4 Bridges and Gaps

2.4.1 *Bridges*

It is incumbent on us as geographers to engage Indigenous peoples in research when they are potentially affected, especially in light of the fact that geography has played a significant role in the colonial encounter here in Canada (Godlewska and Smith 1994). Such research requires us to be "relevant to community priorities and have the potential to produce valued outcomes from the perspective of the community and its members" (CIHR et al. 2010, 124). As such, it behooves researchers to adapt their traditional arms-length objective approaches and accommodate potentially affected communities' interests and inputs.

It is important that researchers "offer the option of engagement, [but also recognize and accept that] a community may choose to engage nominally or not at all, despite being willing to allow the research to proceed" (CIHR et al. 2010, 121). It is well known that disciplinary silos have a history of speaking past each other in the academy and that the jargon of academic discourse is often uninviting to the uninitiated. Thus, it is not surprising that the same lack of engagement has been known to occur in the public domain, including Indigenous communities (Taylor 1995). We should endeavour to make our science accessible and open ourselves to the value of Indigenous science as we try to respond to the pressing environmental issues of the 21st century.

2.4.2 *Gaps*

The time and funding required to assure our conduct was ethically responsible during this project were difficult to manage. Funds for community engagement were difficult to secure, and although such funding can be built into larger grants, smaller pools of funding dedicated towards these ends are limited. Concerning time, the process of relationship building and the mutual understanding required to adapt a research project to suit a community's interests is long and the academic pay-out, in the form of data leading to publications, is little. In the highly competitive academic environment of today, dedicating time to community engagement activities that do not translate into publications is a difficult choice to make, and regrettably, has the potential to slow early career progress. However, the measure of a study's success is more than that granted within our own self-selecting academic circles; there is a larger, more important social landscape surrounding us that we are ethically obliged to be involved with and validated by as well.

2.5 Closing Thoughts

The guest editors of *The Canadian Geographer* (56:2 2012) invited international Indigenous scholars to comment on Canadian geographers' community-based participatory Indigenous research. Brad Coombs of Aotearoa (New Zealand) noted that we are focused on "diversifying research dissemination and not disseminating research production" (Coombes 2012 291); his critique is valid, and something we recognize as a weakness in this thesis. That said, considering the current state of research relations between Indigenous peoples and physical geography, the dissemination of results is perhaps a prerequisite to greater mutual understanding and engagement in research design and production. Like our fellow human geographers, we need to get out of the ivory tower, into the community, and as Castleden et al. (2012a) suggests, "listen (listen, listen) respectfully to the community members, leaders, and Elders concerning issues that are important to them" (p. 173).

I would also reinforce Renee Pualani Louis' commentary (2012) that "[f]rom an Indigenous perspective, speaking about any experience should be considered a secondary source while engaging in that experience is a primary source" (p. 289). There is a constant tension in the academy between theory and practice, and the danger of rhetoric rather than meaningful action is real with respect to research involving Indigenous peoples (Castleden et al. 2012b). As researchers, we must improve our own projects before we can expect a more effective, ethically sound effort in the larger academic community. In my view, developing a community-based approach to physical geography research is an effective and *ethical* way to respond to Idle No More demands for respect and accommodation of Indigenous interests.

2.6 References

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CHAPTER 3 - DOWNWIND OF BIG BITUMEN: A DENDROCHRONOLOGICAL ASSESSMENT OF ATMOSPHERIC POLLUTION EFFECTS FROM ATHABASCA BITUMEN MINING

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3.1 Statement of Student Contribution

G. Kershaw contributed to developing the experimental design of this study. Sample collection, processing, and data analysis were also completed by G. Kershaw. The original draft of this manuscript was written by G. Kershaw and revision based on feedback from co-authors was led by G. Kershaw.

3.2 Introduction

3.2.1 Alberta bitumen mining impact monitoring

In the bitumen sands mining industry, current self-monitoring protocols with provincial government oversight are suspect (Timoney 2007; Kelly et al. 2010; Gosselin et al. 2010). Industry's self-interest to maintain a 'clean' record is obvious, and the government holds economic interests in the industry (Alberta Petroleum Marketing Commission and North West Redwater Partnership 2011) and has stated aims to continue expanding bitumen extraction (National Energy Board 2006). Research conventions monitoring the industry include environmental impact assessments, instrumental data monitoring and regional research projects aimed at assessing the cumulative, long-term effects of bitumen sands development (Gosselin et al. 2010). The efficacy of these protocols has been challenged by independent studies with results contrary to the government and industry position of negligible to minimal impacts of mining activity (Kelly et al. 2010; Jung and Chang 2013; Kurek et al. 2013). This context of conflicting findings makes it difficult to assess the validity of past research on bitumen sands mining's environmental impacts. The often heard claim that there is no evidence of deviation from baseline environmental conditions in the region (Gosselin et al. 2010) is just as often met with mistrust, including from the Indigenous peoples living on the landscape under threat (Poitras et al. n.d.).

Various environmental proxy indicators have been studied in the Athabasca region to assess bitumen mining impacts directly, including lichens (Addison and Puckett 1980; Enns 2001; Berryman et al. 2004), mosses (Wieder et al. 2010), snow pack (Kelly et al. 20109), fish (Timoney and Lee 2009), lake sediments (Hazewinkel et al. 2008; Kurek et al. 2013) and lake waters (Scott et al. 2010). Elevated levels of nitrogen, sulphur (Berryman et al. 2004), heavy metals (Addison and Puckett 1980; Berryman et al. 2004; Timoney and Lee 2009) and polycyclic aromatic hydrocarbons (PAHs) (Timoney and Lee 2009; Kelly et al. 2010; Kurek et al. 2013) have all been measured via these proxies.

3.2.2 The potential for dendrochronology

Annual tree growth has been used as a proxy indicator of ecosystem health because trees are stationary and retain a record of environmental parameters affecting them throughout their lives (Schweingruber 1996). This has led to extensive research on tree-growth relationships with climate (Fritts 1971; Fritts 1976; Cook et al. 2000), fire regimes (Lecomte et al. 2010), insect outbreaks (Hogg et al. 2005) and a host of other environmental hazards including, snow avalanches, rock falls, flooding, and volcanoes (Speer 2010; Stoffel et al. 2010). One of the less commonly explored avenues of dendrochronological investigation is the effects of pollution from anthropogenic sources on tree growth (Frelich et al. 1989). This branch of dendrochronology has illustrated growth suppression associated with site specific (Fox et al. 1986; Long and Davis 1999; Aznar et al. 2007; Ridder et al. 2007) and regional pollution sources (McClenahen and Dochinger 1985; Mclaughlin 1998), as well as dwarfing of growth form (Scott and Scott 2003) and mortality (Linzon 1966) in more extreme circumstances.

The literature concerning what species of tree make valuable bioindicators of pollution via reduced growth responses has documented effective applications for both deciduous and evergreen species (McLaughlin 1998; Balouet et al. 2007; Ridder et al. 2007; MacDonald et al. 2010). Removing that portion of one's selection criteria, the distribution of a species should be considered to assure appropriate study sites can be found once in the field (Weiss et al. 2003). Also, the average age of a species is important as older samples are preferable for dendrochronological analysis as they contain more observations in their annual rings. Given these selection criteria, the ideal candidate species in the Athabasca region would be a long-lived conifer such as white spruce (*Picea glauca)*, known for its longevity and large distribution in the region relative to other common species such as jack pine (*Pinus banksiana*), trembling aspen (*Populus tremuloides*), or balsam poplar (*Populus balsamifera*).

Principal component analysis (PCA) is a statistical method of data reduction used when a data source exhibits high dimensionality and a more essential representation of inherent patterns is desirable (Zuur et al. 2007). This statistical tool has been applied in dendrochronology studies to reduce both tree-growth variance (Andreu et al. 2007; Bogino and Bravo 2008) and the variance of growth influencing factors such as temperature, precipitation (Biondi and Waikul 2004; Payette 2007), and snowpack (Anderson 2012). Assessing the Principal Components (PCs) generated from tree-ring indices and/or the data on potential growth influencing factors often uses regression analysis, such as stepwise linear regressions (Anderson 2012), and multiple linear regressions (Fekedulegn et al. 2002; Hogg et al. 2005) to test the significance of association between the PCs and potentially correlated variables.

As elevated pollutant levels are known to occur in trembling aspen and jack pine trees growing downwind of the bitumen sands (Jung and Chang 2013), it is of great interest to see if white spruce trees register this same exposure to pollutants in their annual-ring's growth. If a relationship exists between tree growth and bitumen mining activity, it should be quantifiable as a statistical correlation between radial-growth and pollution outputs. In this study, a PCA procedure using tree-growth data and a multiple linear regression comparing PCA outputs with data from potential growth influencing factors including climate, pollution, and mining production was conducted to test for this relationship. We hypothesized that both temporal and spatial trends would be evident as greater growth suppression in the trees closest to mining activity and their most recent rings. Furthermore, we hypothesized that more distant sites would exhibit weaker or indiscernible associations with bitumen mining pollution. With a long enough history of annual growth, it should be possible to establish baseline conditions for growth in the region and to make comparisons with growth after industrial mining activity became more intense.

3.3 Study Sites

3.3.1 Site selection

In the summer of 2011, white spruce were sampled at six sites along a transect following the Athabasca and Clearwater Rivers (Figure 3.1). This transect generally follows the dominant direction that atmospheric pollution travels from bitumen mining activities as it is carried by prevailing winds in the region (Alberta Transportation 2006) (Appendix A). All study sites were selected on south facing slopes (with the exception of Site 2) in old growth, white spruce dominant stands with little hardwood intrusion. While it would have been ideal to control for all additional site characteristics, such as soil chemistry and slope, and to select more evenly spaced sites according to distance from bitumen mining activity, these factors were not consistent between sites. The limitations of a transect following a river and the need to be opportunistic in site selection to assure old growth stands were found (deemed the most important factor for site selection), prohibited us from controlling for other site characteristics.

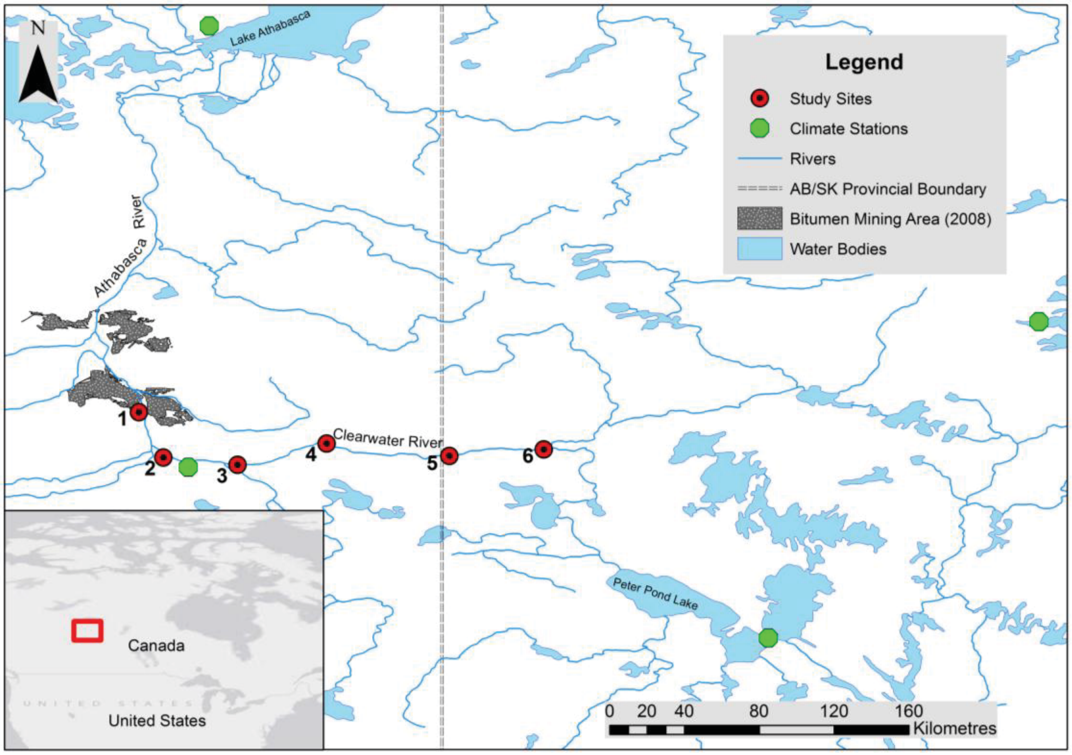

Figure 3.1- Location of the six study sites, bitumen mining activity, climate stations, major rivers, and water bodies in the region.

3.3.2 *Site descriptions*

The six study sites were situated in the boreal plains ecozone (Ecological Stratification Working Group 1995), a region that experiences continental climate conditions with long cold winters (-17.5°C to -11°C) and moderately warm summers (13°C to 15°C). The forest sampled along the river valley was predominantly mixed-wood with trembling aspen, balsam poplar and white birch (*Betula papyrifera*) representing hardwoods; jack pine, white spruce and black spruce (*Picea mariana*) accounting for the softwoods. Jack pine was more prevalent in the eastern portion of the study region and often occurred on steeper inclined slopes and/or riverbank plateaus with sandy soils. Changes in dominant tree species composition along the transect are likely related to the transition from regisolic soils in the east, which are poorly developed, to organic and gleysolic soils along the western portion of the transect (Soil Classification Working Group 1998). The understory of hardwood stands were diverse with an array of shrub and herb species, while the softwoods often developed more feathermosses (Ecological Stratification Working Group 1995).

3.4 Methods

3.4.1 Sampling

At each study site, 36-40 cores were taken from 18-20 trees, with standard 5.15 mm increment borers. Two cores were taken from each tree at breast height with >90° separation on the radius. Once extracted, samples were stored in plastic straws, taped shut, and labelled for transportation to the Mount Allison Dendrochronology Laboratory.

3.4.2 Sample processing

In the laboratory, all cores were mounted on wooden boards and sanded with progressively finer grit paper until a 600-grit polish was attained. A buffing wheel was then used after sanding to clean the cells of sanding dust prior to measurement. Ring widths were measured manually with a 63x microscope and a Velmex-stage micrometer system linked to the computer program J2X (VoorTech 2012). Ring widths were recorded to 0.001mm resolution.

3.4.3 Radial growth crossdating and standardization

Each site's cores were first visually, and then statistically crossdated using the computer program COFECHA (Holmes 1983; Grissino-Mayer 2001) (Appendix B). Among the descriptive statistics generated by COFECHA, high series inter-correlation and mean sensitivity values are desirable, as well as low autocorrelation values. Inter-correlation relates the consistency in signal from each core to a combined site master relative to a 99% confidence threshold (Grissino-Mayer 2001). Mean sensitivity communicates how complacent, or similar, rings are from year-to-year (Speer 2010). Mean sensitivity values ranging from 0.10-0.19 are considered low (highly complacent), 0.20-0.29 intermediate, and above 0.30 high (little complacency) (Grissino-Mayer 2001). Autocorrelation reflects the degree to which one year's radial growth has an influence on the following year's radial growth, with a theoretical value of 1 reflecting total influence and 0 reflecting no influence at all (Grissino-Mayer 2001).

After crossdating, the computer program ARSTAN (Cook 1985) was used to standardize each tree's measurements and remove the portion of the growth signal associated with changes in radial growth due to increasing bole size (Speer 2010). The standardizations applied to each series were either negative exponential, negative linear, or a line through the mean, in that order of priority. Only single detrending was applied and standardized master chronologies were developed using ARSTAN's bi-weight robust mean procedures (Cook and Holmes 1986).

3.4.4 Climate analysis

For each of the six sites, the computer program DENDROCLIM 2002 (Biondi and Waikul 2004) was used to test the relationship between the standardized chronologies and monthly mean temperature and total precipitation within a 16 month window (April previous to current October). Significance of associations between the standardized chronologies and the climate variables were assessed with a bootstrapped PCA procedure generating response values for both precipitation and temperature of each month (Biondi and Waikul 2004) (Appendix C). Response values that exceeded a 95% confidence threshold were considered as a set of test variables for a multiple linear regression (MLR) analysis in the final phase of our methods (see 3.4.6 below).

Homogenized temperature and precipitation records from the four Environment Canada (2010) climate stations closest to the transect were averaged and then input into the DENDROCLIM 2002 analysis. The climate stations were located at Fort McMurray, AB [N56.65, W-111.22], Fort Chipewyan, AB [N58.77, W-111.12], Buffalo Narrows, SK [N55.83, W-108.43], and Cree Lake, SK [N57.35, W-107.13] (Figure 3.1). As no statistically significant differences were present in comparison of climate records using pair-wise t-tests (Appendix D), monthly values used in the analysis were averaged from all four climate stations. Climate data spanned the timeframe 1885-2008 for temperature and 1922-2007 for precipitation.

3.4.5 *Principal component analysis*

Six PCAs were completed using the computer program PCA version 6.02p (Holmes et al. 2013). For each site's PCA, standardized chronologies (n=36-40 cores depending on the site. See Appendix B for more details) were the time series inputs and a common interval of 44 years spanning 1967-2010 was applied. This window was selected for two reasons: 1) to maximize the number of cores available to the PCA matrix as all cores spanned the entire timeframe, and 2) to align with the timeframe of industry pollution and production records in subsequent steps of analysis.

Only PCs which were statistically valid according to the "broken stick model" of significance testing (Jackson 1993) were considered for further analysis. This test controlled for PCs likely reflective of random statistical patterns and not ecologically significant influences on growth (Rexstad et al. 1988). It was also important that the ratio of PCs to sample replication remained in excess of 1:3, given this is the threshold assigned to allow for a statistically viable PCA interpretation (Grossman et al. 1991).

3.4.6 *Multiple linear regression*

For each site, a MLR analysis was conducted comparing each significant PC (y), to the explanatory variables (x) of significant monthly climate variables (see 3.4.4), and industry data measurements of oil sands processed, sulphur production, and sulphur flared and wasted. Pollution and production records represent cumulative data from all operational bitumen mining facilities in the region acquired from the Energy Resources Conservation Board's (ERCB) database of Alberta Oil Sands Plant statistics (ERCB, 2012).

3.5 Results

3.5.1 *Descriptive statistics*

Site chronologies ranged from an average age of 72-152 years old (Table 3.1). Crossdating generated raw chronologies with highly significant inter-correlation values for all sites (ranging from 0.427-0.720). Average mean sensitivity (ranging with intermediate values from 0.204-0.269) indicated how much year-to-year variation each set of cores displayed, with higher values denoting greater sensitivity. Unfiltered autocorrelation values (ranging from 0.737-0.863) signified that the previous year's growth has a strong influence on current year's growth, with the highest valued site (Site 1) indicating the most extreme case of autocorrelation within the group (Table 3.1).

Table 3.1 - Descriptive statistics for all raw chronologies. The 99% confidence level for series inter-correlations is 0.3665 based on the length of the segments (n=40 years) (Grissino-Mayer 2001).

Site (west-east: 1-6)	Mean series length (years)	Number of cores	Mean series inter-correlation	Average mean sensitivity	Unfiltered autocorrelation
1	140.1	36	0.427	0.254	0.863
2	72.0	36	0.529	0.269	0.737
3	152.0	40	0.612	0.224	0.759
4	89.6	40	0.622	0.204	0.791
5	76.9	36	0.548	0.255	0.759
6	80.7	36	0.701	0.254	0.741

3.5.2 *Principal component analysis*

The PCAs generated two to three significant PCs accounting for greater than 70% of the standardized chronology's total variance at each site (Table 3.2). Sites in closer proximity to bitumen mining activity had PC1s with a downward trend through time and negative values consistently following 1998-2000 (Figure 3.2a-d). At Sites 2-4, PC2 had a gentle upwards trend (Figure 3.2b-d). PC1 at Sites 5 and 6 followed an oscillating pattern ending in a positive trend in the late 2000s (Figure 3.2e-f). Site 6's PC2 followed a pattern similar to PC1s from sites 1-4 - a steady decline that steepened after 1998-2000 (Figure 3.2).

Table 3.2 - Principal components at each site with the corresponding variance of the original standardized growth chronology accounted for. Only PCs passing the broken stick significance test (Jackson 1993) are reported.

Site (west-east: 1-6)	PC1 (Variance %)	PC2 (Variance %)	PC3 (Variance %)	Total variance explained (%)
1	57.9	14.0	---	71.9
2	47.7	16.9	10.3	75.0
3	46.5	16.5	7.3	70.3
4	62.1	12.8	---	74.9
5	41.4	18.9	14.1	74.4
6	49.1	18.2	---	74.7

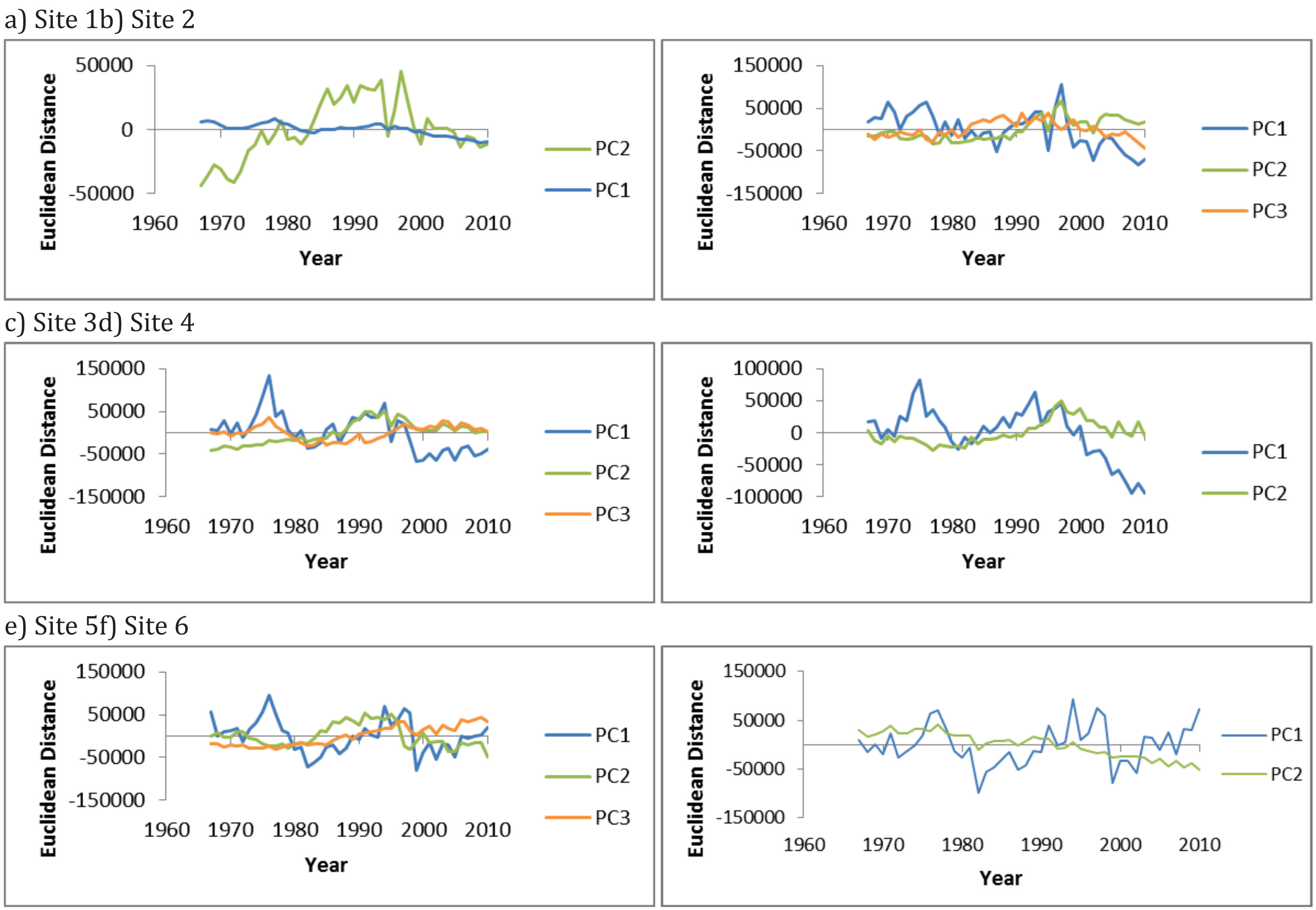

Figure 3.2 - Principal components generated from each site's standardized chronologies over the time interval 1967-2010. Only those principal components that pass the broken stick critical test (Jackson 1993) are presented.

3.5.3 MULTIPLE LINEAR REGRESSION ANALYSIS

Not all potential growth influencing factors assessed had statistically significant associations with PCs. MLR identified oil sands processed, sulphur flared and wasted, and summer/fall precipitation (June-August) both during the year of ring formation and the year previous to ring formation as factors with significant associations to PCs (Table 3.3). Oil sands processed was the most constant and significant growth influencing factor, often associating with PC1s, PC2s, and PC3s at greater than 99% confidence (Table 3.3).

Table 3.3 - MLR results comparing significant PCs for each site to potential growth influencing factors including monthly temperature and precipitation variables identified as important via Dendroclim 2002 (Appendix D), total oil sands processed, and sulphur flared/wasted. The _P denotes previous year. Only significant p-values are reported (red cells >99% confidence, orange cells >95%, green cells >90%).

			Mining activity variables p-values		Precipitation variables p-values			
Site	PC	Adjusted R^2	Oil sands processed (Tonnes)	Sulphur flared/ wasted (Tonnes)	June	August	June_P	Sept_P
1	1	0.652	> 0.000	0.017				
2	1	0.499	0.002				0.013	
2	2	0.621	> 0.000				0.002	0.053
2	3	0.077		0.074				
3	1	0.360	0.004					
3	2	0.280	> 0.000					
3	3	0.109	0.039					
4	1	0.558	> 0.000		0.052		0.037	
4	2	0.426	0.007				0.022	
5	1	0.254		0.066		0.084	0.028	
5	2	0.063					0.052	
5	3	0.788	> 0.000				> 0.000	
6	2	0.842	> 0.000					

Applying a set of simple linear regressions comparing oil sands processed with each PC indicated a reduction in the amount of each site's standardized chronology variance accounted for by oil sands processed as distance from mining activity increased (Table 3.4). The total variance explained by oil sands processed was calculated as $Var_{tot}=(Var_{PC1}*R^2_{PC1})+(Var_{PC2}*R^2_{PC2})+(Var_{PC3}*R^2_{PC3})$ where Var=Percent Variance and R^2 values were taken from the respective regression values comparing PCs and oil sands processed. Var_{PC3} was not applied when PC3 was not significant at a given site.

Table 3.4 - Total variance of each site's standardized growth chronology accounted for by the potential growth-influencing factor of oil sands processed. Only PCs with 99% significant associations with oil sands processed (p value <0.01) were considered in this analysis.

Site	**Oil sands processed (Tonnes) (Var %)**
1	42.9
2	28.4
3	20.8
4	38.2
5	10.7
6	15.6

3.6 Discussion

3.6.1 Documenting bitumen mining pollution effects with trees

3.6.1.1 Growth suppression

Comparing the form of PC1s at Sites 1-4, the dominant signals of each site became less stable, covering a wider Euclidean distance, as distance from the source of mining activity increased (Figure 3.2 a-d). The declining PC1s (Figure 3.2 a-d) resembled PC2 (Figure 3.2f) or were absent (Figure 3.2e) at more distant sites. This suggests a weakening association between standardized growth and a dominant growth-influencing factor shared among sites. The observed decrease in adjusted R^2 values as distance from mining activity increases supports the explanation that this loss of signal consolidation can in part be explained by the potential growth influencing factors considered in this analysis (Table 3.3). The statistically significant association of declining PCs (PC1 at sites 1-4 and PC2 at Site 6) with oil sands processed and sulphur flared/wasted (Table 3.3) corroborates the hypothesis that pollution from bitumen mining is influencing the surrounding ecology and that this influence is greatest closest to the source. For five independent PCAs to generate PCs with such similarity, all with significant associations to oil sands processed, while at the same time illustrating declining trends similar to the original standardized chronologies (Appendix B), is an important finding.

The long term and continuous decline observed in PC1 of Sites 1-4 and PC2 of Site 6 (Figure 3.2) follows a disturbance pattern strongly associated with a historical increase in the amount of oil sands processed (Figure 3.3); this is known as a press disturbance, which is a sustained disturbance that differs from pulse disturbances which occur on shorter timeframes (Krebs 1998). The high autocorrelation values reported (Table 3.1) also support the view of a press disturbance as much of each year's growth relates to the previous, making the data less susceptible to pulse occurrences. The high autocorrelation values reported here are consistent with other studies in the Canadian northern boreal which report values ranging from 0.58-0.81 for jack pine growing above 50°N in Quebec (Huang et al. 2010) and 0.67-0.91 for various species including white spruce above 51°N in Labrador (Nishimura and Laroque 2010; Dumaresq 2011). This is likely reflective of how tree growth at this latitude is limited by a short growing season, where much of a given year's growth depends on the reserves developed during the year previous (Fritts 1976).

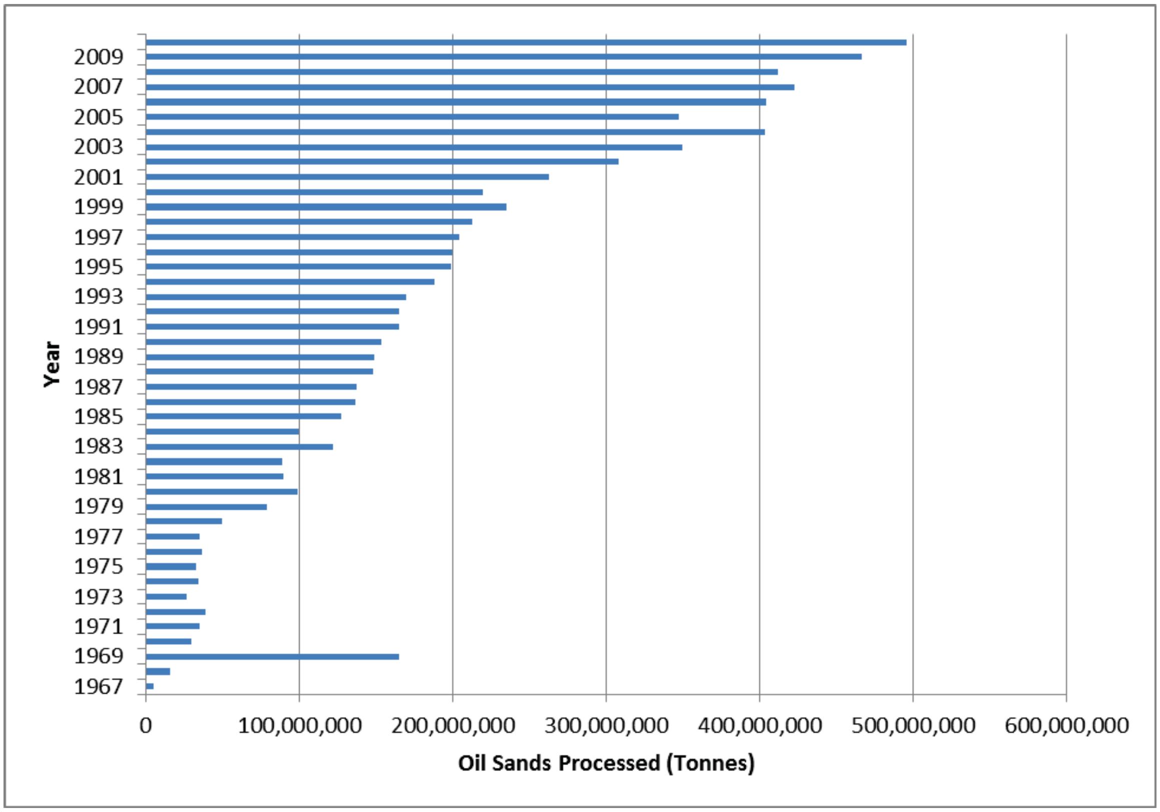

Figure 3.3 - Cumulative amount of oil sands processed reported from mining operations from 1967-2010 (Adapted from ERCB 2012).

The nature of this study's data does not lend itself to detecting pulse disturbances, as the annual resolution of tree growth and reported pollution does not have great enough temporal resolution for this purpose. Pollutant accumulation and growth suppression of trees associated with pollution exposure can be delayed many years, requiring a large temporal window to register the impacts. In other studies of industrial pollution impacts on forests, crown dieback has been observed after 20-30 years of growth reduction (McLaughlin 1985). Although the earliest large scale bitumen mining activity in Alberta initiated in the 1960s, the industry started to expand dramatically in the 1980s (ERCB 2012). The declining growth trends of PC1 at Sites 1-4 and PC2 at Site 6 beginning around the year 2000 (Figure 3.2), likely demarcates the point in time at which pollutants began to substantially accumulate on the terrestrial landscape downwind, interfering with normal tree metabolism. As such, the long-term PC decline and the weakening of this association with increasing distance from bitumen mining activity (Table 3.4) displays both temporal and spatial patterns of growth suppression associated with the disturbance.

3.6.1.2 Mechanisms of growth suppression

A suite of potentially harmful pollutants are introduced to the boreal forest through atmospheric fallout from bitumen mining activities. In 2009, 59 different substances were reported as atmospheric emissions at the Syncrude Mildred Lake facility alone (Environment Canada 2011). Elevated levels of pollutants have been measured in lichens close to bitumen mining (e.g. aluminum, chromium, iron, nickel, vanadium, zinc, sulphur, and nitrogen (Berryman et al. 2004)), and other pollutants, such as polycyclic aromatic compounds (PACs) also have wide distributions in the region, being found up to 50 km from bitumen mining facilities (Kelly et al. 2010).

The statistically significant association between sulphur flared/wasted and Site 1 PC1 gives some grounds for discussing sulphur's role in growth suppression. Atmospheric sulphur dioxide (SO_2) is one of the primary anthropogenic agents of acid rain (Savva and Berninger 2010) and it can be absorbed by plants via the leaf stomata and cuticle (Slovik et al. 1996) as well as roots, where there is very high uptake of sulphur (Weiss et al. 2003). Also, sulphur in solution will change the pH of soil and can mobilize trace metals toxic to trees that would otherwise be unavailable for uptake (Guyette et al. 1989; Kabata-Pendias and Pendias 2001).

Positing sulphur as the single most important growth-affecting agent is, however, an incomplete assessment. Toxic stress experienced by plants is often the result of multiple simultaneous stress factors, with frost damage, drought, and insect infestations being some of the known synergistic stressors (Mulder and Breure 2003; Alberta Environment 2004; Savva and Berninger 2011). Some heavy metal pollutants from bitumen mining, such as mercury and cadmium (Environment Canada 2011), are also known toxins to plant growth (Kabata-Pendias and Pendias 2001; Wang et al. 2012) and can further exacerbate stress on trees. Further research of bitumen mining impacts on the surrounding boreal forest should include an assessment of tree chemistry and how it relates to the observed growth suppression trends. In this study, causal associations between pollution and tree growth cannot be resolved, but the many statistically significant associations observed are important indicators of why additional research is needed to establish these links, should they exist.

3.6.1.2 Mechanisms of growth enhancement

The dominant growth suppression PCs identified in this study are not the only PCs with significant relationships to the amount of oil sands processed: Site 2 PC2, Site 3 PC2 and PC3, Site 4 PC2, and site 5 PC3 also exhibit significant associations (Table 3.3). When the shape of these PCs are assessed, what can be seen is they all tend to trend upwards, with positive values peaking in the mid-1990s and maintaining positive values through to 2010 (Figure 3.2).

Considering the array of bitumen mining by-products that could account for this positive growth trend, nitrogen fertilization is the most likely candidate. Nitrogen dioxide (NO_2) emissions from bitumen mining in the area are increasing in both concentration, and extent of distribution (McLinden et al. 2012). While nitrogen exposure in high enough concentration can cause soil acidification (Seftigen et al. 2012; L'Hirondelle et al. 1992) and nutrient imbalances damaging to trees (Chapin 1980), lower concentrations can serve as growth enhancers in nitrogen limited soils (Pregitzer et al. 1993). Currently, nitrogen concentrations in tree biomass are elevated close to bitumen mining activity, but both jack pine and trembling aspen stands remain nitrogen limited in the area (Laxton et al. 2011). It is important to emphasize that these secondary and tertiary PCs with positive trends are of lesser importance than the dominant growth suppression PCs preceding them (Table 3.3). Other studies comparing the positive effects of nitrogen fertilization relative to the negative effects of sulphur deposition have found the latter as the dominant influence as well (Savva and Berninger 2011).

3.6.1.3 Conflicting findings

This study's findings are contrary to a predating project (Addison et al. 1986) in the Athabasca region that found negligible impacts of proximity to bitumen mining on jack pine cross-sectional area. These conflicting findings are likely due to how early Addison and colleagues' research occurred in the historical record on mining activity. At the time of their work, the intensity of pollution was much less and the cumulative long-term effects had not had sufficient time to accumulate. The differences in results could also be attributed to different tree species sensitivities (Miller and McBride 1975; Mulder and Breure 2003), or perhaps the growing environments of jack pine and white spruce are sufficiently different that the studies produced such contrary results.

Local landscape features such as narrow valleys can also focus pollutant dispersion (Miller and McBride 1975). As a result, following the Athabasca and Clearwater valleys may have increased the likelihood of exposure for the trees sampled in this study, while sampling more uniformly as Addison et al. (1986) did would not. This could account in part for the absence of significant results reported from some of the more distant sites in Addison et al.'s study (1986), as well as findings from a more recent lichenology study in the region (Berryman et al. 2004).

3.6.1.4 Regional versus local pollution impacts

The peer-reviewed literature reliably documents point source pollution effects on tree growth at a local scale (Fox et al. 1986; Innes and Cook 1989; Aznar et al. 2007), but is less consistent when quantifying regional effects (Mclaughlin 1985; Innes and Cook 1989). In this study's analysis, PC1 at Sites 1-4 and PC3 at Site 6 exhibit growth suppression trends significantly associated with the amount of oil sands processed 2.5-120 km downwind from the mining activity (Figure 3.1). Other recent dendrochronology studies in sulphur contaminated regions have also documented a greater range of pollution effects on tree growth, ranging from 25 km distant (Aznar et al. 2007) to across four countries (Savva and Berninger 2010). As such, more recent research applying refined analysis techniques, such as PCA, can provide more reliable accounts of regional pollution effects both abroad and specific to Athabasca bitumen mining.

Alternatively, the amount of pollution generated by bitumen mining could be so far in excess of site specific contaminants studies that regional impacts are registered not due to methodological differences, but rather the sheer volume of pollution generated. Because sampling occurred in a river valley channelling pollution from mining activity in the area (Berryman et al. 2004), the range of association between growth and production is likely indicative of the maximum range of exposure. It would be interesting to sample further into Saskatchewan to see at what distance standardized growth PCs associations with production finally dissipate.

3.6.2 Baseline reference

The timing of this research was opportune as it was recent enough to bitumen mining expansion that the processes of selection for resistant ecotypes (Ernst 2003) had not likely resolved. At the same time, this research occurred after a long enough timeframe following industrial development to allow for long-term cumulative effects of pollution to accrue (Miller and McBride 1975; McLaughlin 1985). As a result, this project transpired at a vital time relative to the beginning of the industry and the delayed response of the surrounding ecology.

The study results provide baseline information prior to bitumen mining impacts in the area, as tree growth in our records extends back in time previous to the industry's substantial increase in production beginning in the 1980s and intensifying around the year 2000 (Figure 3.3). The PC trends associated with oil sands processed and sulphur flared/wasted provide evidence of growth suppression strongly correlated with increasing mining activity. As the pace of bitumen extraction continues to increase, we can expect more prominent impacts on trees. Extreme cases of atmospheric pollution can stunt forest growth, as observed near Flin Flon, Manitoba's zinc and copper smelter (Scott and Scott 2003), or entirely denude a boreal landscape, as seen downwind of the Sudbury, Ontario nickel and copper mining district (Linzon 1966). In the Athabasca bitumen mining region, it is important to register these changes now as it is possible more visible and significant impacts will occur in the future as pollution continues to accrue in the Athabasca region.

3.6.3 Ecosystem level effects of bitumen mining

The growth suppression trends observed in this study could potentially create cascading effects throughout the ecosystem as many other organisms depend on trees for their survival, be they herbivores, microorganisms, or other secondary consumers (Ernst 2003). As pollution effects on canopy species are registered in this study's results, it is likely that understory browse plants are also being impacted (Mclaughlin 1985), affecting the fitness of species dependent on them for forage as well.

Recent dendrochemistry research in the area surrounding Athabasca bitumen mining corroborates our findings, as elevated aluminum concentrations in soil and stem tissue of aspen and white spruce are currently high enough to potentially inhibit seedling growth close to mining activity (Jung and Chang 2013). In lichen, significantly higher concentrations of sulphur, another pollutant commonly associated with tree growth suppression (Addison et al. 1984; Savva and Berninger 2011) occurred in specimens less than 10 km from the pollution source (Addison et al. 1986). Observing temporal and spatial patterns of elevated pollutants in non-biological repositories such as lake sediments (Kurek et al. 2013) and snow pack (Kelly et al. 2010) is concerning, but pairing these findings with increasing pollutants in biological entities including fish (Timoney and Lee 2009), lichens (Addison et al. 1984; Berryman et al. 2004), and now trees (This study as well as Jung and Chang 2013) is much more alarming from an ecological perspective.

It also bears mentioning that our data is unable to directly capture the full complexity of growth influencing factors, let alone translate those tree-level effects to impacts on the whole ecosystem. While bitumen mining activity exhibits significant association with standardized growth PCs in our analysis, so too does precipitation (Table 3.3). There are other stand dynamic factors likely expressed in the PCs driven by fire cycles, insect outbreaks (Payette 2007), and species-competition succession patterns observed in boreal forest studies in eastern Canada (Bergeron 2000; Payette 2007) which we did not have independent data to assess in our MLR. The white spruce associations with production and the possibility of that representing larger ecosystem function is incomplete at this stage and further research with more detailed analyses are required to resolve these relationships with greater certainty.

3.7 Conclusions

It was expected that only those trees closest to bitumen sands mining activity would exhibit growth suppression related to pollution exposure. The observed extent of tree growth suppression associated with bitumen mining in the Athabasca region, instead, extends at least 120 kilometres from the source. The observed reduction in variance explained by oil sands processed and the shift of growth suppression from PC1 at Sites 1-4 to PC2 at Site 6 gives evidence of a reduction in influence of atmospheric pollution as distance from mining activity increased. Temporal patterns are observed through dominant PCs associated with mining activity consistently following downward trends, while secondary PCs explaining less standardized growth variance exhibit upward trends. These associations are correlative and not causal, but it is likely that the dominant PCs represent growth suppression associated with pollution inhibiting metabolic activity in the crown and/or root mass of the trees. The secondary PCs, when present, likely reflect a less influential growth enhancement associated with nitrogen fertilization or other non-industry and non-climatic factors unidentified in this analysis. This study presents a sobering account of how far-reaching bitumen mining's impacts are on the terrestrial landscape. These environmental impacts are likely to continue to expand in both severity and area affected as the industry further develops and the pollutants continue to accrue in forest ecosystems downwind.

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CHAPTER 4 - CONCLUSION

4.1 An Attempt at Ethical Science

The environmental impacts of bitumen mining in northern Alberta are a highly contentious and politically sensitive research topic. Throughout the research process, I have remained conscious of the moral and ethical issues associated with my actions in this study. I feel a sense of pride with respect to my decisions and the support I have received from my thesis supervisors in terms of how they have steered this thesis towards honest, effective responses to the ethical issues I encountered. The rigor of my analysis, the dialogue with the Clearwater River Dene Nation, the care taken when working with the trees themselves, in all respects I feel more effort could have been made to do things in the 'right' way, yet recognizing the limitations of time and finances, I am content with what has been accomplished.

4.1.1 Talking to trees

Throughout this thesis, the wellbeing of the trees and the rest of the non-human environment they are a part of were soberly considered. Dendrochronology is a methodology within the discipline of physical geography that is well suited to recognizing and respecting the value of non-human life as it does not require the killing of its subjects. The use of non-destructive sampling techniques in this thesis was deliberate. While other techniques may have produced more rigorous and defensible findings (e.g. tree sampling requiring mortality (Aznar et al. 2007) or experiments with pollution fumigation applications (Addison et al. 1986; Krupa 1997)), it was considered unethical to pursue these more destructive scientific approaches for the harm it would inflict on the trees.

4.1.2 Talking to people

It was critically important to me - to uphold the fundamental rigours of academic science - that this research project remain independent of industry and government influence. The history of ineffectual environmental monitoring of Athabasca bitumen mining (Dowdeswell et al. 2010; Kelly et al. 2010) was guided by industry and government, and allowing them to direct my own research would make me liable to recreate the same mistakes due to political, intellectual and financial influence. This independence was not an attempt to remain objective, but rather an opportunity to allow other subjectivities to guide the research process, namely myself, others who were involved in the research team, and the Clearwater River Dene Nation.

This study's independence came at a cost. For example, being more integrated with industry and government could have provided funding to apply a better sampling regime. Navigating the Clearwater River drew the study's transect away from the centre of the pollution plume as prevailing winds would direct it (Appendix A). I chose this transect, in part, because I was without the budget required for helicopter support or a power boat to navigate the Firebag River (Figure 1.1) - two options that would have more accurately centred the transect along the plume of exposure, but also because the act of paddling down the river by canoe gave me a sense of connection to the place I was studying. To follow the river and experience the landscape from a slow moving, grounded perspective was an essential part of this project, or as Renee Pualani Louis (2012) would call it, one of the 'primary sources' informing my findings.

Had I engaged in an industry partnership, I could have also gained access to more detailed records of pollution and production. As it was, I only had the budget to buy access to annual figures[11] and had no opportunity to refine analyses to focus on pollution occurring during the growing season when stomata are open and plants are more vulnerable to pollution (Bennett and Hill 1975; Kozlowski and Mudd 1975). Given these drawbacks, the limitations of not associating with government

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[11] The pollution records used in this study are technically public, but the current Energy Resources Conservation Board (ERCB) system of access requires payments ranging from $11-$382 for copies of monthly and/or annual reports (ERCB, 2012). My budget permitted me to acquire 40 records at a cost of $714.00.

and industry interests was an ethical choice that created space for a more meaningful and trusting dialogue to occur with the Clearwater River Dene Nation, helping me fulfill one of the two key interrelated objectives of the thesis (see section 1.4.1). As such, for all the shortcomings that resulted from this choice, I still assert that it was the right choice for this project.

4.2 This Study's Contribution

4.2.1 What the trees say

The results of this study introduce an important terrestrial element to the rejection of the government and industry positions that bitumen mining activity is resulting in no net environmental impacts. The strong association between declining principal component (PC) trends and the amount of oil sands processed is not causal, but a relationship exists with enough statistical strength that further investigation is warranted. The historical nature of these results, with substantial growth reduction occurring after the late 1990s and approximately 30 years of data prior to this helps fill the gap of baseline data that has been so sorely contested in the debate over bitumen mining environmental impacts (Ayles et al. 2004; Timoney and Lee 2009; Kurek et al. 2013). As well, the spatial differences in PCs associated with oil sands production provides a clear picture of how the associations between tree growth and mining activity reduce as distance from the source increases. Considering the minimal use of dendrochronology assessing atmospheric pollution impacts downwind of bitumen mining in the Athabasca region (Addison et al. 1986; Jung and Chang 2013), the findings from this study make a key contribution to understanding the cumulative environmental impacts associated with the industry.

One concern with this study is how all sites are downwind of the pollution source. I originally intended to use the most distant site (Site 6) as a reference, as a previous study in the region identified oil sands contaminants present only up to 5o km from the source (Kelly et al. 2010). As my analysis developed, an isolated reference site in the region became difficult to define as we observed minor reductions in growth associated with industry activity at Site 6, a full 120 km downwind. As a result, future dendrochronology research in the area should sample a reference site elsewhere in the region, although it is worth noting that bitumen mining contaminants have been found 50 km *upwind* of mining activity as well (Kelly et al. 2010).

Alone, these findings provide intriguing correlational results with statistically significant associations to bitumen mining activity, but causal links between pollution and environmental impacts remain beyond the scope of this study. To achieve a better understanding of *if* and *how* that causal link exists, more research will be needed, and dendrochronological analysis is a quality candidate to contribute to this knowledge base.

4.2.2 Continuing the human conversation

It was my intention in this thesis to shift away from the dominant western discourse of objectivity in physical geography - directing my energies towards constructive, mutually developed dialogue involving myself, my thesis supervisors, and the Clearwater River Dene Nation's leaders and other community members. The field trips, presentations and long distance communications with the Clearwater River Dene Nation were all positive experiences for me and I hope for everyone involved. To hear high school students talking about wanting to go to university and to see their excitement working in the field were two of the greatest accomplishments made over the course of my two-year graduate program. Yet the few days of the first field season and few weeks of the second season were not enough to do justice to the process of engagement. With all the long distance correspondence and good intentions made to compensate for physical distance, the fact remains that there was not enough time spent in the community, engaging the Clearwater River Dene People as active agents directing the research and giving feedback about the quality of my engagement efforts.

An important stage of the research process that did not receive attention in this project was a more complete relationship building process with the community before entering their traditional territory to collect data (Ermine et al. 2004; Laveaux and Christopher 2009). Taking this further, the pace of the entire research process could have been slowed to allow for more subtle and delicate communication and negotiation of interests to occur (Castleden et al. 2012a). Part of my inability to respond to these challenges with the full commitment they deserve was financial, having funding enough to only complete this pilot study, but the other major obstacle was time. It was unrealistic to expect two years to suffice for developing the trust and respect required to engage in research with Indigenous peoples concerning an issue as politically and economically contentious as bitumen mining. Hopefully, offering to continue the dialogue with Clearwater River Dene Nation after this research project concludes will be well received, and as our mutual understanding and trust develops, a more complete and effective study design involving dendrochronology and the local community will result.

4.3 A Way Forward

4.3.1 Research concerning bitumen mining environmental impacts

The legacy of misused time and resources as well as flawed experimental design assessing the cumulative impacts of bitumen sands mining (Ayles et al. 2004) is slowly being corrected (Dowdeswell et al. 2010). Recent studies independent of government and industry have begun to document a more substantial scale and intensity of pollution exposure than previously believed (Timoney and Lee 2009; Kelly et al. 2010; Jung and Chang 2013; Kurek et al. 2013). This study's findings similarly suggest that bitumen mining impacts are occurring well beyond the boundaries of the mines themselves. While these findings are important, a larger, cumulative description of environmental impacts must remain the target of geographers and other social, health, and natural scientists in the region if a comprehensive understanding of bitumen mining impacts remains of intellectual and public concern.

An expansion of this study's design to cover a larger area and to represent other tree species' responses to bitumen mining pollution is feasible and likely to be a productive undertaking. Having multiple species to analyze can help resolve ecosystem-level effects as opposed to species-specific responses (Huang et al. 2010; Trindade et al. 2011). In the northern Canadian boreal forest, sampling both conifer and deciduous species would be advantageous as some studies have documented conifers as more sensitive to low dose, chronic exposures, while deciduous trees have been found more sensitive to short-term, high concentration pollution events (Krupa 1997).

Dendrochemistry, a branch of dendrochronology that assesses the presence of pollutants in tree rings and how their concentrations have changed throughout time (Watmough 1997), is another potential application of trees as proxies of environmental pollution. In recent studies, dendrochemistry techniques have successfully documented the presence of pollutants internalized by trees and related changes in their concentrations to neighbouring industrial activity (Watmough 1997; Ridder et al. 2007; Siwik et al. 2010). An assessment of pollutant concentrations in soils and tree stems downwind of bitumen mining has already begun (Jung and Chang 2013), but as with the findings in this thesis, more research is required to establish or refute any causal association between the industry's pollution and impacts on trees. If the results of dendrochemistry and growth-response dendrochronology studies are considered together, the findings will corroborate and refine each other and a more comprehensive and defensible account of environmental impacts (or lack thereof) on trees due to bitumen mining will result.

4.3.2 RESEARCH IN INDIGENOUS LANDSCAPES

Contemporary western academia often has difficulty accommodating Indigenous world views (Kirkness and Barnhardt 1991; Aikenhead 1996; Wilson 2008). This difficulty exists on an institutional level, as well as an individual level, with many academics (especially physical geographers) unprepared to assume responsibility for the relationships that result from collaborating with Indigenous peoples in research. Research in Indigenous spaces in northern Canada has begun to develop institutional structures and long-term relationships between researchers and Indigenous communities (Korsmo and Graham 2002; Gearheard and Shirley 2007), but gaps concerning benefits for the local population, what methodologies are appropriate, and a host of other contentious factors remain (Gearheard and Shirley 2007).

The efforts made to engage Indigenous peoples in northern Saskatchewan during this thesis project were not extensive enough; I acknowledge this, but I also know that I have begun developing the skills to build on in later research when I find myself in Indigenous spaces. Community based participatory research (CBPR) provides many of the tools necessary to help more ethically aware geographers respond to the ethical issues related to working on Indigenous landscapes (Fletcher 2003; Laveaux and Christopher 2009; Castleden et al. 2012b). My lack of capacity to fully commit to the tenets of CBPR was personally experienced as a weakness in my work, be it at the stage of experimental design, sampling, analysis, or final dissemination. Although it may be unachievable for next steps in this project, I feel it is useful to pose the following ideal: the amount of time and resource dedicated to informing the research process should be equitably shared between engaging non-Indigenous academics and Indigenous community partners, such that the research questions asked, processes formulated, and findings interpreted are all developed in a manner that engages Indigenous and western epistemologies and methods (something referred to as 'Two-Eyed Seeing' in eastern Canada – a concept put forward by a respected and renowned Mi'kmaq Elder, Albert Marshall (King 2012)).

Future research attempting to expand on our geographical understanding of Athabasca bitumen mining environmental impacts should consult more than trees and sediment cores. These natural histories will indeed help establish what baseline conditions existed and how the impacts of pollution are expressed today across the living landscape, but all living beings affected have something to contribute to this story. There are none more knowledgeable than the Chipewyan, Dene, Cree and Métis of the Athabasca region who have lived for thousands of years in the area and are with the social memory and language capable of collecting and communicating the changes they experience.

4.4 References

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APPENDIX A – WIND DIRECTION DATA

Environment Canada monthly wind direction data was used to corroborate Alberta Transportation's statement (2006) of prevailing winds in the region moving west to east. Due to a lack of consistency in reporting in the region[12] only Fort McMurray monthly values from 1967-1995 were used in this assessment.

Table A – Average monthly and annual directions of maximum gust (10's Deg) for Fort McMurray, Alberta. 10's deg units denote the direction the wind comes from relative to true north (36), west (27), east (9), and south (180)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Avg
1967	27	9	9	27	27	29	25	16	27	27	32	34	24.08
1968	29	11	25	25	18	25	25	34	32	27	25	11	23.92
1969	9	9	25	27	32	32	25	9		14	27	27	21.45
1970	34	27	9	16	27	11	25	20	32	14	32	27	22.83
1971	27	23	11	20	29	18	32	27	25	27	25	34	24.83
1972	23	11	11	25	27	29	27	36	27	27	25		24.36
1973	29	27	14	29	16	11	25	23	25	27	11	11	20.67
1974	34	29	34	2	25	25	25	2	29	32	27	29	24.42
1975	29	29	29	27	27	9	27	29	27	25	29	27	26.17
1976	29	27	32	7	29	27	29	36	27	29	27	29	27.33
1977	28	31	19	23	23	33	35	2	30	31	31	35	26.75
1978	36	15	31	34	27	27	36	31	30	25	27	27	28.83
1979	24	30	3	14	25	13	27	33	26	29	30	34	24.00

[12] Values for direction of maximum gust were often not available from stations in the Athabasca region. The reader is invited to search the National Climate Data Archive online to confirm this (http://climate.weatheroffice.gc.ca/climateData/canada_e.html))

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Avg
1980	27	31	36	28	26	24	28	28	27	30	26	29	28.33
1981	11	27	28	29	26	31	28	29	34	32	29	10	26.17
1982	30	34	32	36	28	34	32	27	26	28	27	36	30.83
1983	30	13	11	32	33	30	29	28	30	26	12	36	25.83
1984	32	26	35	19	26	22	26	27	28	28	11	34	26.17
1985	27	32	26	30	36	29	25	26	36	32	35	29	30.25
1986	31	28	29	29	29	23	30	28	10	27	28	27	26.58
1987	22	27	35	27	25	27	7	28	28	26	28	12	24.33
1988	30	29	29	28	12	23	28	27	25	27	27	24	25.75
1989	28	30	27	35	15	25	26		32	28	28	11	25.91
1990	28	24	32	27	10	33	27	30	27	26	27	26	26.42
1991	25	26	27	22	27	25	26	31	33	27	25	27	26.75
1992	11	30	28	10	26	30	29	26	32	28	29	34	26.08
1993	25	27	25	24	11	13	34	34	32	29	21	12	23.92
1994	34	29	25	26	28	12	11	28	24	25	26	12	23.33
1995	9	29	11	36	31	27	28	27	28	13	11	31	23.42

APPENDIX B – RAW AND STANDARDIZED GROWTH CHRONOLOGIES

Table B - Raw and standardized master chronologies for each site's entire history of growth (n=1 to n=40 for each year).

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
year	**Raw**	**Std**	**Raw**	**Std**	**Raw**	**Std**	**Raw**	**Std**	**Raw**	**Std**	**Raw**	**Std**
1822					2.707	1.257						
1823					3.045	1.272						
1824					2.526	0.958						
1825					1.919	0.992						
1826					2.014	1.052						
1827					1.574	0.969						
1828					2.233	1.28						
1829					2.398	1.105						
1830	1.082	0.552			1.912	0.985						
1831	1.567	0.829			1.762	1.09						
1832	1.918	1.491			2.308	1.559						
1833	1.518	1.55			2.197	1.482						
1834	1.469	1.333			1.841	1.333						
1835	1.634	1.316			1.653	1.336						
1836	1.894	1.544			1.31	1.059						
1837	1.376	1.441			0.996	0.712						
1838	1.437	1.167			1.231	0.965						
1839	1.21	0.958			1.42	0.96						
1840	1.496	0.976			1.148	0.9						
1841	1.705	1.064			1.216	0.943						
1842	1.495	1.141			1.163	0.896						

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
year	**Raw**	**Std**	**Raw**	**Std**	**Raw**	**Std**	**Raw**	**Std**	**Raw**	**Std**	**Raw**	**Std**
1843	1.893	1.271			1.071	0.835						
1844	1.848	1.198			1.261	0.923						
1845	1.782	1.216			1.345	1.006						
1846	1.507	1.16			1.24	1						
1847	1.302	1.109			1.423	1.116						
1848	1.386	1			1.418	1.112						
1849	1.643	1.129			1.532	1.249						
1850	1.582	1.228			1.662	1.325						
1851	1.718	1.322			1.576	1.262						
1852	1.537	1.279			1.275	1.017						
1853	1.538	1.272			1.239	1.03						
1854	1.399	1.102			0.957	0.78						
1855	1.375	1.193			0.904	0.796						
1856	1.08	0.931			1.035	0.836						
1857	0.911	0.927			0.965	0.741						
1858	0.998	0.878			1.054	0.82						
1859	0.803	0.698			0.853	0.71						
1860	0.818	0.691			0.768	0.572						
1861	0.661	0.559			0.759	0.585						
1862	0.51	0.422			0.515	0.421						
1863	0.462	0.381			0.591	0.512						
1864	0.363	0.298			0.631	0.564						
1865	0.242	0.181			0.553	0.49						
1866	0.163	0.143			0.625	0.511						

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
year	Raw	Std	Raw	Std	Raw	Std	Raw	Std	Raw	Std	Raw	Std
1867	0.11	0.103			0.7	0.554						
1868	0.084	0.077			0.804	0.642						
1869	0.073	0.074			0.889	0.655						
1870	0.074	0.07			0.901	0.694						
1871	0.094	0.098			0.935	0.698						
1872	0.134	0.138			0.855	0.673						
1873	0.092	0.111			0.894	0.718						
1874	0.111	0.108			0.975	0.777						
1875	0.154	0.156			0.857	0.721						
1876	0.174	0.162			0.712	0.549						
1877	0.155	0.146			0.834	0.642						
1878	0.218	0.194			0.815	0.63						
1879	0.272	0.256			0.718	0.556						
1880	0.296	0.291			0.911	0.727						
1881	0.319	0.344			0.882	0.726						
1882	0.355	0.389			0.998	0.768						
1883	0.416	0.45			1.075	0.814						
1884	0.449	0.481			0.958	0.717						
1885	0.507	0.506			0.84	0.636						
1886	0.513	0.486			0.832	0.618	2.475	0.758				
1887	0.503	0.457			0.763	0.579	2.206	0.769				
1888	0.492	0.44			0.752	0.559	1.94	0.735				
1889	0.491	0.421			0.879	0.657	2.134	0.909				
1890	0.469	0.445			0.879	0.665	2.042	0.91				

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
year	Raw	Std	Raw	Std	Raw	Std	Raw	Std	Raw	Std	Raw	Std
1891	0.459	0.438			1.011	0.74	2.344	1.052				
1892	0.3	0.312			0.978	0.742	2.497	1.017				
1893	0.238	0.209			1.031	0.771	1.482	0.657				
1894	0.169	0.159			0.734	0.581	2.529	0.981	4.283	1.498		
1895	0.14	0.121			0.688	0.572	2.024	0.846	1.403	0.491		
1896	0.142	0.107			0.92	0.701	2.097	0.837	2.384	0.835		
1897	0.151	0.132			0.571	0.467	2.378	1.008	1.899	0.666		
1898	0.289	0.212			0.741	0.568	2.13	0.979	2.129	0.747		
1899	0.395	0.242			0.772	0.6	2.711	1.044	1.869	0.656		
1900	0.439	0.326			0.963	0.732	3.08	1.198	1.788	0.629		
1901	0.543	0.456			1.054	0.803	3.159	1.228	2.287	0.805		
1902	0.608	0.515			1.034	0.815	2.458	0.99	1.954	0.688		
1903	0.693	0.583	2.21	1.539	1.073	0.813	2.552	1.12	2.037	0.718		
1904	0.777	0.648	0.953	0.664	1.191	0.918	2.249	0.972	1.916	0.658		
1905	0.792	0.657	0.856	0.596	1.37	0.986	2.129	0.945	1.279	0.445		
1906	0.81	0.707	0.731	0.509	1.132	0.838	1.736	0.743	0.834	0.266		
1907	0.673	0.606	0.951	0.662	0.939	0.689	2.043	0.971	1.4	0.45		
1908	0.764	0.628	1.175	0.818	1.228	0.887	1.917	0.897	1.359	0.44		
1909	0.696	0.579	0.919	0.64	1.229	0.886	2.845	1.192	1.642	0.535		
1910	0.935	0.794	1.079	0.752	1.577	1.101	2.378	1.113	1.979	0.65		
1911	0.963	0.79	1.111	0.774	1.562	1.106	1.585	0.837	2.156	0.749		
1912	0.992	0.817	1.173	0.817	1.398	0.998	2.024	0.939	2.285	0.766		
1913	0.977	0.846	1.458	0.508	1.498	1.049	1.914	0.893	2.523	0.789		
1914	0.959	0.814	1.956	0.692	1.89	1.314	1.997	0.922	2.746	1.043		

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
year	Raw	Std	Raw	Std	Raw	Std	Raw	Std	Raw	Std	Raw	Std
1915	0.936	0.84	1.838	0.73	1.793	1.209	1.791	0.859	2.712	1.047		
1916	1.11	0.919	1.446	0.638	1.567	1.048	2.064	0.963	2.637	1.045		
1917	0.993	0.948	1.756	0.637	1.723	1.163	1.712	0.812	2.584	0.983		
1918	1.099	0.971	2.206	0.663	1.796	1.228	1.561	0.694	2.515	0.997		
1919	1.053	0.896	1.885	0.524	1.535	1.123	1.835	0.828	2.462	0.992	0.75	0.259
1920	0.769	0.683	1.836	0.684	1.362	0.9	1.736	0.748	2.28	1.074	1.57	0.546
1921	1.016	0.892	2.344	0.717	1.841	1.292	1.832	0.842	2.868	1.092	2.75	0.703
1922	0.965	0.805	1.905	0.615	2.107	1.352	1.659	0.752	2.861	1.056	2.54	0.665
1923	1.017	0.867	1.999	0.619	1.73	1.135	1.577	0.713	2.026	0.873	1.929	0.533
1924	1.079	0.82	1.889	0.624	1.3	0.886	1.795	0.804	2.29	0.861	2.283	0.717
1925	1.086	0.908	2.143	0.902	1.793	1.131	1.356	0.602	2.188	0.878	3.584	0.964
1926	0.768	0.7	1.257	0.506	1.332	0.885	1.482	0.68	2.29	0.9	2.956	0.816
1927	0.917	0.748	1.792	0.675	1.009	0.781	1.373	0.639	2.075	0.831	3.023	0.817
1928	0.969	0.774	1.675	0.69	1.192	0.798	1.951	0.858	1.826	0.798	3.444	0.9
1929	1.134	0.917	2.196	0.899	1.749	1.064	2.162	0.953	2.06	0.87	3.081	0.895
1930	1.537	1.016	2.172	0.819	2	1.293	2.293	0.948	2.074	0.813	3.338	0.926
1931	1.111	1.056	2.1	0.818	1.92	1.174	2.226	0.886	2.158	0.884	4.085	1.174
1932	1.517	1.256	2.104	0.783	2.188	1.322	1.962	0.783	2.141	0.891	4.273	1.215
1933	1.652	1.117	2.127	0.782	2.155	1.417	2.069	0.862	2.096	0.892	4.597	1.278
1934	1.771	1.314	2.541	0.885	2.505	1.593	2.368	0.967	2.247	0.952	4.7	1.344
1935	1.914	1.32	2.824	0.994	2.627	1.691	2.189	0.913	2.165	0.85	4.411	1.259
1936	1.899	1.333	3.243	1.032	2.338	1.514	2.153	0.876	1.734	0.733	3.695	1.075
1937	2.064	1.376	2.56	0.931	1.858	1.225	1.94	0.798	0.951	0.573	3.004	0.877
1938	1.639	1.105	2.201	0.848	1.06	0.695	2.063	0.827	1.201	0.55	3.425	0.988

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
year	**Raw**	**Std**	**Raw**	**Std**	**Raw**	**Std**	**Raw**	**Std**	**Raw**	**Std**	**Raw**	**Std**
1939	2.014	1.265	2.383	0.825	1.105	0.749	2.208	0.901	1.057	0.515	3.189	0.944
1940	1.558	1.048	2.403	0.854	1.234	0.874	2.081	0.846	0.836	0.386	3.833	1.154
1941	1.637	0.999	2.036	0.752	0.914	0.651	1.623	0.669	1.039	0.451	3.01	0.909
1942	1.382	0.876	2.592	0.75	0.935	0.66	1.086	0.456	1.091	0.47	2.273	0.688
1943	1.511	0.934	2.109	0.611	0.751	0.501	1.667	0.672	1.135	0.451	2.923	0.91
1944	1.389	0.912	2.581	0.806	0.733	0.515	1.767	0.714	1.125	0.398	2.558	0.789
1945	1.826	1.122	2.489	0.792	1.065	0.761	2.441	0.988	1.704	0.692	2.415	0.783
1946	2.175	1.375	3.721	1.152	1.357	1.072	2.775	1.13	2.527	0.944	3.206	1.055
1947	2.496	1.555	3.271	1.018	2.057	1.443	2.224	0.907	3.195	1.181	3.311	1.123
1948	2.203	1.477	2.216	0.715	1.445	1.055	3.218	1.3	3.126	1.121	3.112	1.048
1949	3.115	2.153	3.3	1.036	1.822	1.275	2.916	1.185	3.35	1.257	3.887	1.339
1950	1.726	1.2	3.023	0.92	1.982	1.433	2.906	1.212	3.367	1.302	2.837	1.015
1951	2.598	1.842	3.208	0.969	2.035	1.422	2.703	1.128	2.971	1.144	3.131	1.11
1952	2.037	1.38	2.852	0.872	1.425	1.01	3.01	1.285	2.594	0.992	3.007	1.063
1953	2.219	1.604	3.283	0.999	1.172	0.822	2.674	1.114	2.841	1.002	2.798	1.009
1954	2.086	1.442	3.507	1.141	1.431	1.007	3.253	1.349	3.599	1.232	2.819	1.004
1955	2.303	1.549	4.046	1.249	1.688	1.18	2.769	1.19	3.553	1.34	2.919	1.071
1956	2.071	1.517	3.259	1.017	1.67	1.156	2.92	1.272	3.806	1.44	3.49	1.287
1957	2.222	1.626	3.425	1.129	1.648	1.137	3.265	1.371	3.154	1.157	2.59	0.948
1958	2.535	1.751	3.568	1.154	1.889	1.347	2.933	1.289	3.108	1.246	2.147	0.809
1959	2.444	1.75	3.115	1.01	1.704	1.205	3.2	1.362	3.094	1.179	2.883	1.106
1960	2.731	2.033	3.67	1.248	1.917	1.379	2.192	0.921	3.312	1.264	3.021	1.174
1961	1.989	1.353	3.215	1.07	1.166	0.87	2.796	1.16	2.919	1.116	2.233	0.866
1962	2.65	1.841	3.571	1.213	1.517	1.13	3.071	1.33	2.87	1.094	2.542	1

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
year	Raw	Std	Raw	Std	Raw	Std	Raw	Std	Raw	Std	Raw	Std
1963	2.213	1.447	3.524	1.21	1.758	1.337	2.565	1.086	2.681	1.095	2.558	1.006
1964	2.333	1.481	2.657	0.926	1.081	0.805	2.458	1.122	2.592	1.028	1.818	0.732
1965	2.778	1.827	2.81	0.989	1.267	0.917	2.498	1.101	3.035	1.198	2.983	1.22
1966	2.307	1.614	3.017	1.074	1.307	0.957	2.513	1.107	2.839	1.12	2.756	1.126
1967	2.384	1.644	3.059	1.093	1.458	1.057	2.407	1.083	3.234	1.301	2.432	1.029
1968	2.552	1.669	3.173	1.131	1.397	1.028	2.595	1.14	2.498	0.976	2.107	0.899
1969	2.394	1.599	3.083	1.15	1.591	1.183	2.028	0.899	2.495	1.007	2.251	0.976
1970	2.136	1.43	3.697	1.394	1.359	0.998	2.311	1.005	2.471	1.05	1.94	0.862
1971	1.892	1.202	3.238	1.229	1.515	1.118	2.27	0.98	2.675	1.075	2.463	1.098
1972	1.831	1.154	2.578	0.957	1.294	0.945	2.726	1.178	2.199	0.899	1.833	0.811
1973	1.723	1.168	3.066	1.162	1.452	1.087	2.596	1.141	2.405	1.026	1.948	0.904
1974	1.663	1.225	3.23	1.251	1.737	1.297	3.307	1.472	2.635	1.113	2.08	0.981
1975	1.884	1.409	3.434	1.333	2.072	1.528	3.577	1.627	2.885	1.286	2.327	1.097
1976	1.976	1.569	3.55	1.4	2.424	1.865	2.569	1.167	3.344	1.522	2.801	1.369
1977	2.452	1.679	2.803	1.125	1.672	1.28	2.718	1.257	2.689	1.186	2.726	1.386
1978	2.582	1.907	2.071	0.833	1.747	1.347	2.403	1.102	2.286	1.012	2.205	1.159
1979	2.132	1.517	2.525	1.06	1.391	1.088	2.298	1.054	2.032	0.955	1.739	0.908
1980	2.1	1.45	2.075	0.872	1.235	0.95	1.934	0.909	1.672	0.737	1.559	0.817
1981	1.659	1.235	2.652	1.116	1.368	1.056	1.684	0.812	1.786	0.796	1.767	0.937
1982	1.465	1.035	2.031	0.854	1.031	0.776	2.108	0.995	1.124	0.506	0.809	0.416
1983	1.219	0.959	2.241	0.941	1.104	0.795	1.835	0.86	1.316	0.586	1.224	0.659
1984	1.02	0.881	1.963	0.871	1.166	0.865	2.056	0.96	1.466	0.663	1.343	0.715
1985	1.296	1.11	2.154	0.943	1.414	1.053	2.282	1.068	1.801	0.838	1.47	0.83
1986	1.296	1.12	2.101	0.942	1.455	1.173	2.038	0.984	1.804	0.879	1.602	0.909

	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
year	Raw	Std	Raw	Std	Raw	Std	Raw	Std	Raw	Std	Raw	Std
1987	1.276	1.073	1.453	0.664	1.099	0.853	2.135	1.033	1.453	0.75	1.263	0.709
1988	1.436	1.178	2.003	0.934	1.322	1.026	2.44	1.166	1.393	0.825	1.315	0.743
1989	1.332	1.134	2.202	1.016	1.506	1.247	2.221	1.075	2.094	1.037	1.525	0.906
1990	1.406	1.129	2.263	1.095	1.484	1.225	2.573	1.264	1.924	0.998	1.492	0.894
1991	1.476	1.209	2.141	1.036	1.564	1.229	2.423	1.208	2.096	1.188	1.942	1.222
1992	1.589	1.28	2.266	1.138	1.537	1.245	2.601	1.296	1.947	1.067	1.544	0.985
1993	1.726	1.422	2.465	1.283	1.524	1.212	2.899	1.45	1.816	1.003	1.598	1.025
1994	1.805	1.452	2.477	1.315	1.816	1.455	2.164	1.079	2.712	1.471	2.319	1.54
1995	1.45	1.038	1.16	0.581	1.112	0.887	2.482	1.241	2.214	1.249	1.571	1.064
1996	1.527	1.257	2.531	1.368	1.424	1.208	2.354	1.28	2.29	1.338	1.623	1.148
1997	1.222	1.142	3.038	1.634	1.425	1.239	2.675	1.326	2.432	1.339	1.943	1.418
1998	1.377	1.124	1.977	1.152	0.999	0.938	1.922	1.041	2.135	1.288	1.798	1.36
1999	1.203	0.931	1.25	0.71	0.822	0.654	1.615	0.884	0.811	0.476	0.74	0.554
2000	1.206	0.935	1.442	0.841	0.805	0.683	1.634	0.989	1.329	0.763	1.049	0.791
2001	0.843	0.787	1.306	0.79	0.897	0.736	1.264	0.741	1.499	0.88	1.017	0.804
2002	0.745	0.639	0.873	0.525	0.806	0.675	1.289	0.771	1.09	0.647	0.85	0.654
2003	0.798	0.7	1.242	0.788	0.933	0.811	1.343	0.754	1.418	0.861	1.313	1.1
2004	0.731	0.652	1.324	0.854	1.013	0.837	1.005	0.613	1.268	0.825	1.241	1.111
2005	0.684	0.593	1.299	0.871	0.743	0.635	0.786	0.444	0.951	0.631	1.053	0.889
2006	0.536	0.476	1.051	0.732	0.932	0.854	0.69	0.417	1.521	0.965	1.236	1.176
2007	0.45	0.436	0.908	0.606	0.991	0.869	0.54	0.322	1.452	0.928	0.937	0.911
2008	0.345	0.334	0.761	0.527	0.855	0.723	0.359	0.203	1.428	0.988	1.162	1.224
2009	0.217	0.207	0.619	0.37	0.871	0.741	0.437	0.307	1.373	1	1.096	1.135
2010	0.203	0.221	0.691	0.512	0.991	0.799	0.383	0.218	1.422	1.022	1.193	1.33

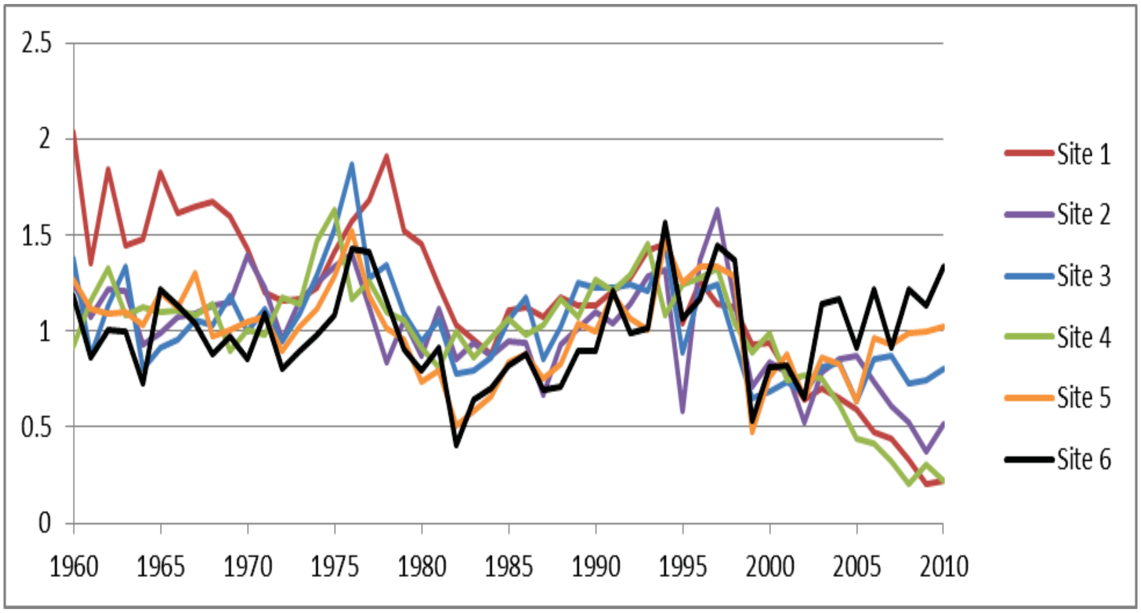

Figure B1 – Comparison of standardized chronologies over the common time interval 1960-2010.

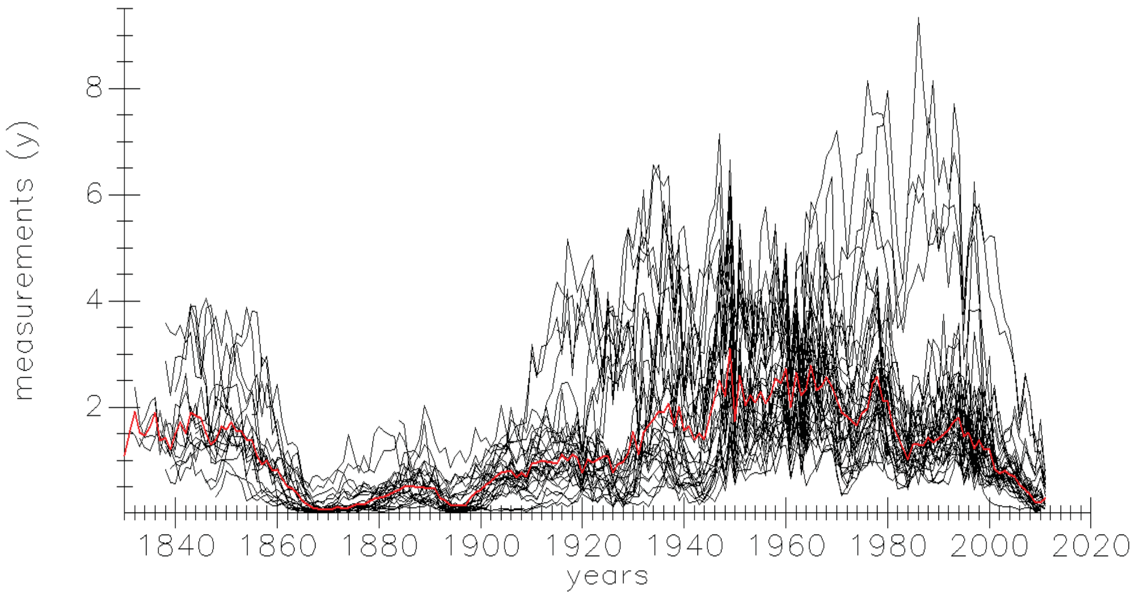

Figure B2 – Site 1 raw chronologies (black) and master chronology (red). Thirty-six cores from 18 trees are presented.

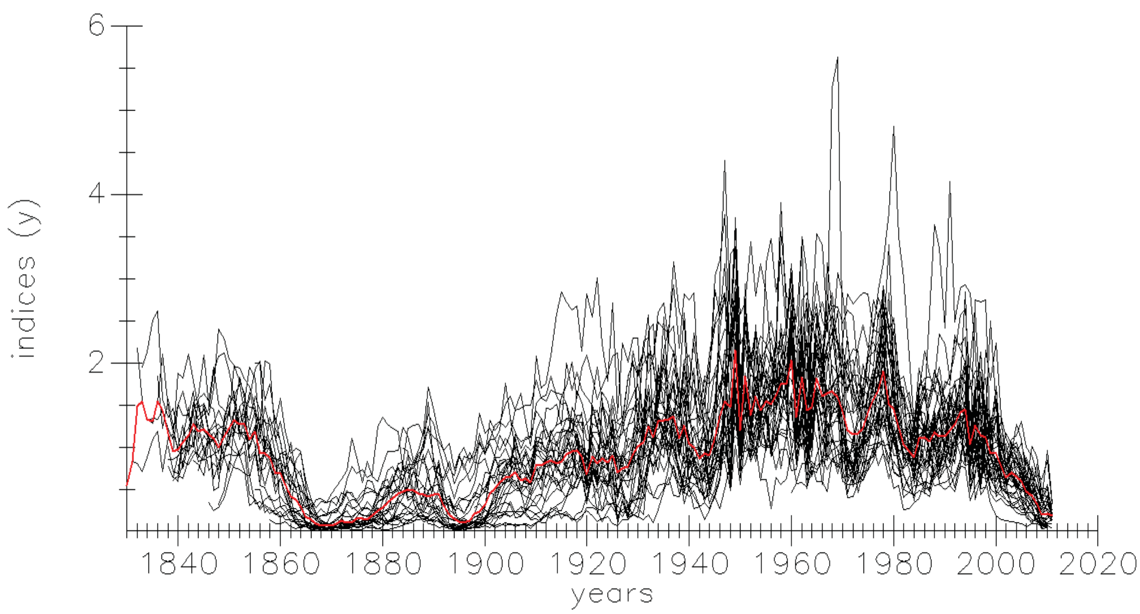

Figure B3 – Site 1 standardized chronologies (black) and master chronology (red). Thirty-six cores from 18 trees are presented.

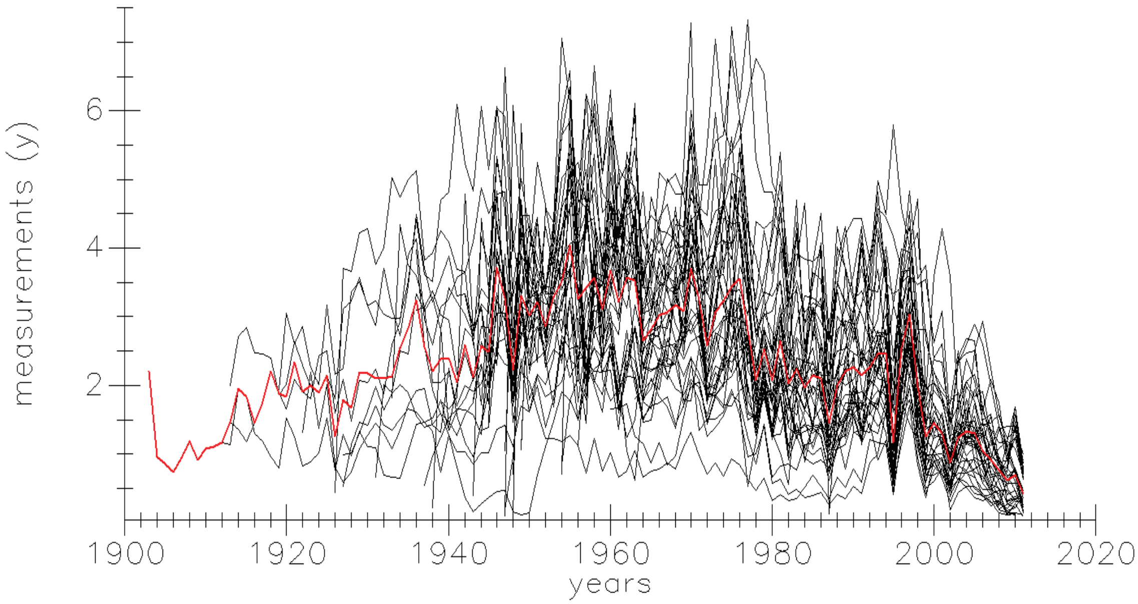

Figure B4 – Site 2 raw chronologies (black) and master chronology (red). Thirty-six cores from 18 trees are presented.

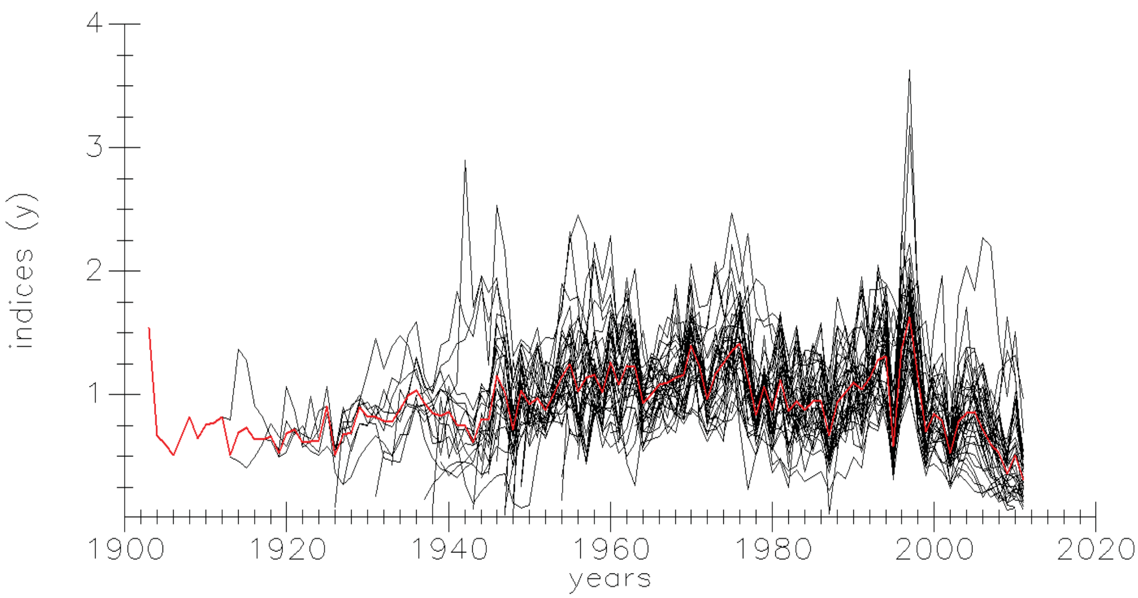

Figure B5 – Site 2 standardized chronologies (black) and master chronology (red). Thirty-six cores from 18 trees are presented.

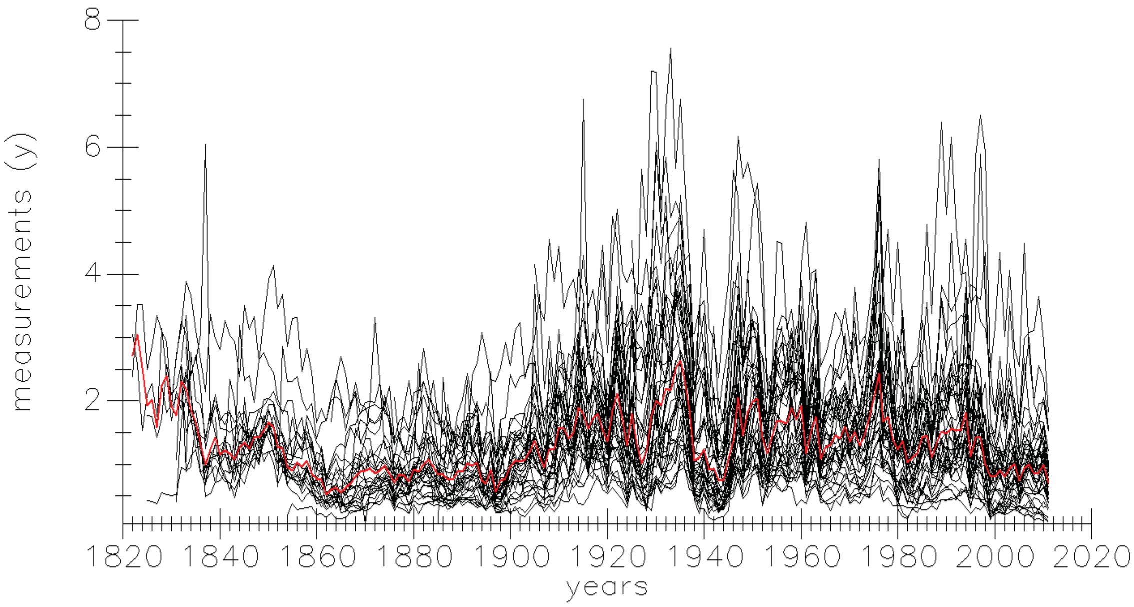

Figure B6 – Site 3 raw chronologies (black) and master chronology (red). Forty cores from 20 trees are presented.

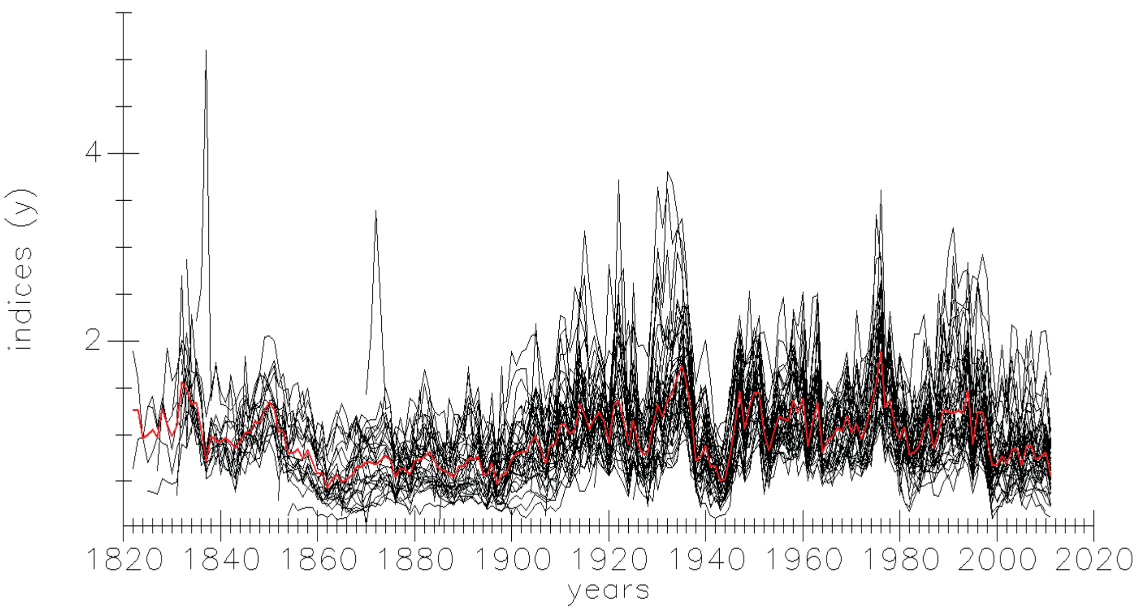

Figure B7 – Site 3 standardized chronologies (black) and master chronology (red). Forty cores from 20 trees are presented.

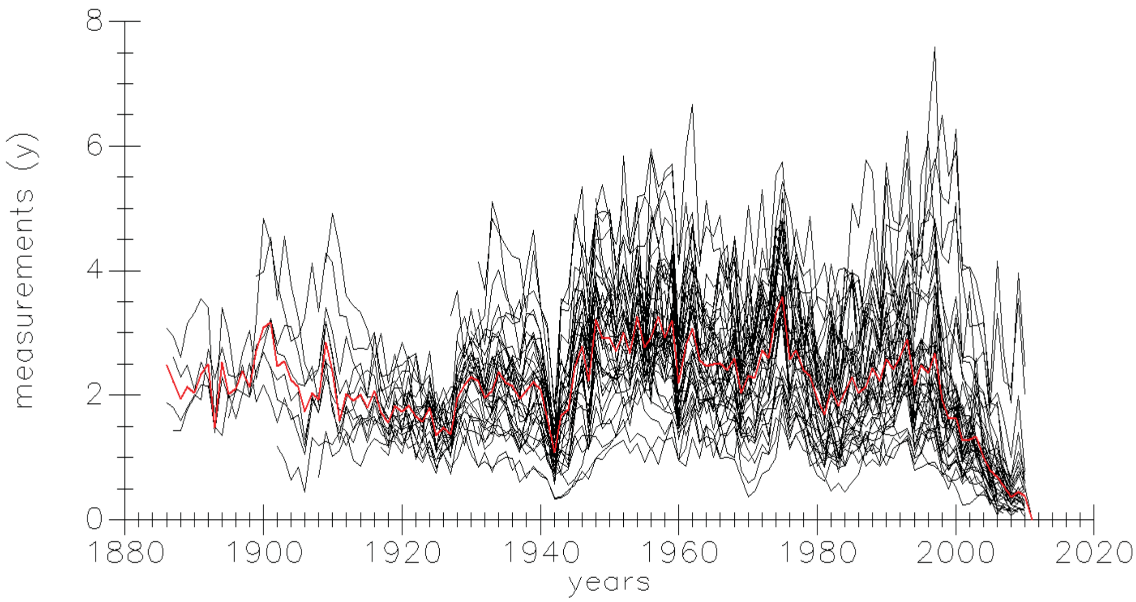

Figure B8 – Site 4 raw chronologies (black) and master chronology (red). Forty cores from 20 trees are presented.

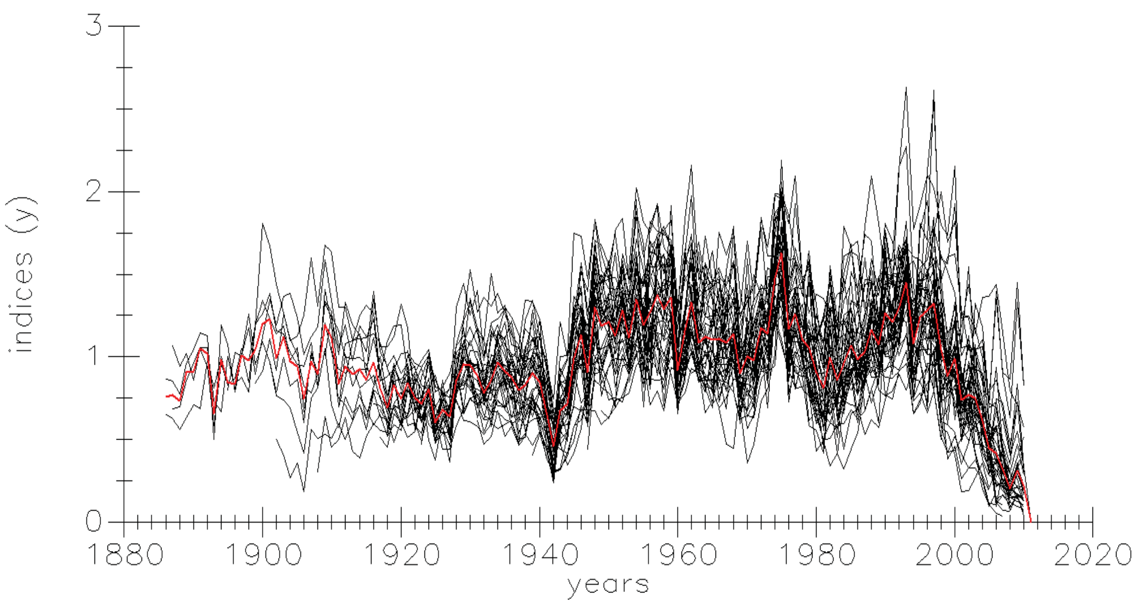

Figure B9 – Site 4 standardized chronologies (black) and master chronology (red). Forty cores from 20 trees are presented.

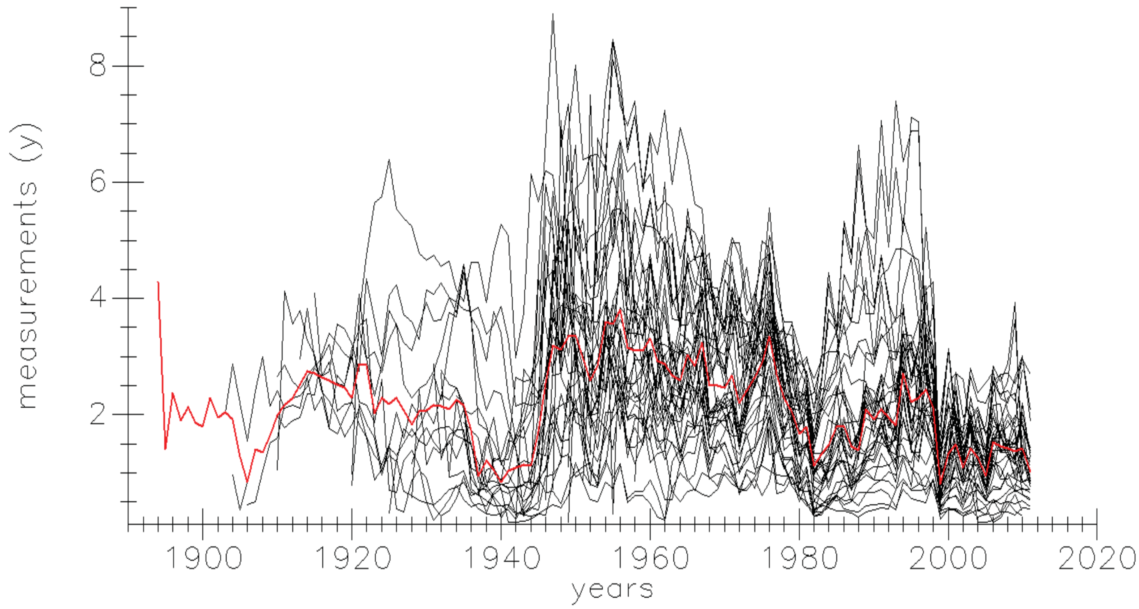

Figure B10 – Site 5 raw chronologies (black) and master chronology (red). Thirty-six cores from 18 trees are presented.

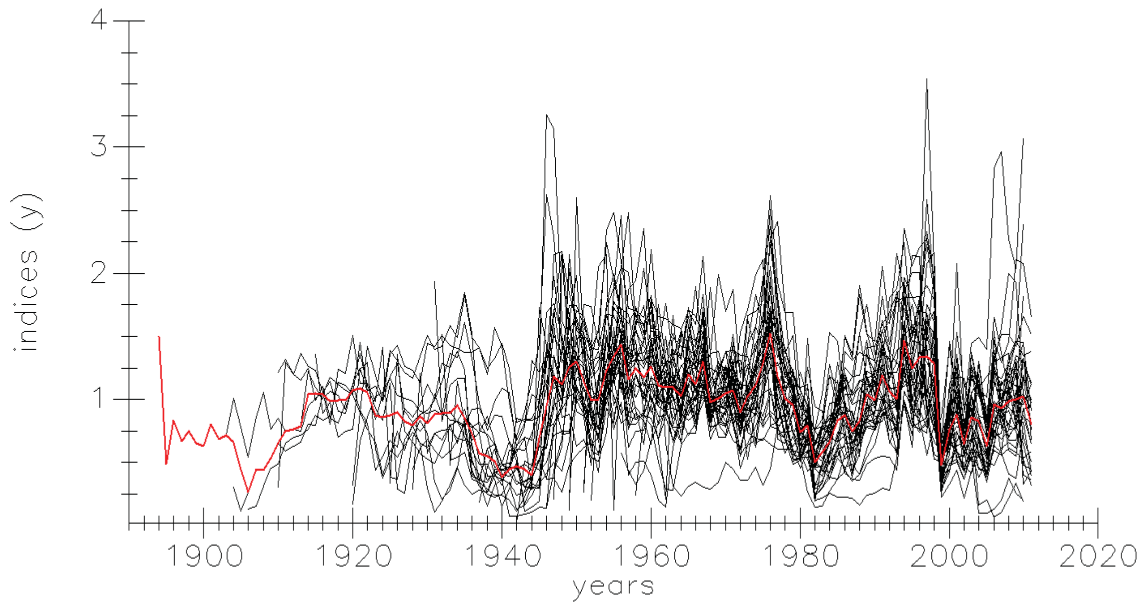

Figure B11 – Site 5 standardized chronologies (black) and master chronology (red). Thirty-six cores from 18 trees are presented.

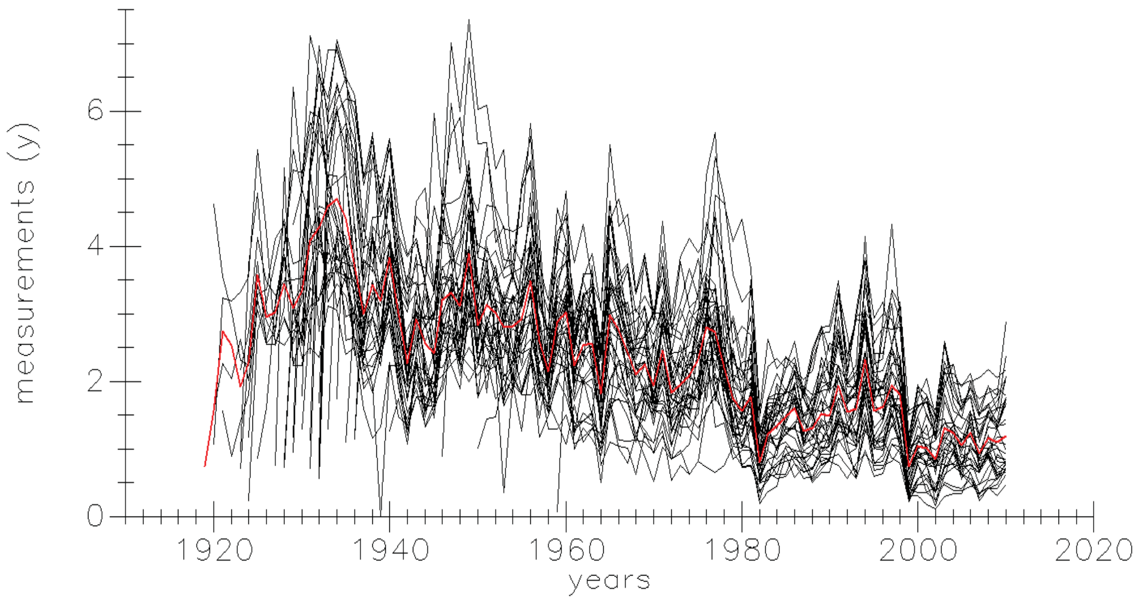

Figure B12 – Site 6 raw chronologies (black) and master chronology (red). Thirty-six cores from 18 trees are presented.

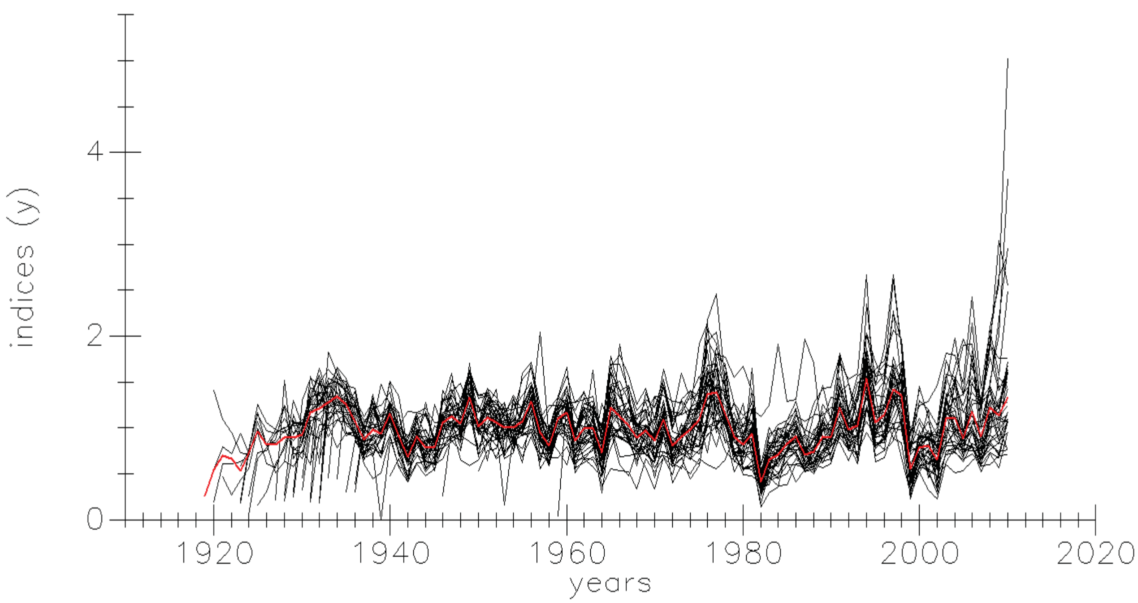

Figure B13 – Site 6 standardized chronologies (black) and master chronology (red). Thirty-six cores from 18 trees are presented.

APPENDIX C – CLIMATE DATA

Table C1 – Monthly temperature (°C) records amalgamated from Fort McMurray, AB [N56.65, W-111.22], Fort Chipewyan, AB [N58.77, W-111.12], Buffalo Narrows, SK [N55.83, W-108.43], and Cree Lake, SK [N57.35, W-107.13] climate stations. T-test comparisons of Alberta records (t Stat=-38.5, p-value=1.6E-211, df=1175), Saskatchewan records (t Stat=33.2, p-value=2.5E-102, df=299), and between both combined Alberta and Saskatchewan records (t Stat=6.9, p-value=1.05E-11, df=550) report no significant differences between records with 99% confidence.

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1895	-26.3	-20.6	-15.3	-1.4	7.9	14.4	16.2	12.7	6.6	-0.3	-13.5	-19.4
1896	-29.2	-18.9	-15.8	-5.6	6.1	12.8	16.2	14.2	7.3	0.9	-15.2	-16.3
1897	-27.7	-23.3	-19.2	-3.5	5.2	12.8	15.8	15.8	8.4	-2.8	-15.3	-18.4
1898	-20.6	-24.5	-15.6	-0.1	9.3	11.3	16.2	14.8	7.0	-4.2	-16.9	-18.2
1899	-26.4	-29.3	-22.7	-7.3	3.8	11.4	15.7	13.9	7.4	0.6	-6.3	-19.2
1900	-25.8	-27.3	-16.8	2.7	9.8	14.0	15.9	14.6	8.3	1.5	-13.6	-16.5
1901	-24.5	-20.5	-12.8	-2.7	7.1	11.5	15.7	15.5	8.7	3.1	-14.6	-18.0
1902	-21.3	-18.7	-17.1	-5.8	5.6	8.9	17.1	14.7	6.8	2.4	-14.8	-20.9
1903	-23.7	-19.0	-15.9	-6.1	2.7	12.8	17.0	15.5	6.3	-0.2	-9.7	-18.4
1904	-25.7	-30.4	-17.6	1.1	5.5	12.1	15.3	13.7	5.6	2.2	-5.5	-20.7
1905	-24.2	-19.2	-11.0	-0.9	9.0	11.5	15.8	13.8	7.5	0.7	-12.7	-21.1
1906	-28.4	-25.5	-15.7	0.0	5.2	14.4	15.8	11.8	7.4	0.7	-12.1	-26.6
1907	-30.8	-24.1	-15.7	-10.3	-1.2	10.1	12.1	10.7	4.2	0.6	-11.4	-21.6
1908	-25.5	-19.5	-15.8	-1.3	8.8	19.5	17.8	15.1	10.8	4.0	-9.2	-19.4
1909	-25.3	-20.9	-12.4	-3.3	7.9	14.3	16.6	13.9	12.3	2.5	-12.2	-16.8
1910	-24.3	-19.8	-9.5	0.7	7.4	14.4	16.7	12.5	8.2	3.7	-12.2	-18.1

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1911	-27.5	-17.5	-11.0	-1.6	8.6	13.5	15.8	13.4	8.2	1.7	-9.2	-15.7
1912	-24.4	-17.9	-12.8	0.1	7.7	14.4	15.7	16.0	8.4	1.6	-6.8	-17.5
1913	-25.5	-20.0	-12.2	0.1	8.1	13.8	15.9	14.1	9.2	2.2	-8.4	-18.7
1914	-24.2	-20.1	-12.3	0.7	8.0	13.7	16.2	14.9	8.4	4.6	-6.7	-19.7
1915	-21.0	-16.2	-8.5	7.8	9.5	11.8	15.8	17.6	7.9	1.4	-8.6	-16.2
1916	-29.4	-18.4	-15.5	1.5	8.2	14.2	16.8	14.1	9.6	1.4	-7.1	-20.5
1917	-26.7	-24.3	-11.3	-1.7	8.6	11.9	17.2	13.8	10.0	-0.2	-1.6	-29.3
1918	-25.1	-22.5	-13.4	-0.6	6.0	11.8	14.4	14.3	9.0	1.2	-7.8	-14.8
1919	-15.3	-20.9	-17.4	3.9	7.5	13.0	14.8	15.5	10.5	-5.2	-13.8	-19.5
1920	-23.1	-11.7	-12.0	-4.5	7.5	11.3	18.0	15.3	9.1	2.3	-6.8	-18.4
1921	-21.3	-15.5	-16.0	2.1	8.3	15.3	16.1	13.2	8.3	3.7	-13.6	-16.0
1922	-19.7	-23.1	-13.6	-0.9	8.8	12.8	16.1	15.5	8.7	1.7	-7.8	-22.3
1923	-22.8	-19.7	-17.9	-2.5	5.5	15.1	15.7	12.6	9.6	4.7	-6.3	-19.4
1924	-24.9	-13.6	-7.5	-4.1	8.0	12.2	16.5	13.5	8.9	3.6	-10.1	-23.1
1925	-26.4	-23.6	-12.8	3.3	8.9	13.3	17.3	14.8	7.6	-2.7	-12.3	-15.3
1926	-17.8	-14.4	-9.1	0.5	9.1	12.5	17.5	13.8	5.7	-0.1	-11.8	-19.3
1927	-22.0	-20.1	-8.1	-1.1	7.2	12.7	17.2	14.9	8.8	2.6	-17.9	-25.7
1928	-16.5	-12.5	-9.0	-6.8	9.0	13.9	17.1	12.2	9.0	1.5	-5.3	-12.9
1929	-28.0	-21.6	-12.2	-2.3	7.1	12.4	16.1	15.1	8.1	5.6	-7.1	-21.6
1930	-23.9	-16.8	-8.7	2.5	7.3	13.9	17.3	16.0	8.2	0.1	-9.0	-10.6
1931	-16.5	-8.6	-14.3	1.0	8.0	12.5	16.5	16.2	9.7	3.8	-8.3	-15.8
1932	-21.3	-22.1	-19.0	1.7	10.0	14.6	17.9	17.8	9.1	-0.8	-14.8	-19.9
1933	-27.2	-25.0	-12.3	-2.0	9.5	13.8	16.0	16.6	8.6	-0.6	-12.0	-31.9
1934	-21.3	-14.3	-13.3	1.4	9.5	13.1	15.4	13.2	5.9	1.9	-8.0	-19.8
1935	-28.7	-10.2	-15.5	-3.9	9.7	13.3	18.2	13.9	9.3	0.4	-14.3	-15.8

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1936	-28.9	-31.5	-9.9	-3.7	10.4	13.5	18.7	15.8	7.5	0.4	-4.6	-19.6
1937	-27.2	-20.3	-9.3	4.1	11.6	15.6	18.1	15.2	9.6	2.1	-10.4	-20.6
1938	-20.5	-20.8	-7.2	-0.4	9.3	15.3	18.3	14.2	14.2	5.2	-9.0	-15.6
1939	-18.4	-26.6	-13.5	1.0	9.6	12.6	17.3	16.3	7.7	-1.8	-5.3	-10.2
1940	-20.0	-16.6	-8.6	2.0	10.0	12.5	15.1	14.9	11.6	3.4	-11.2	-16.6
1941	-21.2	-18.5	-8.5	3.1	9.0	15.1	18.7	15.2	8.6	2.7	-7.3	-17.4
1942	-16.4	-17.9	-7.3	0.8	9.1	14.1	17.2	15.6	9.1	3.4	-11.1	-19.6
1943	-23.5	-12.9	-13.6	3.2	8.0	12.8	17.6	16.2	11.2	6.1	-3.4	-13.4
1944	-13.1	-18.5	-10.4	5.4	12.6	14.4	17.2	14.9	10.5	5.7	-8.3	-13.2
1945	-18.4	-16.1	-5.4	-6.1	5.4	12.8	16.5	15.7	7.3	3.5	-14.7	-20.6
1946	-20.6	-22.2	-4.4	3.8	7.2	12.1	17.0	15.9	9.1	0.4	-11.4	-23.9
1947	-22.0	-23.9	-11.3	-3.7	6.7	13.1	17.7	12.9	7.7	5.0	-10.7	-16.1
1948	-15.6	-22.2	-15.7	-7.1	11.1	15.8	17.5	15.0	10.7	5.0	-7.9	-20.8
1949	-22.0	-24.3	-8.6	5.1	7.9	12.5	16.3	16.2	9.7	-0.1	-2.5	-23.1
1950	-33.8	-19.6	-13.4	-1.4	9.2	14.1	17.1	13.0	10.7	0.2	-14.1	-17.1
1951	-23.5	-18.8	-15.8	-0.5	8.7	11.6	16.2	15.2	9.4	-1.6	-12.1	-25.4
1952	-27.6	-15.6	-10.4	4.7	11.3	14.0	15.6	13.7	9.2	3.7	-4.3	-12.8
1953	-25.7	-12.2	-9.1	-1.2	9.5	12.5	16.2	17.4	9.7	4.3	-5.3	-14.3
1954	-29.6	-13.2	-10.3	-9.2	8.0	14.0	16.9	14.9	9.0	3.3	-2.8	-10.7
1955	-20.4	-20.3	-17.3	1.4	8.7	16.2	17.1	15.4	8.3	3.0	-17.7	-23.2
1956	-23.8	-19.3	-10.6	-1.7	9.8	14.7	17.2	15.4	7.1	1.1	-4.7	-19.7
1957	-21.4	-21.2	-8.9	-0.3	7.5	12.2	16.1	14.5	10.5	0.4	-8.0	-18.3
1958	-13.7	-21.0	-7.7	2.4	9.8	12.2	16.3	15.9	8.2	3.6	-9.0	-17.5
1959	-27.6	-16.2	-7.5	1.5	4.2	11.8	17.1	11.8	8.2	-0.9	-10.8	-9.2
1960	-22.1	-15.8	-13.5	2.3	7.6	12.7	17.5	15.3	9.9	2.0	-11.0	-14.7

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1961	-20.5	-15.1	-9.4	-2.8	9.5	17.1	17.3	17.0	5.8	0.9	-10.0	-26.0
1962	-22.3	-19.0	-12.6	-0.4	7.3	14.7	15.6	16.1	10.4	5.4	-8.6	-17.0
1963	-23.8	-17.1	-11.6	0.0	7.5	13.8	16.5	15.5	9.7	4.0	-10.2	-17.5
1964	-19.7	-11.6	-17.1	0.6	8.2	14.6	17.4	14.4	7.4	3.8	-9.4	-19.0
1965	-24.7	-18.9	-13.3	0.6	7.5	13.6	16.9	15.1	5.3	3.9	-12.2	-15.3
1966	-28.4	-18.0	-9.2	-2.2	8.4	13.4	15.9	15.0	10.5	1.3	-15.1	-17.6
1967	-22.7	-19.2	-14.4	-2.2	7.4	13.0	16.3	16.4	11.8	2.0	-6.8	-16.0
1968	-22.7	-15.5	-4.8	1.2	8.5	13.7	14.5	13.0	8.7	2.8	-6.2	-21.3
1969	-30.8	-16.2	-10.5	3.7	7.3	11.7	16.0	15.8	8.0	0.3	-8.8	-13.8
1970	-23.5	-17.0	-12.4	1.5	7.8	15.7	16.8	15.3	8.6	1.9	-11.3	-22.6
1971	-26.9	-15.2	-11.3	2.0	11.0	15.0	15.4	16.8	9.0	3.1	-10.4	-22.8
1972	-27.2	-23.9	-9.6	-2.5	10.4	15.2	15.1	16.4	3.5	-0.9	-9.6	-22.2
1973	-17.8	-18.2	-6.3	0.9	11.1	14.5	17.2	15.7	9.3	3.2	-13.0	-20.2
1974	-27.1	-18.2	-16.7	1.2	6.5	14.3	16.0	12.9	6.1	2.3	-5.3	-11.1
1975	-22.8	-18.8	-12.8	-0.1	8.0	13.9	18.0	13.4	9.8	2.2	-9.8	-18.4
1976	-19.8	-17.6	-11.9	5.2	10.3	14.0	16.6	16.4	11.1	0.7	-6.9	-19.6
1977	-21.2	-7.7	-7.6	3.4	11.1	14.5	14.7	11.1	9.7	4.1	-9.9	-23.2
1978	-23.4	-16.1	-10.3	-0.1	7.8	13.6	14.8	13.3	8.7	4.0	-11.2	-20.5
1979	-21.5	-28.5	-12.6	-4.0	5.9	13.5	18.6	13.5	9.7	2.8	-6.5	-12.7
1980	-21.2	-14.6	-11.2	7.7	10.2	15.0	16.9	14.3	7.3	4.5	-5.2	-23.0
1981	-14.8	-13.6	-5.0	-1.3	10.2	13.7	17.3	18.7	10.7	0.0	-3.6	-18.6
1982	-32.9	-20.3	-13.5	-2.3	7.7	13.7	16.6	12.6	9.8	3.7	-14.3	-18.1
1983	-19.3	-17.1	-9.7	0.9	5.9	13.6	17.3	16.6	8.2	3.1	-4.8	-23.7
1984	-19.6	-9.1	-8.7	5.2	7.2	14.9	17.7	17.4	7.2	0.6	-13.7	-24.1
1985	-17.7	-23.0	-6.1	1.2	9.7	12.8	15.6	14.1	6.8	0.4	-17.4	-15.5

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1986	-14.8	-17.6	-6.8	-0.2	9.6	13.3	15.7	14.9	8.6	2.8	-14.6	-10.8
1987	-11.8	-10.5	-10.3	3.7	10.1	15.1	16.8	12.8	11.9	2.5	-5.3	-12.1
1988	-21.7	-18.7	-7.4	0.1	8.4	15.6	16.4	15.5	9.4	2.0	-9.7	-15.9
1989	-19.6	-17.3	-16.1	-1.2	8.5	13.8	18.1	16.7	8.7	2.1	-14.3	-20.4
1990	-20.1	-21.3	-6.3	-0.5	8.9	15.0	17.2	15.5	10.1	-1.2	-13.6	-23.1
1991	-21.0	-12.8	-10.6	3.0	10.2	14.8	17.3	18.7	8.9	-2.8	-12.0	-16.6
1992	-15.9	-14.8	-5.5	1.0	8.1	13.6	15.7	14.3	6.4	1.8	-4.7	-21.5
1993	-18.3	-14.4	-3.3	3.1	8.6	13.0	15.4	14.5	8.0	1.0	-9.0	-13.7
1994	-25.4	-24.3	-3.6	1.5	9.9	15.2	17.7	16.2	11.9	4.1	-8.6	-15.3
1995	-14.9	-17.2	-10.6	-1.9	8.5	15.5	14.7	13.4	11.2	2.5	-13.0	-16.8
1996	-27.3	-16.3	-15.3	-0.8	6.3	14.8	17.4	16.2	9.2	0.9	-12.6	-20.6
1997	-22.5	-12.1	-11.2	-0.6	7.8	15.2	18.4	16.3	11.4	-0.1	-5.1	-8.6
1998	-21.9	-7.6	-7.7	5.9	12.0	15.4	18.9	18.0	10.2	4.6	-7.0	-16.4
1999	-20.5	-11.1	-4.1	3.8	8.8	14.4	16.6	17.1	10.1	3.1	-4.5	-12.4
2000	-19.5	-11.5	-5.3	0.5	7.6	12.3	18.0	14.8	8.6	3.0	-6.6	-22.1
2001	-9.0	-17.4	-6.7	2.1	9.9	14.4	18.3	17.3	12.1	1.5	-4.2	-15.3
2002	-19.0	-11.9	-15.9	-4.6	5.4	15.9	17.4	14.7	9.4	-2.4	-8.1	-10.7
2003	-18.2	-20.1	-11.5	2.5	9.2	14.1	18.0	16.9	9.4	4.7	-9.6	-12.6
2004	-22.5	-12.1	-8.0	1.0	4.5	12.8	17.8	13.0	8.5	1.0	-6.1	-19.3
2005	-20.3	-12.6	-6.7	4.0	8.8	14.2	16.7	14.3	9.4	3.8	-3.9	-8.4
2006	-11.9	-14.3	-5.9	6.8	10.1	17.2	17.7	16.0	11.8	1.2	-14.7	-10.1
2007	-14.3	-20.2	-9.2	2.1	9.7	13.8	20.1	13.3	8.6	4.7	-8.0	-16.7
2008	-17.3	-18.3	-8.9	-1.1	10.4	15.7						

Table C2 – Monthly precipitation (mm) records amalgamated from Fort McMurray, AB [N56.65, W-111.22], Fort Chipewyan, AB [N58.77, W-111.12], Buffalo Narrows, SK [N55.83, W-108.43], and Cree Lake, SK [N57.35, W-107.13] climate stations. Two-tailed T-test comparisons of Alberta records (t Stat=-10.7, p-value=6.5E-25, df=704), Saskatchewan records (t Stat=-2.88, p-value=0.01, df=310), and between both combined Alberta and Saskatchewan records (-t Stat=2.5, p-value=0.01, df=538) report with 99% confidence that no significant differences exist between records.

Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
1922	33.1	19.6	43.6	29.1	72.7	43.2	83.4	36.5	37.7	70.5	50.2	22.0
1923	21.7	9.6	22.1	6.0	30.1	29.2	57.2	51.3	24.8	12.1	12.2	18.1
1924	17.3	39.2	24.2	18.8	6.8	43.5	84.9	77.4	27.2	22.0	20.0	16.7
1925	19.0	15.7	31.6	43.5	27.6	18.8	71.6	33.6	33.9	17.4	23.0	30.0
1926	17.0	17.6	17.6	28.0	38.0	17.5	73.8	33.3	27.9	45.0	27.3	36.6
1927	11.9	6.4	34.6	24.5	23.9	66.3	32.2	52.0	44.0	39.8	14.8	20.0
1928	17.8	14.9	27.8	38.0	22.3	52.0	52.2	42.1	28.6	12.6	6.6	18.4
1929	39.6	19.0	19.0	31.6	10.8	62.5	109.6	68.2	69.2	11.8	34.4	18.1
1930	14.3	38.2	2.8	22.5	24.4	44.2	54.4	95.8	57.1	21.1	25.1	28.2
1931	16.3	4.2	23.6	14.2	58.7	39.8	85.1	39.1	91.8	12.9	7.8	26.9
1932	28.4	40.4	40.4	39.8	38.4	86.3	48.2	86.3	20.0	28.5	41.7	24.3
1933	16.6	37.7	30.6	37.6	29.0	57.5	65.2	22.7	120.5	38.9	66.1	30.7
1934	19.2	11.1	30.0	27.5	25.1	34.1	53.7	56.9	36.7	26.9	53.8	11.4
1935	16.9	21.7	41.7	15.4	32.2	57.0	154.0	74.2	37.7	55.6	34.3	25.0
1936	16.6	16.6	14.6	14.6	17.4	49.8	156.2	30.4	94.2	26.1	18.9	16.8
1937	12.5	20.3	6.0	20.1	65.2	23.1	38.9	41.5	8.8	29.7	31.4	40.6
1938	16.8	15.9	22.3	4.6	26.8	38.7	52.8	42.8	16.8	26.4	16.9	18.8
1939	35.3	8.8	16.4	24.1	57.7	23.1	50.6	35.4	43.3	37.9	9.6	16.9
1940	8.0	10.8	12.3	18.2	53.9	52.9	12.2	31.7	33.8	24.5	19.9	20.5
1941	36.6	21.9	32.5	9.9	45.0	68.0	116.2	91.2	99.1	16.7	19.8	6.6

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1942	9.0	11.8	39.5	7.0	8.2	76.6	37.2	37.1	36.2	13.8	7.7	29.0
1943	3.5	21.4	6.7	10.2	33.7	90.3	15.4	46.1	46.1	40.9	5.2	11.3
1944	9.9	19.2	15.9	5.0	54.5	67.4	109.8	86.6	46.8	27.4	19.1	18.8
1945	23.2	6.6	5.0	8.5	26.9	56.7	81.1	56.8	67.9	19.4	27.9	20.4
1946	11.9	14.2	9.0	30.8	30.7	35.7	120.8	57.9	34.5	22.2	3.6	15.7
1947	19.7	12.9	10.4	21.5	51.6	54.5	80.9	63.3	33.1	19.7	16.1	12.9
1948	21.3	7.1	9.0	15.4	15.4	34.1	78.2	34.1	54.5	7.3	19.7	9.6
1949	7.8	7.0	5.9	31.3	29.8	109.4	92.1	80.7	29.8	13.2	23.9	22.2
1950	13.6	40.6	9.4	39.8	15.7	39.4	43.7	77.8	38.0	36.3	55.4	49.8
1951	23.1	5.0	59.6	42.1	62.8	24.6	54.6	39.8	35.5	28.8	36.7	13.4
1952	22.3	11.7	27.1	8.9	33.1	56.6	84.1	76.3	35.4	10.4	14.5	8.3
1953	22.1	7.0	25.0	30.6	5.1	54.9	62.2	55.5	75.5	25.1	11.9	34.7
1954	13.4	38.8	10.4	35.5	32.9	129.7	98.2	58.6	55.4	8.3	14.5	26.9
1955	48.4	23.7	42.6	29.6	38.8	76.0	59.2	70.8	60.8	30.5	44.4	33.4
1956	23.3	50.7	14.7	12.1	11.3	149.6	69.3	87.2	98.0	31.7	23.0	23.4
1957	15.3	9.6	13.3	11.7	40.0	60.4	122.6	63.4	38.5	69.4	39.1	37.0
1958	40.2	33.7	27.7	26.9	25.7	25.4	28.8	107.8	68.7	17.4	17.3	35.9
1959	41.8	18.4	22.1	25.9	34.2	92.9	51.8	138.1	67.1	33.7	42.7	7.9
1960	46.2	17.6	40.9	8.8	63.9	60.5	148.0	101.4	59.7	39.7	15.5	53.0
1961	15.3	34.9	30.8	13.0	14.2	109.3	33.7	33.4	44.8	32.0	36.0	53.7
1962	43.9	14.3	35.6	36.9	34.3	94.6	85.2	74.1	54.1	20.3	27.5	23.7
1963	24.0	24.6	24.3	25.0	37.2	30.9	127.9	67.6	81.0	7.4	32.6	22.8
1964	17.0	47.8	11.5	22.3	73.2	89.8	87.7	63.5	65.7	21.1	35.8	18.9
1965	22.1	27.7	14.7	10.5	17.1	66.5	61.4	92.8	43.6	36.1	35.7	29.0
1966	23.3	15.1	24.8	32.8	43.0	55.6	101.1	65.0	29.2	51.2	39.7	36.9

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1967	22.0	18.3	21.5	19.5	16.2	45.3	92.5	63.3	84.6	33.1	32.6	24.2
1968	24.5	15.9	17.4	20.1	48.6	55.3	49.7	56.3	74.7	21.4	27.0	22.4
1969	23.1	17.8	21.3	37.1	39.7	97.3	71.5	82.3	73.2	43.1	26.1	24.9
1970	19.6	24.6	30.1	21.5	38.1	77.0	69.3	47.3	63.4	30.2	42.7	26.2
1971	29.6	32.0	21.5	25.5	18.2	65.1	70.2	50.4	89.3	31.5	39.2	29.2
1972	33.0	29.4	30.3	38.9	13.5	57.1	102.5	52.4	58.7	54.4	44.5	34.4
1973	29.5	24.5	18.5	17.0	49.1	64.1	132.8	88.9	49.9	42.8	52.2	36.0
1974	36.4	20.4	21.8	28.4	34.0	90.0	79.5	85.2	43.2	25.8	19.6	31.6
1975	34.9	19.3	17.7	18.6	56.6	83.3	89.7	95.4	41.2	58.3	28.4	29.4
1976	20.5	21.6	25.3	12.8	43.5	57.9	114.9	89.0	34.7	39.4	21.1	29.7
1977	18.3	11.1	27.2	21.5	55.6	57.7	81.8	67.3	58.5	30.1	29.9	26.9
1978	16.2	18.2	25.6	32.2	22.4	48.6	56.1	94.8	97.0	45.9	23.6	25.2
1979	16.7	19.0	32.5	18.9	20.0	38.1	81.3	77.6	80.9	23.7	20.2	30.7
1980	17.3	18.3	24.7	14.6	21.5	32.1	61.9	76.3	33.6	30.0	27.6	45.7
1981	19.3	18.5	15.8	30.5	30.6	50.1	104.2	65.0	22.3	33.8	29.5	33.9
1982	25.4	17.6	26.5	23.6	38.5	52.4	63.8	50.2	57.2	23.6	35.7	25.3
1983	25.8	22.9	15.9	17.1	53.7	44.5	64.2	66.5	42.8	51.0	33.8	16.9
1984	26.1	21.9	13.2	44.2	51.9	66.4	70.9	82.1	43.7	70.5	21.3	21.8
1985	21.9	15.1	14.2	35.0	41.5	40.1	105.4	48.9	32.4	48.1	27.0	27.8
1986	31.6	22.7	32.9	33.2	34.3	69.6	76.3	52.5	21.1	32.8	24.0	26.7
1987	34.7	24.7	39.4	21.2	41.6	77.0	78.4	88.9	28.3	38.8	29.4	29.6
1988	35.3	17.7	24.2	23.8	39.8	68.1	104.5	72.6	55.2	32.7	54.8	21.7
1989	26.0	16.9	19.5	28.0	42.5	73.9	72.5	40.3	45.6	47.2	76.0	30.0
1990	22.8	18.0	12.7	27.7	34.4	96.9	56.1	47.8	33.1	37.4	45.3	28.1
1991	32.0	25.2	24.1	19.9	27.5	99.2	87.5	44.3	70.1	33.8	37.7	21.3

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
1992	19.8	23.0	14.7	29.9	24.8	70.2	79.2	60.2	59.0	22.4	22.4	17.2
1993	22.8	17.9	13.0	18.9	60.1	74.8	88.3	25.0	34.8	40.2	30.6	25.4
1994	19.2	37.2	32.6	36.2	33.4	63.5	81.8	104.1	36.5	51.5	21.6	20.8
1995	20.6	34.6	23.6	38.8	24.9	116.7	94.2	86.1	71.6	37.9	37.0	23.1
1996	34.5	25.2	21.6	13.2	25.9	102.5	59.3	78.5	90.7	13.5	13.3	17.5
1997	18.1	12.3	7.8	11.2	15.0	52.0	73.3	55.8	74.8	21.0	21.6	30.6
1998	17.1	15.4	10.0	19.9	36.2	37.8	82.2	32.3	42.7	21.6	20.2	28.8
1999	12.5	7.6	12.2	17.5	46.8	59.5	109.8	80.4	61.4	17.0	23.0	26.4
2000	17.3	11.5	20.1	13.7	47.3	137.7	101.2	61.8	43.2	15.6	15.9	18.9
2001	13.4	14.9	21.6	24.1	28.3	58.9	100.5	60.2	40.2	24.7	19.7	14.7
2002	13.1	15.2	18.6	21.6	37.0	71.9	86.6	50.3	58.9	30.0	18.5	15.3
2003	29.1	24.8	28.3	22.7	49.9	67.2	74.0	59.3	61.7	44.4	19.2	34.3
2004	30.3	19.8	21.1	27.6	56.7	31.4	80.3	63.2	38.1	20.3	11.8	22.6
2005	25.8	23.4	19.7	14.4	42.5	39.8	89.9	67.1	36.5	19.4	33.2	13.3
2006	18.1	29.7	26.0	18.1	37.7	56.4	63.4	68.6	41.7	11.3	39.7	6.8
2007	5.8	8.6	19.5	19.7	18.6	24.3	41.6	77.8	17.0	3.5	21.8	

APPENDIX D – DENDROCLIM 2002 RESULTS

Table D1 - Temperature response values reported by Dendroclim 2002. Monthly temperature values associating with annual growth with 95% confidence are highlighted in red. _P denotes comparison of temperature values the year previous to growth.

Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
APR_P	-0.07	-0.04	-0.03	-0.11	-0.07	0.00
MAY_P	0.07	-0.12	0.01	0.03	-0.12	-0.04
JUN_P	-0.06	-0.02	-0.03	0.03	0.03	0.07
JUL_P	-0.07	-0.18	-0.08	-0.09	-0.08	0.00
AUG_P	-0.11	-0.04	-0.09	0.01	-0.08	-0.05
SEP_P	-0.02	-0.07	-0.06	-0.01	-0.03	-0.04
OCT_P	0.03	-0.08	-0.13	-0.02	-0.12	-0.15
NOV_P	-0.06	-0.01	-0.02	-0.03	-0.08	-0.21
DEC_P	-0.08	-0.04	-0.11	-0.04	-0.01	0.02
Jan	-0.16	-0.25	-0.15	-0.08	-0.07	-0.15
Feb	-0.16	-0.05	-0.09	0.01	0.03	0.00
Mar	-0.10	0.11	-0.13	-0.01	-0.05	-0.04
Apr	0.05	0.08	0.04	-0.09	-0.02	0.10
May	0.15	0.05	0.11	0.09	0.04	0.18
Jun	-0.15	0.02	-0.09	0.00	0.00	-0.06
Jul	-0.21	-0.02	-0.05	-0.19	-0.09	0.00
Aug	0.01	0.13	0.00	-0.09	0.01	0.02
Sep	0.07	0.10	0.10	0.04	0.13	0.19
Oct	0.08	-0.01	-0.13	-0.01	-0.05	-0.06

Table D2 - Precipitation response values reported by Dendroclim 2002. Monthly precipitation values associating with annual growth with 95% confidence are highlighted in red. _P denotes comparison of precipitation values the year previous to growth.

Month	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
APR_P	-0.13	-0.08	0.05	0.00	0.05	-0.05
MAY_P	-0.05	-0.03	-0.02	-0.09	-0.02	0.07
JUN_P	0.07	0.24	0.09	0.20	0.19	0.06
JUL_P	0.09	0.09	0.19	0.08	0.16	-0.07
AUG_P	0.18	0.15	0.13	0.14	0.19	0.08
SEP_P	0.16	0.18	0.07	0.04	0.05	0.11
OCT_P	-0.02	0.07	0.03	0.04	0.00	-0.09
NOV_P	0.06	0.07	0.18	0.07	0.08	0.01
DEC_P	0.13	0.17	0.02	0.15	0.10	-0.04
Jan	0.04	0.17	0.02	0.17	0.06	-0.05
Feb	-0.10	-0.07	0.03	-0.05	0.07	0.03
Mar	0.00	-0.10	0.01	-0.22	-0.05	0.03
Apr	0.00	-0.02	0.08	0.01	0.11	0.07
May	0.09	0.09	0.02	0.01	-0.11	-0.02
Jun	0.11	0.06	-0.06	0.22	0.12	0.05
Jul	0.03	0.09	0.11	0.04	0.05	0.04
Aug	0.16	0.01	0.14	0.10	0.15	0.10
Sep	0.07	0.03	0.00	0.00	-0.01	0.08
Oct	0.01	-0.06	-0.02	0.06	-0.05	-0.03