ASSESSING THE LEGACY OF THE PINE POINT MINE:

POST-INDUSTRIAL LAND COVER AND LAND USE

by

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ABSTRACT

While mining is a major component of the northern Canadian economy, including the contemporary mixed economy of Aboriginal communities, it often leaves legacies of environmental and economic transformation that persist after closure. The legacies of historical mines in northern Canada challenge industry claims of sustainability. This thesis addresses how industrial mineral development and closure continue to affect local environments and economies after abandonment. The abandoned Pine Point mine in the Northwest Territories provides a case study for explaining the ongoing relationships among land cover, land use, and the post-industrial landscape. Drawing from landscape ecology and micropolitical ecology, I adopt an interdisciplinary approach to examine environmental and socioeconomic changes in the wake of industrial development and closure at Pine Point. The results show that passive reclamation is not sufficient for restoring ecological function in a subarctic environment. Land use, however, persists as land users adapt to the post-industrial landscape despite grave concern about its environmental condition. If mining is to be considered sustainable, decommissioning and reclamation must explicitly account for long-term environmental transformation as well as ongoing post-industrial land use, particularly in Aboriginal contexts.

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LIST OF ABBREVIATIONS

AREA_MN – Mean patch area

CONTIG_MN – Mean contiguity

GDP – Gross Domestic Product

IBA – Impact Benefit Agreement

IBCSP – International Boreal Conservation Science Panel

Landsat TM – Landsat Thematic Mapper

LPI – Largest patch index

NP – Number of patches

NTS – National Topographic System

NWT – Northwest Territories

PARA_MN – Mean perimeter-area ratio

PIN – Participant identification number

PLADJ – Percentage of like adjacencies

PLAND – Percentage of landscape

PP – Pine Point

SIDI – Simpson's diversity index

SIEI – Simpson's evenness index

SSHRC – Social Sciences and Humanities Research Council

USGS – United States Geological Survey

WBNP – Wood Buffalo National Park

WRS – Worldwide Reference System

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CHAPTER 1

Introduction

1.1 Introduction

In northern Canada, industrial resource extraction transformed environments and economies, particularly following the Second World War. The history of mining drove economic development and settlement in the territorial North, giving rise to the contemporary environmental and socioeconomic landscape in many parts of the region. Mining is a major component of the northern Canadian economy, including the contemporary mixed economy of northern Aboriginal[1] communities. Today, many northern Aboriginal communities participate in a mixed economy where wage labour, often at mines, is combined with land-based economic activities like hunting and trapping (Berkes et al 1995; Usher et al. 2003; Natcher 2009; Boutet 2014). However, the transformative effects of industrial resource extraction have often wrought negative legacies for nearby Aboriginal communities. Approximately 1,200 Aboriginal communities across Canada have an exploration site, active mine, or abandoned mine located in their traditional territories (Nolan 2009), and relatively few communities garnered lasting benefits from the historical industrial operations that left a degraded environment upon closure (MacPherson 1978; Ali 2003; Sandlos & Keeling 2012). While mining is still a major component of the northern Canadian economy, with nearly 30% of the Northwest Territories' 2014 GDP coming from mining and oil and gas extraction (Northwest Territories Bureau of Statistics 2014), the lasting legacies of development and closure remain poorly understood. Because the land-based economy remains a crucial component of the Aboriginal mixed economy, it is important to understand how the environmental and socioeconomic effects of

[1] Following the official terminology currently used in Canada, I refer to First Nations and Métis peoples collectively as 'Aboriginal' (Desbiens & Rivard 2014).

mine development, closure, and abandonment intertwine to create a problematic legacy of transformation in Aboriginal communities.

Today's mining industry is in the process of distancing itself from its history of immensely profitable resource extraction coupled with an abysmal environmental and human record. Instead, many mining ventures are making concerted efforts to rebrand the industry as environmentally and socially responsible, focused on profitable and sustainable extraction (Fitzpatrick et al. 2011; Laurence 2011; Fonseca et al. 2013; Prno 2013; for a critique of mining sustainability, see Whitmore 2006). However, it should be noted that such rebranding does not always result in meaningful changes. For example, three diamond mines have been opened in the Northwest Territories since 1998, after negotiating impact-benefit agreements (IBA) with local Aboriginal communities that included provisions for Northern Aboriginal employment (Hall 2013). While the negotiation of IBAs is a promising step toward social responsibility in contemporary extractive operations, the failure of these mines to meet their target of 40% Northern Aboriginal employment makes it clear that there is still ample room for improvement (Hall 2013).

Despite current, ongoing efforts to rebrand industrial mineral extraction, the legacies of abandoned mines have been identified as a critical sustainability challenge for the industry (Worrall 2009). A mine is considered abandoned when exploration and extraction have ceased and remediation has either not occurred or was not effective (Keeling & Sandlos 2015). Canada hosts over 10,000 abandoned mines and exploration sites; of the 30 abandoned mines in northern Canada identified as priorities for remediation in 2002, 17 are currently being remediated (NOAMI 2009; Keeling & Sandlos 2015). Remediation is action undertaken to isolate, reduce, or reverse environmental damage, including that caused by extraction operations (Powter 2002;

Bertocchi et al. 2006). At sites where minimal remediation has occurred, like many historical mines, ecological productivity is restored through passive reclamation wherein an ecosystem returns to functionality with no further human intervention (Hodacova and Prach 2003; Worrall et al. 2009). Adopting a passive approach to reclamation usually means that environmental damage caused by the mine remains problematic; reclamation can take decades, especially in northern environments where the processes of vegetation conversion and succession are slow (Bradshaw 1997; Deshaies et al. 2009). The legacy of long-term environmental impacts associated with abandoned mines is especially relevant for Aboriginal peoples for whom the land-based economy is crucial to their mixed economy and cultural continuity.

Given the intricate links among the people, the environment, and the economy in northern Canada, this thesis addresses the ways the industrial history of mine exploration, development, and closure continues to affect local environments and economies long after mine abandonment. As an extensive open pit mine complex that underwent little remediation upon closure and exhibits environmental degradation, the Pine Point mine in the Northwest Territories provides a compelling case study for investigating the long-term, multi-faceted consequences of poor remediation and abandonment. In particular, I examine environmental and socioeconomic changes induced by the Pine Point mine to explain the ongoing, interconnected relationships among land cover, land use[2], and the post-industrial landscape.

1.2 Research Purpose and Approach

The purpose of this research is to examine the environmental and socioeconomic legacies of the minimally remediated, abandoned Pine Point mine in the Northwest Territories. I set out to determine whether there are long-term environmental effects of passive reclamation in a boreal

[2] In this research, I use the term ‘land use’ to refer to the harvesting of plant and animal resources as part of the land-based economy.

environment, and how local land users have adapted to this post-industrial landscape. The contemporary mixed economy is often a part of Aboriginal cultural identity and relies on a dynamic combination of wage labour and land-based activities (Berkes et al 1995; Usher et al. 2003; Gibson & Klinck 2005; Natcher 2009; Sayles & Mulrennan 2010). This project explores the shifting relationships among the environment, economy, and culture in the wake of industrial development and closure.

Given the study's interdisciplinary nature, I opted for a dual approach that used complementary datasets and methods to examine how local environments and people adapt to post-industrial landscapes. Remote sensing and landscape metrics facilitate the long-term detection of land cover change at the abandoned mine to assess its environmental legacy, and map-based interviews provide space for local land users to explain the complexities and nuance in their hunting and trapping practices near the abandoned mine. While not amenable to direct integration and comparative analysis, this two-pronged approach yielded a rich portrait of the multi-faceted legacy of the abandoned Pine Point mine.

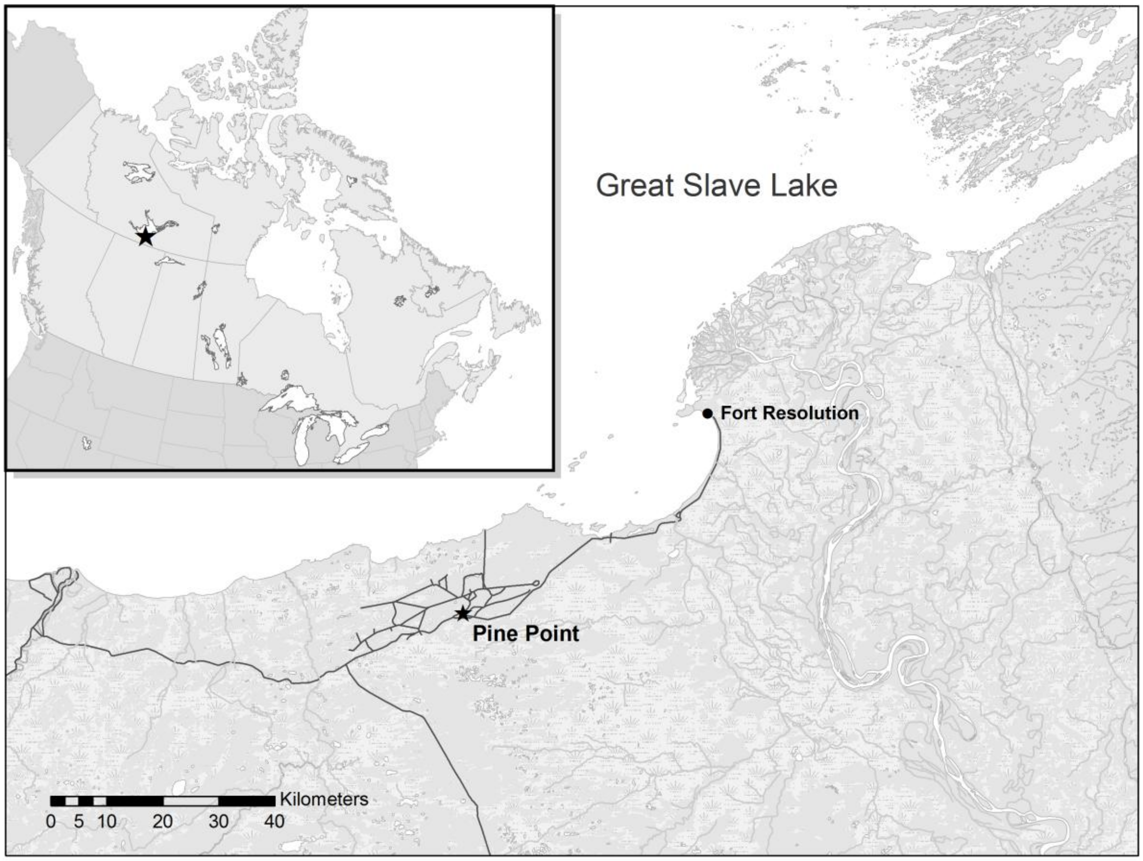

Figure 1. 1 Map of the study area showing the location of Pine Point and Fort Resolution; inset map: northern North America. Map created by Emma LeClerc

1.3 Study Site

The Pine Point mine site is located on the southern shore of Great Slave Lake in the Northwest Territories (Figure 1.1). Opened in 1964 by a subsidiary of Cominco Ltd., Pine Point was an extensive open-pit mine that shipped nearly 13 million tons of lead and zinc, in the form of high grade ore and concentrate, to a processor in British Columbia over the course of its 24 year lifespan (Sandlos & Keeling 2012). The Canadian government contributed nearly $100 million to develop infrastructure for the mine, including a hydroelectric dam, a railway, highway improvements, and a town that housed nearly 2,000 residents during the mine's peak (Deprez 1973; Macpherson 1978). Hundreds of kilometers of seismic cutlines were bulldozed through the boreal forest during the mine's exploration phase; because this occurred without prior consultation of the local community, many of these cutlines destroyed local land users' traplines (Macpherson 1978; Sandlos & Keeling 2012). As development progressed, trees were cleared to make room for the expanding mine, and many of the trees that remained were killed by changes to the water table related to the dewatering of dozens of open pits (Macpherson 1978). The Pine Point mine also experienced repeated malfunctions in their system to manage effluent discharge from the 570 hectare tailings pond (Macpherson 1978; Northwest Territories Water Board 1985). Despite these environmental impacts, and the concerns of the neighbouring community of Fort Resolution, the mine continued production.

Operations ultimately shut down when base metal prices plummeted in the late 1980s (Kendall 1992), but little was accomplished by way of environmental reclamation (Figure 1.2). The purpose-built town and mine infrastructure were erased as all buildings were either removed or bulldozed. Waste rock remained in piles around the mine site, berms were constructed to restrict access to the site, 46 pits were left open, and the tailings pond was capped to prevent dust plumes. Revegetation of the capped tailings was deemed unsuccessful following a pilot study (Gardiner 1990; Sandlos & Keeling 2012). The timeline of development, closure, and decommissioning is detailed in Figure 1.3. Local communities were not included in reclamation planning. In keeping with the requirements of environmental regulations at the time, Cominco's Restoration and Abandonment Plan offered technical strategies for addressing tailings containment and discharge (Cominco Ltd. 1991) but the passive approach to site reclamation left an extensive landscape disfigured by its industrial past.

Figure 1. 2 Oblique aerial photo of a small part of the mine site showing piled waste rock, little vegetation growth, and vertical cutlines through the surrounding forest, ca. 2003. Photo credit: Deninu Kue First Nation

This post-industrial landscape is just 70 kilometers west of the predominantly Chipewyan Dene and Métis community of Fort Resolution. With fewer than 500 people as of the 2011 Census (Statistics Canada 2012), the Fort Resolution community has historically relied on the land for economic purposes, including hunting and trapping for both subsistence and the fur trade. Known in Chipewyan as Deninoo, or Moose Island, Fort Resolution is the oldest community in the Northwest Territories and has been designated a National Historic Site of Canada for its prominence during the fur trade (Parks Canada 2000). Because of its proximity to the Pine Point mine, researchers have been coming to Fort Resolution for decades to study everything from geology to hydrology to climate change and adaptive capacity (e.g. Macqueen & Powell 1983; Evans 1998; Wesche & Armitage 2010).

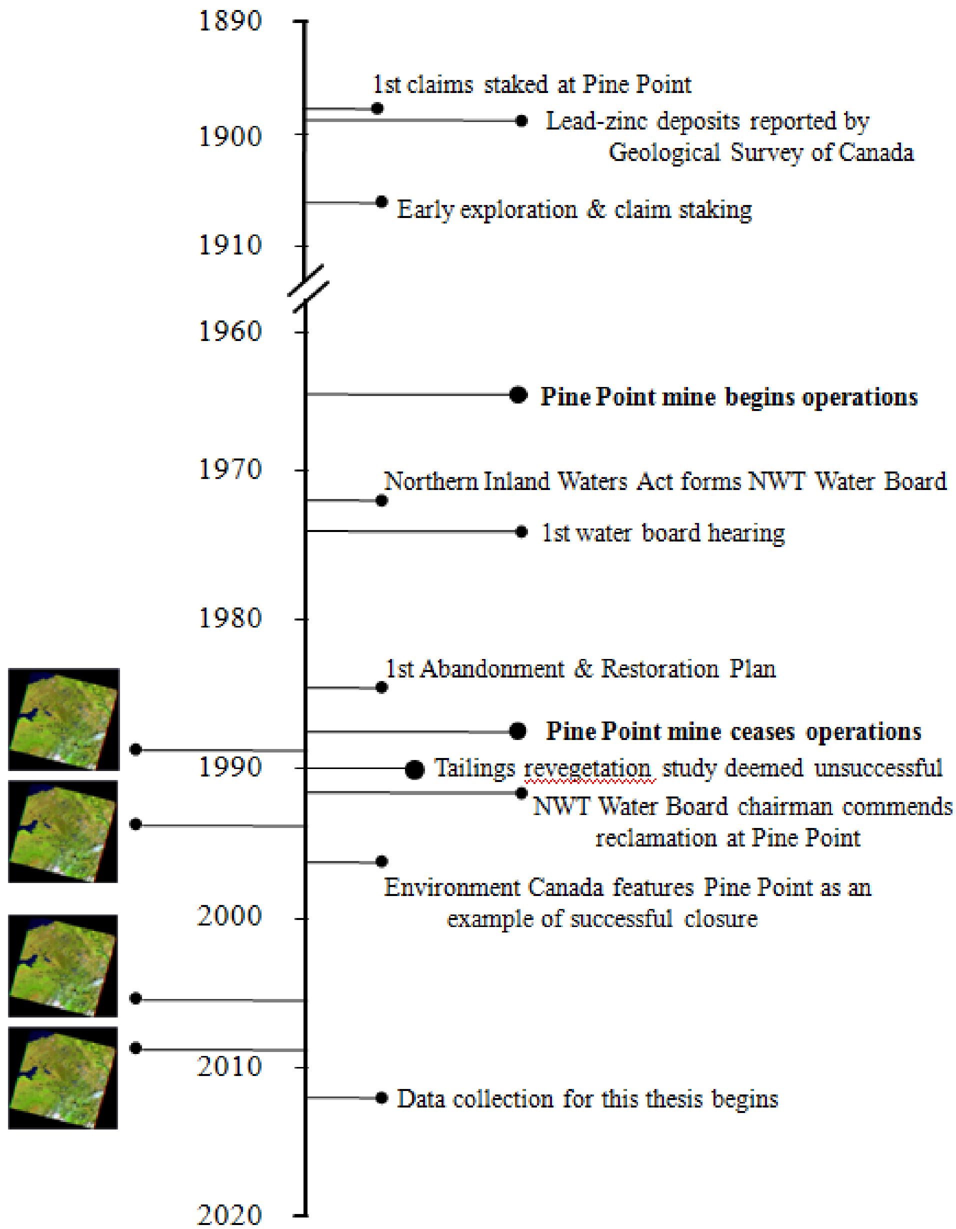

Figure 1. 3 Timeline of exploration, development, closure, decommissioning and abandonment at the Pine Point mine. The collection dates of the Landsat images used in this analysis are indicated left of the timeline. In the interest of clarity, only the first NWT Water Board hearing and the first Abandonment and Restoration Plan are shown.

In spite of its transformation, the abandoned mine was a considered a "well-managed closure" (Kendall 1992, 150) from an industry and government standpoint, both in terms of worker lay-offs and environmental remediation (Kendall 1992; Environment Canada 1996). However, oral histories collected in Fort Resolution in 2010 indicate that many local people disagree with this postive assessment of the post-industrial landscape, referring to the denuded site and still-open pits as evidence of the "devastation" wrought by the Pine Point mine (Boutet et al. 2015, 217). Nevertheless, local land users also report wildlife returning to the area in the years since closure, as well as some early vegetation growth on the site. In order to identify the multi-faceted, long-term impacts of industrial resource extraction followed by abandonment and passive reclamation, this study focuses on the ongoing relationships between industrial landscape transformation, land cover change, and post-industrial land use experienced by hunters and trappers from Fort Resolution, particularly in the twenty years following the closure of Pine Point. I argue that the environmental and socioeconomic legacies of historical mines pose a substantial challenge to industry claims of sustainability, thus reclamation efforts must explicitly account for both long-term environmental changes and local socioeconomic requirements, particularly in Aboriginal contexts.

1.4 Literature Review

Because the long-term effects of industrialism and deindustrialization span disciplinary boundaries, an interdisciplinary approach is needed to examine the relationships among abandoned mines, local communities, and the environment. Industrial mining in the North must be seen as an experience that begins with exploration and extends beyond closure, varying according to global forces and local factors at play in the communities. To document both socioeconomic changes and environmental changes that can be attributed to the abandoned Pine

Point mine, this study is guided by the principles of micropolitical ecology and landscape ecology. These literatures establish the theoretical basis for documenting the local particularities of environment and economy that shed light on the interrelated, dynamic legacies of abandoned mines in northern Canada.

Political ecology compels us to consider how political and economic contexts shape environments and environmental issues (Robbins 2004; Horowitz 2010). In North America, a convergence in favorable political, economic, and technological conditions resulted in a boom in industrial resource extraction in the 19th and 20th centuries. In Canada, subterranean minerals and base metals held the promise of immense profit and thus drew developers north in pursuit of resource wealth (Keeling & Sandlos 2009; Piper 2009; Sandlos & Keeling 2012). This phenomenon was encouraged by federal subsidies of mining ventures in northern Canada, which served as vectors for colonial agendas that sought to replace the fur trade with an economy focused on industrial mineral development (Wolfe 1992; Thompson 2005; Cater & Keeling 2013).

The political ecology of resource development on indigenous peoples' land is often discussed in terms of conflict, political and cultural rights, and environmental impacts (Bebbington et al. 2008; Keeling & Sandlos 2009; Bebbington 2012). Ali (2003) demonstrates that indigenous peoples have dealt with resource development in myriad ways, ranging from resistance to accommodation to encouragement. Gibson and Klinck (2005) discuss the factors that affect individual and community responses to contemporary industrial mineral development. These factors, which include race, gender, age, socioeconomic status, self-determination, and distance from mine, mediate the benefits and costs of industrial resource extraction for individuals and communities (Gibson & Klinck 2005). Prno (2013) points to the growing need for developers to build relationships and address community concerns about sustainability and local benefits in order to establish society and community support that constitutes a social license to operate. Historically, however, mineral resources were often developed and mines subsequently abandoned without consultation or the consideration of long-term, transformative impacts on local environments and communities (Downing et al. 2002; Hipwell et al. 2002; Worrall et al. 2009).

For indigenous and non-indigenous communities alike, abandoned mines can leave potentially troubling legacies. From denuded expanses of land that await costly restoration to the logistical and political difficulties of managing industrial waste, the life of a mine rarely ends at closure (Sandlos & Keeling 2013). For instance, the abandoned Giant Mine near Yellowknife, NT that was once a lucrative source of gold ore now sits atop 237,000 tonnes of arsenic trioxide, a toxic waste product that is at risk of contaminating local waterways (Clark & Raven 2004; Jamieson 2014). Such lingering environmental impacts of development and closure pose a considerable challenge to mining sustainability (Worrall 2009). In addition to the environmental changes introduced by industrial resource extraction, structural socioeconomic changes can outlive economic benefits in nearby communities (Boutet et al. 2015).

The environmental and socioeconomic issues associated with derelict mines are particularly pronounced for Aboriginal communities. Drawing from the political ecology literature, Sandlos & Keeling (2012) have argued that Aboriginal communities in the Pine Point region were subject to a political and economic agenda that simultaneously promoted colonialism and industrial development while yielding few lasting economic benefits to those whose economies were most disrupted. In the Northwest Territories, the environmental and socioeconomic changes that accompanied the development, operation, and abandonment of the Pine Point mine continue to have a profound effect on the nearby community of Fort Resolution.

This study adopts a micropolitical ecology perspective to explain how local Aboriginal peoples engage with Pine Point's deindustrialized landscape. While a political ecology approach can explain the broad context of industrial development in northern Canada, micropolitical ecology accounts for the diversity of responses to environmental change that occur within communities and at the local scale (Horowitz 2011). Micropolitical ecology is a subfield of political ecology which acknowledges that local politics, or "micropolitics" play an important role in shaping community responses to environmental change (Bebbington et al. 2008). Whereas much political ecology emphasizes the broad political and economic contexts of environmental change, micropolitical ecology considers the heterogeneous individual and local perspectives and interactions related to a changing environment (Kirsch 2006; Horowitz 2010; Cater & Keeling 2013). Micropolitical ecology is often applied to industrial expansion in developing nations (e.g. Bebbington et al. 2008; Horowitz 2010; Rasch & Koehne 2015), and is well suited to the study of mining and its related environmental transformations. Kirsch (2006) describes how the Ok Tedi copper and gold mine in Papua New Guinea polluted nearby rivers with tailings, to the detriment of local indigenous peoples' lives and livelihoods. The mine was a substantial source of revenue for the country, and as such was permitted to continue operations for decades despite the mounting environmental impacts. For individuals living with the Ok Tedi mine, the memories and knowledge associated with particular places became jeopardized as those places were transformed by pollution and became unrecognizable. Micropolitical ecology provides a way to understand the disruption or adaptation of local environmental knowledge that often accompanies environmental degradation. In the Ok Tedi case, local indigenous communities organized and launched an international campaign against the mine that resulted in a lawsuit against the mining company. Rather than shut down the mine entirely, their goal was to change the mine's tailings disposal practices. This would allow the communities to receive compensation for the environmental damages while ensuring that further damage was mitigated. However, this approach to the problem did not diminish the sense of loss felt by those whose homes had been transformed. The Ok Tedi case demonstrates that local responses to industrial development are shaped by local circumstances as well as by wider political and economic forces. Micropolitical ecology offers a conceptual space for examining local factors that shape responses to environmental change without losing sight of the role that broader political and economic structures play in creating such change.

This research uses micropolitical ecology as a lens to examine the relationships between local land use and the post-industrial landscape, acknowledging factors like adaptation and culture in shaping Aboriginal experiences of mine development and closure at Pine Point without dismissing the role of broad political and economic forces. Parlee et al. (2007) point out that the relationship with the land, including the health of the land, is central to individual and community health in Aboriginal communities. In emphasizing perceptions of environmental change, micropolitical ecology privileges local environmental knowledge, and it is local understandings of environment that shape land use practices (Horowitz 2015). Given the importance of the land to Aboriginal culture and economy, Pine Point's extensively degraded landscape poses the question of how local land users perceive and interact with the post-industrial space. By interviewing land users from Fort Resolution, I set out to unearth individual perspectives about the long-term socioeconomic effects of mine abandonment. A micropolitical ecology approach enabled the analysis of commonalities in land users' concerns about the environmental state of the site, as well as the contradictions in using elements of environmental degradation to benefit local land use.

Like community responses to industrial mineral development, environmental changes are also shaped by local conditions and broader political-economic forces. The pursuit of resource wealth in northern Canada, from the fur trade to forestry to mining, has resulted in environmental change (Gillanders et al. 2008; Boucher et al. 2009; Piper 2009; Johnson & Miyanishi 2012). Indeed, Johnson and Miyanishi (2012) argue that the boreal environment has been a cultural landscape subject to alteration since the beginning of human occupation, and that the extent and intensity of anthropogenic environmental change has increased with industrial operations like logging and mining. Such environmental transformation is evidenced by changes in spatial patterns on a landscape through time (Delcourt & Delcourt 1988; Turner 1989).

Because it focuses on the relationships between landscape pattern and ecological process, typically at broad spatial extents, the discipline of landscape ecology is well suited to the study of anthropogenically disturbed landscapes like abandoned mines. Indeed, a key theme of landscape ecology is the role humans play in shaping the natural environment (Turner, Gardner, & O'Neill 2001). By quantifying changes in spatial pattern through time, it is possible to investigate the relationships between ecosystem structure and function at a variety of spatial and temporal scales (Turner 1989). Explicit analyses of the myriad ways humans can shape and re-shape landscapes have comprised a significant contribution of the discipline since its inception (Turner 1989). Due to its ability to quantify landscape patterns in ways meaningful to ecological function, landscape ecology has frequently been applied to assess anthropogenic impacts in a variety of ecological contexts, from the effects of historical land use on current vegetation (Lindborg & Eriksson 2004), to natural and anthropogenic sources of forest fragmentation

(Wulder et al. 2008), to the relationship between logging and forest cover (Boucher et al. 2009). Turner (1989) states that "…the landscape (like many ecological systems) represents an interface between social and environmental processes" (189), and it is this interface that is the focus of this thesis. Through its focus on the relationships between landscape pattern and ecological process, landscape ecology offers a theoretical basis for examining landscapes transformed by industry. I draw from landscape ecology to compare landscape structure at the abandoned Pine Point mine site and a comparison site in Wood Buffalo National Park in order to assess the long-term effects of industrial landscape transformation.

The natural revegetation of anthropogenically disturbed landscapes in northern environments is a slow process. When industrial resource development occurs in the north, it can take decades for altered landscapes to return to their former composition and functionality (Harper & Kershaw 1996; Deshaies et al. 2009). Prior to the introduction of stricter environmental regulations in Canada, mining operations ceased when economic benefits at a particular site dwindled and environmental damage was often left unmitigated. Many mining operations were begun and subsequently abandoned well before environmental regulations like the Northern Inland Waters Act (1972) or the Canadian Environmental Protection Act (1988) were enacted, leaving public authorities with the responsibility for remediation (Kendall 1992; Boyd 2003; O'Hara 2007; Richter et al. 2008; Sandlos & Keeling 2012). In Canada, derelict mines often rely on the federal government for costly and logistically challenging environmental remediation (DIAND 2002; MMSD 2002). This situation is complicated by jurisdictional uncertainties that can impede remediation and reclamation, leaving local communities to cope with degraded landscapes for decades after mining operations have ceased (Smyth & Dearden 1998; IIED 2002; deLemos 2009).

Pine Point's industrial history is written on the land. Because landscape ecology is concerned with the relationships between pattern and process (Turner, Gardner, & O'Neill 2001), it provides an ideal framework for analyzing how the mine's degraded landscape differs from a site that lacks an industrial past. Landscape ecology is often applied to assess the impacts of anthropogenic activities like agriculture or forestry on habitats or species assemblages (e.g. Lindborg & Eriksson 2004; Wulder et al. 2008); however, few studies examine the persistent land cover changes at mine sites following closure. Unlike the related discipline of restoration ecology, which is primarily concerned with the process of restoring anthropogenically transformed landscapes to ecological productivity (Van Andel & Aronson 2012), landscape ecology's focus is the spatial and functional relationships that link landscape pattern to ecological process (Turner, Gardner, & O'Neill 2001). Documenting and comparing patterns in land cover at the abandoned mine with those at a reference landscape sheds light on how the ecological processes at work at the post-industrial landscape differ from those at work in a 'natural' context. A better understanding of the patterns and processes at work on deindustrialized landscapes has implications for closure and reclamation planning.

In bringing together micropolitical ecology and landscape ecology, this study offers a unique perspective on the interrelated nature of environmental reclamation and contemporary Aboriginal land use in a post-industrial landscape. The combined approaches yield insight into the broad political conditions during the mine's development and decommissioning that enabled the adoption of a passive reclamation strategy, the long-term environmental consequences of passive reclamation and abandonment, and the nuanced variations in local Aboriginal land users' experience of the post-industrial landscape. Ultimately, the linked environmental and socioeconomic legacies of the Pine Point mine have implications for reclamation planning, community consultation, and the long-term monitoring of abandoned mines in northern Canada.

1.5 Methodology and Methods

The dramatic landscape transformation induced by the development of the Pine Point mine, the lack of remediation upon closure, and the proximity to a community with a historically land-based economy creates a potent case study for understanding the lasting environmental and socioeconomic legacies of abandoned mines in northern Canada. In order to elucidate the complex relationships between the post-industrial environment and contemporary land use practices at the abandoned Pine Point mine, I adopted a dual methodology approach that includes quantitative methods to assess changes in landscape pattern and qualitative methods to document post-industrial land use. I drew from landscape ecology, which links land cover pattern with ecological process, to examine the environmental legacy of the extensively degraded Pine Point site. I focused on whether and how the land cover dynamics at Pine Point differed from land cover dynamics at a comparison site that never experienced industrial development and closure. To complement this quantitative assessment, I interviewed Aboriginal land users to discover how Pine Point's post-industrial landscape affects the contemporary mixed economy in the nearby community of Fort Resolution. Taken together, the combined approaches offer an interdisciplinary portrait of the lasting environmental and socioeconomic effects of industrial development and poor reclamation in northern Canada.

1.5.1 Assessing Land Cover Change

To determine the long-term land cover dynamics at Pine Point mine, I used a combination of remote sensing and landscape metrics (see Chapter 2). For many inaccessible mines, remote sensing offers a cost-effective alternative to *in situ* monitoring because repeat satellite coverage of broad areas provides a platform to track land cover change through time (Schmidt & Glaesser 1998; Antwi et al. 2008; Gillanders et al. 2008; Townsend et al. 2009). Once remotely sensed data are classified into discrete land cover types, it is possible to calculate landscape metrics, which are a means of quantifying patterns in land cover composition and configuration. The interpretation of these metrics yields insights to the ecological processes at work on the landscape (Turner et al. 2001; Narumalani et al. 2004). By comparing land cover at the mine site with land cover at a reference site in Wood Buffalo National Park in the twenty years following the closure of Pine Point, we can determine whether the ecological processes at work in an anthropogenically altered landscape deviate from those at work in a landscape ostensibly unaffected by anthropogenic disturbance.

The land cover change analysis was performed on remotely sensed images from Landsat 5's Thematic Mapper (TM). Landsat TM data have a spatial resolution of 30m and are Level 1 Terrain corrected by the United States Geological Survey (USGS) to ensure consistency across bands and datasets. I selected four near-anniversary images with minimal cloud cover to document land cover change spanning the twenty years after the closure of the Pine Point mine. The images were all recorded in late summer to minimize seasonal variation, which can confound detection of vegetation change (Miller et al. 1997**;** Beaubien et al. 1999; Coppin et al. 2004; Gillanders et al. 2008; Fichera et al. 2012; Ahmed et al. 2013).

Before classifying the images into discrete land cover types, I performed radiometric correction to ensure that changes detected in land cover through time are the result of real changes in spectral response patterns (Lillesand & Kiefer 1994; Jensen 2005; Adams & Gillespie 2006). Following radiometric correction, I performed a supervised classification of bands 4, 5, and 3 of the Landsat images to maximize the difference between the spectral characteristics targeted for land cover change (Gratto-Trevor 1996; Beaubien et al. 1999; Valeria et al. 2012). I classified the images into seven discrete land cover and used image interpretation and ground-truth points to perform a post-hoc validation of the classification. It is important to note, however, that "...the accuracy of the classifications increases with a decrease in the number of classes used" (Gratto-Trevor 1996, 19). The ground-truth data combined with historical fire data from the Canadian National Fire Database informed the image interpretation and identification of classes.

This study employs a space-for-time substitution wherein a site in nearby Wood Buffalo National Park served as a proxy for how the Pine Point region might have evolved in the absence of industrial development. I placed digital buffers around the spatial layers of anthropogenic features at the Pine Point mine to delineate the site for comparison (Woolmer et al. 2008) and to control for shape and edge effects when calculating landscape metrics. I then compared the resultant land cover rasters to assess change in land cover composition and configuration through time. The analysis was completed by quantifying land cover patterns using a series of landscape metrics. The combination of raster algebra and landscape metrics enabled the inference of ecological processes occurring at the Pine Point site and comparison site in Wood Buffalo National Park.

Like all remote sensing products, Landsat TM data have technical limitations. Gratto-Trevor (1996) and Bhatta (2008) discuss how the 30m resolution of most of the Landsat TM bands can confound classifications of land cover type and detection of fine-scale features, some of which may be germane to the study of post-industrial mine sites (discussed further in Chapter 2). However, the Landsat product is commonly used for land cover change analyses at mines (e.g. Antwi et al. 2008; Gillanders et al. 2008; Townsend et al. 2009; Li et al. 2012) due to the distinct advantages of repeat coverage, time depth, and free accessibility. This study proceeded with Landsat TM data with an understanding and acknowledgement of these technical constraints.

1.5.2 Documenting Post-Industrial Land Use

The Pine Point mine was part of a federally subsidized development strategy that promoted extractive industries in northern Canada as a vector of non-Native settlement, leaving widespread environmental degradation in its wake (Sandlos & Keeling 2012). However, stories of resistance, adaptation, and resilience born of local conditions in Fort Resolution complicate the broader political ecology interpretation. Micropolitical ecology provides a guide to delve into these stories because it is sensitive to local particularities of engagement with industrialism while acknowledging the broader forces at work. To evaluate the long-term effects of the abandoned Pine Point mine on local livelihoods, I conducted map-based interviews with 18 land users from Fort Resolution. The interviews offered a nuanced understanding of the relationships between the post-industrial landscape and local livelihoods (see Chapter 3).

For this portion of the study, I adapted the map biography method which was developed in the 1970s to justify the spatial extent of an Aboriginal land claim (Nahanni 1977; Chapin et al. 2005). Structured as surveys, these map biographies pursued quantitative information to provide a thorough and complete spatial record of a community's use and occupancy of the land (Tobias 2009). Unlike the studies conducted for land claims, however, my aim was not to undertake a general study of land use and occupancy for the entire community of Fort Resolution, but rather to tailor the method to accommodate more specific research questions about the influence of the post-industrial landscape on contemporary land use in the Pine Point region. I replaced the survey structure of traditional map biographies with a semi-structured interview approach that allowed me to record spatial land use data while simultaneously unearthing the descriptive and explanatory aspects of the Pine Point mine's influence on local land use. The key advantage of the semi-structured interview is that it relies on "flexible questioning" (Dunn 2010, 110), and thus allows the interview participant to follow his/her train of thought to topics that may not have been anticipated by the researcher beforehand (Huntington 2000). In this study, I asked interview participants about hunting and trapping activities in the Pine Point region, especially focusing on the 25 years since the mine shut down. The semi-structured interview format allowed for a broad range of responses, while still eliciting detailed, spatially referenced information on land use.

Although the map biography method has been applied in many different research contexts (e.g. Freeman 1976; Tobias 2000; Armitage 2010; Aporta 2011), each map biography is essentially "...an account of a person's life on the land, sea or ice" (Tobias 2009, 38) wherein spatial information is recorded on a map during an interview. With support from the Deninu Kue First Nation and the Fort Resolution Métis Council, I focused on land users whose activities were affected, either directly or indirectly, by the Pine Point mine. I used chain referral, sometimes called 'snowball sampling' (Atkinson & Flint 2001), to identify research participants. With chain referral, interview participants identify other members of the community who might be interested in participating (Huntington 2000). While chain referral has been criticized as providing a biased and unrepresentative sample of a population (Atkinson & Flint 2001), it was ideal for my research needs. I knew from the outset that my study would not be a comprehensive, representative land use and occupancy study, but rather a study tailored to address the fundamental questions of how and why the Pine Point mine has shaped (and continues to shape) contemporary, post-industrial land use among hunters and trappers from Fort Resolution. Because this study's ultimate utility is academic rather than legal, I constrained the geographic and conceptual scope of the interview to make it manageable for a single researcher. In targeting hunters and trappers who have used the Pine Point region, the adapted map biography method provided a way to capture the "micropolitics" of land use at the environmentally degraded site. The semi-structured interview approach yielded narratives of local environmental knowledge that helped explain local perceptions of the abandoned mine site and the reasons behind contemporary land use practices.

When I first arrived in Fort Resolution in 2012, no one seemed surprised by my presence, but everyone asked me three questions:

1) 'Where are you from?'

2) 'Who are you working for?', and

3) 'When are you coming back?'

These questions speak to the importance of trust, especially in a community that has been placed under a microscope for decades. There is undoubtedly a deep-seated mistrust of researchers affiliated with the government or with industry. Combined with the potentially contentious issue of land use in the midst of ongoing land claims and renewed interest in mineral development (Roy et al. 2012; CBC News 2012, 2013), establishing trust in this research context was challenging. Following the framework outlined by Wesche et al. (2010), I sought to build relationships with community members as well as possible in the limited time I spent in Fort Resolution. As a young, white, female graduate student who is not a member of the community, I relied on my research contact at the Deninu Kue First Nation to introduce me to as many community members as possible. Despite some challenging political and personal divisions in the community, community members accepted me as a neutral individual and felt comfortable referring me to land users who might be willing to participate in the research. My age, ethnicity, and gender did not seem to inhibit my interactions with the predominantly male, older, Aboriginal land users. This may have been aided by the fact that I interviewed land users in their own homes, often with family members looking on, whenever possible. I drew from my previous experiences in cross-cultural contexts to help put interview participants at ease, and to help keep my own cultural assumptions in check. Prior to fieldwork, I was concerned that community members might be unwilling to share land use information with a white woman whose sole purpose for coming to Fort Resolution was to conduct research, as the situation could be seen to mirror colonialism or the type of extractive research that has been problematic in many indigenous contexts (Brown 2005). However, I was extremely fortunate that community members were actually relieved that my affiliation was with a university, as opposed to government or industry, and I was glad to find that many were very interested in the research project and eager to share their stories of land use.

In addition, this research builds on previous work done by Dr. Arn Keeling and Dr. John Sandlos as part of the Abandoned Mines in Northern Canada Project. Dr. Keeling and Dr. Sandlos had previously conducted oral history research with community members from Fort Resolution in 2010. As part of the Abandoned Mines in Northern Canada Project, I was able to build a new research relationship on this strong foundation. My study was approved by Memorial University's Interdisciplinary Committee on Ethics in Human Research and by the Deninu Kue First Nation and Fort Resolution Métis Council prior to fieldwork. It adheres to the ethical principles of respect, free and informed consent, reciprocity, and confidentiality discussed in the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (CIHR, NSERC, & SSHRC 2010). I conducted the interviews over the course of six weeks in the summer of 2012. Interview participants received honoraria, as agreed upon in the Abandoned

Mines in Northern Canada Project research agreement between the Deninu Kue First Nation and Dr. Keeling and Dr. Sandlos. In 2013, I returned to Fort Resolution to share the results of the research with the community and to present a personalized land use map to each interview participant.

After the interviews were complete, I digitized the land use features and compiled them into composite land use maps that show extensive hunting and trapping, including at the abandoned mine site. Coded interview transcripts provided an analytical complement to the spatial land use data. Drawing from grounded theory, in which themes are inductively derived from data, I used open coding to identify ideas and actions that recurred throughout the transcripts (Crang 1997; Suddaby 1996). By coding and analyzing the transcripts, I was able to glean themes that highlighted some of the relationships between contemporary land use and Pine Point's post-industrial physical and socioeconomic landscape. While the map biography method is inherently constrained by the difficulty of obtaining spatial and temporal precision (Tobias 2009), the combined oral and spatial accounts of land use generated with the adapted method was ideal for documenting how local land users live and engage with the post-industrial Pine Point landscape.

1.5.3 Conclusion

This study's interdisciplinary approach enabled me to examine the long-term environmental and socioeconomic effects of the Pine Point mine since its closure and decommissioning. The combination of remote sensing and landscape metrics generated a better understanding of land cover trends in the twenty years following mine closure. The semi-structured, map-based interviews clarified how local land users have adapted their hunting and trapping practices in the wake of industrial development and closure. While I initially hoped to integrate datasets into a spatial analysis of land use and land cover combined, the resolution of the imagery and the spatial accuracy and precision of memory in recording place-based activities precluded such integration. Nevertheless, the dual approach combined to tell a powerful story about the post-industrial legacy of a poorly reclaimed site.

1.6 Thesis Structure and Chapter Summaries

In accordance with the guidelines of the School of Graduate Studies at Memorial University, this thesis is structured to include an introductory chapter providing context and the overarching goals of the study, two standalone manuscripts for publication, and a concluding chapter. There is an unavoidable degree of repetition, particularly in the study site and methods sections, inherent to including standalone manuscripts in the thesis. However, this structure was deemed logical given the interdisciplinary nature of the study. The manuscripts are summarized below.

1.6.1 Chapter 2: Assessing Post-Industrial Land Cover Change at the Pine Point Mine, NWT, Canada Using Multi-Temporal Landsat Analysis and Landscape Metrics

The first manuscript has been submitted to the journal *Environmental Monitoring and Assessment*. Using remote sensing and landscape metrics, this component of the study examines changes in land use at the Pine Point mine and a comparison site in Wood Buffalo National Park. Near-anniversary Landsat 5 TM data spanning 1989 to 2009 provided the basis for a supervised, maximum likelihood classification of land cover into mutually exclusive categories. Landscape metrics were then calculated to identify patterns in land cover composition and configuration and the mine landscape and reference landscape. The results show that the bare surfaces of the mine site underwent little conversion to vegetation in the twenty years following closure. In addition, post-industrial landscape was characterized by smaller, less contiguous patches of many types of vegetation, while the reference landscape in Wood Buffalo National Park was dominated by large, contiguous patches of dense conifer. The differences between these landscapes indicate that the passive reclamation strategy adopted at the Pine Point mine at closure is insufficient to restore ecological functionality. The dramatic alteration to land cover introduced by mining was not improved by passive reclamation; as such, historical mines remain a critical challenge to sustainability in the mining industry. In addition, the 30 m pixel size of Landsat data made it apparent that the long-term monitoring of land cover dynamics at abandoned mines would be more effective with improved access to high-resolution imagery.

1.6.2 Chapter 3: From Cutlines to Traplines: Post-Industrial Land Use at the Pine Point Mine

Published in the journal *The Extractive Industries and Society* in January 2015 (LeClerc & Keeling 2015), the second manuscript details the transformative and lasting effect of industrial mineral extraction and poor reclamation on land-based economies in northern Canada. The results of the map-based interviews show that local land users were displaced when the mine began operations, which coincided with the broader regional transition from a predominately land-based economy to the mixed economy incorporating wage labor that is common today. Since closure, many land users have begun to reappropriate the post-industrial landscape, as evidenced by the common practices of hunting at the mine site and keeping cutlines open for trapping. However, this use of the post-industrial landscape is coupled with a deeply felt and often expressed concern for the environmental state of the poorly reclaimed site. As such, contemporary land use in the Pine Point region is best understood as the result of local land users' tenacity in adapting the mixed economy to suit the local environmental and socioeconomic reality.

1.7 Co-Authorship Statement

Funding support for this project was provided through the Abandoned Mines in Northern Canada Project (SSHRC grant no. 866-2008-16). Emma LeClerc and Dr. Yolanda Wiersma are co-authors of the first manuscript in this thesis, which has been submitted to the journal *Environmental Monitoring and Assessment*, as they jointly designed the research approach. Emma LeClerc completed the data processing and analysis with guidance from Dr. Wiersma, and both co-authors collected ground-truth data to validate the land cover classifications. Emma LeClerc and Dr. Arn Keeling are co-authors of the second manuscript, which was published in the journal *The Extractive Industries and Society* in January 2015. The co-authors jointly designed the research approach, and Emma LeClerc completed data collection, processing and analysis with guidance from Dr. Keeling. Emma LeClerc wrote drafts of both manuscripts, and both Dr. Arn Keeling and Dr. Yolanda Wiersma provided valuable revisions and approved the final manuscripts prior to submission for publication. Both manuscripts in this thesis have been expanded to include more detail than the versions submitted for publication.

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CHAPTER 2

Assessing post-industrial land cover change at the Pine Point mine, NWT, Canada using multi-temporal Landsat analysis and landscape metrics

This study investigates land cover change near the abandoned Pine Point mine in Canada's Northwest Territories. Industrial mineral development transforms local environments and the effects of such disturbances are often long-lasting, particularly in subarctic, boreal environments where vegetation conversion can take decades. Located in the Boreal Plains ecozone, the Pine Point mine was an extensive open pit operation that underwent little reclamation when it shut down in 1988. We apply remote sensing and landscape ecology methods to quantify land cover change in the 20 years following the mine's closure. Using a time-series of near-anniversary Landsat images, we performed a supervised classification to differentiate seven land cover classes. We used raster algebra and landscape metrics to track changes in land cover composition and configuration in the 20 years since the mine shut down. We compared our results with a site in Wood Buffalo National Park that was never subjected to extensive anthropogenic disturbance. This space-for-time substitution provided an analogue for how the ecosystem in the Pine Point region might have developed in the absence of industrial mineral development. We found that the dense conifer class was dominant in the park and exhibited larger and more contiguous patches than at the mine site. Bare land at the mine site showed little conversion through time. While the combination of raster algebra and landscape metrics allowed us to track broad changes in land cover composition and configuration, improved access to affordable, high-resolution imagery is necessary to effectively monitor land cover dynamics at abandoned mines.

Keywords: Land cover change; abandoned mines; remote sensing; landscape metrics

2.1 Introduction

Canada's boreal forest is increasingly recognized as a conservation priority (Carlson et al. 2010; Valeria et al. 2012; Badiou et al. 2013; Powers et al. 2013). Powers et al. (2013) argue that large reserves of intact boreal forest are important for maintaining biodiversity and long-term ecological processes. Additionally, the International Boreal Conservation Science Panel (IBCSP) formally recognized the boreal forest as an ecologically significant environment, citing in particular its role as habitat for endangered and threatened species and its importance for mitigating climate change through carbon sequestration. The report recommends the conservation of a minimum of 50 percent of Canada's intact boreal forest (Badiou et al. 2013).

However, identifying 'intact boreal forest' for the purposes of conservation and management is complicated by the widespread presence of historical and ongoing anthropogenic disturbances such as industrial resource extraction. This problem is compounded by the dynamic nature of forest ecosystems and the fraught task of defining baselines to establish conservation targets (Coppin et al. 2004; Alagona et al. 2012).

The boreal forest has supported an array of socioeconomic activities through time; like natural disturbance regimes, these activities have varied in frequency and magnitude, leaving legacies that can often be traced on the land. Aboriginal[1] peoples have relied on the boreal ecosystem to support subsistence activities and the fur trade, both historically and in contemporary times (Fumoleau 1974; Ray 1990; Usher et al. 2003; Abel 2005; Natcher 2009; LeClerc and Keeling 2015). In the 20th century, resource development activities including timber harvesting and industrial mineral extraction spread throughout northern Canada's boreal ecosystem (Boucher et al. 2009; Keeling and Sandlos 2009; Piper 2009). Technological advances made it possible to mine lower grade ores at massive scales, generating more waste and higher potential for environmental damage (Cooke and Johnson 2002; LeCain 2009). When economic benefits at a particular site dwindled, mining operations ceased and environmental damage was often not addressed (Cooke and Johnson 2002; Worrall et al. 2009). Prior to the introduction of more stringent regulations and environmental protection mandates (e.g. *Northern Inland Waters Act* 1972, *Guidelines for the Abandonment and Restoration Planning for Mines in the Northwest Territories* 1990) which required companies to articulate reclamation plans from the inception of mine development, the deleterious effects of historical industrial resource extraction, particularly from mining, were frequently overlooked (Bowman and Baker 1998; MMSD 2002; Wenig et al.

[1] We use the term 'Aboriginal' to collectively refer to First Nations and Métis peoples, in accordance with the current terminology used in Canada (Desbiens and Rivard 2014)

2005; Otto 2009; Worrall et al. 2009). The long-term environmental legacies of abandoned mines have been identified as a key challenge for an industry seeking to become more sustainable (Worrall et al. 2009).

While mineral development has created extensive and persistent landscape change in northern Canada (Piper 2009; Keeling 2010), it is often difficult to monitor this change after closure. A mine site is considered fully reclaimed when it has been stabilized, revegetated, returned to ecological productivity, and no longer requires monitoring (CCSG Associates 2001). Reclamation can be accomplished through active intervention or, in the case of many historical mines, by passively waiting for the ecosystem to reestablish ecological productivity (Hodacova and Prach 2003; Worrall et al. 2009). For remote mines, like many of those in northern Canada, monitoring reclamation progress *in situ* is costly and usually undertaken by mining companies or government over a short-term basis (MMSD 2002). At large and/or remote mine sites with extensive landscape change and loss of vegetation, remote sensing is a more cost-effective platform for monitoring landscape-level reclamation over long periods of time. Remotely sensed data are commonly used to monitor land cover change at mine sites (Antwi et al. 2008; Townsend et al. 2009; Li et al. 2012; Li et al. 2015); Schmidt and Glaesser (1998) and Gillanders et al. (2008) indicate that remote sensing provides an important means of monitoring land cover change at mine sites throughout the process of reclamation.

The combination of remote sensing and landscape metrics has immense potential for communities interested in monitoring landscape changes in the wake of industrial development. Because many abandoned mines leave large footprints and are located in places that are difficult to access, remote sensing can be a powerful tool for collecting time series data on land cover post-closure. Landscape metrics quantify patterns in land cover composition and configuration that can yield insight to the ecological processes that shape post-industrial landscapes. For instance, land cover patches tend to be less complex in places that have hosted anthropogenic disturbances (Narumalani et al. 2004). In theory, disturbed sites become more similar in structure and function to the surrounding environment through time as the reclamation process, whether active or passive, progresses (Bradshaw 2000). In this study, we assess the application of remote sensing and landscape metrics as a means of monitoring land cover change at abandoned mines.

The Pine Point mine is one example of an industrial extraction operation whose abandonment pre-dated stricter reclamation policy. Although Pine Point is located in the Boreal Plains Ecozone in the Northwest Territories (ESWG 1995), the development, operation, and closure of the mine occurred before the boreal environment's ecological and socioeconomic importance was formally acknowledged by policy-makers. Indeed, operations began in 1964 and the first laws governing habitat protection and water use in the area were enacted in the 1970s (Boyd 2003). Bowman & Baker (1998) point out that "there is no single piece of legislation that directly addresses the reclamation of mine sites and surrounding impacted areas" (8) in the Northwest Territories; instead, reclamation is guided by discretionary power established through regulations of land leases and water use (Bowman & Baker 1998, Wenig et a. 2005). The first Reclamation and Abandonment Plan for the Pine Point mine was drafted in 1985 in fulfillment of the requirements of its water license, which was governed by the Northwest Territories Water Board established by the *Northern Inland Waters Act* in 1972. Two years after milling operations ceased at Pine Point in 1988, the Northwest Territories Water Board and the Department of Indian Affairs and Northern Development released their *Guidelines for Abandonment and Restoration Planning for Mines in the Northwest Territories* (Bowman & Baker 1998).

Upon closure, the mine site was reclaimed to the standards of the time, which prioritized site stabilization and pollutant containment (Bowman and Baker 1998; MMSD 2002; Otto 2009), but left an extensive post-industrial landscape approximately 1900 km^2 in area, dominated by 46 open pits, piles of waste rock, haul roads, cutlines, and a 570 hectare tailings pond (Sandlos and Keeling 2012). The impacts of industrial anthropogenic disturbance are particularly pronounced in the subarctic, where it can take decades for altered landscapes to reestablish former composition and functionality (Bowman and Baker 1998; Lee and Boutin 2006; Deshaies et al. 2009). For instance, while some cutlines cleared during Pine Point's exploration phase may have begun the process of vegetation succession, others continue to criss-cross the boreal forest decades after closure.

At historical mine sites, it is important to understand how the lack of reclamation has affected the local environment through time. While remote sensing can provide a time series dataset, its limited historical depth is sometimes insufficient to establish pre-industrial baselines. Space-for-time substitutions have been used as a strategy to assess vegetation change when long-term ecological data is lacking (Pickett 1989; Fukami and Wardle 2005; Lecomte et al. 2005; Bond-Lamberty and Gower 2008). We use remote sensing and landscape metrics to compare the post-industrial mine site to a site in nearby Wood Buffalo National Park (WBNP). The space-for-time substitution allowed us to compare the composition and configuration of land cover at the mine site with a reference landscape ostensibly unaffected by industrial development. This space-for-time substitution serves as an analogue for how land cover in the Pine Point region might have changed had the mine never been developed. We hypothesized that the Pine Point site would become more similar to the park site in terms of composition and configuration through time as a result of passive reclamation.

The analysis of land cover change in the Pine Point region offers insight to the long-term effects of industrial development on landscape patterns in a boreal environment. Using a time series of near-anniversary remotely sensed images spanning 1989 to 2009, we classify land cover types and compute a series of landscape metrics at the Pine Point site and comparison site. The comparative nature of this study elucidates how ecosystem dynamics operate at a subarctic site subjected to extensive anthropogenic disturbance and whether such dynamics deviate from those at work in a 'natural' context (Fukami and Wardle 2005; Soverel et al. 2010). Given the growing call for boreal conservation in Canada and the efforts of the mining industry to become more sustainable, it is necessary to explore the utility and limitations of using remotely sensed data and landscape metrics to monitor salient effects of industrial mineral extraction in a subarctic, boreal environment.

2.2 Study Area

The Pine Point mine site is located on the southern shore of Great Slave Lake in the Northwest Territories, just north of the boundary of Wood Buffalo National Park in the Boreal Plains Ecozone (Fig. 2.1). The average temperature in the region ranges from -22˚C in January to 16˚C in July and annual precipitation is approximately 336mm (Environment Canada 2010). The study site's elevation ranges from approximately 150m to approximately 300m, making topographic variability negligible for the purposes of this study. The dominant tree species in the area are black spruce (*Picea mariana*) and jack pine (*Pinus banksiana*), and the understory is characterized by shrubby cinquefoil (*Potentilla fruticosa*), reindeer lichen (*Cladonia* spp.), and feather moss (*Calliergon* spp.). Poplar (*Populus* spp.), white birch (*Betula papyrifera*), tamarack (*Larix laricina*), and alder (*Alnus* spp.) are also common in the region. Fire is the dominant natural disturbance regime in the area, although the anthropogenic effects of timber harvesting and mining in the boreal environment are becoming a disturbance regime in their own right.

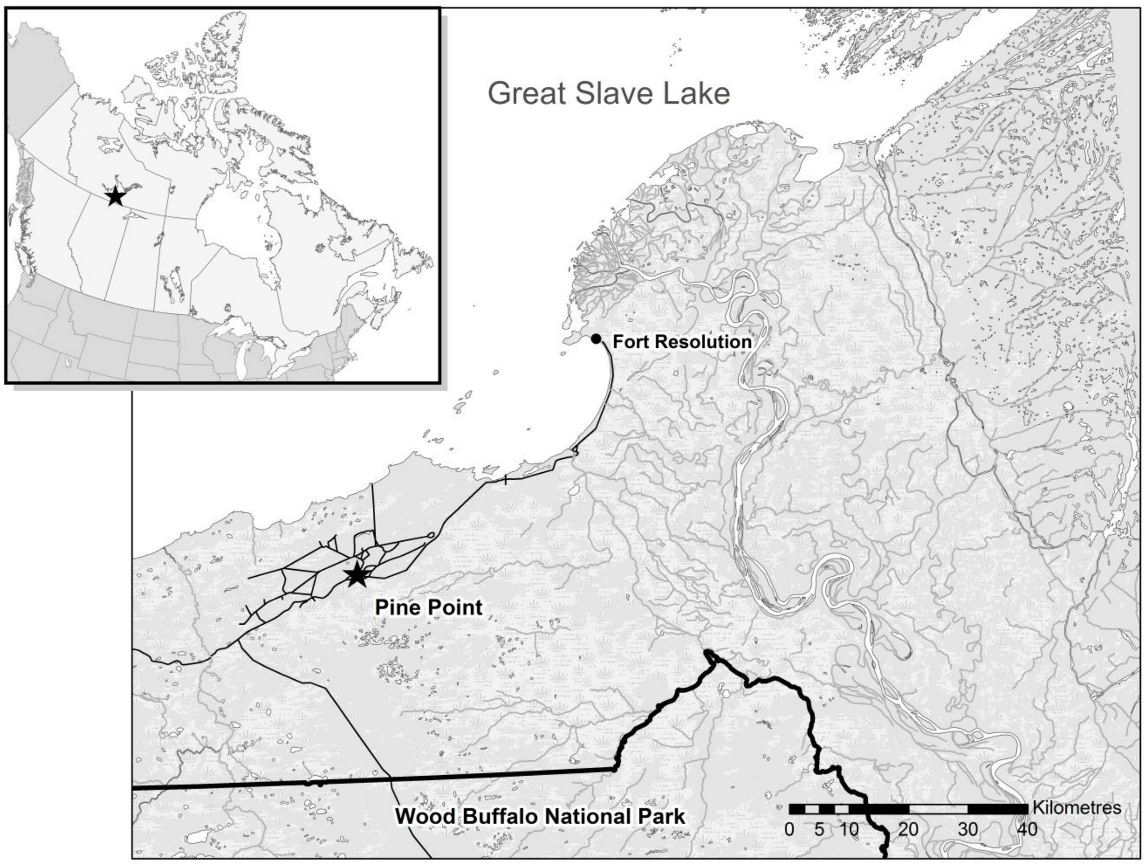

Figure 2. 1 Map of the study region showing the proximity of the Pine Point mine to Wood Buffalo National Park and Great Slave Lake. The star indicates the town site that was abandoned when the mine shut down in 1988. The thin black lines show the roads, including the network of haul roads and the highways. The thick black line is the northern boundary of Wood Buffalo National Park, and the dark grey lines represent waterways. Inset: Map of northern North America showing the location of Pine Point. Map created by Emma LeClerc

Pine Point was an extensive open pit mine that began operations in 1964 and was abandoned in 1988[2] when lead and zinc prices dropped below a profitable level (Kendall 1992). The town of the same name, built expressly to serve the mine, was home to approximately 2,000 residents at its height (Macpherson 1978; Sandlos and Keeling 2012; Sandlos 2015). When the

[2] Although closure and abandonment activities continued into the early 1990s, Pine Point halted milling operations in 1988 (Cominco Ltd. 1991).

mine shut down, 46 pits were left open, the town site was cleared of buildings, and berms or barricades were built to block access to the site (Sandlos and Keeling 2012). A pilot study was undertaken to investigate the viability of stabilizing the 570 hectare tailings pond using vegetation; however, the findings were bleak. Nutrient and moisture deficiencies as well as high concentrations of salt, lead, and zinc were all identified as factors that limited vegetation germination and growth. The sparse vegetation that did establish on the tailings accumulated lead and zinc in levels that were considered hazardous for foraging wildlife. The vegetation pilot study was ultimately deemed unsuccessful and attempts at revegetation were scrapped (Gardiner 1990).

Contemporary standards for mine reclamation are more comprehensive than historical reclamation standards. As documented in Pine Point's Reclamation and Abandonment Plan (Cominco Ltd. 1991), efforts were made to stabilize the site and minimize chemical pollution, but the ecological consequences associated with the mine's lasting footprint on the land were not addressed. Reclamation primarily addressing physical hazards was standard practice at the time; for example, while the revegetation pilot study was not a viable means of stabilizing the tailings, capping the pond with waste rock was considered sufficient. Indeed, the Chairman of the Northwest Territories Water Board, the regulatory body responsible for licensing industrial water use under the *Northern Inland Waters Act*, commended Cominco Ltd. on its reclamation efforts (Nickerson 1992). The mine was later featured as an exemplar of successful closure by Environment Canada (1996). While the reclamation efforts at Pine Point were deemed adequate by governing bodies at the time, they would be considered unsatisfactory by today's standards. Since the closure and decommissioning of the Pine Point mine, environmental policy and regulation in Canada have evolved to require somewhat more comprehensive closure procedures.

However, most of these regulations center on preventing pollution at current operations and fail to address the long-term environmental consequences of historical mines, including the Pine Point mine (MMSD 2002; Bridge 2004; Wenig et al. 2005).

In order to assess the long-term environmental effects of the Pine Point mine, we compared land cover change at the mine with land cover change at a comparison site located in Wood Buffalo National Park. The absence of industrial resource extraction and the close proximity to the mine site makes Wood Buffalo National Park an ideal location for the space-for-time substitution. We apply remote sensing and landscape metrics to determine whether land cover change near Pine Point differs from land cover change in an ecologically comparable area that never hosted industrial resource development. Wood Buffalo National Park is a UNESCO World Heritage Site located in northern Alberta and the southern part of the Northwest Territories. Established in 1922 to protect wood bison (*Bison bison athabascae*), today the park's mandate has expanded to protect whooping crane (*Grus americana*) and their nesting areas, within Parks Canada's broader goal of preserving natural and cultural heritage. At 44,807 square kilometers – just larger than Denmark – Wood Buffalo National Park is Canada's largest national park (Parks Canada 2010). The National Parks Policy stated in 1964 that industrial land uses (e.g. mine development, timber extraction[3]) are no longer permitted in national parks; and Aboriginal hunting and trapping rights in Wood Bufalo National Park are protected in accordance with Treaties 8 and 11 (Boyd 2003; Sandlos 2007; Parks Canada 2010; Will 2015).

[3] While timber extraction continued in WBNP until the early 1990s, the logging occurred in the Peace River Lowlands, well south of the comparison site delineated in this study (Timoney & Peterson 1996; Boyd 2003).

2.3 Materials and methods

2.3.1 Data and Processing

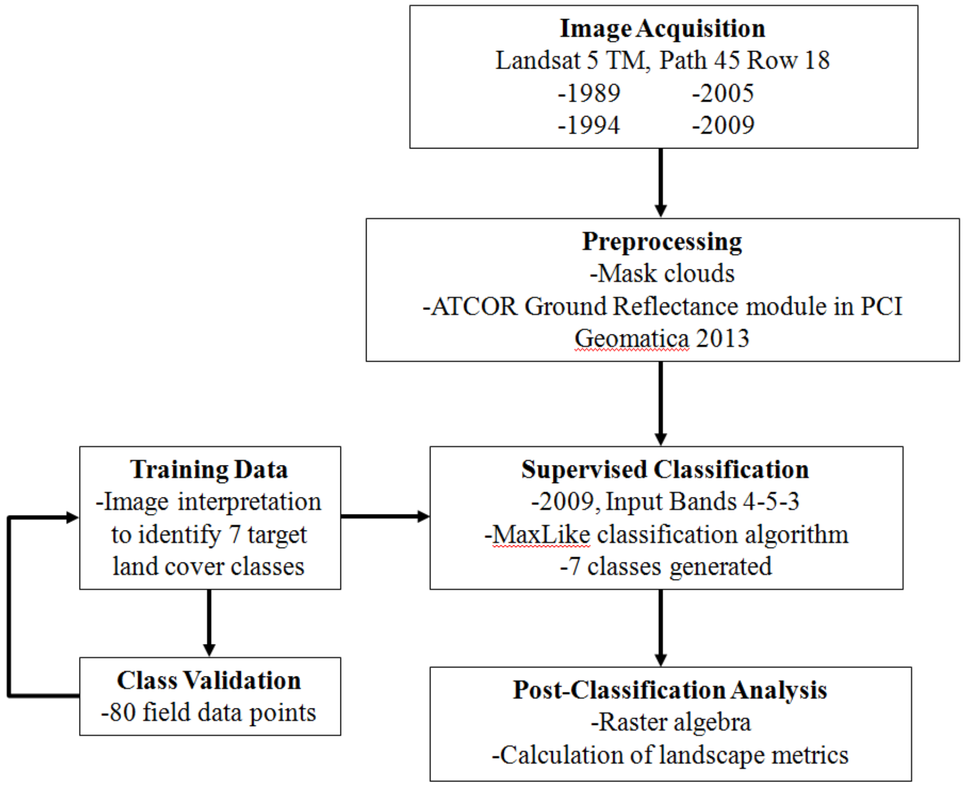

Figure 2. 2 Flowchart of principal steps in image processing and analysis

We used Landsat 5 Thematic Mapper (TM) data from 1989, 1994, 2005, and 2009 to document land cover change since the Pine Point mine shut down. The analysis was restricted to these four years due to cloud cover that obstructed the mine site in the rest of the available imagery; Figure 2.2 summarizes the principal steps in processing and analysis. Landsat TM images have a spatial resolution of 30m and are terrain corrected (level 1T) products. To ensure consistency across the time series, the co-registered images were verified visually prior to analysis. Regular, repeat coverage provides Landsat images that are archived; the United States Geological Survey (USGS) has made data in this archive freely available since 2009 (Woodcock et al. 2008). This makes Landsat products an affordable means for monitoring broad-scale land cover change and forest dynamics, especially in remote or inaccessible regions (Valeria et al. 2012; Ahmed et al. 2013; Czerwinski et al. 2014). A visual assessment of the data showed that major mining features (e.g. pits, roads) were visible, however finer resolution features (e.g. cutlines) were sometimes obscured. This limitation notwithstanding, the temporal depth offered by the Landsat archive made it the most appropriate dataset for this analysis.

The study region is located in Worldwide Reference System (WRS) path 45, row 18 of Landsat 5 TM. For the study period, there were four images with minimal cloud cover in the Landsat archive (Table 2.1). Larsen (1980) indicates that the growing season in boreal environments is from May to October. The selected images were all recorded in the late summer in order to minimize phenological variation and thus maximize the spectral stability of land cover types, as season is an important factor in the study of vegetation change detection (Miller et al. 1997; Beaubien et al. 1999; Coppin et al. 2004; Gillanders et al. 2008; Fichera et al. 2012; Ahmed et al. 2013). For this analysis, we chose a 4-5-3 band combination, representing the near infrared (NIR), mid-infrared (MIR), and red (R) bands of the electromagnetic spectrum. Beaubien et al. (1999) and Valeria, Laamrani, and Beaudoin (2012) recommend this band combination for research in boreal environments with many cover types. Gratto-Trevor (1996) indicates the utility of these bands for differentiating vegetation types, boundaries between land and water, and moisture content in soil and vegetation, making the bands particularly suitable for the characterization of land cover in the Pine Point region.

Table 2. 1 Landsat 5 TM Datasets, from USGS GloVis

Path/Row	Acquisition Date
45/18	10 July 1989
45/18	24 July 1994
45/18	23 August 2005
45/18	3 September 2009

Radiometric correction of the images was performed with the ATCOR model for absolute radiometric correction in PCI Geomatica 2013 (PCI Geomatics, Richmond Hill, ON). The correction established spectral consistency across the images by calibrating for sensor settings, atmospheric and illumination conditions, which served to minimize errors during the classification and comparison processes. This ensures that the change detected in land cover over time corresponds meaningfully to change in the spectral response patterns between pixels (Lillesand and Kiefer 1994; Jensen 2005; Gillanders et al. 2008). We then removed remaining visible clouds and cloud shadows; this masking was performed manually because the data were acquired before USGS began offering Landsat surface reflectance products that include a cloud mask. Once these data were available, we performed a post-hoc comparison which showed that the manual mask removed more than 90% of the cloud and cloud shadow identified in the cloud mask provided by Landsat.

In order to focus on mine-related land cover changes, we placed a series of buffers around the geographic features associated with the Pine Point mine (Fig. 2.3). Sanderson et al. (2002) developed a Global Human Footprint on the understanding that anthropogenic land uses have differential impacts on the surrounding ecosystem depending on the type of use. Woolmer et al. (2008) found that adapting the Global Human Footprint to account for locally available, finer resolution geospatial data improved the utility of the Human Footprint for regional conservation planning. Guided by the human influence scoring framework detailed in Woolmer et al. (2008), we placed a 5 km buffer around the open pits, a 1 km buffer around the major roads, and a 500 m buffer around the cutlines, the abandoned rail track, and the local trails. The open pits, roads, cutlines, abandoned rail, and trail datasets were all retrieved from GeoGratis, which is maintained by Natural Resources Canada. The series of buffers reflects the differential ecological impacts of each of the mine-related anthropogenic features and is easily replicable for future land cover change monitoring. By placing these buffers around mine-related features, we ensure that changes in land cover related to the mine are not subsumed by broader trends in land cover change. Additionally, in order to control for shape and edge effects when calculating landscape metrics, the same polygon was used to delineate the comparison site in the park. We compared the resultant land cover rasters to assess land cover change at Pine Point and the WBNP site through time.

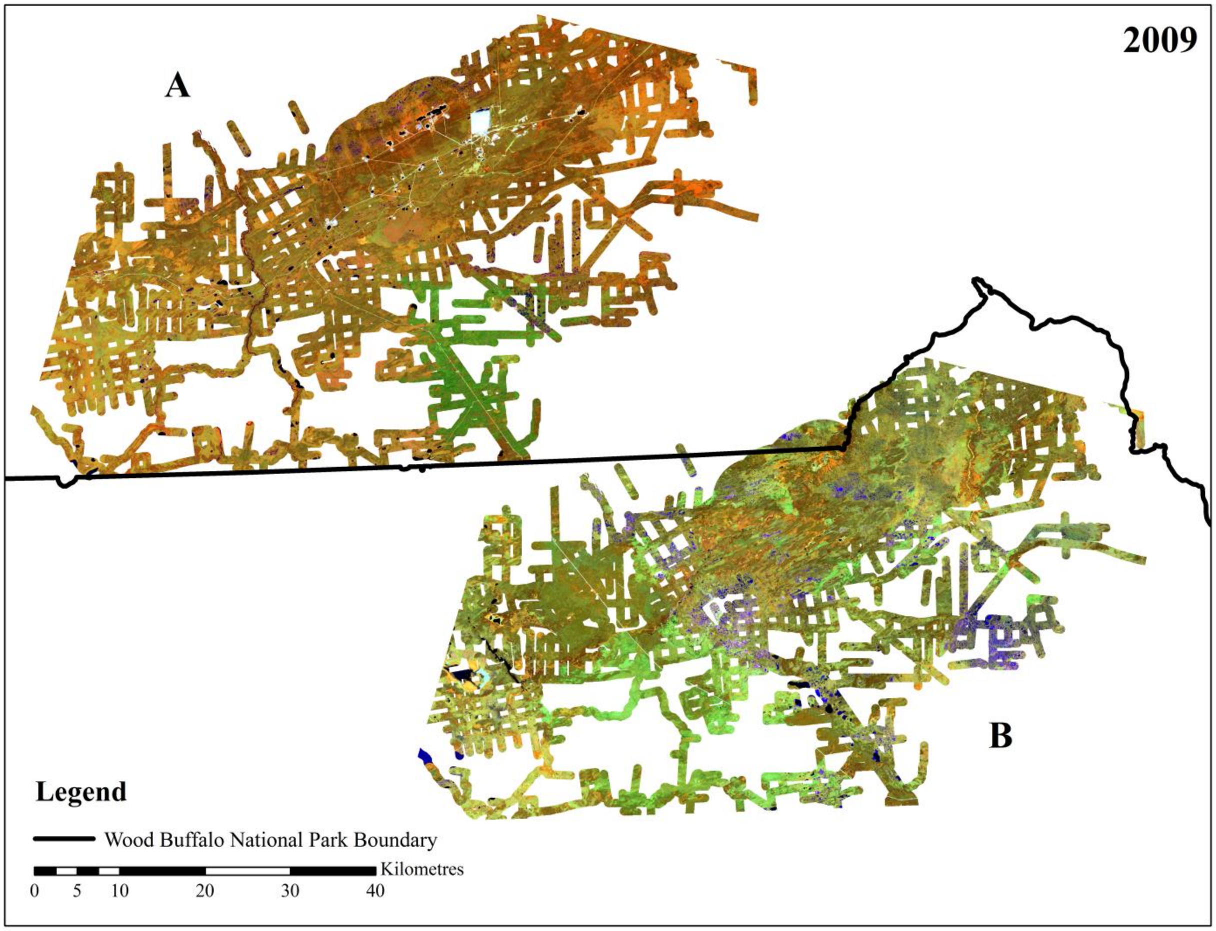

Figure 2. 3 Landsat 5 TM false colour composite (4-5-3) image of the Pine Point site (A) and comparison site (B); the northern boundary of Wood Buffalo National Park is represented in black

2.3.2 Analysis Methods

In order to document land cover change, we classified the satellite images into seven land cover types based on the spectral response pattern of each pixel in the satellite images. We performed a supervised classification to identify land cover in the study region. For each image, we selected training samples representing each of the target land cover classes and used the maximum likelihood classification algorithm in PCI Geomatica 2014 to generate mutually exclusive land cover categories for the four Landsat images. The land cover categories are: (1) water, (2) regenerating disturbance, (3) dense coniferous forest, (4) open coniferous forest, (5) meadow, (6) exposed/bare land, (7) background (Table 2.2). A qualitative, post hoc validation of the cover types was performed based on image interpretation and comparison with 80 ground-truth data points collected in July 2012. Historical fire data from the Canadian National Fire Database, made available by the Canadian Forest Service, were also considered in the validation.

Table 2. 2 Classification scheme with land cover classes and corresponding descriptions

Class	Description
Water	Lakes, rivers, and other water bodies
Regenerating disturbance	Former disturbances, e.g. burns, that have begun the process of revegetation; characterized by coarse woody debris, young jack pines, and fireweed
Dense coniferous forest	> 65% canopy density, dominated by black spruce
Open coniferous forest	< 65% canopy density, characterized by black spruce and jack pine
Meadow	Open, vegetated areas dominated by sedges, alder, and willow
Exposed/bare land	Bare rock or built features like roads, waste rock piles, etc.; extremely sparse vegetation
Background	Pixels with null values

We used raster algebra and landscape metrics to quantify land cover composition and configuration, using the image from 1989 as the common reference year to determine change since closure at the three subsequent points in time. Raster algebra in ArcGIS (v. 10.1, ESRI, Redlands, CA) allowed us to perform a pixel-by-pixel comparison of the land cover rasters and generate a map of change for each of the two study sites (Fig. 2.4). To complete the analysis, we used FRAGSTATS software version 4 (McGarigal et al. 2012) to calculate a series of metrics which quantify patterns in land cover composition and configuration (Table 2.3). The background was considered no data, the 8-neighbour rule was used, and the borders of the selected study sites were not considered edges for this analysis.

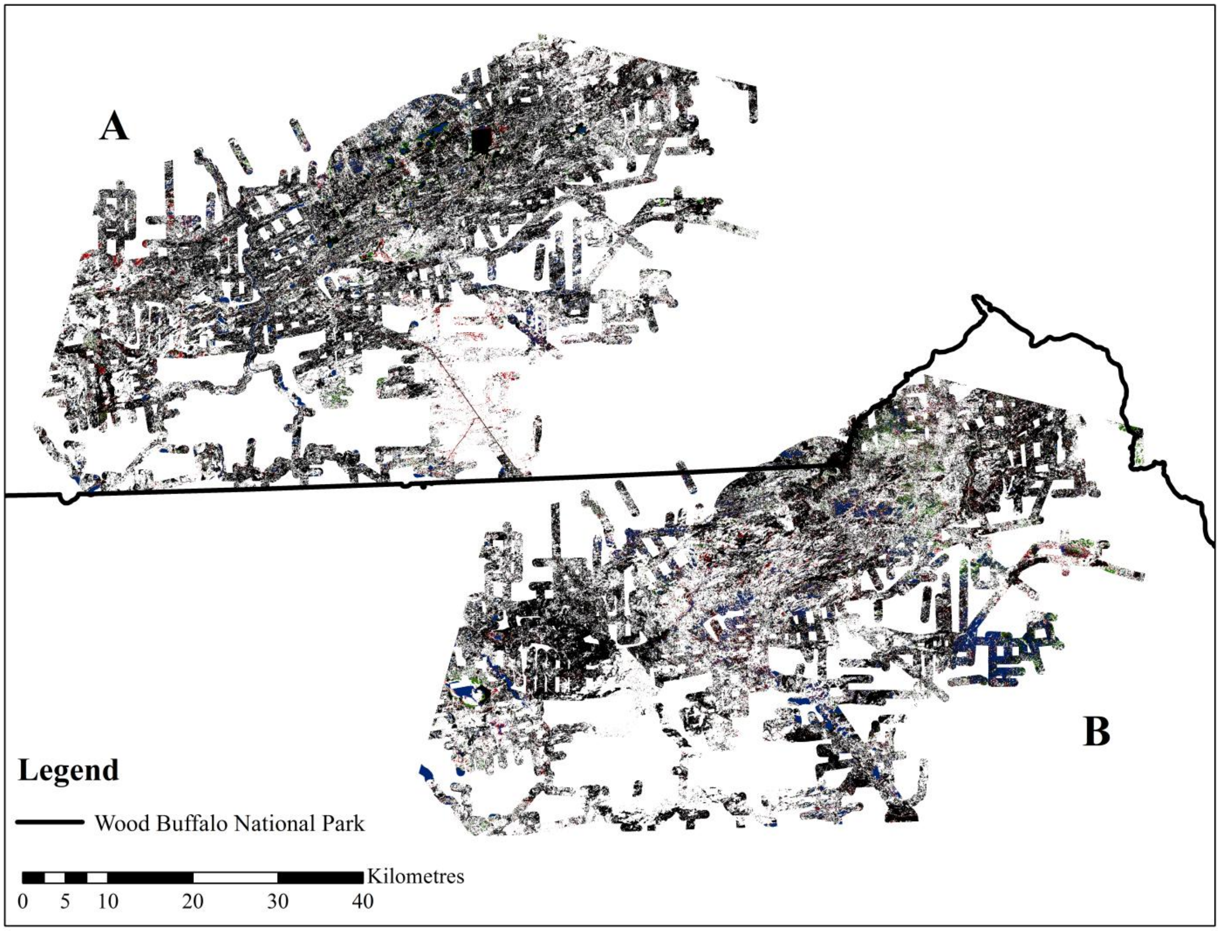

Figure 2. 4 Map showing no land cover change (black), change from vegetated to bare (red), change from bare to vegetated (green), and water (blue) between 1989 and 2009 at the Pine Point site (A) and the comparison site (B). The lack of clear spatial trends in land cover change reflects the dynamism of the boreal environment; the exception is the black spot at the Pine Point site (A), which shows that the tailings pond has not undergone land cover conversion in the twenty years since mine closure.

Guided by the principles for selecting meaningful metrics laid out by Cushman et al. (2008), we selected a suite of metrics that work in concert to quantify landscape structure at the Pine Point and Wood Buffalo National Park sites. Percentage of landscape (PLAND) provided a comparison the proportional abundance of each land cover type at the Pine Point site and the comparison site in Wood Buffalo National Park over the 20-year study period. Largest patch index (LPI) served as a measure of dominance for the cover types. We used mean patch area (AREA_MN) and number of patches (NP) to quantify the size and subdivision of patches in each land cover class. We used mean contiguity (CONTIG_MN) and percentage of like adjacencies (PLADJ) to measure the degree of aggregation in the land cover classes. Mean perimeter-area ratio (PARA_MN) indicates the complexity of patches for each land cover type. For landscape-level metrics, we calculated Simpson's diversity (SIDI) and Simpson's evenness (SIEI) to measure the relative diversity and dominance of each of the landscapes as a whole. Taken together, these metrics yield insight to the ecological processes occurring at each study site.

We expected the comparison site in Wood Buffalo National Park to exhibit large, aggregated patches of land cover and we expected the Pine Point site would be more fragmented, with a higher number of land cover patches and less aggregation. Due to the linear features associated with the mine (e.g., roads and cutlines), we expected the Pine Point landscape would display less patch complexity than the comparison site in Wood Buffalo National Park. At the Pine Point site, we expected the landscape to become less fragmented through time, with an increase in aggregation in the vegetation classes and a decrease in aggregation in the exposed ground class. We also expected patch complexity to increase at the Pine Point site through time, as revegetation starts to occur around the edges of the linear, anthropogenic features.

Table 2. 3 List of landscape metrics calculated using FRAGSTATS (v. 4, Amherst, MA; McGarigal et al. 2012)

Landscape Metric	**Abbreviation**	**Range**	**Units**	**Description**
Percentage of Landscape	PLAND	0 - 100	Percent (%)	Measures the proportional abundance of each land cover class
Largest Patch Index	LPI	0 - 100	Percent (%)	Percent of the landscape comprised by largest patch of each land cover class
Mean Patch Area	AREA_MN	0 - ∞	Hectares (ha)	Average area of patches in each land cover class
Number of Patches	NP	1 - ∞	n/a	Measures the extent of subdivision or fragmentation of each land cover class
Mean Contiguity	CONTIG_MN	0 – 1	n/a	Average spatial connectedness of patches in each land cover class; patches are increasingly contiguous as value approaches 1
Percentage of Like Adjacencies	PLADJ	0 - 100	Percent (%)	Measure of aggregation for each land cover class
Mean Perimeter-Area Ratio	PARA_MN	0 - ∞	n/a	Measure of patch complexity in each land cover class
Simpson's Diversity	SIDI	0 – 1	n/a	Measure of diversity; the probability that any two pixels will be different patch types
Simpson's Evenness	SIEI	0 – 1	n/a	Inverse measure of dominance

2.4 Results

2.4.1 Class-Level

The relative abundance of land cover types at Pine Point and the comparison site in Wood Buffalo National Park show notable differences over the 20-year study period (Fig. 2.5). At Pine Point, meadows and open conifer are the most abundant cover types. Regenerating vegetation decreased until 2005, after which it increased again due to a 2008 forest fire. Exposed ground remained approximately constant[4] over the 20-year study period. By contrast, dense conifer was considerably more abundant at the WBNP site than at Pine Point; dense conifer consistently comprised between 34 and 36% of the landscape. A slight increase in the abundance of regenerating vegetation in 2005 corresponds to a fire that occurred in the park in 2004. Open conifer increased between 1989 and 1994 then decreased, which corresponds to the increase in regenerating vegetation in 2005 after the 2004 fire.

Results from the largest patch index (LPI) also indicate that the dominant cover type at the Wood Buffalo National Park site is dense conifer (Fig. 2.6). Open conifer is dominant at the Pine Point site until 2009, when regenerating vegetation becomes the cover type with the largest patches. At Wood Buffalo National Park, there was a sharp increase in open conifer in 2005 and an increase in regenerating vegetation.

High mean patch area (AREA_MN) and standard deviation (AREA_SD) show that dense conifers occur in large patches in Wood Buffalo National Park, and that there is a lot of variability in the average size of dense conifer patches (Table 2.4). Dense conifer also showed a relatively low number of patches (NP). The average patch sizes for open conifers, regenerating

[4] The 2005 image had a considerable amount of haze, likely due to smoke from a forest fire. While we masked out as much as possible, the spike in the exposed land cover type is a result of high albedo from the haze rather than changes on the ground.

vegetation, and exposed land in the park are considerably lower and exhibit much less variability than dense conifer. Patches of regenerating vegetation in the park became larger overall and the number of patches decreased over the 20 year study period. Mean patch size and number of patches exhibited minor fluctuations in the open conifer class. At the Pine Point site, there was little fluctuation in mean patch size and relatively stable number of patches in both conifer classes. For exposed ground, the mean patch area decreased and the number of patches increased (Fig. 2.7).

At Pine Point, the mean contiguity and percentage of like adjacencies of exposed land both showed a distinct downward trend, indicating that patches became more disaggregated in the 20 years following mine closure. Regenerating vegetation also showed an overall downward trend in mean contiguity. The percentage of like adjacencies for regenerating vegetation decreased until 2005 and increased sharply by 2009, which showed large, contiguous patches of regenerating vegetation. The mean contiguity of open conifer remained fairly constant over the study period; this class also had the highest values for percentage of like adjacencies and a low range.

At Wood Buffalo National Park, the mean contiguity and percentage of like adjacencies of exposed ground also both showed a downward trend. The mean contiguity of open conifer remained fairly constant, and percentage of like adjacencies showed a slight downward trend. Mean contiguity of dense conifer decreased slightly and the percentage of like adjacencies was high with a fairly narrow range of values. The percentage of like adjacencies in regenerating vegetation increased sharply in 2005 before slowly decreasing again (Table 2.5, Fig. 2.8).

At Pine Point, the perimeter-area ratios of regenerating vegetation and exposed land both show an upward trend, indicating increasingly complex patch shapes. The mean perimeter-area ratio of open conifers remains fairly constant over the study period, and that of dense conifers shows a slight increase until 2005, followed by a slight decrease. At Wood Buffalo National Park, the perimeter-area ratio of exposed land showed a distinct upward trend, indicating patches became more complex. Regenerating vegetation and dense conifers both showed a slight upward trend, and regenerating vegetation varied slightly between downward and upward trends (Table 2.6).

Table 2. 4 Mean patch area (ha) with standard deviations; precision is listed to the nearest tenth because one 30 x 30 m pixel in the Landsat imagery equals 0.09 ha

		1989		1994		2005		2009	
Cover type	Site	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Regenerating vegetation	PP	0.7	6.3	0.5	2.4	0.2	0.7	0.9	54.6
	WBNP	0.6	7.9	0.5	3.9	1.8	46.2	1.3	24.7
Dense conifer	PP	1.9	21.5	1.5	16.8	2.1	30.9	2.2	37.6
	WBNP	4.2	104.3	3.6	103.1	5.8	156.3	4.2	120.3
Open conifer	PP	2.8	58.2	3.2	64.9	4.0	94.7	2.5	45.2
	WBNP	1.1	13.1	1.8	24.9	1.5	50.4	1.3	25.1
Bare	PP	1.2	41.1	1.0	45.9	0.5	14.8	0.5	24.1
	WBNP	1.0	22.5	0.6	6.0	0.8	12.5	0.4	3.5

Table 2. 5 Mean contiguity with standard deviations; precision is listed to the nearest thousandth because the measure of contiguity is not constrained by pixel size

		1989		1994		2005		2009	
Cover type	Site	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Regenerating vegetation	PP	0.135	0.179	0.127	0.171	0.072	0.123	0.078	0.136
	WBNP	0.130	0.169	0.130	0.171	0.113	0.173	0.117	0.182
Dense conifer	PP	0.201	0.219	0.184	0.210	0.169	0.204	0.188	0.212
	WBNP	0.193	0.219	0.184	0.212	0.180	0.217	0.178	0.215
Open conifer	PP	0.166	0.203	0.176	0.206	0.165	0.201	0.170	0.203
	WBNP	0.165	0.193	0.181	0.200	0.171	0.196	0.172	0.196
Bare	PP	0.180	0.195	0.150	0.179	0.114	0.157	0.093	0.146
	WBNP	0.165	0.185	0.138	0.170	0.125	0.167	0.101	0.146

Table 2. 6 Mean perimeter-area ratio with standard deviations; precision is listed to the nearest thousandth because the measure of perimeter-area ratio is not constrained by pixel size

		1989		1994		2005		2009	
Cover type	Site	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Regenerating vegetation	PP	1131.133	267.711	1141.724	257.486	1222.222	195.350	1216.302	210.908
	WBNP	1138.414	255.445	1136.269	258.986	1162.723	257.915	1157.789	269.543
Dense conifer	PP	1030.326	318.666	1057.150	307.506	1077.919	298.234	1049.349	309.687
	WBNP	1043.459	318.189	1056.950	309.631	1062.398	315.166	1065.793	312.650
Open conifer	PP	1082.921	297.731	1067.889	302.444	1084.909	294.824	1077.017	296.979
	WBNP	1084.881	285.867	1061.806	294.822	1076.472	289.354	1074.739	288.671
Bare	PP	1061.488	289.592	1107.078	269.659	1160.403	239.942	1192.346	224.637
	WBNP	1082.876	276.376	1125.457	257.502	1146.122	251.277	1180.879	225.228

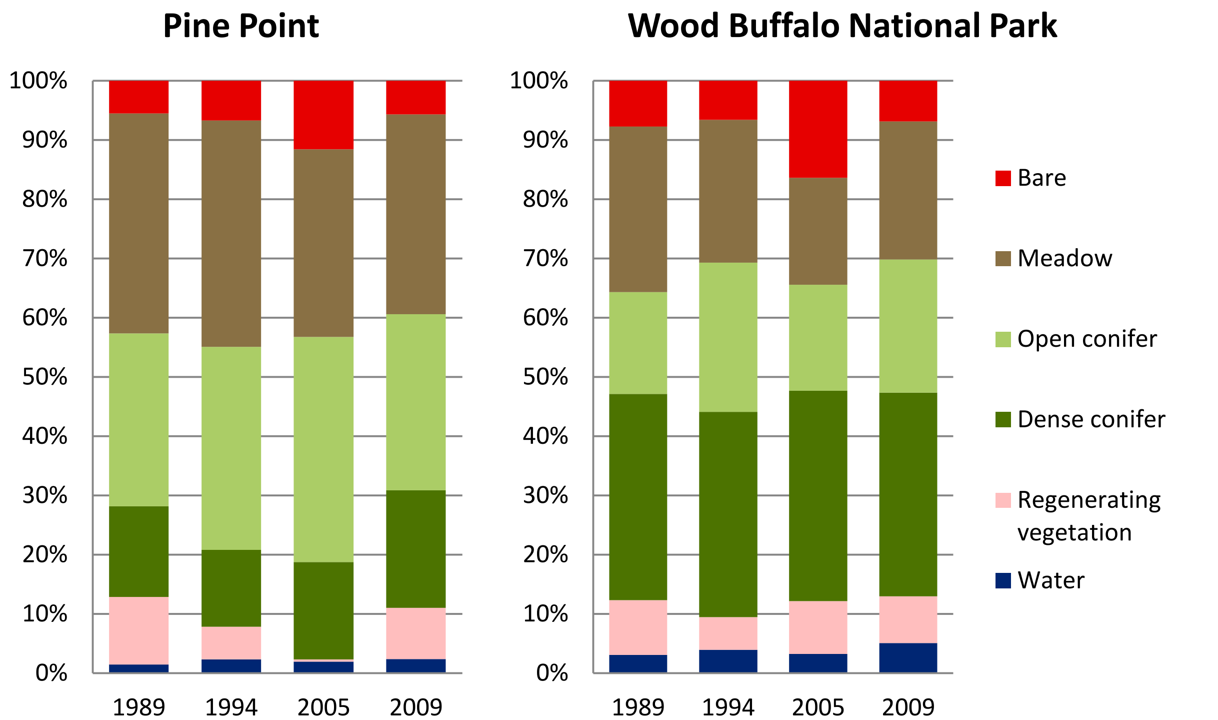

Figure 2. 5 Percentage of landscape (%) showing the proportional abundance of land cover types at the Pine Point and Wood Buffalo National Park study sites

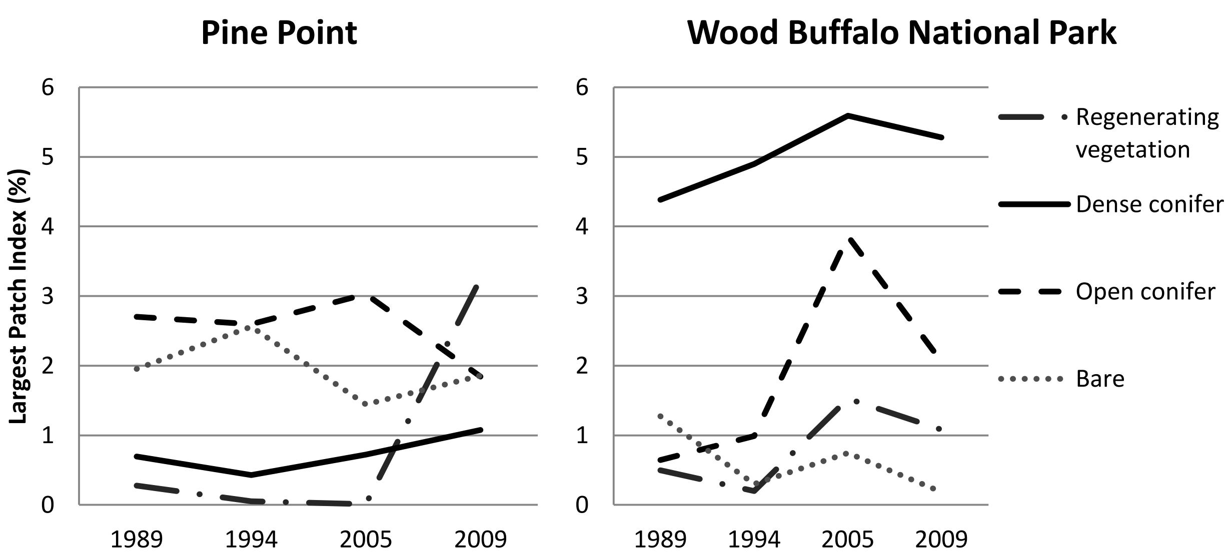

Figure 2. 6 Largest patch index showing the dominance of land cover types at the study sites. At Pine Point, there is no clear dominant cover type, but regenerating vegetation increases following a 2008 forest fire. Dense conifer is the dominant cover type in Wood Buffalo National Park during the study period. Exposed land is less dominant in the park than at Pine Point

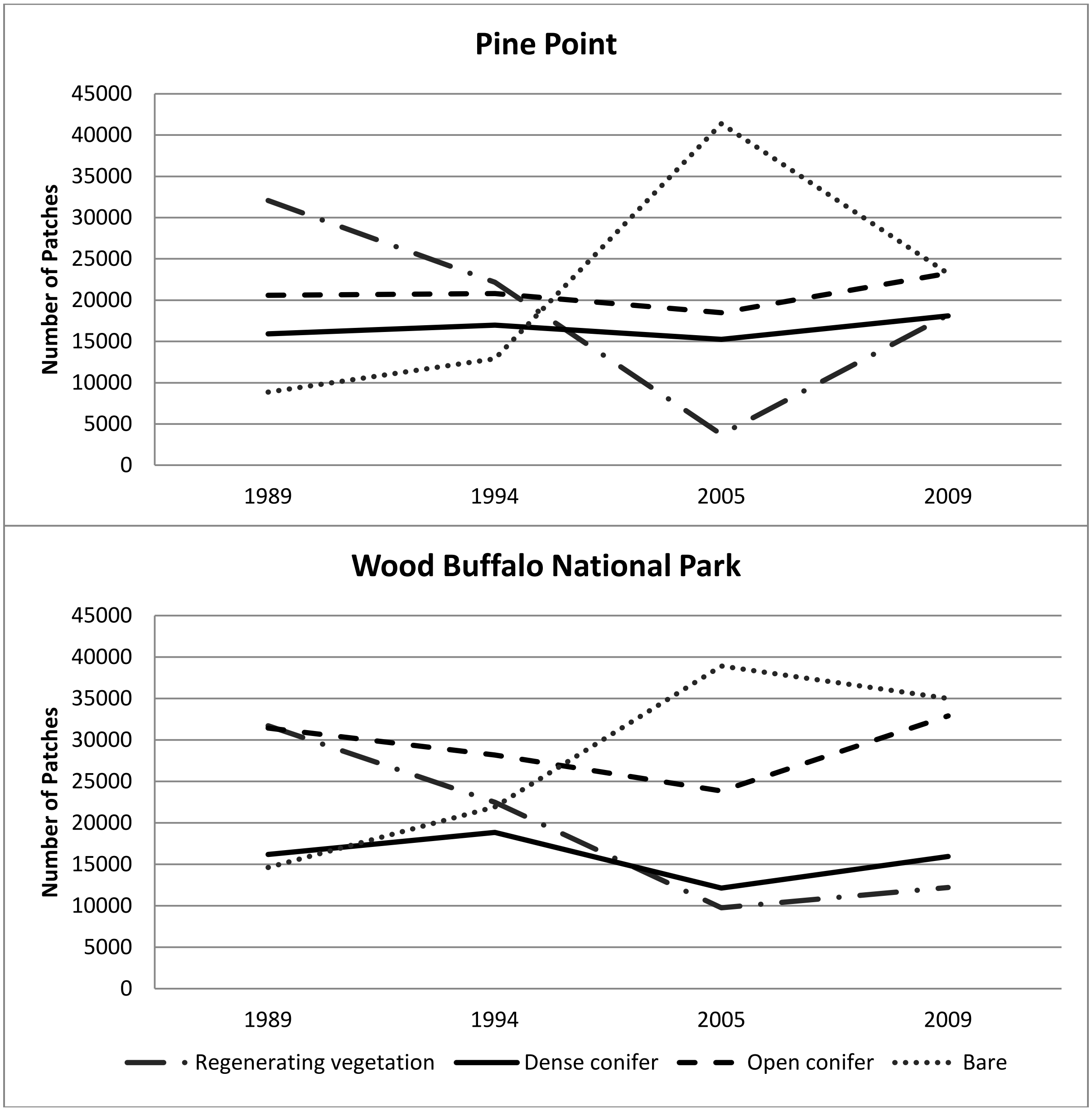

Figure 2. 7 Number of patches showing fewer patches of dense conifer in Wood Buffalo National Park compared to Pine Point

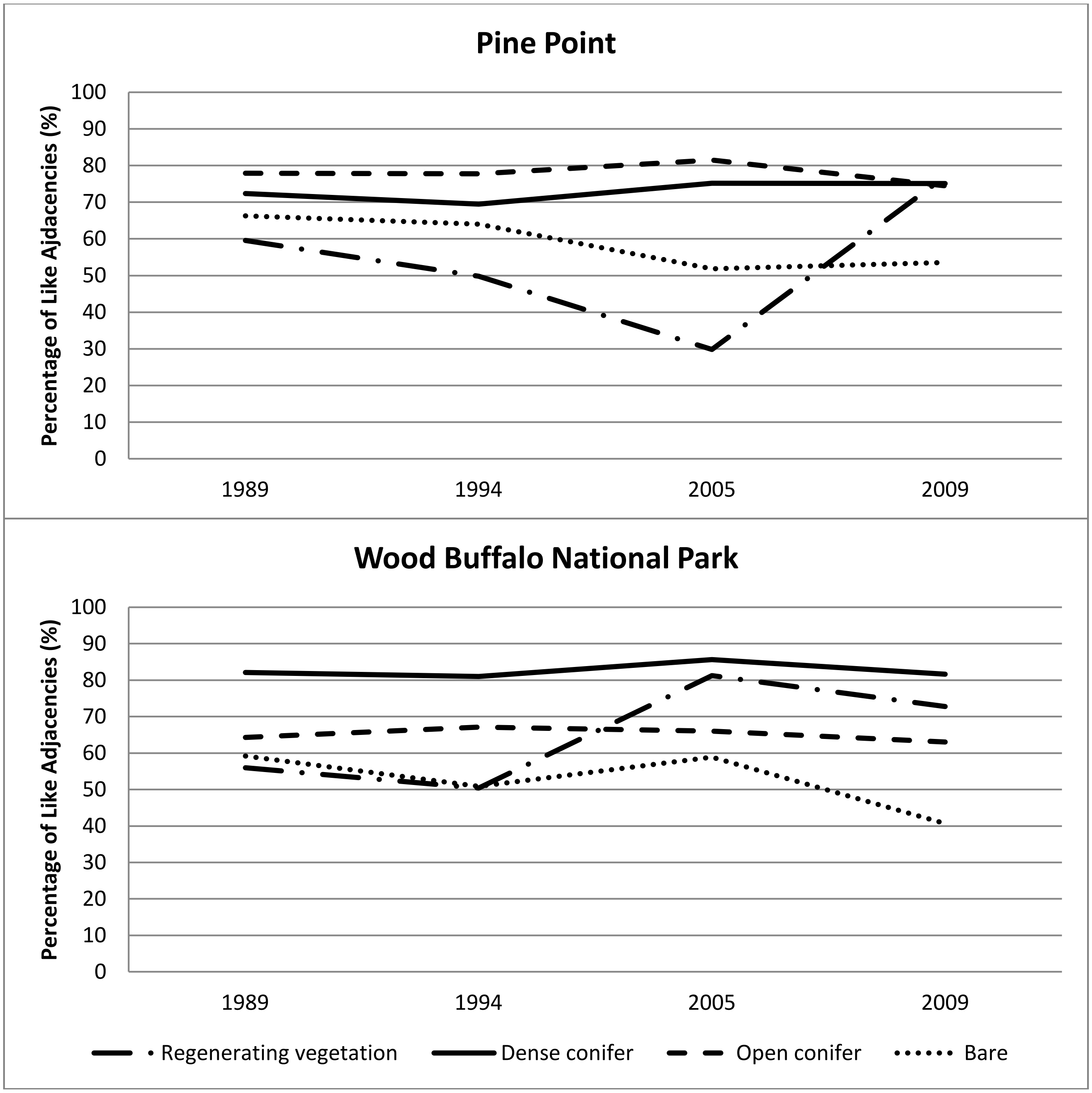

Figure 2. 8 Percentage of like adjacencies showing aggregated conifer classes and increasingly disaggregated bare land

2.4.2 Landscape-Level

At Pine Point, Simpson's diversity decreased in 1994 and 2005, then increased dramatically in 2009. This indicates that the landscape became less diverse for a time, then more diverse by 2009. At Wood Buffalo National Park, Simpson's diversity decreased slightly, then increased in 2005, then decreased slightly in 2009. The values for Simpson's evenness exhibited a very similar pattern to the values of Simpson's diversity, indicating more dominance and less evenly dispersed land cover classes at the Pine Point site than the park site (Fig. 2.9).

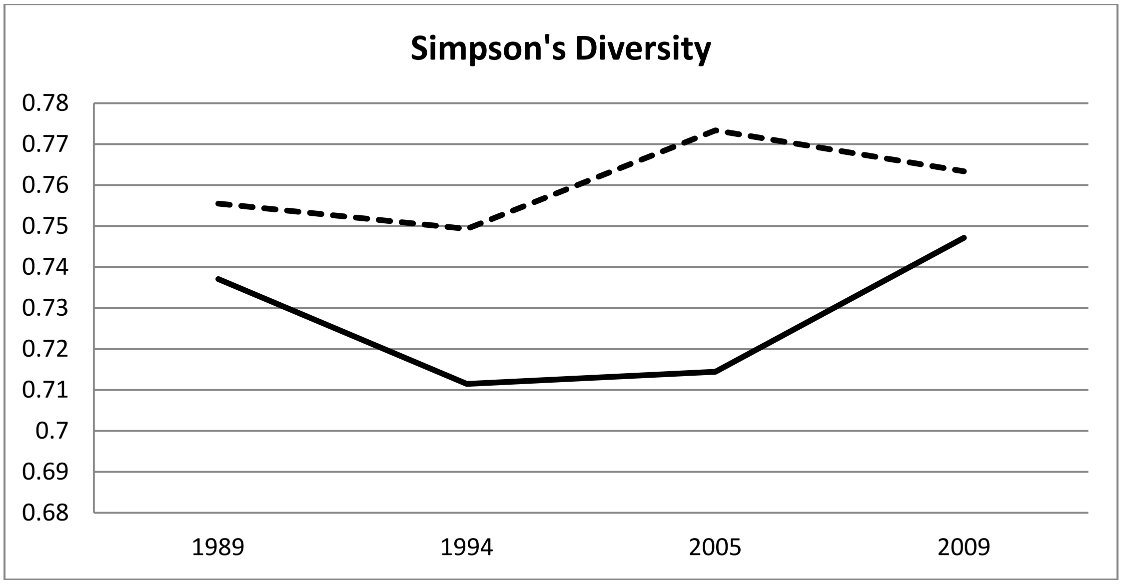

Figure 2. 9 Simpson's diversity index (SIDI) showing that the study site in Wood Buffalo National Park is a more heterogeneous landscape than its post-industrial counterpart

2.5 Discussion

2.5.1 Interpretation of metrics

While we expected that the land cover composition and configuration at the Pine Point site would become more similar to the comparison site in Wood Buffalo National Park through time, our analysis shows that, 20 years after mine closure, the Pine Point site is still considerably different from the park site. At the Pine Point site, the downward trend in the proportional abundance of regenerating vegetation corresponded with an upward trend in open conifer, indicating that regenerating vegetation was converting to open conifer until the 2008 fire. The overall slight increase in the abundance of dense conifer likely indicates that some open conifer was converting to dense conifer. The relatively constant proportion of exposed land suggests that little vegetation conversion occurred at the mine site itself (Fig. 2.10). At the park site, dense conifer was considerably more abundant than at Pine Point. Both study sites underwent changes in land cover composition indicative of fire activity, specifically an increase in regenerating vegetation after a 2004 fire in Wood Buffalo National Park and a 2008 fire closer to the Pine Point mine. However, the site in Wood Buffalo National Park is characterized by consistently abundant dense conifers, while Pine Point is characterized by open conifers and meadows.

In Wood Buffalo National Park, dense conifer is clearly the dominant cover type. At Pine Point, the overall differences in largest patches among the land cover classes were smaller, indicating less dominance by a particular cover type than at the park site. While the proportional abundance of exposed land was comparable for Pine Point and Wood Buffalo National Park, the largest patch index indicates that bare land is a more dominant cover type at the mined landscape than in the park. At Pine Point, the spike in large patch sizes of regenerating vegetation in 2009 was caused by the 2008 fire near the mine site. At Wood Buffalo National Park, the sharp increase in open conifer in 2005 coupled with an increase in regenerating vegetation indicates that the 2004 fire reduced the size of some dense conifer patches.

Little fluctuation in mean patch size and a relatively stable number of patches indicates that fragmentation at the Pine Point site remained constant for both conifer classes in the 20 years following closure. For exposed ground, the mean patch area decreased and the number of patches increased. This means that bare land is becoming more fragmented, possibly as a result of conversion to vegetation at the mine site. Patches of regenerating vegetation in the park became larger overall and the number of patches decreased, indicating that this cover type became less fragmented over the 20 year study period. The high mean patch area and relatively low number patches show that dense conifers are less fragmented than the other cover types in the park.

At Pine Point, the distinct downward trend in mean contiguity and percentage of like adjacencies of exposed land indicates that patches became more disaggregated through time as vegetation conversion started to occur at some parts of the mine site. The overall downward trend in mean contiguity of regenerating vegetation is indicative of vegetation conversion. The sharp increase in percentage of like adjacencies for regenerating vegetation in 2009 is likely the result of a 2008 fire which created large, contiguous patches of regenerating vegetation. The high values for percentage of like adjacencies and low variability in mean contiguity indicate that open conifer remained consistently aggregated over the 20 year study period.

Mean contiguity and percentage of like adjacencies for exposed land likely decreased through time due to the slight seasonal gradient of the four images. The slight downward trend in percentage of like adjacencies of open conifer shows that this cover type gradually became less aggregated. The values for mean contiguity and percentage of like adjacencies for dense conifers in the park indicate a consistently aggregated cover type. The sharp increase in 2005 of percentage of like adjacencies for regenerating vegetation was likely the result of larger, contiguous patches created by the 2004 fire, and the subsequent decrease is consistent with what we would expect to see as vegetation conversion occurred.

At Pine Point, the perimeter-area ratios of regenerating vegetation and exposed land both show and upward trend, indicating increasingly complex patch shapes that could be the result of vegetation conversion at the mine site. Finally, the results from Simpson’s diversity and Simpson’s evenness indicate that the site in Wood Buffalo National Park is a more heterogeneous landscape than the Pine Point site.

In summary, the park site is dominated by large, contiguous patches of dense conifer and subject to the fragmentation and vegetation conversion typical of fire disturbances. By contrast, the Pine Point site is comprised of smaller patches of vegetation with overall much less dense conifer. The post-industrial landscape differs from the ‘natural’ control in that it exhibits less fragmentation in the conifer classes than the park site. There is some land cover conversion at the Pine Point mine, evidenced by the increasingly disaggregated exposed land cover class and the change from exposed to vegetated land, but the stability of the proportional abundance of exposed land indicates that this conversion is happening very slowly. There is very little conversion of exposed mine land to vegetation, mostly occurring at the edges of mine features (Fig. 10). While subject to a similar fire disturbance regime as the park site, the Pine Point site is overall less heterogeneous and dynamic at this scale. In the absence of industrial mineral development, the Pine Point site might have been dominated by large, contiguous patches of dense conifer and a higher degree of fragmentation, similar to the park site. It is clear that the passive reclamation strategy adopted at Pine Point has effected little vegetation conversion at the mine site in the 20 years since closure (Fig. 2.10).

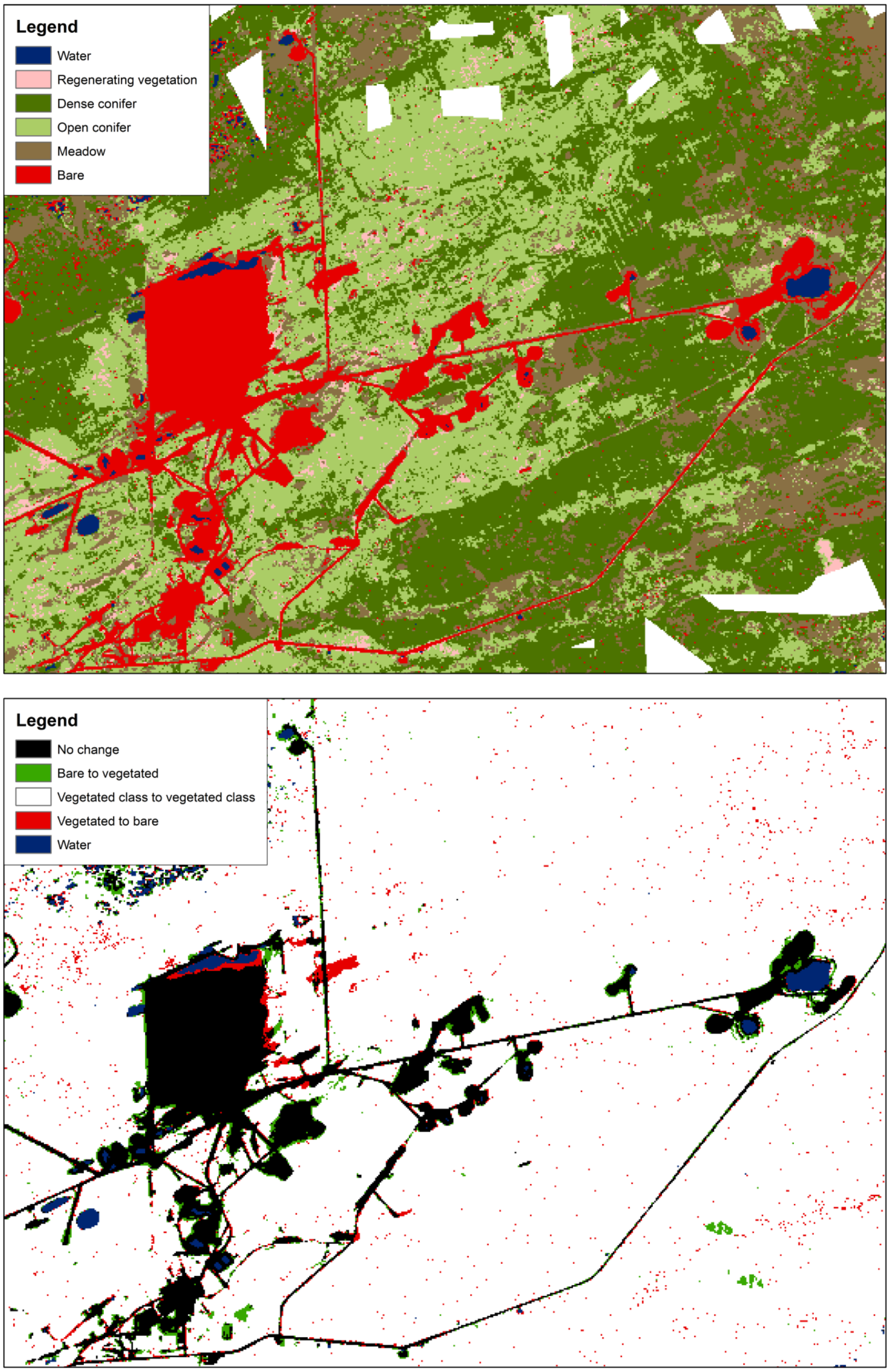

Figure 2. 10 (a) Close-up of part of the Pine Point mine showing land cover in 2009. Some cutlines are visible as linear patches of dense and open conifer, but many that were visible in the field are too fine to be detected with 30 m Landsat data; (b) Close-up of part of the Pine Point mine showing changes in land cover between 1989 and 2009. Some conversion to vegetation is occurring around the edges of the pits and roads, but most of the mine site has remained exposed over the 20-year study period

2.5.2 Monitoring reclamation at abandoned mines

By combining remote sensing and landscape metrics, we were able to track broad land cover changes at the abandoned Pine Point mine. However, this type of monitoring has noteworthy shortcomings. Some of these shortcomings, like spatial and temporal resolution of remote sensing datasets, can be addressed. However others, like the launch date of satellites, are inherent constraints that limit the application of remote sensing and landscape metrics at historical mine sites.

Due to its history of intensive industrial extraction and poor reclamation, we expected patches at the Pine Point site to exhibit less complexity (lower perimeter-area ratio) in the open conifer and exposed land classes than at the park site, however this was not the case. It is possible that the 30m spatial resolution of the imagery was insufficient to observe less complex patches of vegetation (e.g., cutlines less than 30m wide). This is a technical limitation of using Landsat TM data to monitor land cover change at abandoned mine sites. Because the spectral response pattern of each pixel is comprised of the average reflectance of land cover within that pixel (Bhatta 2008; Chen et al. 2004), the spectral response pattern from each pixel— and consequently the reliability of the supervised classification— is dependent on the resolution of the satellite image. With the 30m spatial resolution of Landsat TM images, it is possible that land cover change occurring at a finer resolution was not detected. Indeed, while many cutlines were observed on the ground during the 2012 field season, relatively few are visible on the 2009 image.

Long-term monitoring of land cover dynamics at abandoned mines would benefit from affordable, high-resolution satellite imagery. Given that the USGS provides a freely accessible data archive which offers repeat coverage of the study region, Landsat TM data were the best option for this study. Indeed, Landsat has often been used to study land cover change at mine sites (e.g. Schmidt and Glaesser 1998; Antwi et al. 2008; Gillanders et al. 2008; Townsend et al. 2009; Li et al. 2012). At Pine Point, the Landsat product allowed us to document overall trends in land cover composition and configuration. However, some ecological processes occurring at Pine Point at fine scales were likely obscured by the coarse grain size.

Landscape metrics are also susceptible to scale effects (Lausch and Herzog 2002; Wu et al. 2002; Li and Wu 2004). At Pine Point, linear features like roads and cutlines are present but not always discernible with imagery that has a 30m grain size. While less important for analyses of landscape composition, this missing information is crucial for understanding how and where land cover conversion happens after passive reclamation. For example, a cutline that is 12m wide may show up in 30m imagery as individual pixels in a stepladder pattern but not necessarily contiguous, while with finer grained imagery we might be able to detect the same cutline as a narrow, contiguous patch of land cover that is less complex than its surroundings. The overall measure of composition may not change much, but the configuration would be meaningfully different. In effect, valuable information about landscape pattern is obscured by broader-scale trends in land cover due to image resolution. Because metrics are dependent on the resolution of the imagery from which they are derived, the resolution must be sufficiently fine to quantify patterns relevant to the process of reclamation on post-industrial landscapes.

As is often the case with satellite-derived data in remote locations, collecting ground-truth data to validate the land cover classes is time-consuming, costly, and limited by road access (Ferguson 1991; Foody 2002; Franklin et al. 2003; Barnett et al. 2004). In this study, each validation point collected for this study was collected within 200m of a road. In addition, the GPS ground-truth data were collected during the 2012 field season and as such can only inform the land cover classification of the most recent satellite image, which was recorded three years beforehand. Contemporaneous validation of the historical images was not possible, and we relied on image interpretation to inform the supervised classification. Finally, the study was also limited by coarse temporal resolution, as there were few cloud-free, near-anniversary images of study area.

DeFries et al. (2007) have stated that imagery cost is a barrier to monitoring deforestation, and Turner et al. (2015) call for improved access to affordable, high-resolution remotely sensed data to inform conservation strategies. The same need exists for monitoring post-industrial landscapes. Remotely sensed data have the potential to be a cost-effective means for local communities to monitor nearby industrial developments, both during operations and after closure, but consequential barriers remain. There are many active satellites in orbit, often with multiple sensors per satellite. Of these, only some are built for Earth observation and few are available at no cost (see the ITC database of satellites and sensors). Local communities and land managers may be reluctant to allocate limited funds to expensive imagery and the specialized software required to process the data and generate a useful product. The application of remote sensing and landscape metrics to monitoring mine reclamation requires careful consideration of the geographic coverage, spatial resolution, temporal resolution, and historical depth of free satellite imagery in order to be certain that the patterns reflecting ecological processes at work are discernible in the remotely sensed dataset.

2.6 Conclusions

At Pine Point, it is clear that the industrial development of the mine and the lack of active reclamation after its abandonment altered the land cover composition and configuration in the area. While there appears to be some vegetation conversion happening at the edges of the mine site, the slow rate of this conversion indicates that passive reclamation has so far been insufficient to restore ecological function at the site. The degraded environmental state of this post-industrial site is keenly felt by land users from the nearby community of Fort Resolution (Sandlos and Keeling 2012; LeClerc and Keeling 2015). The results from the comparison site in Wood Buffalo National Park suggest that the Pine Point site might have been dominated by large, contiguous patches of dense conifer and a higher degree of fragmentation had the mine not been developed.

We have shown that it is possible to trace overall trends in the composition and configuration of land cover on post-industrial landscapes using 30 m satellite imagery. We posit that monitoring the legacy effects of historical mines in northern Canada would be improved by better access to affordable, high-resolution imagery. Satellite remote sensing and landscape metrics are unquestionably valuable tools for environmental monitoring. Although broad- or medium-scale products like Landsat TM data are immensely useful for tracking broad-scale forest changes (Wulder 2008), these datasets are not necessarily adequate for monitoring the legacy effects of abandoned mines because some ecological processes are taking place at a scale finer than the scale of observation available from such imagery. Landscape metrics are influenced by scale effects and resolution (Lausch and Herzog 2002; Li and Wu 2004); in this case, we expected to see simpler patch shapes at the mine site. We hypothesize that the 30m resolution of Landsat imagery is insufficiently fine to detect simplicity in patches when features of interest (e.g. cutlines) are often only a pixel or two wide. Satellite remote sensing is potentially a powerful means of monitoring mine reclamation, however the land cover dynamics at abandoned mined sites might be operating at scales that remain inaccessible with 30m Landsat data.

While certain obstacles to using remote sensing for monitoring historical mines will always exist due to the limited temporal depth of satellite technology, remote sensing is well-suited for monitoring the closure and reclamation success of mines currently in operation. However, the issues of affordability and access still pose significant challenges. Land managers or local communities interested in monitoring the reclamation progress of abandoned mines must weigh the relative importance of spatial resolution, temporal resolution, historical depth, and cost of imagery before land cover can be classified and landscape metrics calculated. The effective monitoring of long-term land cover change on post-industrial landscapes requires an improvement in the accessibility and affordability of high-resolution time series data sets.

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CHAPTER 3

From cutlines to traplines: post-industrial land use at the Pine Point mine

Industrial mineral extraction in Northern Canada has had lasting, transformative effects on landscapes and land-based economies. This paper examines post-industrial hunting and trapping at the former Pine Point mine, Northwest Territories, to clarify the effects of environmental and socioeconomic change on land use in the nearby, predominantly Aboriginal, community of Fort Resolution. Pine Point was an extensive open pit mine where failed attempts at remediation have resulted in a landscape that remains drastically altered 25 years after closure. Although the mine employed few individuals from Fort Resolution, the introduction of industrial mineral extraction in the region coincided with a transition from a primarily land-based economy to a mixed economy heavily reliant on wage labour. Map-based interviews with local land users documented ongoing, contemporary interactions between land users and the abandoned Pine Point mine which demonstrate that some of the physical and socioeconomic transformations associated with industrial development continue to shape land use in the Pine Point region. From maintaining a reliance on the mixed economy to appropriating the post-mining landscape in ways that benefit hunting and trapping, land users from Fort Resolution continue to be influenced by the Pine Point mine long after its abandonment.

Keywords: post-industrial land use; post-industrial landscape; abandoned mine legacies; Aboriginal mixed economy

3.1 Introduction

Industrial resource extraction introduces profound changes to local economies and landscapes, which often persist long after extractive operations cease. Globally, the impact of “legacy mine lands”, including abandoned mines, on local environments and communities is identified as a critical challenge for environmental sustainability the mining industry (Veiga *et al.*, 2001; MMSD, 2002a; Worrall *et al.*, 2009; Sandlos and Keeling, 2013). In places that have hosted large-scale industrial developments, ecological and landscape changes may be observable for decades or longer (Francaviglia, 1991; Hilson, 2002; Bridge, 2004). This is especially true in northern regions, where natural revegetation is slow even under optimal circumstances (Marshall, 1982; Harper and Kershaw, 1996; Johnstone and Kokelj, 2008; Deshaies *et al.*, 2009). The lasting environmental effects of mineral extraction are compounded by the socioeconomic changes that can occur at various points in a mine’s life cycle, including mine closure itself

(Kendall, 1992; Gagnon, 1992; MMSD, 2002b; Laurence, 2006; Bridge, 2004; Keenan *et al.*, 2007). For indigenous communities around the world, whose livelihoods and cultural practices are often tied closely to the local environment, these long-lasting environmental effects may be particularly devastating (Howitt, 2001; Ali, 2003; Ballard and Banks, 2003; Kirsch, 2006; Halvaksz, 2008; Keeling and Sandlos, 2009). In this study, we examine post-industrial land use at the abandoned Pine Point mine in Canada's Northwest Territories to broaden understanding of how the environmental and socioeconomic legacies of mining are manifested in nearby indigenous communities, long after closure.

We examine this complex interplay between extractive development, indigenous land use, and deindustrialization through the lens of a "micropolitical ecology" (Horowitz, 2010; Horowitz, 2011) of land use change. The literature on the political ecology of extractive development focuses on resource conflicts and environmental impacts on indigenous peoples' traditional territories (Bebbington *et al.*, 2008; Keeling and Sandlos, 2009; Bebbington, 2012). Indigenous encounters with development may be characterized by a complex combination of accommodation, resistance, adaptation, and engagement (Ali, 2003). The investigation of the "micropolitics" of land use and environmental change can reveal the local particularities and diversity of these encounters, while recognizing their connection with wider social and economic processes that are typically the focus for political ecologists (Kirsch, 2006; Horowitz, 2012; Cater, 2013). Employing a grounded, ethnographically informed method for mapping land use change, this study models an approach for capturing the complex, ongoing legacy effects of mineral development on indigenous lands and communities.

In the twentieth century, industrial development expanded throughout Canada's subarctic as developers were drawn north by the promise of resource wealth. The federal government supported industrial resource extraction through subsidies that served to advance neocolonial agendas in the North (Asch, 1977; Notzke, 1994; Manseau *et al.*, 2005; Piper, 2009; Sandlos and Keeling, 2012). Federal officials sought to replace what they saw as a dying Aboriginal[1] fur trade with an economy based on natural resource extraction, particularly mineral development (Wolfe, 1992; Thompson, 2005; Sandlos and Keeling, 2012). While these policies helped pave the way for rapid industrial expansion in the North after the Second World War, the hunting and trapping economy that preceded extractive development never truly ended (Fumoleau, 1974; Usher *et al.*, 2003; Myers *et al.*, 2005; Sandlos and Keeling, 2012). Abel (2005) characterizes the industrial economy and the land-based economy as independent from each other, while Wenzel (1983) and Gagnon (1992) suggest that they are essentially separate but in a dynamic state of coexistence. By contrast, Berkes *et al.* (1995), Usher *et al.* (2003), and Natcher (2009) assert that these economies are truly mixed, intertwined within Northern Aboriginal communities and households.

The establishment of the Pine Point mine similarly gave rise to a mixed economy that Natcher (2009) calls an “overall livelihood strategy” (p. 91). We argue that this ‘strategy’ has been perpetuated well after the end of mineral development as land users continue to adapt their economies and environments to create and maintain viable post-industrial livelihoods amidst a degraded, post-industrial landscape. As a poorly reclaimed, open pit mine complex located in an area with a long history of Aboriginal land use, the abandoned Pine Point mine in the Northwest Territories illustrates how the ongoing “micropolitics” of extractive development and local land use persist long after the putative end of development.

[1] The linguistically related peoples indigenous to western subarctic North America are collectively referred to as ‘Dene.’ Participants in this study were either Chipewyan Dene or Métis, a term that refers to people of mixed Euro-Canadian and First Nations heritage. In this paper, we refer to Dene and Métis peoples collectively as ‘Aboriginal,’ following the official terminology currently used in Canada (Helm 2000, Desbiens and Rivard 2014).

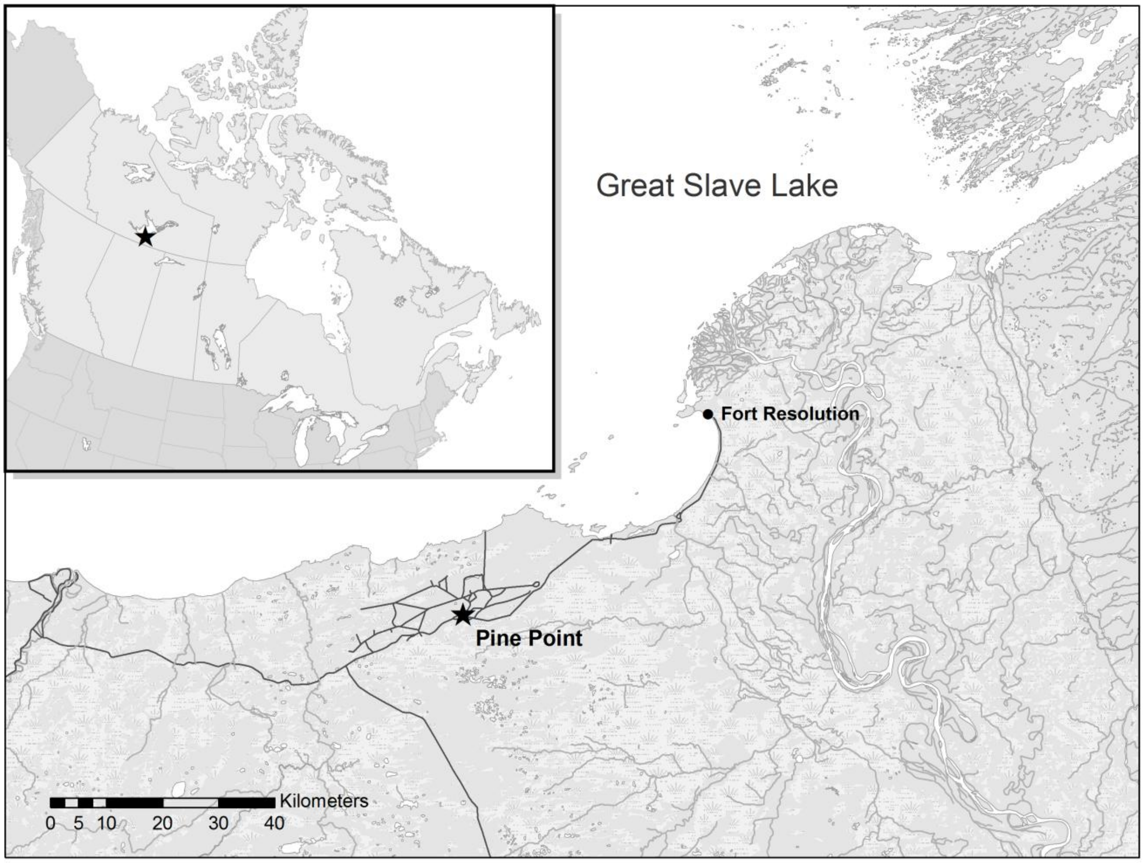

Figure 3. 1 Map of the study area showing the proximity of the Pine Point mine to Great Slave Lake and Fort Resolution. The star indicates the abandoned Pine Point town site, which was built for the mine and was demolished upon abandonment in 1988. The black lines show roads in the area, including haul roads built for the mine and the highway extension to Fort Resolution, which was completed in 1974. Inset: Map of northern North America indicating the location of Pine Point. Map created by Emma LeClerc

The mine, located on the southern shore of Great Slave Lake (Figure 3.1), was an extensive open pit operation opened in 1964 by a subsidiary of Cominco Ltd. At its peak, Pine Point shipped 1,000 tons of high grade lead and zinc ore to Cominco's smelter in Trail, British Columbia, each day. During the mine's initial development phases, the Canadian Government contributed nearly CAN$100 million for infrastructure, including a railway, hydroelectric dam, highway improvements, and a town site that was home to approximately 2,000 residents at its peak (Deprez, 1973; Macpherson, 1978). While oral histories, reports, and traditional knowledge studies from the Pine Point region indicate that local land use was affected throughout the mine's lifespan and after its abandonment (Nahanni, 1977; Macpherson, 1978; Sandlos and Keeling, 2012), no previous studies have closely examined the various environmental and socioeconomic factors that helped give rise to contemporary land use near the abandoned mine.

The Pine Point mine is located in a region with a rich and ongoing history of Aboriginal land use. The mine site is flanked by the predominantly Dene and Métis community of Fort Resolution 70 km to the east and the Hay River (Katl'odeeche) Dene Reserve 90 km to the west. Both of these communities have historically relied on the land for economic purposes, including hunting and trapping for both subsistence and the fur trade (Smith, 1976). This study focuses on Fort Resolution, a community of fewer than 500 people as of the 2011 census (Statistics Canada, 2012). Known in Chipewyan as Deninoo (Moose Island), Fort Resolution is the oldest community in the Northwest Territories. It formed around a prominent fur trade post and shipping hub in the early 1800s and hosted a Roman Catholic mission by the 1850s (Fumoleau, 1974; Macpherson, 1978; Helm, 2000; Abel, 2005). Smith (1976) chronicles part of the colonial history of Fort Resolution, and Helm (2000) describes the predominance and character of the land-based economy in Dene communities prior to the emergence of the contemporary mixed economy.

These traditional land uses were fundamentally altered by the landscape changes and the introduction of wage labour associated with the development and operation of the Pine Point mine (Macpherson, 1978; Sandlos and Keeling, 2012). The mine development predated contemporary standards of community engagement; there were neither community consultations nor impact benefit agreements to address the local environmental, social, and economic impacts associated with industrial mineral extraction (Macpherson, 1978; Notzke, 1994; Hipwell *et al.*, 2002; Angell and Parkins, 2011). An extensive network of cutlines was bulldozed through the boreal forest during seismic exploration, displacing some local land users who hunted and trapped in the area. Highway construction and the process of dewatering open pits disrupted the local hydrology, causing localized flooding that also forced local land users to abandon trapping in the area (Sandlos and Keeling, 2012). During its 25-year operation, the Pine Point mine embodied an appropriation of land and resources for industrial use and, post-closure, it remains a highly visible "symbol of the political and economic power of outsiders to shape local environments" (Sandlos and Keeling, 2012, p. 11).

In the post-industrial era, these far-reaching environmental and socioeconomic impacts continue to influence Deninu Kue First Nation and Métis land users in Fort Resolution. When the mine was abandoned in 1988[2], the Pine Point town site was cleared of buildings, 46 pits remained open, waste rock was left piled around the mine site (Figures 2(a) and 2(b)), and attempts at tailings revegetation were abandoned after an unsuccessful pilot study (Gardiner, 1990; Sandlos and Keeling, 2012). Cominco's Restoration and Abandonment Plan dealt primarily with tailings containment and discharge (Cominco Ltd., 1991) but accomplished little by way of restoring the extensively degraded landscape to its former condition. Indeed, reclamation was considered a technical problem of hazard mitigation; we argue that the detrimental impacts of the abandoned landscape on Aboriginal land use were not considered. While Sandlos and Keeling (2012) demonstrate that community members in Fort Resolution still associate the abandoned mine with dispossession and environmental degradation, Environment Canada featured Pine Point as a successfully decommissioned mine in a 1996 report

[2] While the announcement of closure occurred in 1987 and procedures for closure and abandonment continued into the early 1990s, milling operations at Pine Point ceased in 1988 (Kendall 1992, Cominco Ltd. 1991).

(Environment Canada, 1996). This apparent contradiction shows that the processes of reclamation and abandonment must be more than a technical fix; if reclamation and abandonment are to be truly successful, the process must also account for the mine's afterlife and how it shapes the long-term concerns and practices of local communities.

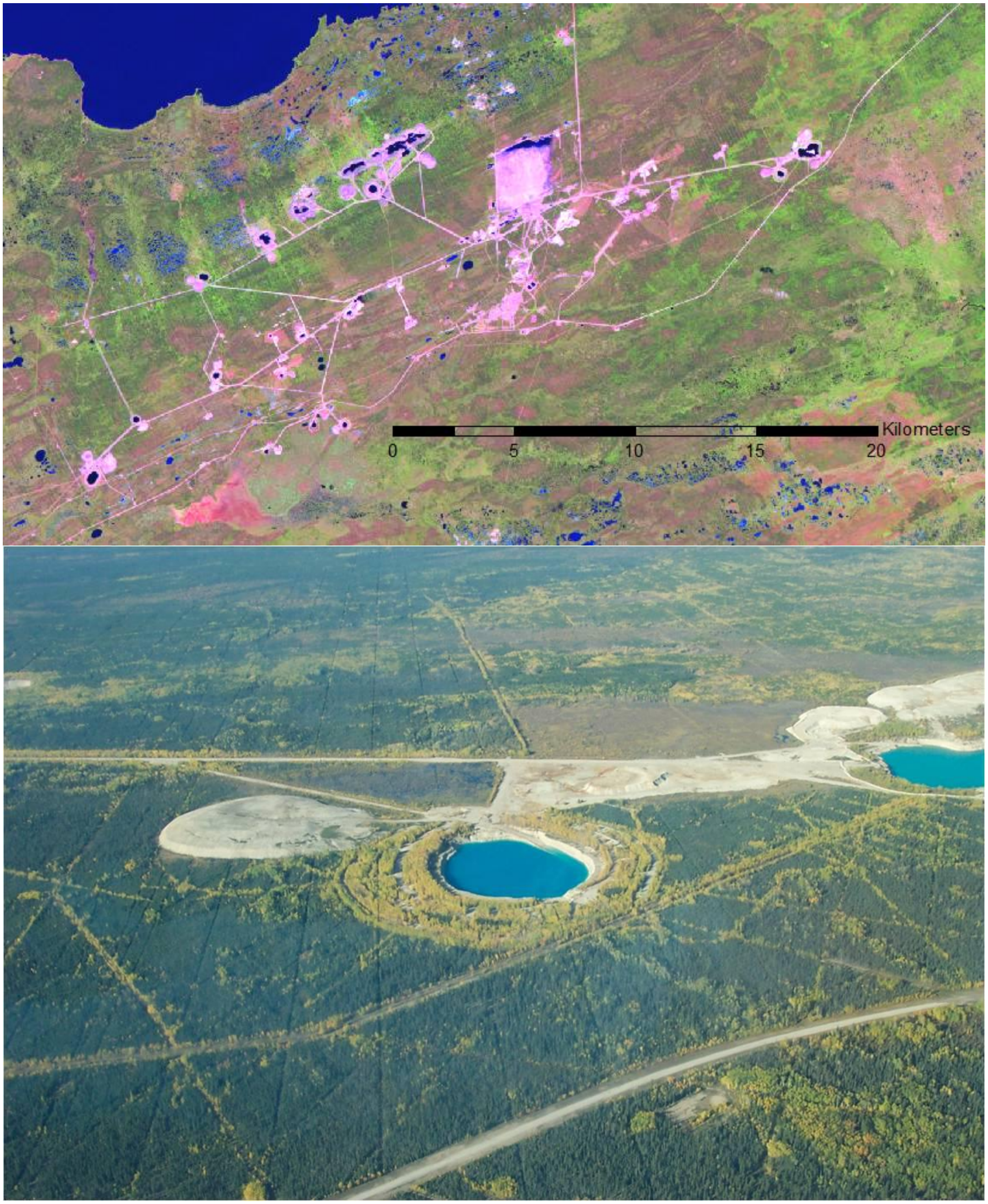

Figure 3. 2 (a). False colour composite satellite image (1:200,000) of the Pine Point mine site in 1989, just after closure. Water is visible in the open pits connected by a network of white haul roads. (Source: Landsat 5 TM, available from United States Geological Survey GloVis at http://glovis.usgs.gov/) **(b).** In this oblique aerial photo ca. 2003, the grid of cutlines running through the boreal forest is clearly visible around the footprint of the mine site. (Photo credit: Deninu Kue First Nation)

3.2 Research Objectives and Methods

The purpose of this study is to examine the relationship between Pine Point's post-mining landscape and the contemporary land use of Aboriginal land users from Fort Resolution. It is particularly important to understand this relationship because Tamerlane Ventures Inc., a British Columbia-based junior mining company, is in the process of renewing production at the Pine Point site (Roy *et al.*, 2012). Another company, Avalon Rare Metals, Inc., has signed an Impact-Benefit Agreement (IBA) with the Deninu Kue First Nation (CBC News, 2012) and expressed interest in processing ore from Thor Lake at the former Pine Point mill site, although that plan was being reconsidered at the time of this writing (CBC News, 2013). In light of the renewed industry interest at the site, it is critical to understand whether and how the poorly remediated, long-abandoned industrial landscape continues to influence contemporary land use.

The meaning of the term 'land use' depends on the intent of the person using it. In the mining and environmental management literature, 'land use' has been used to describe the specific industrial designation of the land, like 'mining,' 'agriculture,' or 'forestry' (Marshall, 1982; Hilson, 2002). Hilson (2002) contrasts industrial uses with local, subsistence-focused uses in the context of reducing land use conflicts between industry and local communities. In addition, land use is often combined with descriptions of land cover type, creating the joint designation land use/cover change (LUCC) that refers to changes in the broad categories that demarcate spatially explicit natural or anthropogenic systems that cover the Earth's surface (Veldkamp and Verburg, 2004). However, for the purposes of this study, land use refers specifically to the harvesting of animal and plant resources as part of the land-based economy (e.g. hunting and trapping) in an Aboriginal community (Natcher, 2009). Examining Aboriginal land use near the abandoned Pine Point mine through the lens of micropolitical ecology provides a nuanced narrative of local adaptations to — and perceptions of — environmental and socioeconomic change in the wake of industrial development and closure. This paper posits that poor environmental reclamation and the continuation of the mixed economy work in concert to explain ongoing post-closure patterns of hunting and trapping in the Pine Point region.

To examine whether and how post-industrial land use is influenced by the abandoned Pine Point mine, we used the map biography method for documenting Aboriginal land use and occupancy. Because land use is simultaneously social, cultural, economic, and spatial, the map biography method was adapted from its conventional survey form to a semi-structured interview designed to characterize post-industrial land use among hunters and trappers from Fort Resolution. This approach enabled the collection of spatial land use data while simultaneously unearthing the qualitative aspects of the degraded landscape's influence on local land use. The resultant descriptive and spatially explicit land use data yielded insight as to some of the environmental and socioeconomic factors that influence contemporary land use in the Pine Point region.

A map biography is essentially "...an account of a person's life on the land, sea or ice" (Tobias, 2009, p. 38), wherein spatial information is recorded on a map during an interview. Typically structured as surveys, the map biography method was developed by indigenous peoples and became common in the 1970s as a way to document the spatial extent of Aboriginal land use and occupancy in order to provide a thorough and representative record for areas that were being contested during land claims negotiations (Usher, 2003; Tobias, 2009). The Dene Mapping Project of the mid-1970s was one such study in the Northwest Territories (Nahanni, 1977). At the time, land use and occupancy studies generated individual map biographies which were then overlaid to create composite maps for use in land claim or treaty negotiations (Chapin *et al.*, 2005; Tobias, 2009).

It was beyond the scope of this study to undertake a comprehensive analysis of all hunting and trapping activities among Aboriginal land users from Fort Resolution, where land use is a source of food and income as well as a fundamental element of cultural expression. To document this ubiquitous livelihood would require a team of researchers conducting multiple interviews with each land user in the community, from adolescents to elders, over the course of several field seasons (Nahanni, 1977). Unlike a general study of land use and occupancy for the entire community of Fort Resolution, the map biography method was adapted to focus on the fundamental questions of how and why the Pine Point mine has shaped (and continues to shape), historical and contemporary, post-industrial land use among hunters and trappers from Fort Resolution. Rather than survey all land users in Fort Resolution, the study targeted those users whose activities were affected, either directly or indirectly, by the mine. Because this study's ultimate utility is academic rather than legal, the geographic and conceptual scope of the interviews was constrained to make it manageable for a single researcher. Base maps were created from three National Topographic System (NTS) maps, 1:250,000 scale, centered on the study region, providing a spatial reference for the interviews.

This study targeted land users who were active in the Pine Point region and is by no means representative of land use among all hunters and trappers from Fort Resolution. During the interviews, participants[3] were asked about hunting and trapping activities in the mine area, especially focusing on the 25 years since the mine shut down. Interview participants were identified using chain referral, sometimes called 'snowball sampling' (Huntington, 2000;

[3] Interviews were conducted in Fort Resolution by Emma LeClerc. Study participants are kept anonymous in order to disassociate individuals from personal and/or potentially sensitive information related to their land use practices. Throughout this text, we differentiate the land users by referring to Participant Identification Numbers (PINs). This methodology adheres to the standards of participant consent and confidentiality outlined in the *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans*. This project was subject to approval through a research agreement with Deninu Kue First Nation in Fort Resolution and a Northwest Territories Scientific Research License.

Atkinson and Flint, 2001), in conjunction with lists of land users in the community provided by both the Deninu Kue First Nation and the Fort Resolution Métis Council. This strategy ensured that the adapted map biography interviews were done with the target population, namely hunters and trappers from Fort Resolution. Of the 18 land users interviewed, only two were women, and few research participants were under 40 years old. Although this sample of land users from Fort Resolution had clear gender and age bias, the research accessed the target population of hunters and trappers who historically used and continue to use the Pine Point region.

Once the interviews were completed, the maps were scanned and the land use features were digitized using ArcGIS (v. 10, ESRI) (Figures 3.3 and 3.4) [4]. The interviews were transcribed using ExpressScribe software (v. 5.50, NCH Software) and coded, a process that involves qualitatively grouping the data into categories or themes (Cope, 2010). Some of these categories were anticipated, and indeed helped guide the research questions from the outset of the study, while others emerged organically throughout the course of the research. Drawing from grounded theory, in which themes are inductively derived from data, open coding was used to identify ideas and actions that recurred throughout the transcripts (Crang, 1997; Suddaby, 2006). The initial open coding revealed several descriptive categories that were used as broad codes which were subsequently divided into subcategories. These codes served as the basis for interpretation through thematic analysis (discussed in section 3). Through coding and analysis of the transcripts, themes emerged that highlighted some of the relationships between contemporary land use and Pine Point's post-industrial physical and socioeconomic landscape.

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[4] Data from the 18 interviews were aggregated after digitization to create the composite land use maps shown in Figures 3 and 4.

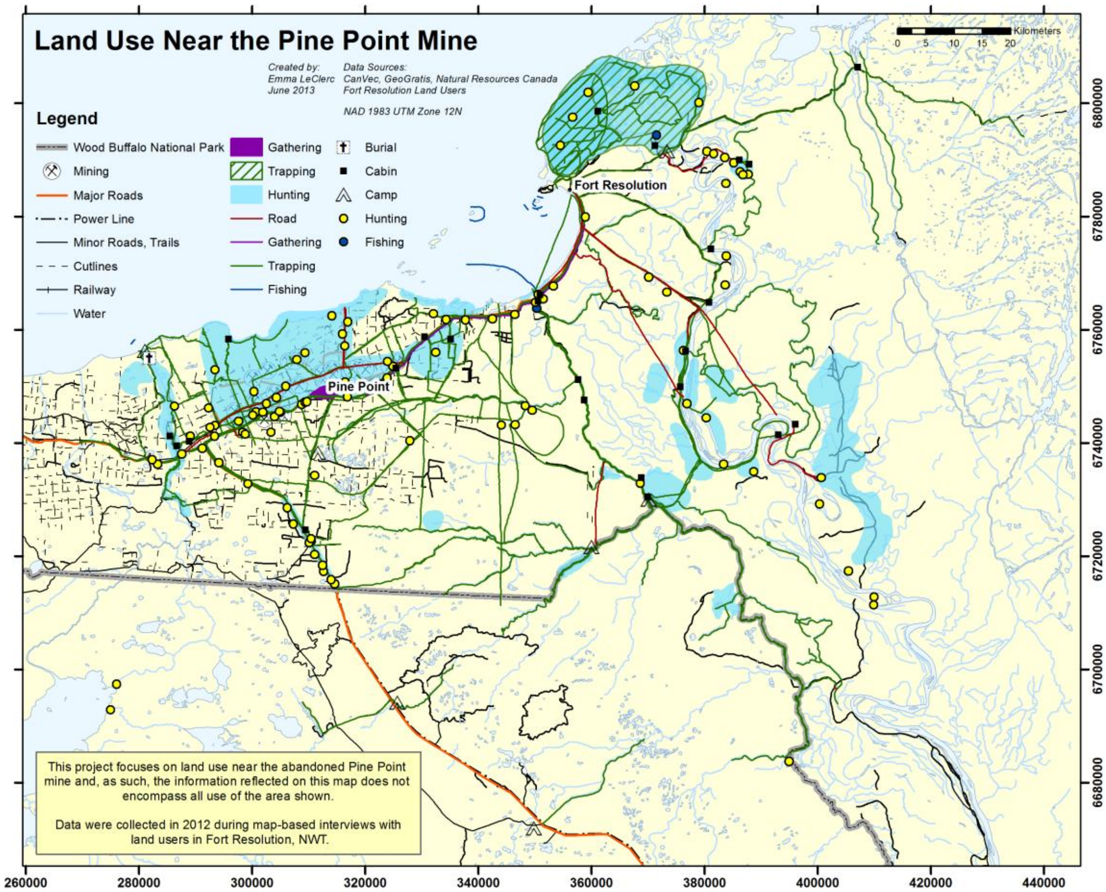

Figure 3. 3 Composite map of land use data from all eighteen interview participants who hunt and trap near the abandoned Pine Point mine. It is evident that land users have returned to hunting and trapping the extensive abandoned mine site. Map created by Emma LeClerc

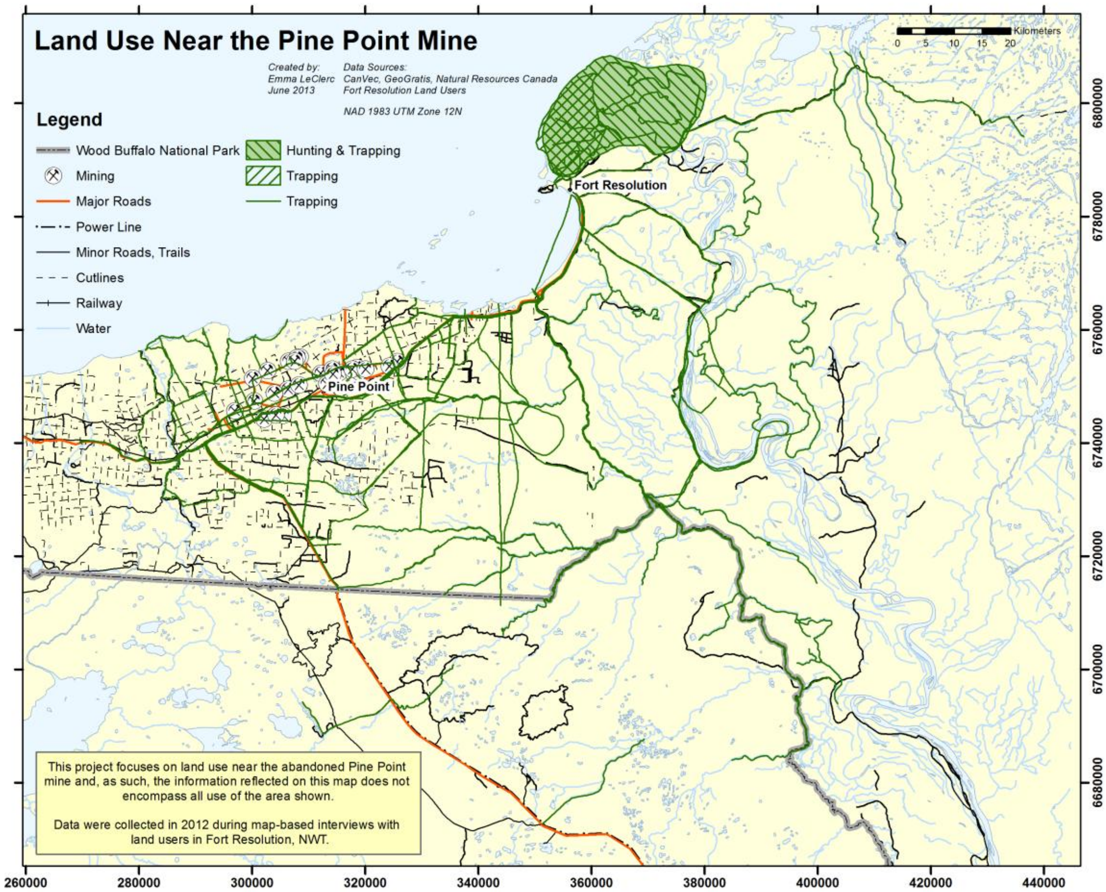

Figure 3. 4 Composite map of trapping data from all eighteen interview participants. At the abandoned mine site traplines are short and straight since they coincide with abandoned cutlines, while farther from the mine site the traplines are longer and curve with the waterways they follow. Map created by Emma LeClerc

The adapted map biography method is an imperfect way to trace the influence of the Pine Point mine on land use through time. While it allowed simultaneous collection of oral and spatial accounts of land use, the data were still only one part of a deeper story about how and why local people use the land. As Tobias asserts, “Even the best map biography is truly only a glimpse in that it necessarily remains a simplified and incomplete representation of a respondent’s life on the land” (2009, p. 38). There is an unavoidable degree of reductionism in recording land use as a combination of points, lines, and polygons. Similarly, the interview transcripts are at best a partial record of land use and the influence of the Pine Point mine. However, by structuring the interviews as map-based discussions, we were able both to record land use and to place it in an ethnographic context that revealed recurring themes about the problems and benefits of the abandoned Pine Point landscape in the post-industrial era.

3.3 Land Use in the Pine Point Region

The composite spatial data from the 18 participants show that land use in the region is intensive as well as spatially extensive. Land users from Fort Resolution hunt and trap over the entire post-mining landscape as well as venture farther afield to use other areas (see Figure 3). Ironically, given the mine's history of dispossessing local land users (Sandlos and Keeling, 2012), the poor reclamation at the mine site is now somewhat conducive to access, as land users often hunt big game like moose along the roads. Also, many cutlines have become popular places for trapping furbearers like marten or mink. Since abandonment, the importance of continuing traditional activities means that the people of Fort Resolution have reappropriated the Pine Point area in spite of its degraded condition. However, the maps alone do not show the concerns that these same land users have about the environmental condition of the abandoned mine site, and their trepidation about pursuing some land use activities there.

In addition to the spatial data, several key narrative themes emerged from the semi-structured map biography interviews: (1) accessing the land, (2) hunting, trapping, and working, and (3) environmental effects of the Pine Point mine. Combined with the spatial manifestations of land use, these themes illustrate the complex, and sometimes contradictory, ways in which contemporary land users interact with Pine Point's post-industrial landscape.

3.3.1 Accessing the Land

One of the predominant themes to emerge from the interviews was the importance of accessing the land. Natural and anthropogenic routes, like rivers, sloughs, roads, or cutlines, are passages into the bush, a means by which land users can penetrate the boreal habitat for the purposes of hunting and trapping. During the mine's exploration and development phases, bulldozers cleared hundreds of kilometers of cutlines for seismic exploration. Previous oral histories and historical testimony during water licensing hearings have described the displacement of land users and loss of traplines that occurred when these cutlines were cleared for the mine (NWT Water Board, 1979; Sandlos and Keeling, 2012). In his presentation before the Northwest Territories Water Board at the Pine Point mine's 1979 water licensing hearing, the president of the Hunters and Trappers Association of Fort Resolution stated that approximately 30 families relied on the area around Pine Point for year-round land use before they were displaced by industrial development (NWT Water Board, 1979).

While the mine was in operation, it created physical changes to the landscape that were detrimental to land use. For instance, the altered groundwater regime caused problems for some land users. One participant described his trapline being flooded by the mine: "So my line was being two feet underwater, something. I had to quit trapping that year" (PIN17). Some participants described the changes that some of their family members were compelled to make in response to the environmental impacts of the mine. One participant's father was affected in the following way:

> "[W]e hunted on Buffalo River. My father had his trapline on this here. And he was getting all the waters from the mines. Flooding into the Hanbury Creek, so he had to move his line. Further away. That was one of the...one of the downsides. He used to go this way, but it started getting flooded out. So he abandoned this portion of it. And then he went straight cross-country, down to this area in here. He changed his trapline completely." (PIN14)

Another participant whose father's trapline was directly affected by the mine described discovering the damage when he was a child out trapping with his father,

> "We used just dog team to run the trapline. And then I remember...the first cutline come through the trapline. […] Just after we took off and it was a big clearing where the CAT goes right over the line. And I kinda stopped my dad and I looked back, kinda walked back, walked on the trapline and I knew right from then. Didn't look good. […] That's when all these lines came in. All through my dad's trapline. Then we had people runnin' in from Pine Point, coming and going on our trapline, taking fur and...Then we were running into...people doing exploring and stuff. And after that, they started polluting it with all that waste water." (PIN10)

Lee and Boutin (2006) have shown that the wide seismic lines typical of mid-20th century industrial exploration in Canada's boreal forest are very slow to revegetate, leaving a lasting physical imprint. This imprint is evident in the Pine Point region, where cutlines criss-crossing the landscape remain visible 25 years after closure. In the post-industrial era, these long, straight corridors provide entryways into the bush and as such have been appropriated to benefit local land use. The conversion of former seismic lines for other anthropogenic uses is not uncommon; Lee and Boutin (2006) note that many seismic lines in Alberta have become travel routes. At Pine Point, cutlines originally cleared for industrial purposes have been similarly repurposed and are often converted to traplines. Nearly every participant who actively trapped in the Pine Point region mentioned using cutlines for a combination of travel, trapping, and hunting. The tenacity of the land-based economy as a tradition means that the very cutlines that forced the initial displacement of land users from the region are being (re)claimed to benefit contemporary indigenous land use.

Some of the cutlines were used by hunters and trappers even before the Pine Point mine shut down in 1988. When asked about his trapping activities before closure, one elderly participant said, "I used to trap in the cutline…I can't tell you which one now. You know? Every...every hundred feet there's a cutline, cutline, eh? No sign on it. Can't tell you...where I go.

But on the river, sure. And on the highway, too, trap[ped]" (PIN13). This individual was no longer able to trap for health reasons, but testimony from other land users echoed his description of using cutlines for trapping and hunting.

Many participants described hunting moose or caribou along cutlines after the mine shut down, and several participants pointed out cutlines on the map that they had used for trapping. One land user recalled, "I used to trap on this cutline right here. Right here, all the way right to here. That was probably about...ten years ago, or better. Ten, fifteen years ago" (PIN12). The participant noted above whose father's trapline was disrupted by the cutlines at the mine's inception noted that in the post-mining era, "[N]ow I kinda use those cutlines. Claim them because they're running right alongside my trapline, and if I didn't claim them, people would be trapping right beside me" (PIN10). In a contemporary context, this land user chose to appropriate the cutlines that destroyed his father's trapline in order to continue trapping in the area.

In addition to using those cutlines that have not yet revegetated, some participants actively prevented regrowth in existing traplines in order to travel and trap along them. One participant said,

> "From here...I just made my own road. This used to be a cutline before. I just kept it goin', open and open I just kept going all the way back. […] That, I've been trappin' in there probably about 30 years now." (PIN12)

It is clear that the ongoing interactions between land use and the environment ultimately shapes both; as land users from Fort Resolution appropriate the disturbed landscape for hunting and trapping purposes, they maintain certain elements of that disruption (i.e., cutlines).

Many land users from Fort Resolution also use the abandoned mine site itself for hunting. As one interview participant explained, "You can still drive in there, all around here. There's little roads in there, and that. So...that's where we were callin' moose last year, and we had moose come to us last year. We didn't get it, but...there were moose in the area" (PIN14). Several interview participants said that they use “every road,” and proceeded to describe extensive use of the area for hunting. When asked if he ever went hunting just after the mine shut down, one interview participant answered, “Yeah, we did. But then there was still a lot of traffic in there at that time because they were still movin' everything out, they were still haulin' stuff and all the equipment and they were still doing a little bit of mining that time. Yeah. So it wasn't quite right after, but yeah” (PIN12). As one land user put it, “After the mine shut down, we figured out everything” (PIN03).

This extensive use of the post-mining landscape and abandoned infrastructure contrasts with the severe restrictions on access to the site and the surrounding area during the mine’s operations. As one land user described,

> “Well...during the life of the mine, we didn't have any land use there. Because we weren't allowed in that area to hunt. Or to trap. While the mining was in operation. So, during the life of the mine, there was no land use for the people at all. We didn't have anywhere...We did hunt along the highways and stuff like that, but...we couldn't get into this whole area. Northwest of the highway. Because it was all restricted. And, to an extent, some of the areas back in here too, because there was always exploration activities going on. You didn't want to shoot some crazy old...geologist or something like that, so.” (PIN14)

After the mine shut down, the company tried to minimize the safety hazards of the post-industrial site. Access to the site was impeded by berms, tall blockades of mounded waste rock and/or gravel, that were built across the haul roads and around the open pits. Some of the interview participants were visibly annoyed with the bermed roads. One remarked, “Why? You know. We're not crazy, drive in a hole, you know” (PIN11). Another land user explained that he is not deterred by the berms; he simply goes around them. “Can't stop me from going on my land” (PIN18), he declared. One participant stated,

> “I hunted every one of these roads here, all the time, right now to today. Since Pine Point shut down, it's good for us 'cause we get to use those roads, the ones that they didn't block off. And the ones they blocked off, we made trails around 'em so you can get around them with a truck.” (PIN01)

However, participants also described being cautious on the mine site: “Some places we still don’t go, though. The dangerous places, you know, like pits and...We don't bother with those but every other place we open, and we went” (PIN03). It was clear that every safe road on the abandoned mine site is used. The cutlines and haul roads that were created when the mine was active have not been successfully rehabilitated from an environmental standpoint, but in the 25 years of industrial inactivity land users have reoccupied some of these formerly industrial spaces. In this way, the abandoned mining infrastructure associated with the initial displacement of land users has actually facilitated some access to the land since the Pine Point mine closed, despite potential environmental hazards.

This use of mining infrastructure is part of a broader trend in which land users travel existing routes into the bush, including highways, roads leftover from formerly active sawmills, and naturally existing waterways such as rivers, creeks, and sloughs. The interview participants’ land access and use is by no means limited to the Pine Point area, and land users spoke of the combination of routes, both anthropogenic and natural, that typify their access to hunting and trapping areas across the region. Individuals appropriate formerly industrial spaces, not only the abandoned Pine Point infrastructure, but also former logging roads. Land users’ use of haul roads at the mine site, as well as their use and maintenance of cutlines from seismic exploration associated with the mine, is a continuation of this practice.

3.3.2 Hunting, Trapping, and Working

The shifting patterns of Aboriginal land use in the Pine Point area during the operational and post-closure phases are also attributable to changes to local livelihood strategies that were induced in part by the mine and town development. Historically, the Pine Point development coincided with a fundamental shift from a predominantly hunting and trapping economy to a mixed economy, wherein Aboriginal land users supplemented income from wage labour with land use. In Fort Resolution, which received little direct economic benefit from the mine, some land users were displaced by the mine and were forced to adjust their livelihoods accordingly. Others took jobs at the mine and began altering their hunting and trapping practices to meet the demands of wage labour. After the mine was abandoned in 1988, the mixed economy remained and persists today. In the post-closure period, many contemporary land users continue to combine wage employment with hunting and trapping on the post-industrial landscape.

Sandlos and Keeling (2012) describe the poor overall record of local Aboriginal employment at the Pine Point mine. While few land users interviewed were employed by the mine, many of those who were also hunted and trapped to supplement their income. Participants described trapping on the weekends and in the evenings after work. An elderly land user who also worked at Pine Point said, “And while I'm workin' I was trappin', same time, too. When I got time. Weekends and that, yeah. Only on the roads. Only on the highway. Wherever the highway is” (PIN07). Another elderly participant described a similar pattern: “After I work, then I found out it was a good place to trap, so I just trap around there. On my days off, I just go” (PIN13).

This trend has continued into contemporary times. Most of the interview participants spoke extensively about adjusting their trapping activities to fit with their work schedules. A young active land user explained:

> “I've got a full time job, I work for the government. I’m a highway truck driver, and after work, I'll go for traps even in the dark. Because you've got to maintain it, make some money, and if I leave it they'll get eaten or damaged, so. You gotta go every, like, two, three days. So I...like I said, do it on the weekend, then during the week, I'll maybe have a friend do it for me. So. It still gets done, yeah. No matter what, it'll get done.” (PIN18)

Occasionally, contemporary land users mentioned taking a hiatus from trapping to exclusively pursue wage labour opportunities. For example, one participant said, “It's just some years I never trap. I was working at the sawmill" (PIN10). Because land use activities tend to be flexible, especially since the advent of mechanized transportation, land users adjust hunting and trapping to accommodate the consistent hours which are characteristic of most wage employment. Sometimes this adjustment is seasonal—"Work in the summertime, trap in the winter" (PIN09) —but more commonly land use is incorporated into the work week, which remains defined by wage labour. In contemporary times, many land users are "weekend trappers" (PIN09), simultaneously maintaining traplines and full-time wage employment.

In some instances, land users from Fort Resolution altered the locations of their trapping to better accommodate integration with wage labour. Some participants described moving to new trapping areas nearer their place of work. For example, one participant used to trap in the Taltson River area, to the east of Fort Resolution. However, when he worked at Pine Point, he trapped near the mine. After he stopped working at the mine, he resumed trapping by the Taltson River (PIN01). Similarly, contemporary land use among hunters and trappers from Fort Resolution is sometimes defined by geographic convenience. Another participant began a new trapline in order to trap near his place of work and ceased running the line when he changed jobs (PIN12).

These examples illustrate how people in Fort Resolution maintained their "mixed economy" of wage labour and land-based activities both during and after the mining period. However, a few participants described an overall decline in trapping in recent decades and attributed the decline to wage employment. One elderly participant explained, "It's not like the olden days, we don't have that many trappers left now. […] All these jobs" (PIN06). Other land users mentioned restricting their trapping areas because of work demands: "Well, when I was at the mine, that's the only place I trapped. But before I started workin', well, I trapped all over"

(PIN13). The type of work also influences how land users alter their trapping. For example, one younger land user detailed how different jobs affect his trapping areas,

> "I used to own a bed and breakfast down the road. [...] So I used to go and do all my trappin' then. So I had lots of time. Because I did and looked after the bed and breakfast, and I trapped. […] Yeah, it was good, so. Then I went back to work, last few years, for [the Department of] Transportation again, so. That's why I just do this little short line now." (PIN12)

As economic practices shifted, so did the locations of land use. To accommodate the demands of wage labour, hunters and trappers began using shorter traplines located closer to their homes or places of work (Figure 4). Because these traplines required less time to access, land users were better able to incorporate the land-based economy with wage labour. While contemporary land use still broadly follows trends like historical family trapping areas, issues of access and convenience have made the former mine site a popular location for hunting and trapping. However, the reappropriation of the former mine site is a source of concern for some contemporary land users because of the enduring environmental damage at the abandoned site.

3.3.3 Environmental Effects of the Pine Point Mine

Participants' discussion of land use in the Pine Point region was often tinged with serious concerns about lasting environmental damage attributed to the abandoned mine. As one interview participant summarized:

> "We usually go into all these little cutlines and stuff like that when we do get seriously into the hunting. [...] We don't only use the highway corridor, we use...pretty well all of the Pine Point area. For a number of reasons, too, the...accessibility is there, you know, the access roads are there still, some of them. So we take advantage of that. That's one...of the good things about that mine, I guess, but other than that it's an eyesore." (PIN14)

In Fort Resolution, land users have grown accustomed to navigating the tension between environmental degradation and maintenance of their livelihoods; many spoke about the persistent negative environmental effects of the mine but use the land anyway (indeed, taking advantage of those negative effects to the extent they can). Their concerns range from issues of water to vegetation to wildlife, and many participants were critical of remediation attempts at the mine site and surrounding area. In his description of underground mining, Bridge (2004) argues that "...the unfamiliarity of the mining landscape can provoke alienation and distrust" (242). Although mostly a surface mine, the same can be said of Pine Point's poorly remediated site. Some of the participants' environmental concerns were generalized, some linked the current condition of the mine to their observations of high rates of cancer in the community, and other concerns addressed the effects that the degraded environment has had—and continues to have—on land use in the region.

The Pine Point mine was decommissioned and remediated according to the relatively weak reclamation regime in the Northwest Territories (compared with other North American jurisdictions—see Wenig and O'Reilly [2005]). The tailings were covered with gravel, berms were built as a safety precaution, culverts were removed to restore drainage, and the town was cleared of buildings and leveled (Environment Canada, 1996; Sandlos and Keeling, 2012). Testimony from the 1990 Northwest Territories Water Board hearing indicates that the Fort Resolution community was deeply dissatisfied with the reclamation and abandonment procedures. Today, there is still widespread concern with the environmental condition of the site and surrounding area over 25 years after abandonment. Critical of the remediation, one participant said, "Now we're feeling, some 20 years after the mine shut down, we're starting to see some of the stuff that was neglected. At the time, they probably thought it was cool to leave it. But as the years went, goes on, you know, it's starting to...you can start to see the effects of a lot of that water" (PIN14). Another land user said:

> "[T]he open pits are still open. You know, so. They should have replanted it and made it look like the way they found it, you know? It never did happen. I think so, I don't know. It's hard to say. [...] But...there's not enough area, not enough trees for animals to hide in, so there's hardly any left now, eh? I'm pretty sure that's what it is. 'Cause there used to be a lot of animals there before. There's not that many now. But now they're starting to come back,

> little by little, eh? [PIN10] traps in there lots now and he's saying there's more every year." (PIN05)

Several participants specifically mentioned the open pits, which were not filled at the time of closure, as a safety concern. One elderly participant who worked at Pine Point said, "[T]he pit is open, eh? Outside, the dark, you can fall in there too. They should have packed the dirt back in the hole, but they never did. Just left it open" (PIN13). Another elderly participant explained that the community was told the pits were not filled because, "Extra cost, and then, the holes, they have some low grade ore in there yet. That was [the company's] excuse" (PIN11). The relationships among land users and this post-industrial space are complex; for instance, the berms built to block access to the site are simultaneously an inadequate safety measure and an impediment to access that must be overcome by land users interested in hunting at the mine.

The perception of environmental quality at the site has resulted in a conflicted relationship between land users and the abandoned mine. While most land users remain dissatisfied at the lack of remediation, this has not entirely deterred them from hunting and trapping in the area. One land user described hunting for ducks and geese at the site, explaining that hunters target the marshy areas while avoiding the pits. He said:

> "[I]t's all chemicals and stuff and they don't trust it. And you gotta pluck the birds and somebody's eatin' it, so they don't really bother it. But I know we get them because they go from here to here and we shoot them over here. So I know we ate, we've been eatin' birds out of here [the pits]. [...] [But] we don't shoot 'em right here." (PIN01)

When describing where he collects medicinal plants, the same land user said, "I don't take nothing around the whole Pine Point tailings pond [...] because the dust comes up and blows, contaminants come down on the soil. So I stay completely away from this for...I take most of my stuff from, oh say, at least ten miles away from this" (PIN01). Thus, in spite of ongoing use of the site for hunting, the abandoned Pine Point mine remains a disturbed and potentially dangerous landscape in the view of many land users.

Some participants characterized the vegetation at the mine site as minimally recovered. One land user described the vegetation as follows:

> "Nothing's coming back yet. Well, there's a few trees and that on the roads. Yeah. Things are starting to grow, but where that tailings pond stuff is, there's nothing growing. But where the roads used to be, there's some grass coming out of the roads." (PIN16)

Other participants, however, described some revegetation and discussed its role in influencing contemporary land use. As an elderly participant described the current status, "I don't know who trap in there right now, the kids, but I don't know what they get. They get a few things but I think...I think they say it's ok now, a little better. Because...[it] started grow up, everything grow back, eh?" (PIN08). Another participant discussed the transition that has occurred at the mine site since closure:

> "...[S]ince then...the mine shut [and]...for years later, it was just like a wasteland. Total wasteland. Everything was dead. Roads all over, just like in the Mad Max movies. That we see. You know? There's roads there, and there's...all the vegetation was dead. Just about all the vegetation. And...just roads and roads all over the place and nobody there. And...that was 1986. Now, lately, past few years, I've spent a lot of time in that area. And I see a lot, a lot comin' back." (PIN15)

This participant went on to describe the mine site as a good place to pick berries, "When the mine was going, I didn't notice any berries around there. But the berries is right in the town site now...Early summer. And you go there and just everywhere, you can't walk around anywhere without stepping on berries. That's how much there is" (PIN15). It seems that there is a high degree of variability in terms of how local land users perceive vegetation recovery and safety around the mine.

The renewed industrial interest in the Pine Point region was an additional cause for concern among a few participants. While Avalon Rare Metals has signed an impact and benefit agreement with Deninu Kue First Nation, Tamerlane Ventures has yet to do so. One elderly participant spoke at length about the impacts of previous development at Pine Point, especially regarding land users in the area. He felt that the new developers have not improved in terms of community consultation. He said:

> "[P]eople were trapping the area, they [Pine Point Mines] just...you know, no respect. Just run machines over, you know. There must have been a better way of doing. You know, they could have came to Res, you know, 'We're gonna do this in the area. Can you pick up your traps,' or...something like that. I'm pretty sure they could have got an interpreter to...if some elders didn't speak […] English, then...But they just...no respect, they just went over the land. It bothers me when I think about it. And now they're gonna do it again. And we're saying...We're hitting the table, said it will never happen to us again. And here, it's happening." (PIN11)

In addition, some participants raised concerns about new developments inflicting damage comparable to that of the original Pine Point mine. When asked whether some of the vegetation has begun to recover, one elderly participant said, "Now it's a little better, I think I heard. Now they're gonna dig up another mine again, [it will] be nothing again. Yeah. That's what is gonna happen again" (PIN08). Another elderly participant echoed this concern, saying "I'm not for it. For the mine. From the future, my kids...I'm still worried. [Pause] Not good. They should...like the elders, like I told you again too, soon as they put the CAT down, you damage the land. Soon as you start digging, the land is damaged" (PIN07). The lack of adequate reclamation at the Pine Point mine site has contributed immensely to concerns about the new developments. As one participant said,

> "[R]ight now, there's still no cleanup and yet they're gonna put another development right over that whole area. Which, my people are saying, is only starting to heal itself now. And I don't think it's sitting very well with some of the elders, you know. Well, shit, we just got rid of one development there and now this place is starting to come back and now they want to put another one in there. What is going on?" (PIN14)

It is important to note that many of participants who discussed the proposed developments expressed a mixture of sentiments, from the above concerns about environmental damage to a hope that the new companies would provide more employment opportunities than the limited opportunities of the original Pine Point mine. When it comes to new industrial developments in the area, the predominantly negative perceptions of the environmental effects of the abandoned mine are by no means the only consideration of the land users; however, these negative perceptions do shade opinions of new proposals, illustrating the complex connections between historical and contemporary experiences of development.

3.4 Conclusion

The physical and socioeconomic changes associated with the development and operation of the Pine Point mine have persisted throughout the post-industrial era. Contrary to the expectation of the federal government, industrial wage employment has not supplanted hunting and trapping. Instead, land users in the Pine Point region have adjusted the way they use the land to best serve their needs. Although the lasting environmental damage inflicted by the mine remains a point of concern for land users from Fort Resolution, many of these same land users are taking advantage of the persistent environmental changes to benefit their hunting and trapping.

Map biography interviews revealed that major changes in Aboriginal land use patterns occurred during the development and operational phases of the Pine Point mine, and were part of a broader transition from a heavy reliance on hunting and trapping to a mixed economy. These patterns have persisted throughout the post-mining era, and shaped local land users' practices on the post-industrial landscape. Contemporary land users create their own unique combinations of land use and wage employment, altering locations of harvesting to suit their individual needs. Land users' geographic variability is constrained, to a degree, by the locations of other land users; however this constraint is born of mutual respect and is not rigid. These changes occurred in concert with physical environmental changes brought about by the Pine Point mine; the cumulative result of these changes is the pattern of contemporary land use as it exists today among hunters and trappers from Fort Resolution.

Contemporary land users, though no longer entirely reliant on hunting and trapping as a primary source of income, have appropriated the post-industrial landscape because it facilitates access to the bush. By today's standards, the environmental remediation that occurred at the time of closure yielded poor results. The poorly reclaimed state of the site remains a concern for hunters and trappers from Fort Resolution; nevertheless, the interviews reveal that the post-industrial landscape has become a place of fairly wide-ranging land use. The maps served to ground individual conversations about land use near the post-industrial landscape, and combined to become a snapshot of the extensive and varied contemporary indigenous land use. The accompanying narratives added ethnographic depth that became the explanatory component of the analysis. Many land users described hunting for various species at the mine site, and some participants described limited trapping at the site as well. In the area surrounding the former mine site, most of the participants in this study have engaged in intensive hunting and trapping, especially in cutlines that have remained accessible. In some instances, the lack of reclamation has facilitated contemporary land use. The use of abandoned roads and cutlines as entryways to the bush, and indeed the maintenance of some cutlines for trapping purposes, indicates that land users have effectively reappropriated parts of Pine Point's post-industrial landscape.

However, land users' adaptation to a degraded landscape is only one part of their complex relationship with the abandoned mine. The poorly reclaimed landscape has negatively influenced local land use and perceptions of environmental health. The collective avoidance of the open pits, as well as ongoing concerns about the effects of contaminated water, indicate that land users' dissatisfaction with Cominco's paltry attempts at remediation permeates the community's relationship with the post-industrial landscape. Notwithstanding the resilience of local Aboriginal land use traditions, the ongoing legacy of environmental degradation at Pine

Point reinforces the inequitable distribution of benefits and impacts from industrial development seen in many Aboriginal encounters with development in Northern Canada and elsewhere (Downing *et al.*, 2002; Kirsch 2006; Keeling and Sandlos, 2009). The adaptability of local land users does not exculpate past industrial practices and their long-term effects; rather, it sheds light on the local complexity of cultural encounters with extractive developments—factors worthy of consideration in development planning and consultation.

The continuity of participation in the land-based economy despite environmental concerns speaks to the "micropolitics" of extractive development in the Fort Resolution community. While contemporary land use in the Pine Point region represents an adaptation to local conditions, broader economic forces are still at play in shaping the balance between wage labour and the land-based economy at Fort Resolution. Because of the local nature of the land-based economy, Pine Point's legacy is best understood as a story of conflicted perspectives and socioeconomic adaptation, embedded within the broader experience of dispossession, environmental degradation, and abandonment (Sandlos and Keeling, 2012). As is often the case at abandoned sites, the mine that contributed to the environmental and socioeconomic changes experienced by people from Fort Resolution was long outlived by the changes themselves (Veiga *et al.*, 2001; Sandlos and Keeling, 2013).

Ali (2003) claims that community engagement in the negotiation process of industrial development plays a crucial role in shaping indigenous response to development proposals. Our study shows that meaningful engagement necessarily extends beyond the operational life of the mine because Aboriginal land use persists and is affected long after abandonment. For Aboriginal communities, the mixed economy is dynamic and intrinsically bound to the environment, making the long-term impacts of industrial development especially critical. In response to large-scale developments, local communities adapt their land use to suit their environment, whether or not they are consulted prior to development. If industrial mineral extraction is to become truly sustainable, it must address the complex impacts on local land use at each stage of the operation, from exploration to remediation and post-closure.

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CHAPTER 4

Conclusion

As industrial mineral extraction continues to expand throughout northern Canada, it is essential to reflect on the future implications of such expansion for local environments and communities. Contemporary lessons for industrial mineral development and abandonment in the territorial north can be drawn from the analysis of the legacies of historical extractive operations. The purpose of this thesis was to explain the long-term environmental and socioeconomic consequences of industrial development, closure, and abandonment without comprehensive remediation in a subarctic, boreal environment. Natural revegetation is a slow process in the arctic and subarctic; thus, the poor remediation of extractive sites in northern Canada can result in persistent environmental change. When local Aboriginal communities rely on the land to sustain the mixed economy, this change has lasting socioeconomic consequences. Using the abandoned Pine Point mine in Canada's Northwest Territories as a case study, I set out to study the interrelated legacies of environmental transformation and socioeconomic adaptation.

Sandlos and Keeling (2013) have argued that closure and remediation are not the end of a mine's life cycle. This thesis demonstrates that the life of a mine extends well beyond closure and remediation, leaving an indelible mark on local environments and communities. The Pine Point mine was developed and shut down in an era of massive industrial expansion with little community consultation and environmental oversight (Piper 2009; Keeling & Sandlos 2009). The mine transformed the local boreal environment with the excavation 46 open pits, the construction of a town site, and the bulldozing of hundreds of kilometers of seismic lines. Upon abandonment, barriers or berms were constructed around the pits, the 570 hectare tailings pond was capped with waste rock, and the town site was cleared of buildings, leaving an abandoned industrial landscape whose denuded surface bore little resemblance to the boreal environment that preceded development. This extensive transformation was not adequately addressed by the passive approach to reclamation. I aimed to understand how the environment had changed in the twenty years following the mine's closure, and how hunters and trappers from the nearby community of Fort Resolution used the post-industrial landscape.

I adopted a dual approach to investigate the environmental and socioeconomic legacies of the poorly reclaimed, abandoned Pine Point mine in the Northwest Territories. Drawing from landscape ecology, I first used remote sensing techniques and landscape metrics to assess land cover change at the mine in the 20 years following closure. At Pine Point, industrial resource extraction transformed the landscape, and the findings in Chapter 2 indicate that this transformation has persisted. I used a reference landscape that never experienced industrial mineral extraction as a proxy for how the Pine Point landscape might have developed in the absence of the mine. Through this comparison, I was able to evaluate the long-term effects of industrial development and passive reclamation in a subarctic, boreal environment. The reference landscape in Wood Buffalo National Park was dominated by dense conifers and larger, more contiguous patches of vegetation, while the Pine Point site exhibited smaller, less contiguous patches throughout the twenty year study period. The exposed land at the mine site exhibited very little conversion to vegetation in the twenty years following closure. It is evident that the passive reclamation strategy at Pine Point has not been effective in restoring ecological function in this subarctic environment. The post-industrial landscape remains conspicuously degraded more than two decades after abandonment, which underscores the difficulty of striking a balance between industrial development and conservation in a boreal environment that is both economically and ecologically important.

The lingering environmental legacy has implications for local land users who, as discussed in Chapter 3, continue to use the post-industrial landscape despite grave concerns about its environmental state. Because the contemporary mixed economy is a key component of Aboriginal cultural identity (Usher *et al*. 2003, Natcher 2009), many local land users in Fort Resolution have adapted their hunting and trapping activities to accommodate their local environmental reality. Some avoid the mine area when gathering plants or hunting waterfowl, for fear of contamination. However, some land users also actively maintain elements of the mine's abandoned infrastructure (i.e., cutlines) to facilitate trapping. The diversity of these adaptive responses illustrates the complexity of the local community's ongoing relationship with the post-industrial landscape. Although land users voice concerns about the environmental impacts of the mines and the safety of eating animals taken from the mine site, land use persists in the post-industrial space. This land use embodies a reappropriation of the same land from which hunters and trappers were displaced by the development and operation of the mine. The expansion of natural resource extraction in the territorial north changed the character of the mixed economy and these changes are evident today as land users continue to balance hunting and trapping with wage labour opportunities, often at mines. Contemporary land use speaks to cultural continuity as it demonstrates the cultural and economic importance of the land-based component of the contemporary mixed economy. In the wake of industrial development and abandonment at Pine Point, land users from Fort Resolution have responded to the poorly reclaimed landscape and increased reliance on wage labour by adapting the mixed economy in ways that are economically necessary and aligned with cultural practices.

The interdisciplinary approach adopted for this study yielded complementary datasets which combine to tell a complex story of the interrelated environmental and socioeconomic legacies left by the Pine Point mine. While the datasets could not be integrated for direct comparative analysis, they tell parallel stories of lasting environmental degradation and socioeconomic adaptation. The integration of remote sensing techniques and landscape metrics detailed in Chapter 2 enabled the investigation of spatial patterns at the abandoned mine, and the qualitative analysis of map-based interviews described in Chapter 3 accessed the nuanced explanations for contemporary Aboriginal land use near Pine Point. The use of maps was effective in grounding discussions of Aboriginal land use in post-industrial landscapes, and has further potential to document ongoing socioeconomic adaptations as well as perceptions of environmental damage and risk at active and abandoned mines throughout northern Canada. Because land use practices are distributed in space, and because the interview participants were comfortable relaying both the spatial and explanatory components of their land use, the adapted map biography method creatively captured the story of Aboriginal land use in a post-industrial landscape. The maps were both a method for recording information about land use in the vicinity of the former mine, as well as a tool that propelled conversations forward. By combining the spatially explicit techniques from landscape ecology and the nuanced local narratives available through a micropolitical ecology approach, it is also possible to assess ecological change in light of potentially changing perceptions of the post-industrial landscape through time. The integration of these long-term environmental and social datasets in follow-up studies could be useful in determining whether land users' perceptions of environmental damage or recovery corresponds meaningfully to the ecological condition of the site, or whether such perceptions could be attributed to shifting baseline syndrome (Pauly 1995, Alagona et al. 2012). It is important to apply interdisciplinary approaches to account for the spatial and temporal dynamics of land use and the environment as they change in tandem in response to industrial development, closure, and reclamation. Taken together, the parallel stories presented in this thesis become a compelling portrait of abandonment with implications for community consultation and reclamation planning.

Land cover conversion and land use near the abandoned mine are dynamic, ongoing processes of which the two components of this thesis are merely a snapshot. Further research on Aboriginal land use near the abandoned mine will be necessary as vegetation conversion gradually occurs over the course of many decades. Additionally, due the current reliance on wage labour at mines as a component of the mixed economy in Fort Resolution, future research on socioeconomic adaptation will be necessary if mining efforts proposed by Tamerlane Ventures are renewed at the Pine Point site. Finally, increased affordability of and access to high resolution satellite imagery would no doubt improve spatial analysis of how land cover at post-industrial landscapes behaves over time in the absence of active reclamation efforts.

Given the importance of land to the Aboriginal mixed economy and cultural identity, this thesis examined the changing relationships among environment, culture, and economy in the wake of industrial development, closure, and abandonment. The Pine Point case illustrates that the experience of industrial resource extraction in northern Canada does not end with the cessation of operations. Substantial environmental damage and Aboriginal land use both persist despite the mine having been shut down for more than twenty years. It is apparent that contemporary reclamation planning must account for local environments and economies in all stages of industrial development, from exploration to post-closure. Worrall (2009) points out that the extended impacts of a mine after abandonment poses a serious challenge to industry claims of sustainability. By identifying the long-term environmental and socioeconomic changes created by the development, closure, and abandonment of the Pine Point mine, the research presented in this thesis reinforces that point. If mining is to become sustainable, extractive industries must work with communities to craft a post-closure legacy that adequately addresses the environmental and socioeconomic needs of local people after remediation. This includes acknowledging and accounting for the relationships between post-industrial environments and fluid land use practices.

The ongoing use of the land as part of the Aboriginal mixed economy brings issues of abandonment, environmental damage, and community consultation to the fore in northern Canada. Globally, most current regulations for closure and remediation emphasize mitigating environmental impacts and reducing health and safety risks, with some jurisdictions also requiring formal consideration of socioeconomic impacts (Otto 2009). In Canada's territorial north, however, mine closure and remediation are governed by environmental regulation, which defers issues of socioeconomic impacts to the realm of corporate best practices (MMSD 2002). Many of these broad regulations fail to account for the particularities of local use after closure, which is especially important in Aboriginal contexts. Nolan (2009) calls for consultation with local Aboriginal communities during plans to clean up abandoned mines, acknowledging the interrelated nature of environmental health and socioeconomic wellbeing. Informed by the principles of micropolitical ecology, this thesis echoes the call for developers and policy-makers alike to explicitly consider the local environmental and socioeconomic conditions when undertaking remediation at extractive sites. Creating a post-industrial landscape that meets environmental standards and local, long-term socioeconomic needs requires consultation and collaboration throughout the process of closure and remediation.

The Pine Point case study demonstrates that the environmental effects of mining are persistent and that use of the degraded mining landscape continues after closure. This underscores the necessity of meaningful consultation during each phase of industrial development, including mine closure, remediation, and abandonment. Reclamation planning in northern Canada must be undertaken in collaboration with the local communities who use the land, and it must account for the shifting relationships among the environment, economy, and culture throughout each phase of industrial development. It is therefore apparent that meaningful engagement with local communities who used the land before industrial development and will use the land again after closure is essential if resource extraction is to be considered sustainable. The potential to improve reclamation planning and closure practices lies at the juncture of landscape ecology and micropolitical ecology. By accounting for broad political and economic forces as well as local environmental and socioeconomic conditions, developers and regulators can shape positive environmental and socioeconomic legacies and avoid the ongoing post-industrial challenges evident at the abandoned Pine Point mine.

By analyzing the varied, interrelated legacies of abandoned mines, it is possible to improve the practices of contemporary extractive operations. This thesis has shown that industrial mineral extraction results in long-term changes to the local landscape, from both an environmental and a socioeconomic perspective. As mining operations continue to expand, throughout northern Canada and globally, the requirements for closure, reclamation, and abandonment must become more inclusive and more comprehensive. Detailed plans for closure, reclamation, and abandonment must be developed in collaboration with local communities prior to exploration and development, and such plans must explicitly consider local environmental and socioeconomic conditions. By doing so, the long-term environmental and socioeconomic changes associated with industrial mineral development can be shaped into sustainable legacies for local environments and communities.

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APPENDICES

Appendix I: Sample Consent Form

MEMORIAL UNIVERSITY

INTERVIEW CONSENT FORM

Research Project:
Mapping Land Use and Landscape Change around the former Pine Point Mine

Researcher(s):
All researchers involved are from Memorial University of Newfoundland, and include:

- **Emma LeClerc** (principal researcher), Department of Geography
- **Dr. Arn Keeling** (co-supervisor), Department of Geography
- **Dr. Yolanda Wiersma** (co-supervisor), Department of Biology

Introduction
This research aims to document land use and landscape change in the region of Pine Point since the mine was shut down.

You are invited to take part in a semi-structured map biography interview in which I will ask you about your hunting, trapping, and other land use activities in the region of the abandoned Pine Point mine. Your insight will be used to create a more complete understanding of the long-term effects of the mine and the use of the land by the people of Fort Resolution.

Method and Duration
The principal researcher will carry out the map biography interview at a time and location convenient to you. The interview will last approximately one hour. I will ask you questions about hunting and trapping, and together we will record your responses on a paper map of the Pine Point region. To help accurately record your responses, the interview will be audio-recorded (with your consent). After your map biography interview, you will be able to review the map biography itself as well as the transcript of your interview. When you review these documents, you can add, change, or remove information as you see fit. A copy of your map biography will be provided to you upon completion of the study.

Interview Guidelines & Confidentiality

- The information obtained from the map biography interview will be used strictly for this research.
- Participants can request that the recording device be turned off at any time and can have responses removed from the map biography and the recording.
- Information of a private nature will not be sought during the map biography interview process and will not be published.
- Interview data files and interview transcripts will not be distributed, sold, or disseminated in any way, though selected quotes may be used in a published essay or book, *with permission*.
- Map biography interview participants will have the right to view and comment on this material prior to publication.
- Map biography interview participants may consent to allow their names to be used in a publication or may choose to remain anonymous. Participants that choose to remain anonymous will be identified generically or through a pseudonym, and other personal identifiers (such as gender) will be avoided.

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INTERVIEW CONSENT FORM

Data Storage
Map biographies, interview transcripts, and audio files will be securely stored by the researcher for a minimum of five (5) years, as per Memorial University policy on Integrity in Scholarly Research, and maximum of ten (10) years, after which the researcher's copies will be destroyed by deleting the electronic files and shredding any paper material that contains primary data (interview transcripts, field notebooks, etc.). Individual participants and the First Nation will retain copies of the information beyond this time.

Right to Refuse or Withdraw
The participant will be able to withdraw from the research project at any time, without having to give a reason and will not suffer any kind of prejudice for doing so. Should the participant choose to withdraw, all of his/her data will be destroyed and will not be used in this research.

Consent Statement
I, ________________________________ (print name), freely consent to participate in the following aspects of the research project (check appropriate boxes):

- ☐ Conduct of an individual map biography interview
- ☐ Identification of participant
- ☐ Recording of responses on a paper map & secure storage of this map biography
- ☐ Digital recording of the interview and secure storage of this audio recording
- ☐ Transcription, printing, & secure storage of the audio recording
- ☐ Use of map biography interview material (both the map biography itself & the transcript of the audio recording) for research & publication purposes related to the topic of the study as indicated above only
- ☐ Storage of audio recordings, transcripts, & map biographies with DKFN or Métis Council; further use subject to consent of participant

Signature of Participant _______________________ **Date** _________

Signature of Researcher _______________________ **Date** _________

The proposal for this research has been reviewed by the Interdisciplinary Committee on Ethics in Human Research (ICEHR) and found to be in compliance with Memorial University's ethics policy. If you have ethical concerns about the research (such as the way you have been treated or your rights as a participant), you may contact the Chairperson of the ICEHR at icehr@mun.ca or by telephone at 709-864-2861.

If you have any concerns, please contact Emma LeClerc or her co-supervisors (see contact info below), who will do their best to answer your questions.

Emma LeClerc (principal researcher)
Email: ekl205@mun.ca

Dr. Yolanda Wiersma (co-supervisor)
Email: ywiersma@mun.ca
Phone 709-864-7499

Dr. Arn Keeling (co-supervisor)
Email: akeeling@mun.ca
Phone: 709-864-8990

Appendix II: Sample Interview Questions

Sample Map Biography Interview Questions

Information Category	Question
Biographical	Name
	Age (or year born)
	Where are you from?
	Where do you live now?
Hunting	What kinds of animals do you hunt?
	What general purpose does each animal serve? (e.g. food/ sale/other)
	Where do you hunt each kind of animal?
	What season(s) do you hunt each kind of animal? (e.g. July-October)
	What time period(s) do you or did you hunt each kind of animal? (i.e. at closure, in-between, at present)
	How do you access these locations?
Trapping	What kinds of animals do you trap?
	What general purpose does each animal serve? (e.g. food/ sale/other)
	Where do you trap each kind of animal?
	What season(s) do you trap each kind of animal? (e.g. July-October)
	What time period(s) do you or did you trap each kind of animal? (i.e. at closure, in-between, at present)
	How do you access these locations?
Plant Collecting	What kinds of plants do you collect?
	What general purpose does each plant serve? (e.g. food/ medicinal/sale/other)
	Where do you collect each kind of plant?
	What season(s) do you collect each kind of plant? (e.g. July-October)
	What time period(s) do you or did you collect each kind of plant? (i.e. at closure, in-between, at present)
	How do you access these locations?
Other Land Uses	What other ways do you use the land, that we haven't talked about?
General Landscape Change	What kinds of landscape change, if any, have you noticed since the mine closed?
	Have these changes affected your use of the land in any way?
Final Questions	Is there any story about using the land that you would like to share? Anything we haven't covered that you would like to discuss?

Appendix III: Interview Coding Structure

Category Codes	Axial Codes	Key Quotes
Hunting, Trapping, & Working		
	Changing LU to accommodate wage labour	
	Mine as general/unspecified impediment to hunting/trapping	
	Mine as physical/environmental impediment to hunting/trapping	
	Mine as socioeconomic impediment to hunting/trapping	
	Mine encouraging hunting/trapping	
	Post-closure use	
	Benefits of hunting/trapping	
	Industrial work	
	Hunting/Trapping as main income	
	Other reasons to stop trapping	
Accessing the Land		
	Mine impeding access	
	Post-mining	
	During operations	
	Mine facilitating access	
	Undefined time period	
	During operations	
	Maintenance of infrastructure (e.g. cutlines) for hunting/trapping	

	Cutting lines through uncleared bush	
	Other industrial improvements to access (e.g. logging roads)	
	Natural access	
Environmental Effects of Pine Point		
	Changes in water	
	Dead vegetation or recovery	
	Fewer animals	
	Direct damage	
	Other/general concerns	
Family & Sharing		
	Passing on knowledge	
	Hunting/trapping partners	
	Safety	
	Sharing meat	
	Older family hunting/trapping	
	Other	
Wildlife Observations		
	Variability, defined and undefined	
	Influence of the mine	
	Wildlife near the mine	
	Unusual	
	Other	
Transportation		
	Accessibility	

	Multiple modes of transportation	
	Advantages of snowmobiles	
	Vehicle facilitating land use	
	Dog team	
	Other	
Influence of Other Land Users		
	Respecting unofficial boundaries	
	Sharing areas	
	Teaming up	
Money		
	Making a living hunting/trapping	
	Difficulty of hunting/trapping	
	Working at Pine Point	
	Other work	
	Other	
Other Environmental Concerns		
	Avalon proposal	
	Tamerlane proposal	
	Tar sands	
	Over-harvesting	
	Hydroelectric development	
	Anthrax	
	Forests fires	
	General	

Mapping Land Use		
	Too much to map/remember	
	Hard to find exact place	
	"No use marking it"	
	Map too small	
	Map scale too broad	