Assessing the Cumulative Effects of Environmental Change on Wildlife Harvesting Areas in the Inuvialuit Settlement Region through Spatial Analysis and Community-based Research

by

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Bachelor of Arts, Colby College, 2009

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Supervisory Committee

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Abstract

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Arctic ecosystems are undergoing rapid environmental transformations. Climate change is affecting permafrost temperature, vegetation structure, and wildlife populations, and increasing human development is impacting a range of ecological processes. Arctic indigenous communities are particularly vulnerable to environmental change, as subsistence harvesting plays a major role in local lifestyles. In the Inuvialuit Settlement Region (ISR), in the western Canadian Arctic, indigenous land-users are witnessing a broad spectrum of environmental changes, which threaten subsistence practices. Local cumulative effects monitoring programs acknowledge the importance of subsistence land use; however there are few cumulative effects assessments that measure the impact of environmental change on land-based activities. My MSc addresses this gap with a broad-scale spatial inventory that measures the distribution of multiple disturbances in the mainland ISR, and assesses their overlap with community planning areas, land management zones, and caribou harvesting areas. I also generated nine future disturbance scenarios that simulate increases in both human development and wildfire occurrence, in order to understand how additional environmental change may affect the availability of un-impacted harvesting lands. I used the conservation planning software, Marxan, to assess the impact of increasing environmental perturbations on the availability and contiguity of 40 subsistence harvesting areas. Results show that the study region is

already impacted by multiple environmental disturbances, and that these disturbances overlap considerably with wildlife harvesting areas. This limits the success of Marxan runs that attempt to conserve high percentages of subsistence use areas. It becomes increasingly difficult to conserve large, contiguous assortments of wildlife harvesting areas when using Marxan to assess conservation potential in future disturbance scenarios.

In a separate study, I conducted 20 semi-structured interviews in the communities of Inuvik, Aklavik, and Tuktoyaktuk that explored the impact of environmental change on Inuvialuit land-users. Participants in my study indicated that wildlife harvesting in the region is being affected by a range of environmental disturbances and that this change is typically considered to be negative. Climate change-related disturbances were noted to affect travel routes, access to harvesting areas, wildlife dynamics, and the quality of meat and pelts. Human activity, such as oil exploration, was noted to impact both wildlife populations and harvesters' ability to use the land. These observations are an important contribution to local cumulative effects monitoring because they highlight local accounts of environmental change, which are often missed in broad-scale assessments, and they emphasize the concerns of local land-users. This underscores the importance of including indigenous insights in cumulative effects monitoring and suggests that combining quantitative assessments of environmental change with the knowledge of local land-users can improve regional cumulative effects monitoring.

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Dedication

This thesis is dedicated to Steven George Gerrard.

Chapter 1

INTRODUCTION

A multitude of human activities (resource extraction, industrial activity, road construction, etc.), combined with a changing climate, are dramatically altering ecosystems worldwide. Habitat loss and fragmentation due to human development are well established drivers of biodiversity loss (Noss et al. 1996, Debinski and Holt 2000) and global climate change is impacting biodiversity worldwide (Brooke et al. 2008, Garcia et al. 2014). Individual changes may seem insignificant due to their small spatial or temporal scales, however when combined with other disturbances over space and time, the cumulative effects of these perturbations significantly alter ecological values (Spaling 1994). This phenomenon of cumulative effects is well documented in scientific literature, particularly in areas where increasing levels of natural resource development and human activity overlap with altered natural disturbance regimes (Spaling 1994, Hegmann et al. 1999, Duinker et al. 2013). While cumulative effects lack a singular definition, they are typically referred to as changes to the environment that combine with other current, previous, or near future disturbances, often impacting a specific valued ecosystem component (VEC) and existing over large spatial and temporal scales (Hegmann et al. 1999). Cumulative effects modeling is increasingly used to understand the impact of a variety of stressors on a multitude of ecological values, ranging from specific wildlife habitat (Gunn et al. 2011, Strimbu and Innes 2011) to the broad human footprint in an ecosystem (Ban and Alder 2008, Halpern et al. 2008, Terra and Santos 2012).

The cumulative effects of environmental change are of particular concern across the Arctic, where climate change and increasing human disturbance are rapidly altering ecological processes. Climate change is resulting in shrub proliferation and changes in vegetation structure (Lantz et al. 2010), increased permafrost thaw and slumping (Kokelj et al. 2010, 2013), more frequent and intense wildfires (Higuera et al. 2008, de Groot et al. 2013), and altered wildlife patterns and behavior (Post et al. 2009). Increased human disturbances, such as road construction and mineral and oil exploration, are also affecting a range of ecological processes across Arctic landscapes, including vegetation structure and wildlife populations (Johnson et al. 2005, Myers-Smith et al. 2006, Gunn et al. 2011, Gill et al. 2014). The significance of these changes is reflected in the increasing use of cumulative effects assessments to evaluate the impacts of proposed development projects in an effort to monitor and mitigate the effects of environmental change in the Arctic (Government of Canada 1998, National Energy Board 2009, SLUPB 2013).

Landscape change has the potential to significantly affect human communities that regularly interact with their local environment through subsistence harvesting (Berkes and Jolly 2001, Parlee et al. 2012, Shanley et al. 2013). This is particularly true in many northern indigenous communities, where the impacts of environmental change may have far-reaching effects due to a high reliance on local landscapes for subsistence use and cultural continuity (Furgal and Seguin 2006, Parlee et al. 2012). For example, Arctic communities that rely on local ecosystems for subsistence harvesting may suffer a decrease in food security as regularly hunted wildlife populations are affected by environmental change (Young and Einarsson 2004). Concern regarding the impacts of environmental change on local communities has resulted in an emerging sub-field of cumulative effects research that seeks to understand the impacts of environmental disturbance on culturally important ecosystem components (Ehrlich and Sian 2008, Mitchell and Parkins 2011, Parlee et al. 2012, Spyce et al. 2012). However, this field is still relatively young, and few studies have assessed the impacts of environmental change on cultural practices (Mitchell and Parkins 2011).

My MSc explores this gap by researching the cumulative effects of environmental disturbance on wildlife harvesting areas in the Inuvialuit Settlement Region (ISR). Located in the western Canadian Arctic, the ISR provides critical habitat for a suite of marine and terrestrial species (Alunik et al. 2003) and is the traditional territory of the Inuvialuit, who rely on the land for hunting, trapping, whaling, and fishing (Alunik et al. 2003, Joint Secretariat 2003, Furgal and Seguin 2006). As such, this area holds great cultural and ecological significance. It is also rapidly changing. Industrial development accompanied major hydrocarbon exploration in the 1960s and '70s and is expected to restart with renewed interest in resource extraction. The region is also experiencing increasing environmental transformations associated with climate change (Burn and Kokelj 2009, Pearce et al. 2011, Kokelj et al. 2013). The impacts of these perturbations have raised questions among residents - many of whom depend on the land for subsistence use - about the ecological and cultural effects of landscape change (Bennett and Lantz 2014). Despite the recognized importance of cumulative effects monitoring in regional governance (Government of Canada 1998, Mackenzie Valley Review Board 2005, National Energy Board 2009), there is a lack of literature that: 1) quantifies the degree to which culturally important landscapes are impacted and 2) explores the specific impacts of disturbance on wildlife harvesting in ISR.

Based on this gap in research, the overarching goal of my MSc is to assess the cumulative effects of environmental change on wildlife harvesting areas in the ISR. In addressing this goal, I have four main research objectives: 1) to spatially assess the cumulative effects of environmental disturbance on culturally significant terrestrial ecosystems in the ISR; 2) to model the impact of these disturbances on conservation potential in the region; 3) to identify how Inuvialuit knowledge can contribute to our understanding of cumulative effects in culturally important landscapes; and 4) to assess the implications of these changes for Inuvialuit subsistence wildlife harvesting. I address these objectives using two approaches. The first is a spatial analysis of landscape disturbances and their impact on Inuvialuit harvesting areas (Objectives 1 and 2). The second is a series of semi-structured interviews that explore Inuvialuit knowledge of the impacts of landscape change on wildlife harvesting (Objectives 3 and 4). In this thesis, these approaches are presented as stand-alone papers, intended for journal submission.

The first paper is presented in Chapter 2, and uses spatial analysis to explore the following question: *What are the cumulative effects of environmental disturbance on culturally significant ecosystems in the ISR and how does this impact conservation potential in the region?* To answer this question, I conducted a spatial analysis of the southern ISR, in which I assembled GIS data on known disturbances in the region, and assessed their impact on areas that Inuvialuit Community Conservation Plans identify as important for wildlife harvesting (AICCP 2008, IICCP 2008, PCCP 2008, TCCP 2008). As part of this research I also generated nine future disturbance scenarios, in which I simulated increased human development and wildfire occurrence in the region. Subsequently, I used the conservation planning software, Marxan (Ball et al. 2009), to assess the impact of these scenarios on the availability of contiguous, un-impacted wildlife harvesting areas in the region.

The second paper is presented in Chapter 3, and explores the questions: *(1) How can Inuvialuit knowledge and observation contribute to our understanding of cumulative effects on culturally important landscapes? and (2) What are the implications of these changes for Inuvialuit subsistence wildlife harvesting?* To answer these questions, I conducted 20 semi-structured interviews in the communities of Aklavik, Inuvik, and Tuktoyaktuk, asking Inuvialuit land-users to: 1) describe the impacts of specific environmental disturbances on their hunting and trapping efforts, 2) discuss major historic changes in the region, and 3) identify concerns for the future of wildlife harvesting in the ISR. I analyzed interview transcripts to identify emergent patterns by coding responses using 17 themes that reflected: 1) the type of changes witnessed, 2) the positive and negative effects of specific environmental disturbances, and 3) general attitudes towards environmental change and the state of wildlife harvesting in the ISR. Participant responses were also categorized based on the area and time period to which they applied.

In Chapter 4, I synthesize the research presented in Chapters 2 and 3 and discuss the benefits of utilizing both quantitative modeling and community-based research to understand cumulative effects on culturally important ecosystems. In this chapter, I also discuss possible avenues for future research and potential applications of this type of work.

The remainder of this chapter is dedicated to providing critical context for my research, and provides important background information on Inuvialuit land use and occupancy, the use of indigenous knowledge in environmental research, cumulative effects assessments, and Marxan modeling.

INUVIALUIT LAND USE AND OCCUPANCY

The Inuvialuit are the Inuit occupants of the western Canadian Arctic. Six Inuvialuit sub-groups traditionally occupied a large region that included areas presently known as the Yukon coast, Herschel Island, the Mackenzie River, Kugmallit Bay, Husky Lakes, Cape Bathurst, and Anderson River (Alunik et al. 2003). This area is biologically rich in comparison to many other regions of the Circumpolar Arctic, and its abundance and diversity of wildlife has helped to shape an Inuvialuit cultural identity that is strongly influenced by subsistence harvesting (Alunik et al. 2003).

The region supports numerous marine and terrestrial wildlife species that are relied on for hunting, trapping, whaling, and fishing (Berkes and Jolly 2001, Alunik et al. 2003, Pearce et al. 2011). Both marine and terrestrial species are routinely harvested by the Inuvialuit (Harwood et al. 2002, Alunik et al. 2003, Joint Secretariat 2003), and continue to serve as culturally, nutritionally, and economically important resources in a region with few wage earning opportunities and minimal options for store-bought foods (Schlag and Fast 2003, GNWT 2008, Andrachuk and Smit 2012). Harvesting patterns in each community vary based on their proximity to terrestrial or marine habitats, but key species in the ISR include caribou (*Rangifer tarandus groelandicus),* muskrat *(Ondatra zibethicus),* snow geese *(Chen caerulescens)*, beluga whales *(Delphinapterus leucas)*, muskox *(Ovibos moschatus)*, ringed seal *(Pusa hispida),* bearded seal *(Erignathus barbatus)* and numerous fish species (Usher 2002, Alunik et al. 2003, Joint Secretariat 2003).

In 1984, the Inuvialuit Final Agreement (IFA) was signed, establishing the Inuvialuit Settlement Region (ISR), an area covering 906,430 square kilometers and including six small communities; Inuvik, Aklavik, Tuktoyaktuk, Paulatuk, Sachs Harbour, and Ulukhaktok. The IFA is the guiding document for land-use planning in the region, and was a response to recommendations put forth for increased conservation planning and management in the face of growing development pressure from the oil industry (Fast et al. 2005). While the IFA does not result in self-government, it provides a co-management framework that allows for meaningful input in the political process, a strong Inuvialuit voice in development decisions, and a means for seeking compensation for damages that occur to lands within the ISR (Alunik et al. 2003, Pearce et al. 2011).

The IFA provides a framework "*a) to preserve Inuvialuit culture and values within a changing Northern society; b) to enable Inuvialuit to be equal and meaningful participants in the Northern and national economy and society; c) to protect and preserve the Arctic wildlife, environment and biological productivity,"* and governance in the region resulted in the creation of a number of local and regional co-management bodies that monitor and respond to trends in wildlife harvesting (Department of Indian and Northern Affairs Canada 1984). Local Hunter Trapper Committees provide avenues for wildlife harvesters to inform research and management initiatives through observations that emerge directly from subsistence harvesting (Department of Indian and Northern Affairs Canada 1984, Harwood et al. 2002, Cobb et al. 2008, Environment and Natural Resources 2011) and regional management increasingly incorporates the knowledge and practice of local harvesters (Kocho-Schellenberg and Berkes 2015). The importance of natural resources is also reflected in a growing effort to monitor environmental disturbances in the region by drawing on expert land-users to both identify changes to the land and give cultural context to their significance (Nickels et al. 2002, Kokelj et al. 2012, Bennett and Lantz 2014).

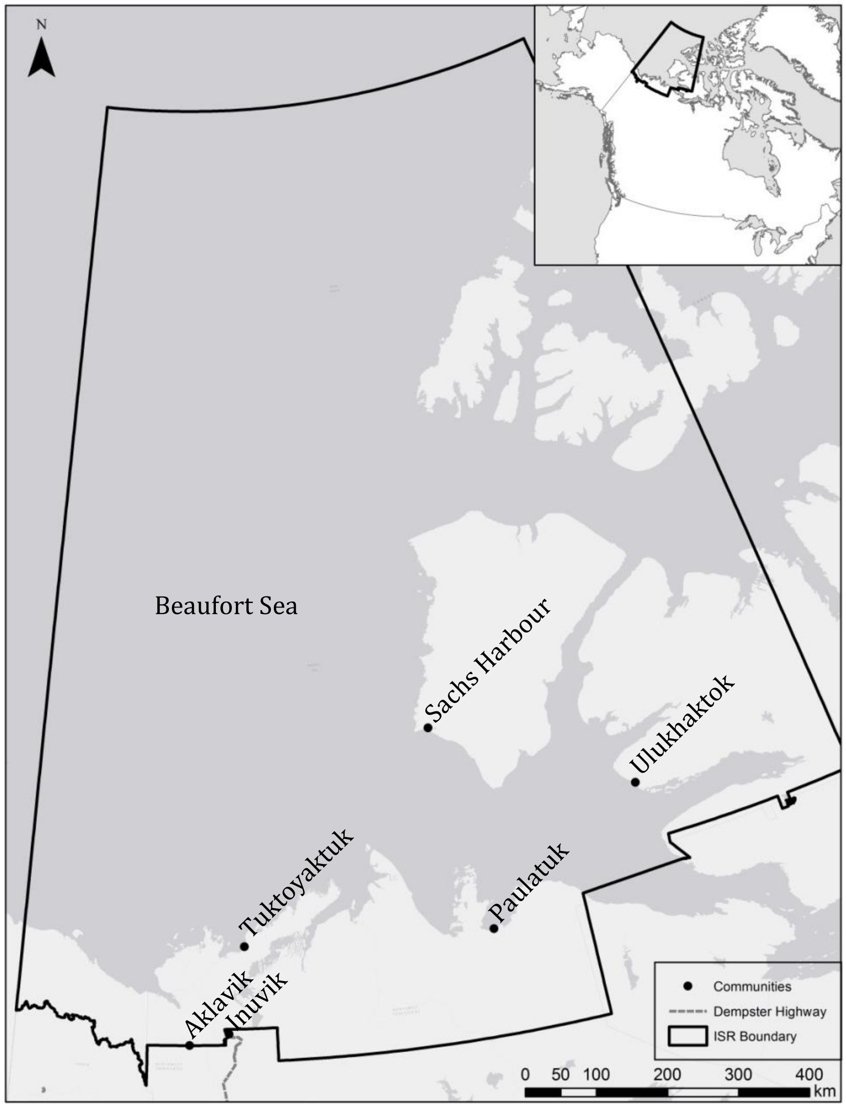

Figure 1-1: The Inuvialuit Settlement Region (ISR) is located in the Western Canadian Arctic, contains six communities, and covers 906,430 km^2.

CUMULATIVE EFFECTS ASSESSMENTS

Landscape management must consider the effects and interactions of multiple disturbances, arising from a variety of sources. Individual stressors may seem insignificant due to their small spatial or temporal scales, however when combined with other disturbances over space and time, perturbations can accumulate to create a significant environmental impact (Spaling 1994). This phenomenon is well documented in the scientific literature, particularly in Canada, where increasing levels of natural resource development have led to the wide usage of cumulative effects assessments (CEAs) to evaluate the impacts of disturbances ecosystems (Spaling 1994, Hegmann et al. 1999, Duinker et al. 2013). While cumulative effects lack a singular definition, they are typically referred to as changes to the environment that combine with other current, previous, or near future disturbances, often affecting a specific valued ecosystem component (VEC) and existing over large spatial and temporal scales (Hegmann et al. 1999).

Efforts to model these effects have become an integral part of the CEA process and a review of relevant literature shows that a diversity of approaches have been taken to address the impacts of numerous forms of human development on a wide array of VECs (Johnson et al. 2005, Halpern et al. 2008, Seitz et al. 2010, Gunn et al. 2011, Dubé et al. 2013). Cumulative effects modeling is conducted across a broad spectrum of ecosystems (Johnson et al. 2005, Halpern et al. 2008, Seitz et al. 2010, Terra and Santos 2012), and models operate at widely different scales. Cumulative effect studies range from broad, landscape-scale, assessments of human-induced change (Halpern et al. 2008, Schultz 2010, Terra and Santos 2012), to studies that assess the specific impacts of selected disturbances on individual wildlife species or ecological values (Gunn et al. 2011, Strimbu and Innes 2011). Models that focus on a select VEC, such as wildlife habitat, may incorporate specific measures of degradation caused by the accumulation of particular disturbances (Johnson et al. 2005, Myers-Smith et al. 2006, Gunn et al. 2011), while more broad, additive approaches towards cumulative effects modeling are typically used to assess the general human footprint in a large region through inventorying a list of disturbance types (Ban and Alder 2008, Halpern et al. 2008, Terra and Santos 2012).

CEAs increasingly acknowledge that environmental disturbance impacts cultural practices, and a growing field of literature attempts to apply a cumulative effects framework towards culturally significant values (Ehrlich and Sian 2008, Francis and Hamm 2011, Parlee et al. 2012, Spyce et al. 2012). This is particularly important in indigenous communities, which often face a choice between industrial job opportunities and maintaining cultural practices and a place-based identity (Francis and Hamm 2011, Parlee et al. 2012). Thus far, approaches towards cultural cumulative effects research are varied, and include: historical analyses of development and associated cultural shifts (Christensen and Krogman 2012), assessments of current community observations of environmental changes (Parlee et al. 2012), and focus group surveys regarding the significance of environmental change (Ehrlich and Sian 2008). My research builds on this growing sub-set of cumulative effects research by creating a tractable measure of cumulative effects in culturally significant ecosystems and using interviews to provide cultural context regarding the significance of the impacts in the study region.

INDIGENOUS KNOWLEDGE IN ENVIRONMENTAL RESEARCH

Indigenous land-users who spend extensive amounts of time on the land often possess a wealth of information regarding local ecosystems (Berkes 1999, Usher 2000, Riedlinger and Berkes 2001). This is one aspect of a domain of knowledge referred to as Traditional Ecological Knowledge (TEK). TEK is usually defined as *"the cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment"* (Berkes 1999).

TEK is increasingly incorporated in environmental research and has proven to be beneficial and reliable in both academic and management contexts. Local land-users can provide expert insight into ecological conditions, based on their extensive knowledge and first-hand experience of local landscapes (Dowsley 2009, Kokelj et al. 2012, Polfus et al. 2014, Bennett and Lantz 2014), and comparisons between these observations and quantitative research in the natural sciences have proven that TEK is reliable in describing local ecological patterns, such as wildlife behavior or habitat selection (Gilchrist et al. 2005, Dowsley 2009, Polfus et al. 2014). As such, there has been a proliferation in research that relies on TEK for a variety of purposes ranging from understanding local ecological processes, to monitoring environmental change, or guiding conservation efforts (Riedlinger and Berkes 2001, Garibaldi and Turner 2004, Kokelj et al. 2012). This is particularly true in regions that are logistically complex or costly to study, such as the Arctic (Riedlinger and Berkes 2001). As TEK has become an increasingly valued source of information, there has been a parallel growth of government policy that calls for the explicit integration of indigenous knowledge, observation, and practice in land use management, particularly in Canada (Department of Indian and Northern Affairs Canada 1984, Usher 2000, Berkes and Jolly 2001, Armitage et al. 2011).

Academic literature contains a wide variety of approaches to utilize the TEK of indigenous people in natural resource management (Berkes 1999, Usher 2000, Wohling 2009). The collection and dissemination of TEK frequently occurs through: participatory mapping of indigenous land-use, recorded interviews, or workshops on environmental observations (Tobias 2000, Houde 2007). These products often serve as the primary means of representing indigenous interests in land-use management (Houde 2007).

Despite the growing integration of indigenous knowledge with Western science and land management practices, the simple acknowledgement of TEK does not guarantee its successful incorporation with management regimes. In contrast to Western science, TEK includes values, beliefs, and practices, which form an integral part of local natural resource management (Berkes 1999, Usher 2000, Houde 2007), As such, efforts to apply TEK to pre-existing management practices may result in the compartmentalization of complex knowledge systems or the misapplication of knowledge beyond the realm of indigenous observation (Nadasdy 2003, Houde 2007, Wohling 2009). Placing indigenous knowledge within the confines of Western land management can also constrain the effectiveness of TEK, subjugating it in comparison to scientific knowledge that is more easily integrated with bureaucratic governing structures (Nadasdy 1999, 2003, Cruikshank 2001). This is especially true in instances where the belief that TEK is less reliable or valuable than quantitative research can create power dynamics and mistrust between Western scientists and indigenous knowledge holders (Nadasdy 1999).

Instead of placing TEK at odds with Western science, advocates of indigenous knowledge increasingly suggest that both forms of knowledge have the potential to inform one-another and are best used in tandem (Moller et al. 2004, 2009, Berkes 2009, Kokelj et al. 2012). For example, in regards to wildlife harvest monitoring, traditional knowledge can be used to provide knowledge of historical population levels and detailed accounts of local conditions, while biological sampling is not tied directly to harvesting and can, therefore, offer insights on a greater spatial scale (Moller et al. 2004). Indigenous knowledge and Western science are both utilized in the co-management of the ISR. For example, in the case of an Arctic storm surge, Western science and TEK were used in tandem to document the historical significance of ecological impacts and the ramifications of saline incursion on local ecosystems (Kokelj et al. 2012).

My thesis research explores another area where indigenous knowledge and quantitative research may complement one-another. Based on the established history of Inuvialuit knowledge and scientific research working in tandem (Kokelj et al. 2012), this research uses both spatial modeling and expert insight from land-users to explore the impacts of environmental change on subsistence harvesting in the ISR. Using both approaches seeks to draw on the strengths of each, such as the ability for quantitative research to address larger spatial scales and create replicable methods (Moller et al. 2004) and the ability of indigenous knowledge to provide extremely detailed, local observations and provide context for the significance of ecological change (Riedlinger and Berkes 2001, Moller et al. 2004, 2009, Pearce et al. 2010, Kokelj et al. 2012).

MARXAN MODELING

Marxan is spatial selection software designed to identify efficient solutions to conservation problems (Ball et al. 2009). Marxan was developed in order to address the problem of identifying the minimum reserve set design: the conservation area that protects the minimum total area necessary to conserve all species in question (Possingham et al. 2010). Marxan can be used to identify protected areas that conserve user-defined conservation values (e.g. species habitat), while incurring a low cost and maintaining a contiguous area. In Marxan analysis, the study area is divided into multiple planning units (e.g. grid cells, hexagons, hydrological units, etc.) and outputs consist of assemblages of planning units that meet conservation targets, while incurring a low cost. The cost data used to drive Marxan optimizations typically refers to value that the process seeks to minimize, such as the actual socio-economic cost of including an area in a conservation output. However, this can also include any other type of undesirable feature, such as the level of degradation that currently exists in an area (Fischer et al. 2010). For example, if cost is defined as the actual monetary price of acquiring land and the conservation values in question are plant species, Marxan optimizations can be used to determine the lowest monetary investment required to protect a given percentage of all species' ranges (Possingham et al. 2010). Marxan relies on heuristic (non-exact) algorithms, which generate a number of near-optimal solutions, rather than creating a single optimum solution (Ball et al. 2009). The generation of a range of solutions, rather than a single output, also allows Marxan-users to compare across solutions, analyzing the frequency in which certain planning units are selected in optimizations, and identifying "irreplaceable" planning units; areas that are selected in most or all of the iterations (Fischer et al. 2010).

Marxan analysis has proven useful in a number of conservation contexts, including: marine protected area planning in the face of climate change (Levy and Ban 2013), global conservation prioritization of terrestrial mammal habitat (Ceballos et al. 2005), and retrospective evaluation of existing conservation areas (Hansen et al. 2011). Marxan is useful in such a broad range of scenarios because its parameters are easily manipulated and users can prioritize a range of characteristics, such as the importance placed on maintaining output contiguity, the value of including all conservation targets in an output, or the degree to which high-cost planning units are avoided (Fischer et al. 2010, Possingham et al. 2010). My MSc research uses Marxan to assess the potential to conserve wildlife harvesting areas in the ISR under current and future conditions by identifying spatial outputs that include varying percentages of 40 individual subsistence use areas, while tracking the changes in output success rates, spatial configurations, and overall cost (disturbance levels).

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Chapter 2

Cumulative Effects of Environmental Change on Culturally Significant Ecosystems in the Inuvialuit Settlement Region: a spatial analysis

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ABSTRACT

The Inuvialuit Settlement Region (ISR), in the western Canadian Arctic, is experiencing environmental change that impacts subsistence harvesting practices and is of concern to local communities (Berkes & Jolly 2001; Pearce et al. 2010; Bennett & Lantz 2014). In order to assess the impacts of multiple disturbances on culturally important ecosystems in the ISR, we created a cumulative disturbance map that represents relative intensity of terrestrial disturbances across the study region. We then assessed the relative level of environmental disturbance in important harvesting areas and management zones. Subsequently, we modeled nine future disturbance scenarios that included combinations of increased human impacts and higher occurrences of wildfire. Using the conservation planning software, Marxan, we assessed the potential to conserve large, contiguous areas of un-impacted harvesting lands across all scenarios. Results show that important management zones, wildlife harvesting areas, and community planning zones are all impacted by environmental disturbances. Marxan optimizations show that existing disturbance levels create thresholds for current conservation potential and indicate that future disturbances will further limit conservation potential. This suggests that, in order to maintain conservation objectives, land-use planning must account for future disturbances associated with climate change.

INTRODUCTION

Intensifying human impacts on the environment, combined with a changing climate, are dramatically altering ecosystems worldwide (Steffen et al. 2015). Habitat loss and fragmentation due to human development are well established drivers of biodiversity loss (Noss et al. 1996; Debinski & Holt 2000) and the interaction between these disturbances and a changing climate are accelerating ecological transformations (Brooke et al. 2008; Garcia et al. 2014). This is particularly relevant in the Arctic, where increases in air and ground temperatures are well above the global average (Serreze et al. 2000), and human development is occurring in previously un-impacted ecosystems (Johnson et al. 2005; Kiggiak 2011). On the surface, individual changes may seem small and insignificant, but when combined with other disturbances, the cumulative effects of environmental perturbations can significantly alter ecosystem function (Spaling 1994). Cumulative environmental impacts are often measured over large spatial and temporal scales and refer to the accumulation of current, previous, or near future disturbances, impacting valued ecosystem components (VECs) (Hegmann et al. 1999).

Cumulative landscape change has the potential to affect communities that are linked to their local environment through subsistence harvesting (Berkes & Jolly 2001; Parlee et al. 2012; Shanley et al. 2013). This is particularly true in Arctic indigenous communities, where a high reliance on local landscapes for food security intensifies the impact of environmental change on human health and community well-being (Furgal & Seguin 2006; Corell 2006). An emerging sub-field of cumulative effects research seeks to understand the impacts of environmental change on cultural VECs (Ehrlich & Sian 2008; Mitchell & Parkins 2011; Parlee et al. 2012; Spyce et al. 2012). However, to date very little research has explored the overlap between cumulative environmental change and landscape-scale patterns of subsistence use (Mitchell & Parkins 2011).

To address this gap, this research explores the cumulative effects of multiple environmental disturbances on culturally important ecosystems in the Inuvialuit Settlement Region (ISR), in the western Canadian Arctic. Ecosystems in the ISR provide critical habitat for a suite of marine and terrestrial species (Yukon Ecoregions Working Group 2004; Ecosystem Classification Group 2009, 2012). This region is also the traditional territory of the Inuvialuit, who rely on the land for hunting, trapping, whaling, and fishing (Usher 2002; Alunik et al. 2003; Furgal & Seguin 2006; Bennett 2012). The ISR has also been impacted by industrial development associated with hydrocarbon exploration, and is experiencing environmental transformations associated with climate change (Burn & Kokelj 2009; Pearce et al. 2011). The impacts of these perturbations have raised concern among residents - many of whom depend on the land for subsistence use - about the ecological and cultural effects of landscape change (Bennett and Lantz 2014). However, we are not aware of research that quantifies the cumulative impact of environmental change on culturally significant landscapes in the ISR.

To investigate the cumulative effects of environmental change on wildlife harvesting areas in the ISR, as well as the vulnerability of these areas to future disturbance, we quantified the amount of environmental change that has occurred in culturally significant ecosystems across the mainland ISR over the past 50 years. We also assessed future impacts by developing nine scenarios of increased disturbance, and used Marxan software (Ball et al. 2009) to explore the impact of increasing environmental disturbance on the amount of contiguous habitat and the spatial configuration of intact wildlife harvesting areas.

METHODS

Study Area

This study focuses on the southern Inuvialuit Settlement Region (ISR), which we define as the mainland portion of the ISR (Figure 1). Vegetation structure in this region changes with increasing latitude, and can be divided into four broad zones: high boreal forest, low subarctic, high subarctic, and low arctic tundra (Timoney et al. 1992). The northern portion of the ISR is characterized largely by upland tundra, while subarctic boreal forest extends through the southern portion of the Mackenzie Delta and southeastern ISR (Burn & Kokelj 2009; Ecosystem Classification Group 2012). Alpine tundra dominates the Richardson Mountains to the west (Yukon Ecoregions Working Group 2004). There are four small communities in the study area: Inuvik (Pop. 3,484), Aklavik (Pop. 594), Tuktoyaktuk (Pop. 854), and Paulatuk (Pop. 313). Beyond the municipal boundaries of these communities, human impacts to the land stem largely from a history of hydrocarbon exploration in the region (Burn & Kokelj 2009). To quantify the cumulative impact of natural and human-caused disturbance in the region, we divided the 131,331 km^2 area into a grid of 5,815 (25 km^2) planning units (Figure 1).

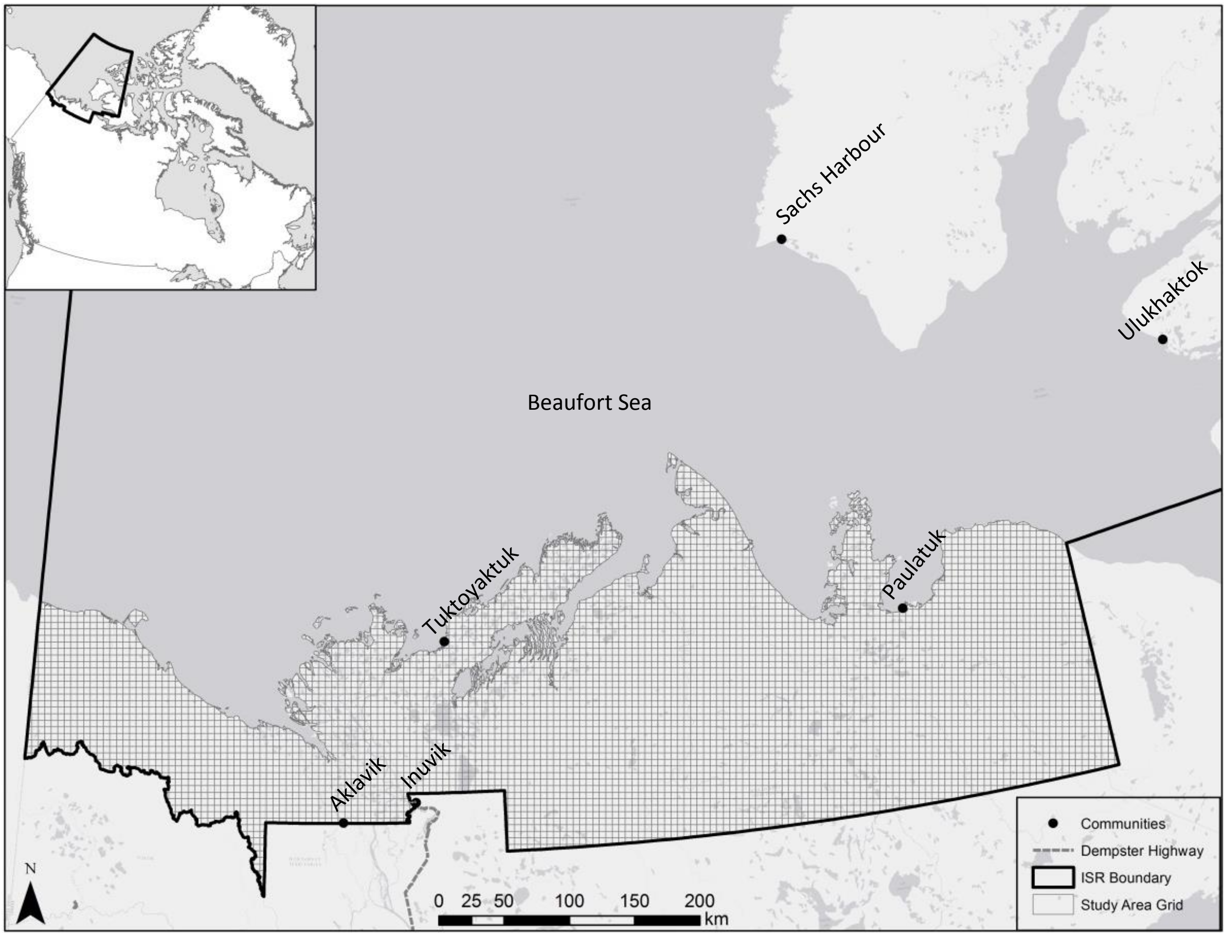

Figure 2-1: Study area map. The Inuvialuit Settlement Region (ISR) is located in the western Canadian Arctic, and covers an area of 906,430 km^2, including communities on both the mainland and Arctic Islands. We defined our study area as the mainland ISR, which covers an area of 131,331 km^2. This area includes the communities of Inuvik, Aklavik, Tuktoyaktuk, and Paulatuk. We applied a grid of 25 km^2 cells to the region, creating 131,331 unique planning units, which were used to tabulate levels of environmental disturbance.

Disturbances

Current Disturbances

To assess cumulative impacts to terrestrial ecosystems in the region, we obtained spatial data on disturbances from a variety of sources (Table 3), and used them to estimate the proportion of each planning unit directly affected by the disturbance.

Seismic lines were mapped using polyline coverage available for both the Yukon (Yukon Energy, Mines, and Resources 2014) and Northwest Territories (WWF 2002). Air photos from the Tuktoyaktuk Coastlands (NWT Geomatics 2004) with a resolution of ~0.5m were used to estimate the width of a typical seismic line. Subsequently, polylines were buffered to create shapefiles that extended 3.5 m on either side of the line features, the average width we measured in air photos. Similarly, to map the Ikhill Pipeline, which extends from Inuvik to a gas field approximately 49 kilometers to the north, we used aerial imagery to determine that the right of way typically extends 7.5 meters on either side of the pipeline (NWT Geomatics 2004). We combined aerial imagery of Inuvik, Tuktoyaktuk, Aklavik, and Paulatuk (NWT Geomatics 2004) with data on municipal boundaries (Government of Canada 2010) to estimate the spatial footprint of each settlement. Using these data, the footprints of each settlement were delimited as the maximum north, east, south, and west extent of community infrastructure. Point locations of drilling mud sumps (locations of buried drilling fluids and other waste from resource exploration) were obtained from the Environmental Studies Research Fund sumps database (INAC 2005). To estimate the total area of each PU impacted by sumps, we multiplied the number of sumps per planning unit by the mean sump area visible in aerial imagery (22.3 ha) (NWT Geomatics 2004).

The area of each planning unit affected by natural disturbances was also estimated using GIS data. Historic wildfires were mapped using the Yukon and Northwest Territories historic fire databases (WWF 2002; Department of Community Services 2014). The area impacted by a severe storm surge along the Beaufort coast was mapped using data on vegetation change presented in Lantz *et al.* 2015. The footprint of retrogressive thaw slumps (areas of ground subsidence and erosion due to permafrost thaw) in each planning unit was estimated using a broad-scale map of slump density in the NWT (Segal et al. 2015). This dataset portrays the density of slumps in 225 km^2 cells as: no slumps, low density (1-5), medium density (6-14), or high density (15 or more). To use these data to estimate slump coverage in each planning unit, we assumed that, on average, low-density grid cells contained three slumps, medium-density grid cells contained 10 slumps, and high-density grid cells contained 20 slumps. We then multiplied the number of slumps in each cell by the mean slump size in the region (3.02 ha) (Segal et al. 2015). This produced an estimate of the total area of each 225 km^2 grid cell disturbed by slumps. The percentage of each 225 km^2 grid cell affected by slumps was then attributed to every 25 km^2 PU that occurred within its boundary. In instances where a 25 km^2 PU was split by the boundary of multiple 225 km^2 grid cells, the 225 km^2 grid cell that contained the largest amount of the PU area was used to determine the percentage of PU affected by slumps.

Future Disturbances

To explore the impact that more frequent wildfires and increasing industrial development might have on the footprint of disturbances in the region, we generated spatial data representing scenarios of increased industrial activity and wildfire over the next 50 years. We restricted the modeling of future human impacts to development that is either in progress or potential development that has publicly available plans. This limited our modelling to the inclusion of an all-season road that is currently being built from Inuvik to Tuktoyaktuk (Kiggiak 2011), the proposed route of the Mackenzie Valley Pipeline, which enters the ISR near Inuvik and runs northwest to the Beaufort Sea (Joint Review Panel 2010), and an area of existing mineral claims near Paulatuk (WWF 2002). The future road was mapped at a width of 20 meters, based on the assumption that it will be similar in size to the Dempster Highway (Gill et al. 2014). The pipeline was mapped by applying a right of way with the same width as the Ikhill pipeline. To simulate the impacts of future mineral exploration in the Paulatuk area, we used the boundaries of existing mineral claims in the region (WWF 2002). In the absence of data on the level of planned development, we modelled a scenario where mineral extraction directly impacted approximately 20% of the area in each PU affected.

To simulate future natural disturbances, we focused on wildfire because it can be modeled in a systematic fashion, based on known vegetation zones (Timoney et al. 1992) and historic fire rates (Department of Community Services 2014; WWF 2002). The spatial extent of future wildfire was estimated by generating disturbances using the Geospatial Modeling Environment (GME) software (Beyer 2014). The first step in this process involved parameterizing GME to simulate fires with a size and frequency that was consistent with historical wildfires in each of the vegetation zones in the region (WWF 2002; Department of Community Services 2014). This was accomplished by calculating the size and density of historic wildfires in the vegetation zones described by Timoney et al. (1992): high boreal, low subarctic, high subarctic, and low arctic. Using the spatial boundaries for each of these vegetation zones (Timoney et al. 1992) and data on historical fire frequency (Department of Community Services 2014; WWF 2002), we adjusted the frequency of ignition, the rate of spread, and the time that a fire was active on the landscape until GME yielded outputs that mimicked the percentage of area disturbed by fire over the past 50 years in each vegetation zone (Appendix A).

We then created three ‘future fire’ scenarios intended to reflect the impacts of rising air temperatures (Serreze et al. 2000; Hassol 2005) and increasing fuel accumulation (Lantz et al. 2013; Fraser et al. 2014) on fire frequency. Scenarios were based on the assumption that the future size and density of fires in a given zone would be similar to the patterns now common in the vegetation zones immediately to the south (Table 1) .The Mackenzie Delta was excluded from fire simulations because the high density of rivers and lakes limit the potential for large or frequent fires (Burn & Kokelj 2009). In the southern part of the study area our scenarios are highly conservative, because the rate of fire activity in the boreal forest was not increased to reflect forecasted changes in fire frequency in this biome (de Groot et al. 2013).

Table 2-1: Percent of the landscape impacted in wildfire scenarios. Simulations were created to represent shifts in fire frequency resulting from changes in climate and vegetation structure (fuel load). Simulation 1 is the base-line scenario, where fire rates over the next 50 years are held constant in each zone. Simulations 2 and 3 assume that increasing fuel loads, warming temperatures, and greater frequency of lightening over the next 50 years will yield disturbance regimes similar to those in lower latitude vegetation zones, and fire rates are increased in a stepwise manner.

Fire Simulation	Forest	Forest/Tundra	Tree Limit	Upper Tundra
1 (Baseline)	20	3.7	0	0
2 (Moderate)	20	20	3.7	0
3 (High)	20	20	20	3.7

Using these data layers we constructed nine future disturbance scenarios, involving combinations of future fire and human development (Table 2). In each future scenario, current disturbances were combined with potential future disturbances to represent a range of possible disturbances levels over the next 50 years. The modeled intensity of each disturbance and its persistence on the landscape are described in the following section.

Table 2-2: Disturbance scenarios based on combinations of current and future disturbances. All future disturbance scenarios included current disturbances and the simulated impacts of more widespread fire or anthropogenic disturbance. Disturbance intensity increases in each scenario, based on the introduction of either greater fire occurrence or increased human activity in the study area.

		Thaw Slumps	**Storm Surge**	**Anthropogenic Disturbance**			**Fire**			
	Scenario	Existing	Existing	Existing	Planned	Potential	Historic	Baseline	Moderate Increase	Large Increase
Current	1	X	X	X			X			
Future	2	↓	↓	↓				X		
	3	↓	↓	↓	X			X		
	4	↓	↓	↓	X	X		X		
	5	↓	↓	↓					X	
	6	↓	↓	↓	X				X	
	7	↓	↓	↓	X	X			X	
	8	↓	↓	↓						X
	9	↓	↓	↓	X					X
	10	↓	↓	↓	X	X				X

Weighting

The intensity of environmental impacts vary based on the ecological variable being measured, the nature of the disturbance, the ecosystem component(s) it affects, and the conditions of the landscape on which it occurs (Duinker et al. 2013). There is no standard method for weighting disturbances based on their intensity and frequency, and cumulative effects research typically weights disturbances differently, based on the ecosystem component in question (Johnson et al. 2005; Gunn et al. 2011; Raynolds et al. 2014). We developed a weighting scheme that accounts for differences in: 1) the impact that disturbances have on vegetation structure, soils, and ground temperature (disturbance severity), and 2) the time it takes to recover following disturbance (recovery time). This relative scheme was developed using existing data on the impacts of disturbances on vegetation, soils, and permafrost conditions (Table 3).

Disturbances were weighted in relation to each other by multiplying a severity and recovery score for each disturbance type (Table 3). Severity scores ranged from 1-10, with a score of 10 representing total land transformation and 1 representing minimal ecological alteration. Recovery time was ranked using a scale ranging from 0-1 to represent the length of time a disturbance persists on the land. If a disturbance, such as a community development, is likely to persist over a 50-year period, it received a score of 1. If a disturbance, such as seismic lines, is likely to show significant recovery of vegetation structure and ecological processes over a 50-year period, it received a score between 0.1 and 0.9. Lower scores represented a less persistent disturbance that is likely to exhibit significant recovery over a 50-year period. Cumulative disturbance scores for each Planning Unit were calculated by multiplying the percentage area impacted by each disturbance, by the disturbance weight and summing these scores in each planning unit.

$$\text{Disturbance Score} = \sum_{Dist=1}^{n} \left(\frac{Disturbance\ Area}{Planning\ Unit\ Area}\right) x\ Disturbance\ Weight$$

In simulated future scenarios, all existing disturbances were included, but we recalculated the original disturbance score by multiplying by the recovery score, again (Table 3). This approach allowed us to simulate the cumulative impacts of disturbances over time, while also acknowledging the decreasing impact of current disturbances in the future.

Table 2-3: Disturbances mapped in the study area and their recovery score, severity score, weight, and future weight were used to calculate the disturbance score in each planning unit. To represent continued recovery in future disturbance scenarios, existing disturbance weights were multiplied by the recovery score. *The future weight of thaw slumps was not adjusted, because we estimated that active slumps will continue to occupy a similar area.

	Disturbance Weighting					
Disturbance	Recovery	Severity	Weight	Future Weight	Attributes	Sources
Thaw Slumps	0.5	7	3.5	3.5*	Alters the chemistry of soils, lakes, and rivers, transforms vegetation structure and permafrost conditions	(Kokelj et al. 2013; Thienpont et al. 2013; Lantz & Kokelj 2008)
Fire	0.4	4	1.6	0.64	Transforms vegetation structure, community composition, and permafrost conditions	(Bret-Harte et al. 2013; Joly et al. 2010; Lantz et al. 2010; Jandt et al. 2008; Racine et al. 2004)
Tundra Seismic Lines	0.2	1	0.2	0.04	Alters permafrost conditions, vegetation structure, and reduces lichen cover	(Williams et al. 2013; Kemper 2006)
Forested Seismic Lines	0.4	3	1.2	0.48	Alters permafrost conditions, vegetation structure, and reduces lichen cover	(Williams et al. 2013; Kemper 2006)
Drilling Mud Sumps	0.5	10	5	0.25	Alters topography, permafrost conditions, and vegetation structure and composition	(Kokelj et al. 2010; Johnstone & Kokelj 2008)
Pipeline	1	2	2	2	Permanent right of way, alters vegetation structure and composition, and can cause ground subsidence	(Williams et al. 2013; Walker et al. 1987)
Municipality	1	10	10	10	Permanent settlement	(NWT Geomatics 2004)
Saline Storm Surge	0.5	10	5	5	Soil salinization kills vegetation driving long-term modifications to habitat quality	(Lantz et al. 2015; Kokelj et al. 2012; Pisaric et al. 2011)
Mineral Development	1	10	10	10	Permanent infrastructure	(WWF 2002)
Road	1	10	10	5	Permanent right of way that alters vegetation, soil, and permafrost	(Gill et al. 2014; Myers-Smith et al. 2006)

Analysis Units

The spatial pattern of current landscape disturbance was examined by mapping disturbance scores across the study area (Figure 1). We also compared disturbance frequencies between individual planning areas that are designated to each community and priority management zones, which are areas of high cultural or ecological significance that are managed to avoid environmental disturbance (AICCP 2008; IICCP 2008; PCCP 2008; TCCP 2008). Additionally, we assessed disturbance levels in caribou harvesting zones. While, many other types of harvesting are common in the region, caribou is an important species for multiple communities (Usher 2002; Alunik et al. 2003; Joint Secretariat 2003) and conservation plans provided consistent data across the study area. In every analysis unit, we measured the percentage of planning units containing environmental disturbance and the amount of unique disturbance types occurring in planning units. We also measured the percentage of planning units containing high levels of environmental disturbance, which we defined as a disturbance score ≥ 80 (the equivalent of half the planning unit being impacted by wildfire). The impact of current and future disturbances on multiple additional harvesting values was examined in our Marxan analysis.

Marxan Analysis

The spatial prioritization software, Marxan (Ball et al. 2009) was used to analyze the impact of each disturbance scenario on the area and contiguity of low-disturbance terrain in the study area. Marxan is spatial planning software designed to find a near-optimal solution to a conservation problem by maximizing the acquisition of valued habitat while minimizing the cost associated with protecting these lands. In our analysis, we used the cumulative disturbance score as the cost layer, so that Marxan would prioritize the selection of lands with the lowest disturbance score. Forty terrestrial harvesting areas, identified in Inuvialuit Community Conservation Plans (AICCP 2008; IICCP 2008; PCCP 2008; TCCP 2008), were selected as the use values that Marxan simulations attempted to conserve. These use areas ranged in size and significant overlap occurs among many values. To identify near-optimum spatial configurations of wildlife harvesting areas, multiple Marxan optimizations were run for each disturbance scenario. Marxan selections began by identifying the near-optimal spatial output that ensured limited disturbances in 50% of all harvesting areas. Subsequent iterations targeted a higher percentage of each harvesting area. Optimizations were run until the threshold for each disturbance scenario was reached, and Marxan failed to achieve the targeted percentage of wildlife harvesting areas. Each of these optimizations was comprised of 100 runs, in which Marxan attempted to select the targeted percentages of each use value, while incurring the lowest possible cost (i.e. minimizing the disturbed terrain selected) and maintaining contiguity. Marxan parameters were set so that optimizations prioritized maintaining a low overall cost and avoided areas of high disturbance intensity. Table 4 shows important parameters that were adjusted in these simulations. For a full list of Marxan parameters and the 40 terrestrial harvesting areas used in this analysis, see Appendices B and C.

Table 2-4: Parameters used in this Marxan analysis and their treatment across all simulations. For a full list of Marxan parameters, see Appendix A.

Parameter Treatment	Importance
Value of 1 added to each PU	Cost scores of 0 represent "free" land. In order to avoid Marxan over-selecting land, all PUs were adjusted to reflect a base cost of 1.
Boundary length modifier (BLM) Set to 1	The BLM is Marxan's prioritization of contiguity. In order to ensure that simulations responded most directly to changes in disturbance levels, the BLM was set to a low value of 1.
Species penalty factor (SPF) Set to 1	The SPF reflects Marxan's prioritization of meeting targets for each use value. A high SPF results in a greater penalty for not meeting the specified percent-protected area for a certain use value. In order to ensure that simulations responded most directly to changes in disturbance levels, the SPF was set to a low value of 1 for all 40 use values.
PU Disturbance Score > 80 "Locked Out"	In order to emphasize the impact of increasing disturbance, any PU with a disturbance score greater than 80 was locked out of simulations and not included in output. A disturbance score of 80 represents the equivalent of 50% of a PU disturbed by wildfire, based on our disturbance weighting system.
Target Features set to 50, 75, and 90%	Three sets of simulations were run for all disturbance scenarios in order to explore the feasibility of conserving a range of use values.

We compared Marxan outputs across all simulations to investigate the impact of changing disturbance levels on the availability and community-defined harvesting areas. In order to measure connectivity of outputs, we compared the average number of PU edges per PU for all Marxan solutions in each disturbance scenario. In order to measure the level of disturbance in Marxan outputs, we measured the average cost per PU. Patterns were analyzed between all 10 disturbance scenarios and across each conservation target of use values.

RESULTS

Current Disturbance Footprint

Our compilation of GIS data shows that disturbance impacts most areas of the southern ISR, but also reveals substantial spatial variation in the intensity of these impacts (Figure 1). Over half of Planning Units (PUs) contain at least one disturbance type, while PUs containing two or more disturbances impacted 14.8% of the study area (Table 5). Slumping and historic seismic lines were the most widespread disturbance types (Table 6), and most of the study region was affected by low to moderate disturbance intensity (Figure 1). Large expanses of un-impacted areas existed in the Richardson Mountains, Amundsen Gulf Lowlands, Anderson River Plain, Bluenose Lake Plain, the eastern Dease Arm Plain, and Coronation hills (Figure 1). Well-defined hotspots of high intensity disturbances were found in the Tuktoyaktuk Coastal Plain, the western Dease Arm Plain, and the Great Bear Lake Plain (Figure 1), which represented a low percentage of total PUs (Table 5).

The percent of PUs disturbed also varied among community planning areas (PAs), management zones, and key wildlife harvesting areas. The percentage of disturbed PUs in Aklavik, Inuvik, and Tuktoyaktuk PAs was higher than the disturbance rate for the entire study area, while the Paulatuk PA contained a much lower percentage of disturbed PUs (Table 5). All three management zones included in this analysis had a level of disturbance similar to the entire study area, while caribou harvesting zones contained a greater percentage of disturbed cells than the entire study area (Table 5).

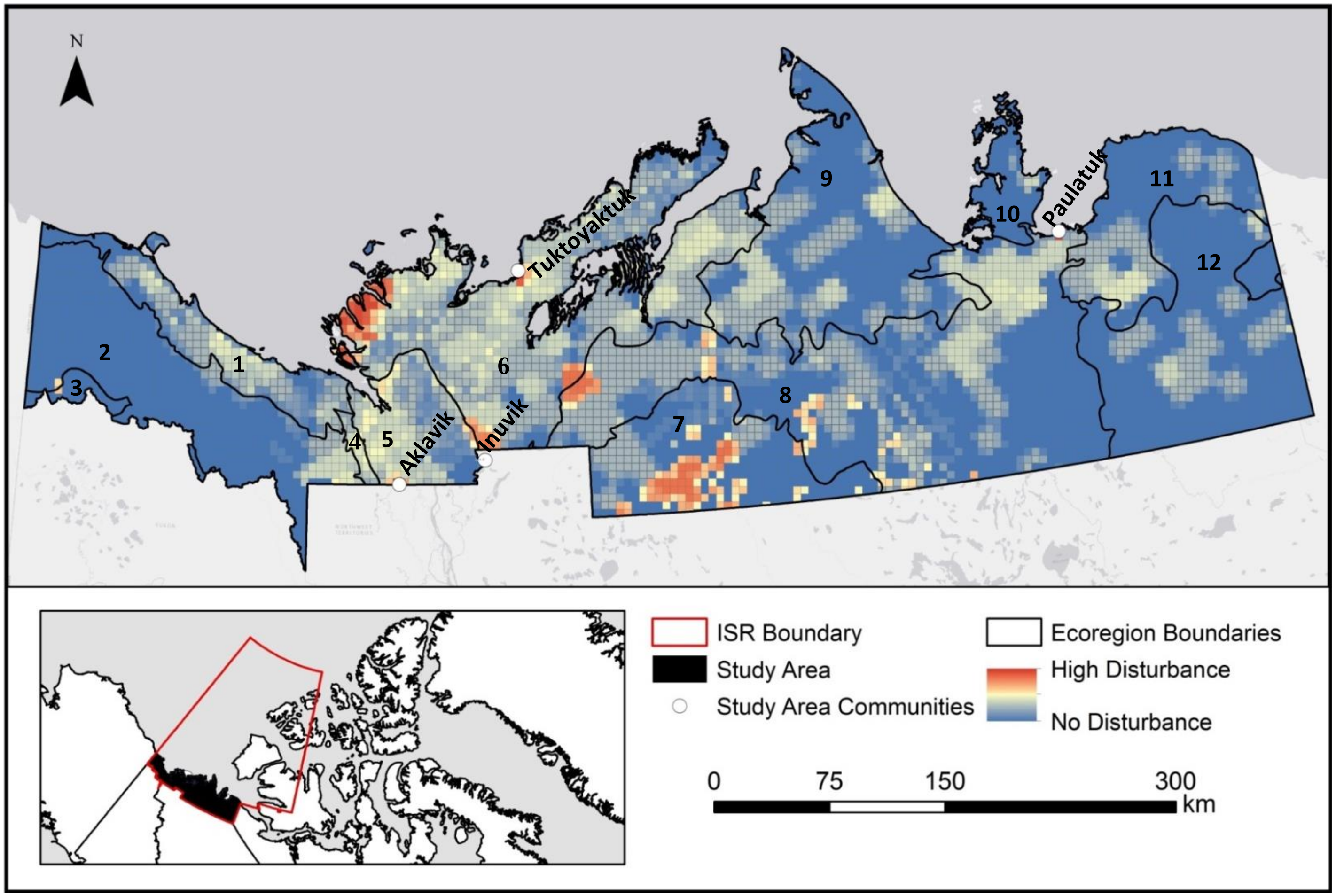

Figure 2-2: Current disturbance levels in the study region and their distribution across major ecoregions: **1:** Yukon Coastal Plain. **2:** British Richardson Mountains **3:** Old Crow Basin **4:** Peel Plateau **5:** Mackenzie Delta **6:** Tuktoyaktuk Coastal Plain **7:** Great Bear Lake Plain **8:** Dease Arm Plain **9:** Anderson River Plain **10:** Amundsen Gulf Lowlands **11:** Coronation Hills **12:** Bluenose Lake Plain. Inset in the bottom left corner shows the study area location in black and the entire ISR boundary in red.

Table 2-5: Patterns of disturbed Planning Units (PUs) across multiple analysis units. We calculated the percent of disturbed PUs and the percent of PUs containing high disturbance levels (disturbance score ≥ 80) in every analysis unit. We also inventoried the count of unique disturbance types occurring in impacted PUs (1-5) for every analysis unit.

Analysis Unit	Percent of PUs Containing Environmental Disturbance	Percent of PUs Containing High Environmental Disturbance	Percent of PUs containing disturbances (1-5)				
			1	2	3	4	5
Entire Study Area	55.0	1.6	39.2	13.1	1.6	1.0	0.1
Aklavik PA	66.37	2.5	26.5	12.2	1.6	1.0	0.1
Inuvik PA	71.43	2.7	26.4	12.2	1.6	1.0	0.1
Tuktoyaktuk PA	69.60	2.9	23.3	9.3	1.0	0.8	0.1
Paultatuk PA	40.32	0.1	14.8	1.9	0.1	0.0	0.0
Most Significant Management Zones	56.11	1.8	20.9	8.0	0.8	0.6	0.02
Particularly Significant Management Zones	49.14	2.5	6.7	2.6	0.4	0.2	0.02
Seasonally Significant Management Zones	56.47	0.6	18.3	4.2	0.7	0.4	0.03
Caribou Harvesting Zones	64.30	1.7	24.1	9.5	1.1	0.7	0.02

Table 2-6: Percent of PUs affected by each disturbance type in the study area.

Disturbance Type	PUs Affected (%)
Thaw slumps	38.8
Tundra seismic lines	24.7
Forested seismic lines	3.2
Historic wildfire	3.0
Drilling mud sumps	1.7
Ikhill pipeline	1.7
Storm surge footprint	0.9
Community footprint	0.2

Future Disturbances and Marxan Simulations

Simulations of future fires and increased human activity created nine distinct future disturbance scenarios (Figure 2). Comparing the spatial distribution of disturbances in future scenarios to the baseline scenario revealed that the frequency and intensity of environmental disturbances in the region increased throughout all ten scenarios (Figure 2). Scenarios 2, 5, and 8 involved major shifts in fire-occurrence, and displayed the greatest increase in study area disturbance levels (Figure 2). Increasing human disturbance alone (Scenarios 3, 4, 6, 7, 9, and 10) resulted in a much smaller increase regional impacts (Figure 2).

When disturbance scenarios were used to modify the cost layer in Marxan optimizations, we observed two distinct thresholds where Marxan could not achieve conservation targets. In disturbance scenarios 1-7, failure rates were 100% when optimizations attempted to conserve 82% of all use values. In Scenarios 8-10 the failure threshold was 76% (Table 7). At targets of 50 and 75% Marxan also encountered a significant failure rate in disturbance scenarios 8-10 (Table 7).

The average measure of solution edges per PU and the average cost per PU increased in scenarios with greater disturbance. Increases in cost and edge ratios were much larger in scenarios that included shifts in fire frequency, compared to scenarios that simulated increased human activity (Figures 3 and 4). As conservation targets increased, the distance between cost scores and the edge to PU ratios among simulations also increased (Figures 3 and 4). The impact of disturbance on habitat contiguity was also evident in maps showing Marxan outputs; scenarios with a higher level of disturbance had less contiguous solutions with much longer edges (Figure 5)

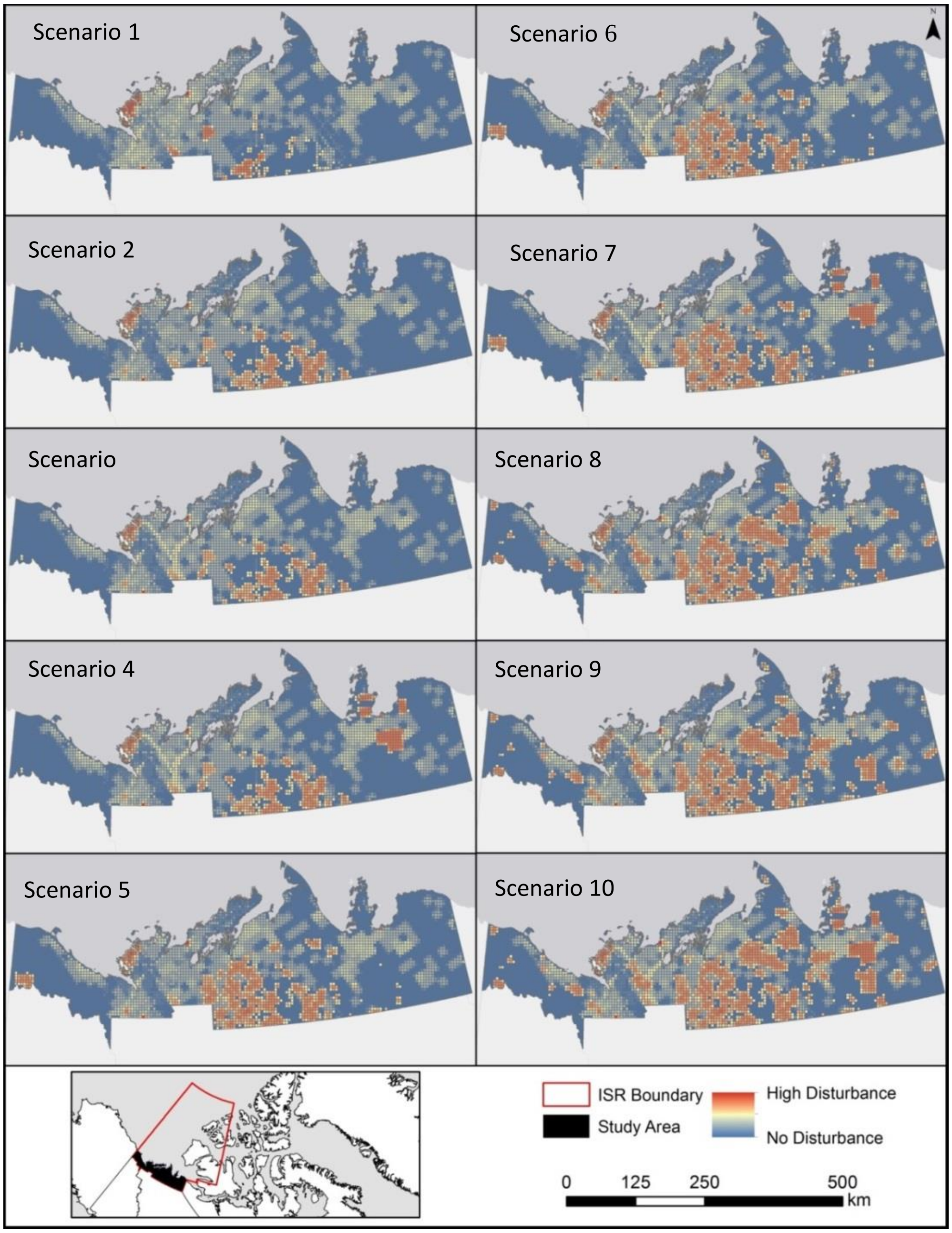

Figure 2-3: Spatial output of each disturbance scenario. Scenario 1: current disturbance levels, 2: baseline future fire rates, 3: baseline future fire rates and road and pipeline development, 4: baseline future fire rates and road, pipeline, and mineral development, 5: moderate increase in future fire rates, 6: moderate increase in future fire rates and road and pipeline development, 7; moderate increase in future fire rates and road, pipeline, and mineral development, 8: high future fire rates, 9: high future fire rates and road and pipline development, 10: high future fire rates and road, pipeline, and mineral development. Inset in the bottom left corner shows the study area location in black and the entire ISR boundary in red.

Table 2-7: Percent of Marxan runs in which the solution failed to conserve the targeted percentage for at least one use value, due to a lack of available PUs with a low enough disturbance score for inclusion. Two distinct thresholds exist, where Marxan solutions are unable to meet conservation targets for all use areas. The failure threshold in scenarios 1-7 is 82% of use values conserved, while the threshold for failure in scenarios 8-10 is 76%. Scenario 1: current disturbance levels, 2: baseline future fire rates, 3: baseline future fire rates and road and pipeline development, 4: baseline future fire rates and road, pipeline, and mineral development, 5: moderate increase in future fire rates, 6: moderate increase in future fire rates and road and pipeline development, 7: moderate increase in future fire rates and road, pipeline, and mineral development, 8: high future fire rates, 9: high future fire rates and road and pipline development, 10: high future fire rates and road, pipeline, and mineral development.

	Scenario	Fails at 50% Target	Fails at 75% Target	Fails at 76% Target	Fails at 82% Target
Increasing Disturbance ↓	1	2	0	0	100
	2	2	0	0	100
	3	2	0	0	100
	4	4	0	0	100
	5	1	0	0	100
	6	1	0	0	100
	7	2	0	0	100
	8	18	32	100	100
	9	17	28	100	100
	10	20	27	100	100

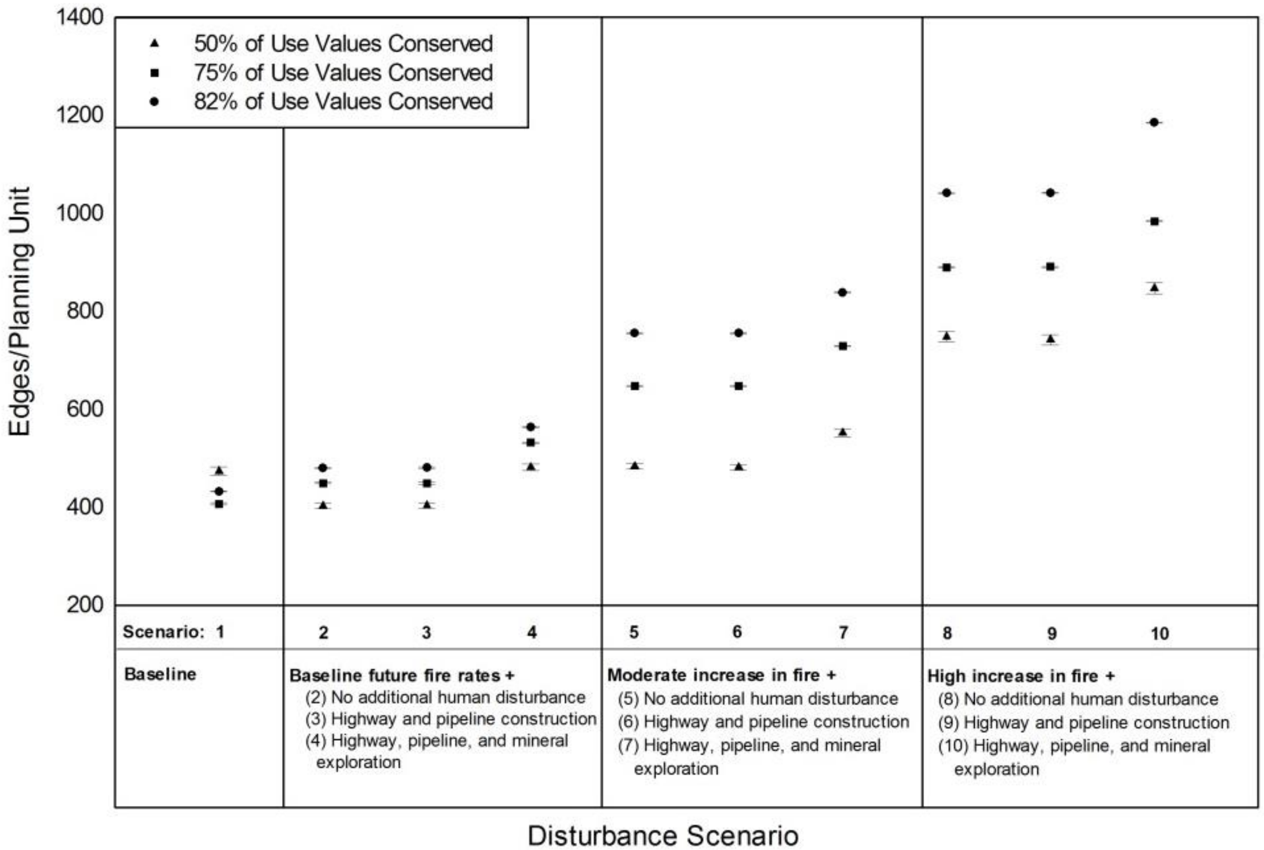

Figure 2-4: Average edge score per planning unit (PU) for across all Marxan analyses. Three sets of simulations were run for each disturbance scenario, attempting to reach conservation targets of 50%, 75%, 82%. We averaged the Marxan edge score per PU to assess the contiguity of solutions. Symbols show the mean connectivity score and 95% confidence intervals around the mean. Note: scenarios that attempted to conserve 82% of use values all failed to meet targets for at least one value. Connectivity scores for these outputs represent the mean score of unsuccessful solutions.

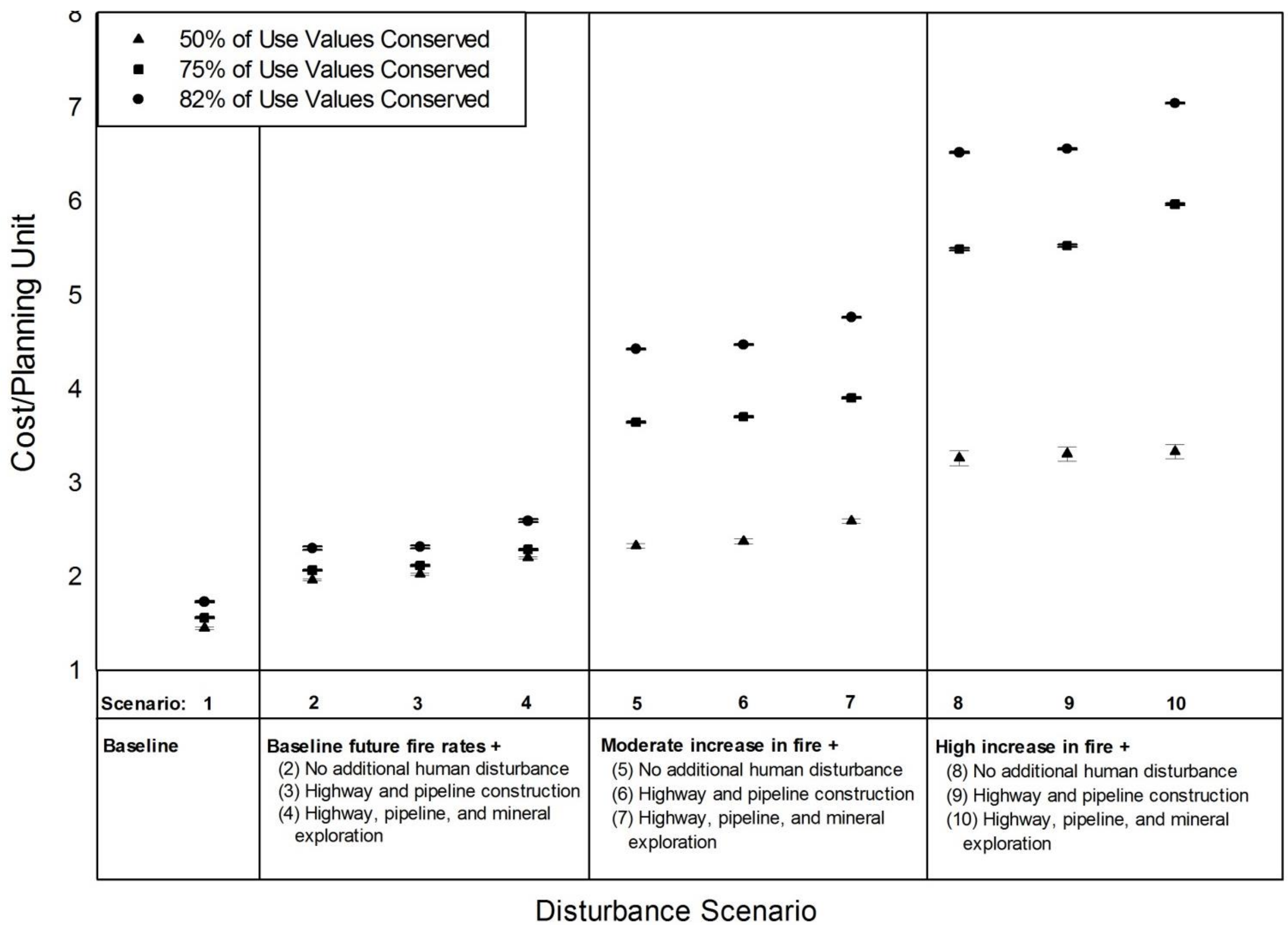

Figure 2-5: Average cost scores per planning unit (PU) for Marxan solutions from each of the 10 disturbance scenarios and three conservation targets (50%, 75%, 82%). Symbols show the mean cost per PU for each solution and 95% confidence intervals around the mean. Note: scenarios that attempted to conserve 82% of use values all failed to meet targets for at least one value. Cost scores for these outputs represent the mean disturbance score of unsuccessful solutions.

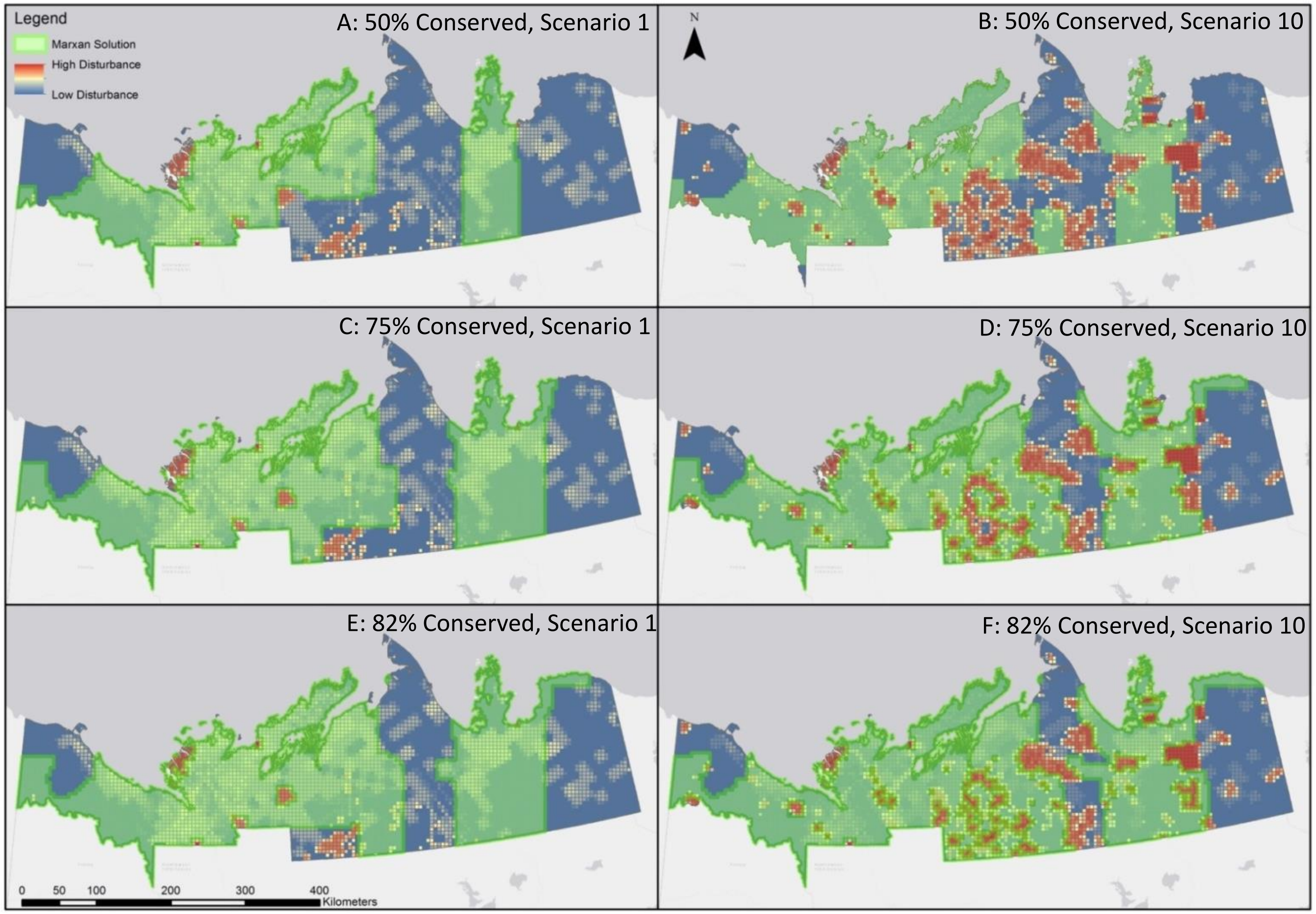

Figure 2-6: Maps showing the "best output" from Marxan runs, using disturbance scenario 1, 50% conserved (A); scenario 10, 50% conserved (B); scenario 1, 75% conserved (C); scenario 10, 75% conserved (D); scenario 1, 82% conserved (E); and scenario 10, 90% conserved (F). The shading on the base maps represents disturbance intensity from low (blue) to high (red). Areas selected are shown in green. As disturbance levels and conservation targets increase, the contiguity of Marxan outputs decreases**.**

DISCUSSION

Current Disturbance Levels

This study highlights the importance of cumulative effects assessments in regions with a strong reliance on subsistence harvesting. Our analysis shows that the Inuvialuit Settlement Region (ISR) is more impacted by natural and human disturbances than is suggested in Community Conservation Plans that call for the avoidance of disturbances across large management areas (AICCP 2008; IICCP 2008; PCCP 2008; TCCP 2008). This underscores the potential to overlook cumulative impacts that occur in large regions. Our mapping shows significant overlap between widespread disturbances and wildlife harvesting areas, important management zones, and community planning areas. We found that this overlap is substantial enough to limit the availability of un-impacted harvesting zones, creating thresholds for successful Marxan optimizations and reducing conservation potential in the region. To our knowledge, this is the first comprehensive cumulative effects assessment in the ISR and it suggests that Inuvialuit land use is already impacted by a wide range of perturbations.

Our findings also highlight the importance of broad-scale cumulative effects assessments for conservation planning in the region. Numerous co-management organizations in the ISR have the mandate to protect biodiversity and traditional harvesting (Department of Indian and Northern Affairs Canada 1984), and cumulative effects monitoring is incorporated in regional management across the Northwest Territories and Canada (Government of Canada 1998; MVEIRB 2004; Duinker & Greig 2006; Ehrlich 2010). However, to date there have been few initiatives that effectively translate the general consensus regarding the significance of cumulative effects into effective monitoring and management practices (Duinker & Greig 2006; Gunn et al. 2011). This gap is alarming because the combination of climate change impacts and industrial development represent a significant threat to northern food security and biodiversity (Furgal & Seguin 2006; Corell 2006; Fuller et al. 2008). To avoid crossing thresholds where subsistence harvesting is severely impaired or no longer possible, strategies for monitoring and managing cumulative environmental impacts are needed (Parlee et al. 2012). The method for weighting disturbances presented here provides a means to include both widespread, low-intensity disturbances (e.g. seismic lines), and high intensity impacts (e.g. salt-water vegetation kill) in a cumulative effects assessment. The maps produced can be used to evaluate conservation potential across a gradient of disturbed to undisturbed landscapes, and as input for spatial planning activity (Ball et al. 2009; Moilanen & Wilson, Kerrie A. 2009; Moilanen et al. 2011).

Arriving at clear definitions of thresholds remains a challenge in cumulative effects management, and approaches range from restrictions on any development in pristine landscapes (Ehrlich 2010) to explicit levels of allowable impacts on specific valued ecosystem components (Gunn et al. 2011). Regardless of the methods for defining a threshold, if land-use planning evaluates projects on a case-by-case basis, it risks exceeding acceptable disturbance levels by ignoring the combined effect of multiple stressors (Duinker & Greig 2006). The approach used in this analysis makes it possible to include a range of disturbances in the evaluation of multiple stressors across a landscape. Combined with data on proposed developments, this approach may be particularly useful in identifying when additional impacts will exceed thresholds for acceptable disturbance levels.

Future Disturbance Scenarios

Our analysis based on future disturbance scenarios showed that additional perturbations reduce the potential to conserve un-impacted harvesting areas in the ISR. Scenarios 2-6 maintain the same 82% failure threshold that exists under current disturbance levels, while scenarios with high increases in fire frequency (7-10) have a higher failure rate at all targets and a lower threshold of 76%. This emphasizes that predicted increases in natural disturbance frequency and intensity (Hassol 2005; Jandt et al. 2008; de Groot et al. 2013) are likely to limit flexibility in meeting conservation targets, and alter the potential to maintain un-impacted harvesting areas in the ISR. Global climate change and increasing pressure from human development require conservation strategies that anticipate these types of change (Pressey et al. 2007; Trombulak & Baldwin 2010a; Groves et al. 2012; Brodie et al. 2013), and cumulative effects management has proven effective when it considers reasonably foreseeable impacts in addition to those that are most likely to occur (Ehrlich 2010). Our Marxan simulations of future disturbance scenarios demonstrate that climate change will reduce the availability of high quality harvesting areas in the ISR, and highlight the importance of conservation planning efforts that limit direct human disturbance in order to allow ecosystems to absorb climate change impacts (Doak et al. 2013).

Our results also indicate that increasing disturbances will reduce the quality of conservation outcomes by increasing fragmentation. Even if optimizations are able to meet conservation targets, increasing disturbance levels in our scenarios limit the potential for large contiguous configurations of harvesting areas. This is concerning because habitat fragmentation is directly correlated with species decline (Lindenmayer & Fischer 2006; Collinge 2009). Even large protected areas have struggled to meet conservation goals, as surrounding landscapes become increasingly disturbed (Trombulak & Baldwin 2010b), raising the possibility that the conservation solutions in our scenarios may not represent adequate protection of harvesting areas if they are highly fragmented or surrounded by significantly impacted PUs.

Our scenarios coupled modest industrial development in the region with a range of natural disturbance intensities. These scenarios provided a simplified method for exploring the conservation implications of development in a future impacted by climate change. These simulations were based on the likelihood that wildfire will become more common with increases in temperature (Hassol 2005; Jandt et al. 2008; de Groot et al. 2013) and are used as estimations, not predictions. Given the likelihood of additional increases in permafrost degradation (Kokelj et al. 2015) and storm surges (Lantz et al. 2015), our future scenarios are conservative generalizations of potential impacts.

The large range of variation in fire frequency and narrow range of human disturbance used in our simulations does not represent the relative significance of human impacts in the region. Human disturbance modeling was restricted to potential development that is either in progress (Kiggiak 2011) or has publicly available plans (WWF 2002), which limited the spatial extent of human disturbances relative to simulated wildfire. Roads, pipelines, and infrastructure all significantly affect Arctic wildlife (Nellemann & Cameron 1998; Johnson et al. 2005; Gunn et al. 2011), ecological processes (Myers-Smith et al. 2006; Kokelj et al. 2010; Raynolds et al. 2014; Gill et al. 2014), and land users' ability to hunt and trap (Tyson and Lantz In Prep). Their impacts should not be discounted based on their relatively small footprint in this analysis. Even development projects with a small spatial footprint may be undesirable in particularly sensitive or culturally important ecosystems (Ehrlich 2010). To assess the full range of potential human disturbance, future research should simulate human disturbance in the region by projecting a number of scenarios that represent more widespread potential resource extraction in the region (Holroyd & Retzer 2005).

CONCLUSION

The results of this analysis emphasize three main points: 1) the ISR is already widely affected by environmental disturbance; 2) the potential to conserve large contiguous areas is limited by existing disturbances; and 3) future environmental disturbances, particularly those associated with climate change, will further reduce the potential to conserve large amounts of contiguous, un-impacted harvesting areas. These findings indicate that land-use planning in the ISR needs to account for increasing environmental change, in order to maintain conservation objectives in culturally important ecosystems. By providing methodology for broad-scale inventorying of environmental impacts across a large area, the methods described in this study make an important contribution to cumulative effects research. Our mapping and weighting approach can be used to quantify the impacts of environmental change on subsistence land-use, particularly where local communities are concerned about changes across a large landscape (Ehrlich 2010) and represent a method for creating tractable representations of the impacts of environmental change on culturally important ecosystems.

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Appendix A

Parameters for Geospatial Modeling Environment (Beyer 2014) Fire Scenario Generation:

Parameters were adjusted for fire simulation in each vegetation zone. Each simulation created a range of outputs, based on the write frequency and the number of iterations. Outputs contained progressively more area disturbed by fire in later iterations and timesteps. After simulations were run, three outputs were chosen for each vegetation zone to represent the scenarios of low, moderate, and high future fire occurrence shown in Table 2-1.

Vegetation Zone	Susceptibility	Spread	Event Rate	Timesteps	Iterations	Write Frequency
Boreal	0.2	0.25	0.3	50	5	25
Forest/Tundra Boundary	0.25	0.23	0.48	50	2	10
Tree Limit	0.26	0.23	0.49	50	10	10
Upper Tundra	0.25	0.23	0.48	50	2	10

Appendix B

Parameters Imported from Marxan Input File (input.dat)

```
VERSION 0.1

BLM 0.1
PROP  0.5
RANDSEED -1
BESTSCORE  10
NUMREPS 10

Annealing Parameters
NUMITNS 10000000
STARTTEMP -1.00000000000000E+0000
COOLFAC  6.00000000000000E+0000
NUMTEMP 10000

Cost Threshold
COSTTHRESH  0.00000000000000E+0000
THRESHPEN1  1.40000000000000E+0001
THRESHPEN2  1.00000000000000E+0000

Input Files
INPUTDIR input
SPECNAME spec.dat
PUNAME pu.dat
PUVSPRNAME puvspr2.dat
BOUNDNAME bound.dat

Save Files
SCENNAME output
SAVERUN 2
SAVEBEST 2
SAVESUMMARY 2
SAVESCEN 2
SAVETARGMET 2
SAVESUMSOLN 2
SAVELOG 2
OUTPUTDIR output
```

```
Program control.
RUNMODE 1
MISSLEVEL  1
ITIMPTYPE 0
HEURTYPE -1
CLUMPTYPE 0
  VERBOSITY 3
```

Appendix C

Wildlife Harvesting Areas Included in Marxan Analysis (imported from Marxan spec.dat file): 40 wildlife harvesting areas were used in this analysis, based on their inclusion in Community Conservation Plans for Inuvik, Aklavik, Paulatuk, and Tuktoyaktuk (AICCP 2008; IICCP 2008; PCCP 2008; TCCP 2008). Use areas for this analysis were included based on the indication of wildlife harvesting occurring within the area. In many instances, this was noted in the label of the area (i.e. Tuktoyaktuk Fall Caribou Harvesting). In other instances the importance for wildlife harvesting was noted in the metadata for a particular area (i.e. Husky Lakes was noted as an important harvesting area for multiple communities).

```
1    Tuktoyaktuk Fall Caribou Harvesting
2    Tuktoyaktuk Fall Fishing
3    Tuktoyaktuk Fall Goose Harvesting
4    Tuktoyaktuk Fall Seal Harvesting
5    Tuktoyaktuk Spring Caribou Harvesting
6    Tuktoyaktuk Spring Fishing
7    Tuktoyaktuk Spring Goose Harvesting
8    Tuktoyaktuk Spring Moose Harvesting
9    Tuktoyaktuk Summer Caribou Harvesting
10   Tuktoyaktuk Summer Fishing
11   Tuktoyaktuk Summer Goose Harvesting
12   Tuktoyaktuk Winter Caribou Harvesting
13   Tuktoyaktuk Winter Fishing
14   Tuktoyaktuk Winter Wolverine Harvesting
15   Bluenose Caribou Winter Range
16   Caribou Hills
17   Eastern North Slope
18   First Creek Watershed
19   Firth Creek and Babbage Watersheds
20   Fish Hole, Cache Creek, and Big Fish River
21   Fish Lakes and Rivers
22   Husky Lakes
23   Inner Mackenzie Delta
24   Kugaluk River Estuary
25   Kugmallit Bay
26   Mackenzie Bay and Shallow Bay
27   Mackenzie River Delta Key Migratory Bird Habitat
28   Paulatuk Spring Caribou Harvest
29   Paulatuk Spring Fishing
```

30 Paulatuk Spring Grizzly Bear Harvesting
31 Paulatuk Spring Muskox Harvesting
32 Paulatuk Spring Wolf Harvesting
33 Paulatuk Summer/Fall Caribou Harvesting
34 Paulatuk Summer/Fall Fishing
35 Paulatuk Summer/Fall Grizzly Bear Harvesting
36 Paulatuk Winter Caribou Harvesting
37 Paulatuk Winter Fishing
38 Paulatuk Winter Muskox Harvesting
39 Paulatuk Winter Wolf Harvesting
40 Paulatuk Winter Wolverine Harvesting

Chapter 3

Cumulative Effects of Environmental Change on Wildlife Harvesting in the Inuvialuit Settlement Region: Understanding the impacts of ecological disturbance on subsistence harvesting culture.

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Authorship statement: WT and TCL conceived study; WT performed research; WT analysed data; WT and TCL wrote manuscript

ABSTRACT

The Inuvialuit Settlement Region (ISR), in the western Canadian Arctic, is experiencing rapid environmental change. A wide range of environmental disturbances are impacting Inuvialuit people who rely on local ecosystems for hunting trapping, whaling, and fishing. To assess the cumulative effects of environmental change on wildlife harvesting in the ISR, 20 semi-structured interviews were conducted in the communities of Aklavik, Inuvik, and Tuktoyaktuk. Interviews asked expert land-users to describe the impacts of specific terrestrial disturbances related to both climate change and human activity in the region. Participants were also asked to described the effects of historical events, such as major oil exploration in the region, and discuss concerns for the future of wildlife harvesting in the region. Results show that Inuvialuit wildlife harvesting is being impacted by both climate change-related and human-caused disturbances. Climate change was widely noted to impact wildlife harvesting and participants described a variety of specific effects ranging from decreased quality of meat and pelts, to altered species migrations and increasingly difficult travel and access to harvesting areas. Human impacts, such as oil exploration, were also widely discussed. Responses varied among participants and communities, and observations were often linked to specific experiences or locations. Our findings emphasize the benefits of incorporating indigenous knowledge in cumulative effects monitoring. Interview responses occur at scales that are largely unaddressed in other research and provide context regarding the cultural impacts of environmental disturbance. Many interviewees also stressed the impact that socio-economic and cultural changes can have on wildlife harvesting. This indicates that there is a need to include non-

environmental changes in cumulative effects research, as issues such as community transitions to wage labor and the high cost of travel can significantly impact local harvesting practices.

INTRODUCTION

Arctic ecosystems are in the midst of a rapid transformation. Climate change is altering vegetation structure (Lantz et al. 2010), permafrost conditions (Kokelj et al. 2010, 2013), disturbance regimes (Higuera et al. 2008, de Groot et al. 2013), and impacting biodiversity (Post et al. 2009). Increased human disturbances, such as road construction and resource exploration, are also affecting ecological processes across Arctic landscapes (Johnson et al. 2005, Myers-Smith et al. 2006, Gunn et al. 2011, Gill et al. 2014a). Although individual disturbances are often small, the sum total of these environmental perturbations can significantly impact ecosystems (Hegmann et al. 1999, Raynolds et al. 2014). The accumulation of past, present, and near future environmental disturbances are typically referred to as cumulative effects, and are often measured over broad spatial or temporal scales (Spaling 1994, Hegmann et al. 1999). Due to the rapid pace of change in the Arctic, cumulative effects assessments have become part of the lexicon of environmental management, particularly in regards to human development that may significantly alter northern ecosystems (Government of Canada 1998, Renewable Resources & Environment 2010, SLUPB 2013).

In many resource dependent regions there is concern that environmental change will fundamentally alter the ecosystems that are the foundation of local livelihoods (Gummer et al. 2000, Kruse et al. 2004, Francis and Hamm 2011, Parlee et al. 2012). In areas where local people regularly harvest wildlife for subsistence purposes, environmental change threatens food security because wildlife harvesting makes a major contribution to local diets and community health (Nickels et al. 2002, Young and Einarsson 2004, Furgal and Seguin 2006). Significant impacts to wildlife harvesting also affect place-based identities and local cultural practices (Francis and Hamm 2011, Parlee et al. 2012). In Arctic indigenous communities that are impacted by ecological change (Krupnik and Jolly 2002, Bennett and Lantz 2014, Gill et al. 2014a), there is growing interest in research that measures the impact of both climate change and human disturbance on indigenous cultures (Berkes and Jolly 2001, Nickels et al. 2002, Pearce et al. 2009, Ford and Pearce 2010). While many environmental disturbances in the Arctic have been studied from an ecological perspective, there is substantially less literature that summarizes the impact of these disturbances on the cultural landscape. To date, only a few studies have directly explored the impact of northern environmental change on indigenous culture (Nickels et al. 2002, Ford and Pearce 2010, Andrachuk and Smit 2012). Similarly, most cumulative effects assessments refer almost exclusively to ecological values (Johnson et al. 2005, Myers-Smith et al. 2006, Gunn et al. 2011, Raynolds et al. 2014, Gill et al. 2014a).

In this paper, we explore the cumulative effects of ecological change on subsistence harvesting in the Inuvialuit Settlement Region (ISR) of the Western Canadian Arctic. The ISR was established in 1984, with the signing of the Inuvialuit Final Agreement, and is co-managed between the Canadian government and the Inuvialuit, an Inuit people of the western Arctic (Department of Indian and Northern Affairs Canada 1984). The ISR provides critical habitat for marine and terrestrial wildlife (Burn and Kokelj 2009) and is vital for Inuvialuit hunting, trapping, whaling, and fishing (Alunik et al. 2003, Furgal and Seguin 2006, Bennett and Lantz 2014). Both marine and terrestrial wildlife are being impacted by environmental change in the

ISR (Berkes and Jolly 2001, Pearce et al. 2009, Ford and Pearce 2010) and, because of their frequent interaction with local landscapes, many Inuvialuit land-users have a detailed understanding of these changes (Pearce et al. 2009, Kokelj et al. 2012, Bennett and Lantz 2014). In this project we worked with Inuvialuit land-users to identify the major environmental disturbances affecting the region and better understand their impacts on subsistence harvesting. Specifically, we conducted semi-structured interviews in the Inuvialuit communities of Tuktoyaktuk, Inuvik, and Aklavik, asking land-users to describe the major ecological changes they have witnessed and identify their impacts on subsistence harvesting. A central goal of this research was to better understand the impacts of environmental change on subsistence practices, and to highlight the effects of ecological disturbance on the cultural landscape.

STUDY REGION

There are six communities in the ISR, spread across an area of 906, 430 km^2. The communities of Inuvik, Aklavik, Tuktoyaktuk, and Paulatuk are located on the mainland, while Ulukhaktok is located on Victoria Island and Sachs Harbour is located on Banks Island (Figure 1). This region is generally described as having a mixed-cash economy, where wildlife harvesting continues to play a large role in meeting local needs (Usher 2002). With the exception of Inuvik, which contains more government and commercial infrastructure, employment options are limited. Most residents rely on varied and sporadic sources of income or government support (Pearce et al. 2011). Subsistence harvesting is important in all six communities, but specific practices vary based on each community's proximity to marine and terrestrial resources. Across the ISR, widely harvested species include barren-ground caribou (*Rangifer tarandus* *groelandicus)*, muskrat *(Ondatra zibethicus)*, snow geese *(Chen caerulescens)*, beluga whale *(Delphinapterus leucas)*, muskox *(Ovibos moschatus)*, ringed seal *(Pusa hispida)*, bearded seal *(Erignathus barbatus)* and numerous fish species (Alunik et al. 2003, Joint Secretariat 2003).

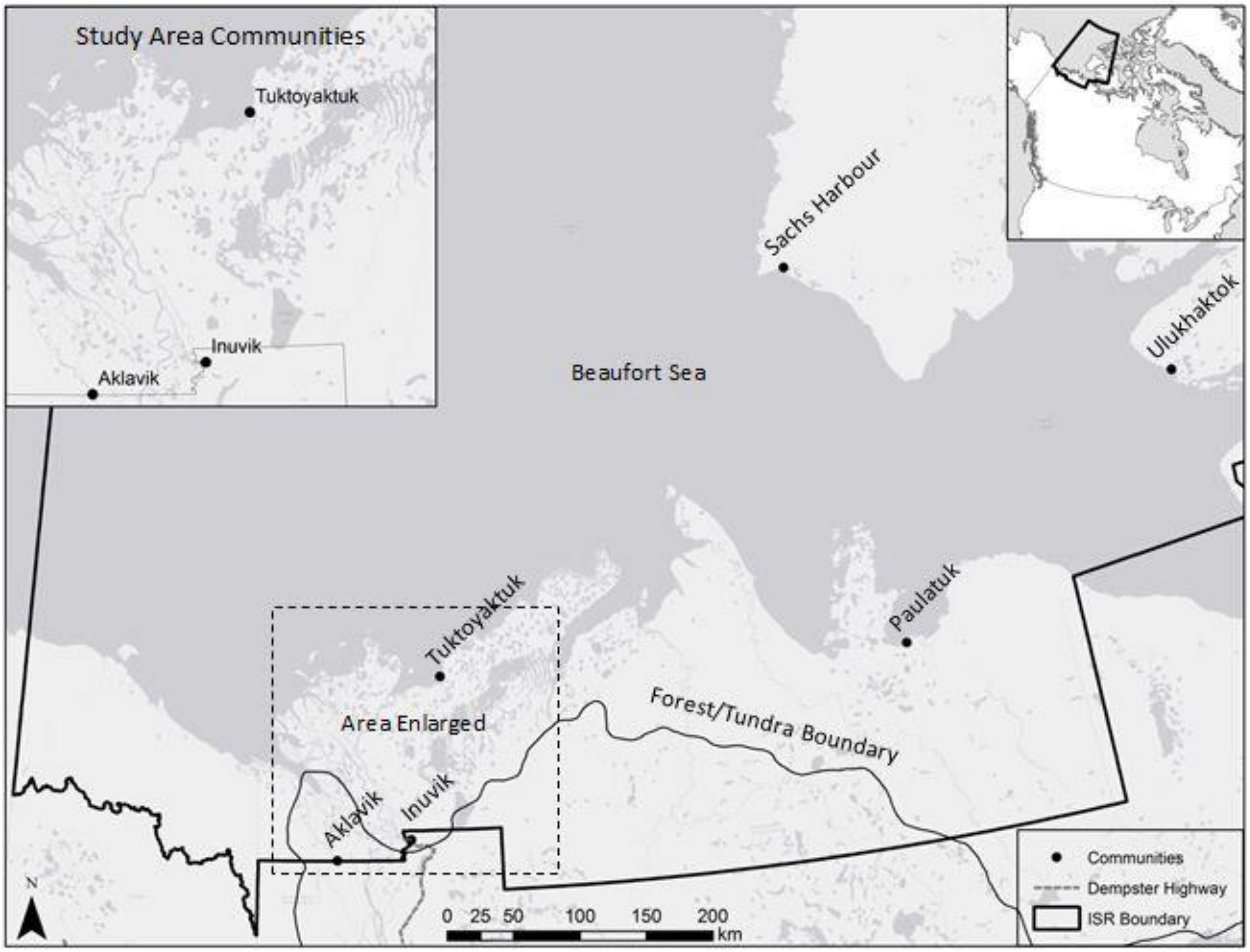

Figure 3-1: The Inuvialuit Settlement Region (ISR). Vegetation across the ISR includes subarctic boreal forest in the south and Arctic tundra in the northern mainland and Arctic Islands (Timoney et al. 1992, Ecosystem Classification Group 2012, 2013). The position of the tree line is strongly correlated with summer temperature, which decreases with proximity to the Beaufort Sea (Burn and Kokelj 2009). As such, most of the ISR is above the tree limit, and characterized by shrub and graminoid tundra (Yukon Ecoregions Working Group 2004, Ecosystem Classification Group 2012, 2013). The ISR is topographically diverse, and in addition to large expanses of upland tundra, includes the Mackenzie Delta, the British Richardson Mountains, and long stretches of coastline along the Beaufort Sea and Arctic Islands. The enlarged inset at the top left shows the study region for this research.

This study focuses on the southern ISR and the communities of Inuvik, Aklavik, and Tuktoyaktuk. Inuvik (Pop. ~ 3,484) is the only settlement in the ISR that is currently accessible by road, year-round. The town is near the limit of the northern boreal forest and is bounded by the Mackenzie Delta to the west and the tundra of the Tuktoyaktuk coastlands to the north (Ecosystem Classification Group 2012). Aklavik (Pop. ~ 594) is located on the western edge of the Mackenzie Delta. The Mackenzie Delta is the second largest Arctic delta in the world and is characterized by thousands of small lakes and river channels. It is a productive environment that hosts an abundance of wildlife and provides critical migratory bird habitat (Yukon Ecoregions Working Group 2004, Burn and Kokelj 2009, Ecosystem Classification Group 2012, 2013). Residents of Inuvik and Aklavik frequently travel along the major waterways of the Mackenzie Delta for harvesting purposes. Aklavik is also within close proximity to the Richardson Mountains and Yukon North Slope, and residents frequently travel to these areas to hunt. Tuktoyakutk (Pop. ~ 854) is located above the tree line, on the mainland coast of the Beaufort Sea. It is the only focal community in this study that has direct access to the ocean, and travel to harvesting areas often occurs along the coastline. Tuktoyaktuk and Aklavik are only accessible by boat or plane until winter, when they are linked to Inuvik and areas to the south by ice roads. There are few consistent wage-earning jobs in the region, and much of the area's economic history is associated with oil and gas resource exploration (Alunik et al. 2003).

METHODS

To investigate the impact of environmental change on subsistence harvesting practices, 20 semi-structured interviews were conducted in the communities of Inuvik, Aklavik, and

Tuktoyaktuk over the course of two field visits. Nine interviews were conducted between August 10 and September 1, 2014 and 11 interviews were conducted between November 26 and December 16, 2014. Interview participants were selected based on recommendations made by Inuvialuit land-users who have participated in an existing community-based environmental monitoring program (Bennett and Lantz, 2014). All participants self-identified either as active land-users, or as individuals with a long history of hunting and trapping in the region. Seven interviews were conducted in Tuktoyaktuk and Aklavik, and six interviews were conducted in Inuvik (n=20).

In the ISR, both men and women actively use the land and have knowledge of environmental change. In this study, our previous interactions with local Hunter and Trapper Committees, which are comprised largely of men, strongly biased participant selection to include 20 men, ranging in age from 26-81. Consequently, our results represent a highly gendered account of the impacts of environmental change on subsistence land-use. Interviewees were asked a series of questions regarding their knowledge of environmental change in the region, its effect on hunting and trapping, and their major concerns regarding the impacts of environmental change on subsistence harvesting. Questions were designed to elicit information regarding changes in the abundance and quality of harvested wildlife, as well as other factors important for wildlife harvesting, such as travel or access to harvesting areas. Each participant was also asked about the specific impacts of known environmental disturbances in the region. These included: seismic lines, drilling mud sumps, road construction, pipelines, wildfires, permafrost slumping, and saline incursion from coastal storms. Participants were asked general questions regarding changes in weather, historical periods of resource exploration, and any societal changes they noticed over their lifetime. Participants were also given an opportunity to discuss any other changes that they considered important. For a complete list of interview questions, see Appendix A. Interview transcripts were analyzed to identify emergent patterns by coding responses using 17 themes that reflected the type of changes witnessed (i.e. changes in weather, changes to the land, etc.), the positive and negative effects of specific environmental disturbances (i.e. easier travel, fewer animals present, etc), and general attitudes towards environmental change (i.e. concerns about future change, the ability to adapt, etc.). Participant responses were also categorized based on the area and time period that they applied to. For a full list of coding themes, see Appendix B. This research was approved by the University of Victoria's office of Human Research Ethics (Protocol Number 14-178) and licensed by the Aurora Research Institute (License Number: 15416). All participants volunteered to take part in the study and agreed to have their responses shared as part of this research. All interviewees were compensated for their participation in the study using locally established rates. Most participants also consented to have their interview transcripts and related media files archived for community access and future reference on the Inuvialuit Knowledge Keeper website: https://inuvialuit.knowledgekeeper.ca/.

RESULTS

Observed Environmental Change

When asked to describe the current state of the land, 19 of 20 participants noted a significant change in environmental conditions over their lifetimes. Erosion, along riverbanks and coastlines or due to permafrost slumping, was the most frequently mentioned change in the region.

> "I've been traveling up the coast…with a boat…since about 10 years, now, and it's constant [erosion]. Even to Inuvik, you could see a lot of erosion when you go up to [the] Mackenzie. A lot of permafrost dropping along the bank."- Charles Pokiak, Tuktoyaktuk.

Participants also noted role of other natural disturbances, such as wildfires and storm surges, in changing local landscapes. Participants described the effects of a variety of man-made changes that they encountered in their time on the land, such as seismic blasting associated with historic oil exploration and the current construction of an all-weather highway linking Tuktoyaktuk and Inuvik (Table 1). Seismic lines were the most frequently identified man-made disturbance (Table 1). Concern regarding specific disturbances varied regionally based on their frequency, severity, or proximity to communities. For example, individuals who frequently traveled along rivers or coastlines tended to voice concerns regarding coastal and riverbank erosion, while less frequently encountered disturbances, such as tundra fires, were acknowledged, but were not typically viewed as significant threats.

> "Well I haven't really noticed anything… been no fires, except for little bit down the highway, it gets smoky sometime, but it hasn't really changed lots since back then." – Colin Day, Inuvik.

All interview participants cited climate change or increasingly erratic weather as a major disturbance in the region. Participants referred to climate change both directly; often citing warmer winters, changes in precipitation patterns, or an increase in wind events, and indirectly; citing permafrost thaw, changes in the timing of freeze up and break up, changing wildlife patterns, and increased vegetation growth. Climate change was typically discussed in relation to its effect on daily life. For example, one participant noted:

> "…people are becoming a lot more aware of climate change and stuff like that, just because what they're starting to see. People are seeing cabins falling in the rivers, they're seeing animal migration patterns changing, the timing of the migration changes…quality of the meat, the pelt..." -Douglas Esagok, Inuvik

In general, participant responses were conservative, focusing only on changes that individuals had personally witnessed. Participants often qualified their statements by noting the local nature of an observation or the fact that a respondent was speaking in relation to his own personal experience in reference to a particular area, and not for the sub-region or ISR as a whole. Interviewees were also generally hesitant to discuss changes to the land that they had not witnessed first-hand and made it clear when they were speculating instead of speaking based on experience. For example, when asked about coastal flooding, Edward Lennie of Inuvik responded "Well, I don't know…I haven't been hunting for a long time in that area. So, the place to find out is…from people in that area, from Tuk [Tuktoyaktuk]…"

Impacts on Wildlife Harvesting

The majority of participants described an overall decrease in the quality of wildlife harvesting in the region (Table 2). These observations ranged from detailed accounts of a particular species to general observations regarding the abundance of wildlife or the ability to access specific hunting areas. Commonly cited examples of changes to harvesting included lower numbers of caribou or muskrat, lower quality fur or meat of harvested species, increasingly difficult navigation of rivers and coastlines, and an inability to access certain areas due to late freeze up or early thaw (Table 1). Participants often noted that disturbance (erosion, changing ice conditions, etc.) made accessing harvesting areas increasingly difficult. In many cases participants also linked changes in hunting success with a specific impact on the target population. For example, individuals whose muskrat trapping lakes had drained all noted the direct relationship between altered habitat and a decreased abundance of this species.

> "In the Delta…lakes that were good trapping before are falling into the river…there's not enough water for them [muskrat] to make pushups." – Hank Rogers, Inuvik

Interviewees also described negative impacts to harvesting following specific events. This was particularly true of older participants, who almost all described the oil boom of the 1970s and '80s, noting that it significantly altered their hunting and trapping efforts, both due to a physical disruption of traplines and widespread disturbance of wildlife.

Not all observations of environmental change were described as directly impacting harvesting. Many participants encountered certain environmental disturbances in their time on the land, but indicated that these did not negatively their wildlife harvesting. For example, while 13 individuals reported the impact of oil exploration on the landscape, only 10 individuals indicated that this activity negatively affected wildlife harvesting. Seismic lines were also widely observed, but their presence rarely was cited as a negative impact to wildlife harvesting (Table 1).

There were notable differences among communities, in terms of frequently discussed environmental changes. For example, residents of Tuktoyaktuk referred to harbor dredging and its impact on local herring populations as a major disturbance in the region. Individuals in Tuktoyaktuk also emphasized human activity and disruption to local harvesting during periods of historic oil exploration more strongly than individuals in Inuvik or Aklavik. Residents of Aklavik expressed a lower level of concern regarding the impacts of human disturbance on hunting and trapping, and placed a greater emphasis on the impacts of climate change on wildlife harvesting, citing difficulties such as increasing erosion, changes in weather, and access to wildlife populations. Responses from residents of Inuvik varied significantly based on individual patterns of land use, but most individuals tended to note changes to major waterways and lakes due to erosion, slumping, and increased beaver activity in the region. Variation also occurred within communities, and was likely related primarily to differences in individual harvesting patterns and land use. Most participants described the regular use of specific traplines, bush camps, or hunting areas and discussed the impacts of environmental change as they related to these places.

There were also instances when participants identified decreases in species health or abundance, but did not attribute specific drivers of these changes. For example, when discussing caribou decline, one participant stated that:

“2014 was…not a really good year for caribou," but that this could be caused by “anything …, could be weather, could be… like some years it’s good and some years [not], it changes every year.” -Dean Arey, Aklavik.

Table 3-1: Major disturbances described by interview participants and their impacts on wildlife harvesting. Interview participants were asked to identify major changes to the land that they have witnessed and whether observed changes had any impact on wildlife harvesting. Disturbances marked with an asterisk were not mentioned explicitly in our questions, but were raised independently by participants.

Disturbance	Participants Observing	Participants Observing Negative Impact	Observed Negative Impacts	Participants Observing Positive Impact	Observed Positive Impacts
Slumping/Erosion	19	9	More difficult travel along rivers, hazards on land	0	NA
Changing Climate/Weather	18	13	Difficult to predict weather, storms impact travel, altered wildlife migrations, disturbed habitat, poor winter fur quality, increased insect harassment of wildlife	2	Improved over-wintering for wildlife, more wildlife activity
Changes in Ice Formation*	13	9	Dangerous travel due to weak ice, inaccessible harvesting areas due to late freeze-up or early break-up	0	NA
Seismic Lines	17	1	Creates brush piles and steep banks that are travel hazards	8	Easier travel, good trapping area, wildlife corridor
Storm Surges	13	4	Destroys vegetation/wildlife habitat, makes water travel difficult	1	Cleans coastline
Oil Exploration	13	10	Disturbs wildlife, alters habitat, interferes with traplines	0	NA
Wildfires	11	7	Destroys wildlife habitat, disturbs wildlife, can create snags and other travel hazards	4	Increased fur bearing mammals in years following fire
Sumps	10	3	Disturbs wildlife, unknown safety levels, susceptible to flooding, leaks can destroy habitat	0	NA
Road Construction	9	7	Disturbs wildlife, crosses traplines, interferes with existing travel routes	2	Will create safer/easier travel, more wildlife sightings
Increasing Beaver Population*	8	8	Disturbs waterways and vegetation, disturbs fish and muskrat habitat	0	NA
Drained Lakes*	6	6	Destroys muskrat habitat	0	NA
Pipeline	5	2	Disturbs wildlife	1	Travel route
Overhunting*	5	3	Decreases local wildlife	0	NA
Harbour Dredging*	3	3	Disturbs herring populations	0	NA
Disease*	2	2	Decreases wildlife population and meat quality	0	NA
Wildlife Research*	2	2	Radio collaring disturbs caribou	0	NA

Table 3-2: Threats to subsistence harvesting and observed causes identified by participants.

Theme	No. of individuals observing	Cause	No. of individuals reporting
Fewer/Lower Quality Wildlife	19	Oil exploration/industrial activity	10
		Other wildlife interference/predation	8
		Unsure/unclear	8
		Changes in climate/weather	8
		Other human activity	5
		Overhunting	5
		Vegetation change	2
		Natural variation	2
		Drained lakes	2
		Wildfire	6
		Storm Surge	2
		Road Construction	6
More Difficult Travel	16	Changing ice conditions	11
		Erosion/slumping	9
		Changing weather	6
		Changing water levels	4
		Vegetation change	1
		More people/traffic	1
		Seismic lines	1
		Road construction	1
		Wildfire	1
Non-Environmental Changes	19	Cultural change	15
		Increased cost of living	10
		Management restrictions	3

Cultural Change and Increased Cost of Living

Although our interview questions focused primarily on environmental changes in the region, almost all participants noted the impact of socioeconomic factors on wildlife harvesting. Half of the respondents identified the increased cost of travel, particularly fuel, as a significant hindrance to spending time on the land. 15 participants also cited cultural change as a reason for decreased wildlife harvesting in the region (Table 2). Elements of cultural change described by participants included a move towards wage labor and a transition from a lifestyle based on year-round life in bush-camps to one based on residence in permanent settlements. Older participants often cited the oil exploration that occurred between the 1960s and 1980s as the critical turning point in the transition from a subsistence lifestyle to wage-based employment. These individuals also made it clear that this cultural shift and the associated decline in traditional activities have had a much larger impact on subsistence harvesting than environmental change.

Adaptation and Positive Aspects of Change

When asked if current or future changes to the land might improve wildlife harvesting in the region, most participants responded negatively. However, when speaking about specific environmental disturbances, some individuals noted several changes that have improved wildlife harvesting (Table 1). This was most apparent in discussing seismic lines, which are often used to facilitate travel and to set traplines. Similarly, while wildfire in itself was not viewed as a positive occurrence, some participants noted that years after a fire, burnt landscapes contained high levels of fur bearing mammals.

Some participants also stressed the local capacity to adapt to changes and expressed their belief that traditional harvesting will continue in the future. A consistent theme across interviews was the importance placed on all four seasons of subsistence harvesting. Many individuals noted that if weather patterns, species populations, or access to harvesting areas shift, harvesters will focus on alternative species or travel farther to meet their subsistence needs. Other participants suggested that they tend to respond to immediate environmental changes, noting the difficulty of planning too far in the future, given the rapid pace of regional change. Certain individuals also stressed the importance of the community, noting that information sharing and frequent communication among harvesters is important in harvesting success.

DISCUSSION

Impacts to Harvesting

Interviews with Inuvialuit land-users show that the cumulative effects of regional environmental change are negatively impacting subsistence harvesting. Nearly all participants identified significant changes to the land, a decline in the abundance and quality of wildlife, or difficulties traveling due to environmental disturbance. Participants tended to speak conservatively, rarely citing a single disturbance as catastrophic or attributing major changes in harvesting to a single event, and gave no indication that disturbance has crossed a social-ecological threshold (Parlee et al. 2012) that precludes the continuation of traditional harvesting. However, in many instances, participants linked specific environmental disturbances, such as oil exploration, erosion, or wildfires with particular impacts to harvesting, such as animal disturbance, increasingly difficult travel, or degraded habitat. These responses echo the findings of previous research in the region, which has highlighted the impacts of a changing landscape on travel routes, access to harvesting areas, and the availability of wildlife resources (Berkes and Jolly 2001, Krupnik and Jolly 2002, Pearce et al. 2010, Ford and Pearce 2010). Detailed accounts of specific environmental changes and their effects on harvesting, such as the influence of increasing beaver populations on fish and muskrat habitat, add new insights to a growing body of research, and highlight the need for ongoing and detailed consultation of local land users. Local knowledge is vital in rapidly changing environments because it provides up-to-date insights on the intricacies of ecological change and the impacts that are experienced directly by local land-users.

Climate Change Impacts

Our interviews with Inuvialuit land-users clearly demonstrate that climate change is significantly impacting land-use practices in the ISR. Although we did not specifically ask about climate, participants made it clear that climate change affects multiple aspects of wildlife harvesting (the quality of meat and pelts, the safety and ease of travel, animal abundance, etc.). It is likely that more participants would have noted the impacts of climate change, had they been explicitly addressed in all interviews. Our findings are consistent with previous research on the impacts of climate change in Arctic communities (Berkes and Jolly 2001, Krupnik and Jolly 2002, Corell 2006, Pearce et al. 2010, 2011) and underscore the severity and large scale of the challenges posed by this aspect of environmental change.

Indigenous Knowledge in Cumulative Effects Assessments and Environmental Monitoring

Our findings also highlight the importance of engaging indigenous knowledge holders in cumulative effects assessments. Recent research has identified the growing impact of climate change and human disturbance on ecosystems across the Arctic (Johnson et al. 2005, Johnstone and Kokelj 2008, Kokelj et al. 2010, Gunn et al. 2011, Bret-Harte et al. 2013, Gill et al. 2014a), but these studies typically focus on narrowly defined ecological values. Co-management policy in the ISR and elsewhere acknowledges the impacts of ecological change on indigenous culture (Government of Canada 1998, Renewable Resources & Environment 2010, SLUPB 2013), but scientific assessments of environmental disturbance do not address impacts to land use and subsistence harvesting (Pearce et al. 2011). Adding an indigenous perspective to cumulative effects monitoring creates a more comprehensive representation of environmental impacts. For example, riverbank erosion is not typically regarded as a significant disturbance for wildlife species such as caribou; however community members describe erosion as a major hindrance to hunting (Table 1). Land-users interviewed in this study also indicated that roads impact traplines, create noise disturbance for hunters, and conflict with pre-existing travel routes (Table 1). By describing the impacts of environmental change in the context of subsistence land use, this research identifies the concerns of local land-users and highlights perspectives that are generally not addressed in scientific or cumulative impacts literature (Nellemann and Cameron 1998, Johnson et al. 2005, Gunn et al. 2011). This provides a more complete representation of cumulative effects and offers a framework for assessing the cultural impacts of environmental change in other regions.

Our interviews also emphasize the importance of engaging indigenous knowledge holders in ongoing environmental monitoring. For example, many of the land-users we interviewed described the negative effect of drained lakes and increasing beaver populations on muskrat trapping. These insights occur at an extremely local scale, which may be overlooked in broad-scale, regional ecological assessments (Johnson et al. 2005, Post et al. 2009), underscoring the importance of local knowledge in understanding rapid change in large areas where logistics are complex and expensive (Riedlinger and Berkes 2001, Pearce et al. 2009, Kokelj et al. 2012, Gill et al. 2014b, Bennett and Lantz 2014).

Cultural Change and Non-Environmental Impacts

Our research also highlights the need to consider social factors in cumulative effects research. Many participants made it clear that socioeconomic factors have the single largest impact on regional wildlife harvesting. Major oil exploration in the 1960s and ‘70s was described as a turning point for the region, initiating a transition away from full time travel between bush camps and a move towards wage-based labor. Today, the increasing cost of bush travel, coupled with a lack of employment opportunities (Young and Einarsson 2004, Nelson 2013) is a major impediment to wildlife harvesting. At the time of December field visits, gas prices were as high as $2.25 CAD/liter in Tuktoyaktuk, and some participants noted the high cost of travel made regular harvesting trips difficult or impossible. Participants also described declining interest, especially among youth, in the continuation of subsistence harvesting. Taken together, these responses indicate that cumulative effects assessments are profoundly incomplete without an analysis of cultural and socioeconomic impacts. Integrating these impacts in cumulative effects assessments remains a challenge, and few studies deal explicitly with socioeconomic factors (Mitchell and Parkins 2011). However, industrial developments, societal change, and an increasingly globalized Arctic are poised to dramatically alter communities (Hovelsrud et al. 2011), underscoring the need to develop a methodology for incorporating cultural change in cumulative effects assessments.

The Nature of Observations and Issues of Scale

Our findings also highlight the importance of integrating indigenous knowledge at an appropriate scale. The information shared in the interviews for this study focused on specific observations of environmental change, which were tied to individual traplines, personal experience, and local landscapes. While several general themes emerged from the aggregate body of interviews, variation amongst individuals and communities indicates that investigations of environmental change should be conducted at fine-scales. Additionally, our interviews were not comprehensive and gaps remain in understanding the full range of impacts to wildlife harvesting in the region. The application of indigenous knowledge at an inappropriate scale has been identified as significant barrier to the meaningful incorporation of indigenous views in environmental monitoring (Nadasdy 1999, Cruikshank 2001, Wohling 2009), and our results emphasize that generalizing at a regional scale may mischaracterize the range of impacts experienced in the Inuvialuit harvesting community, and that monitoring programs should consider observations at the specific scale in which they are made.

Implications for the Future of Subsistence Wildlife Harvesting

Rapid ecological change in the Arctic will require communities to adapt to new conditions (Berkes and Jolly 2001, Young and Einarsson 2004, Pearce et al. 2010, 2011). Our interviews suggest that the impacts of environmental change are largely negative. However, despite the difficulties posed by increased environmental disturbance, many participants expressed a belief that communities will adapt to changing conditions and continue to harvest across all four seasons. Our interviews indicate that harvesters respond to short-term challenges and typically do not plan for future environmental disturbances because they are hard to predict. Participants highlighted the importance of adaptive strategies such as food and information sharing, flexible travel methods, hunting locally available species, and utilizing new technology, all of which support previous research on climate change adaptation in Arctic communities (Berkes and Jolly 2001, Riedlinger 2001, Pearce et al. 2010, 2011, Ford and Pearce 2010). To develop longer-term strategies that will help communities develop strategies for adaptation to disturbance associated with climate change and human development, there is a need for research that employs Inuvialuit observations and research on landscape change to predict and plan for future environmental conditions.

CONCLUSION

This research shows that ecological change in the Inuvialuit Settlement Region is impacting local subsistence harvesting. The Inuvialuit land-users we interviewed described the negative impacts of both climate change and varied environmental disturbances on hunting and trapping in the region. Participants indicated that changes affect many aspects of wildlife harvesting, including wildlife quality and availability, species habitat, the viability of travel routes, and access to harvesting areas. Research that focuses on local knowledge of environmental impacts is vital in cumulative effects assessments because it highlights the direct effects of environmental change on cultural practices. Our interviews also show that socioeconomic changes have had a large effect on subsistence harvesting and should be included in cumulative effects assessments. The approach described in this paper recognizes the importance of utilizing local observations in assessments of cumulative effects and provides a framework that can be used to evaluate the impact of ecological, cultural, and socioeconomic change in other Arctic regions.

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Appendix A

Questions used in Semi-Structured Community Interviews

1. How long have you lived in (community name)? What is your history and experience on the land?

2. How would you describe the current health of the land? Has this changed over your time on the land?

3. This project is particularly interested in understanding how environmental disturbances affect wildlife harvesting. How has wildlife harvesting in the ISR changed during your time on the land? Have you noticed any changes in the environment that affect your ability to hunt and trap?

4. Are you able to harvest the same species today that you used to harvest?

5. Are there specific disturbances that affect hunting and trapping differently? We are interested in both man-made disturbances; *checklist: seismic lines, roads, pipelines, and sumps*, and natural disturbances; *checklist: wildfires, slumps, and saltwater flooding*.

6. Do you notice areas where multiple disturbances occur in the same place? If so, does this affect wildlife harvesting in these areas?

7. Can you remember if/how hunting and trapping changed following major events in the history of the region (i.e. creation of Inuvik, large tundra fires, seismic exploration/oil boom, storm surge, recent oil exploration, other events)?

8. Are there aspects of a changing landscape that have helped your ability to hunt or trap? If so, what?

9. Besides species health, what are the biggest factors that influence your success hunting or trapping (i.e time, access, weather, etc.)?

10. Looking towards the future, what do you feel are the biggest threats that are facing wildlife harvesting in the region? Do you feel that the community is prepared to adapt, if these changes occur?

11. Are there future environmental changes that may improve hunting and trapping in the region?

12. With the increasing cost of travel, is it important to have un-impacted harvesting areas nearby, or will you travel as far as you need to in order to hunt or trap?

13. Recap: confirm the biggest threats/issues raised by the participant and the major changes that he has witnessed in his time on the land.

Appendix B

Themes used for coding interview responses in NVivo: Interview transcripts were coded to identify major themes in participant responses. Any transcript text that referenced one of the following 17 themes was coded accordingly. Pieces of text often referred to multiple coding themes

1. Access
2. Climate and Weather
3. Cost of Living
4. Cultural Change
5. Specific Disturbance Type: subdivided into drained lakes, erosion, human activity, oil exploration, overhunting, pipeline, road, seismic line, slumping, storm surge, sump, wildfire
6. Fewer Wildlife
7. Future Change
8. Specific Interview Question: subdivided into 13 categories, based on the interview questions in Appendix A
9. Management
10. Migrations (Animal)
11. Multiple Disturbances Occuring in the Same Area
12. Personal History
13. Quality of Change: subdivided into positive, negative, and neutral
14. Safety
15. Significant Historical Event

16. Travel
17. Wildlife: subdivided into beaver, caribou, ducks, fox, geese, grizzly bears, lynx, marten, moose, muskox, muskrat, polar bear, wolverine, and wolves

Chapter 4

SYNTHESIS AND FUTURE RESEARCH

Summary

Climate change and increases in human and natural disturbance are impacting Arctic vegetation structure, permafrost stability, and wildlife populations (Johnson et al. 2005, Myers-Smith et al. 2006, Post et al. 2009, Lantz et al. 2013, Bret-Harte et al. 2013, Gill et al. 2014). In the Inuvialuit Settlement Region (ISR), environmental change affects regional ecosystems and subsistence harvesting practices in local communities (Pearce et al. 2010, Ford and Pearce 2010, Bennett 2012). Inuvialuit land-users rely on local ecosystems for hunting, trapping, whaling, and fishing (Alunik et al. 2003, Joint Secretariat 2003), all of which are being impacted by environmental change (Berkes and Jolly 2001, Pearce et al. 2009, Bennett and Lantz 2014). My MSc research focused on the southern ISR and combined community-based research in Tuktoykatuk, Aklavik, and Inuvik with a broad-scale mapping approach that assessed the cumulative effects of environmental change on culturally significant ecosystems in the ISR.

The main objectives of this research were to 1) spatially assess the cumulative effects of environmental disturbance on culturally significant ecosystems in the ISR; 2) to understand their impact on conservation potential in the region; 3) to identify how Inuvialuit knowledge can contribute to our understanding of cumulative effects in culturally important landscapes; and 4) to assess the implications of these changes for Inuvialuit subsistence wildlife harvesting. To address these objectives, I developed a new approach to map the cumulative effects of multiple disturbances, measured the overlap of disturbance and important harvesting areas, and used Marxan simulations to assess the impacts of current and future disturbances on the potential to conserve large, contiguous harvesting areas (Chapter 2). Subsequently, I conducted a series of semi-structured interviews with Inuvialuit land-users in the communities of Inuvik, Aklavik, and Tuktoyaktuk that explored the impacts of environmental change on hunting and trapping in the region (Chapter 3).

My spatial modeling and Marxan research demonstrate the extent of existing environmental disturbances in the southern ISR, and highlight the impact of multiple perturbations on the potential to conserve wildlife harvesting areas. Chapter 2 also provides a benchmark assessment of disturbance frequency and intensity in the region and suggests that regional conservation potential has already been impacted by environmental change. Future impact scenarios show that increasing environmental disturbances, particularly those associated with climate change, will further reduce conservation potential, underscoring the need for cumulative effects management that plans for future perturbations.

Semi-structured interviews with Inuvialuit land-users complemented my spatial analysis by describing the impact of environmental change on wildlife harvesting. Interviews showed that land-users are witnessing significant environmental change and that environmental disturbances are negatively impacting regional wildlife harvesting. The depth of knowledge shared by participants regarding a wide range of disturbance types highlights the importance of incorporating indigenous observations into cumulative effects monitoring and provides cultural context regarding the impacts of environmental change on local harvesting practices.

Synthesis of Research and Benefits of Using a Mixed-methods Approach

My MSc research demonstrates the benefits of using both quantitative and qualitative methods to assess cumulative effects. Broad-scale mapping and Marxan modeling provided an effective way to identify spatial patterns of environmental disturbances and to assess the impact of perturbations on conservation potential. Interviews with Inuvialuit land-users provided a fine-scale perspective on environmental change, and highlighted the socioecological implications of these changes. Overall, this created a fuller representation of environmental impacts in the region.

The strength of my broad-scale spatial analysis of the region lies in the ability to map a range of impacts across a large area. To our knowledge, this is the first cumulative effects assessment in the ISR that maps a wide range of disturbance types across the entire mainland. This provides a benchmark assessment of disturbance levels in the region and highlights instances where highly disturbed areas overlap with important harvesting and management zones. In large regions such as the ISR, combining broad-scale analyses with local observations is critical because the expertise of most land-users is restricted to one part of the study area. Without a regional inventory, identifying landscape-wide patterns would be difficult. Broad-scale spatial modeling is also required to identify areas where the accumulation of disturbances may approach thresholds for acceptable impact levels. The disturbance weighting and mapping approach described in this thesis provides a tractable measure of environmental change throughout the region that can assist land managers in avoiding threshold levels of cumulative impacts.

Our land-user interviews provide context for the disturbances mapped in our spatial analysis. Interviewee descriptions of the impacts of environmental disturbances generally supported our ecological ranking of disturbance severity. For example, our spatial analysis ranks seismic lines as low-intensity disturbances, and land-users generally indicated that seismic lines are not a major concern for wildlife harvesting. Similarly, we ranked permafrost slumping as a severe ecological disturbance, and many land-users confirmed that slumping and erosion create major travel hazards.

Interviews also provided a greater level of detail than the information included in our spatial analysis. Many interviewees referred to non-spatial disturbances that significantly impact harvesting. For example, many land-users noted that periods of oil exploration activity resulted in large amounts of noise pollution, physical disruption of traplines, and significant impacts to local wildlife populations. Additionally, interviewees emphasized that changes in weather patterns and ice formation (none of which were mapped in our spatial analysis) play a major role in impacting wildlife harvesting. Local observations regarding the impact of drained lakes or increasing beaver populations in the region provide detailed accounts of changes that also go unaddressed in broad-scale assessments (Nellemann and Cameron 1998, Johnson et al. 2005). Finally, interviewees also noted the importance of socio-economic changes in the region, an element of cumulative effects research that was not addressed in our spatial analysis. Combining local observations with broad-scale spatial assessments is integral to gaining a fuller representation of cumulative effects in the region.

Taken together Chapters 2 and 3, emphasize the importance of combining local and indigenous knowledge and scientific research in environmental monitoring. Recent literature suggests that both forms of knowledge can inform one-another, and are best used in tandem, rather than placed at-odds (Moller et al. 2004, 2009, Berkes 2009). Inuvialuit knowledge has already played a major role in scientific research in the ISR (Nichols et al. 2004, Bell and Harwood 2012, Kokelj et al. 2012, Bennett and Lantz 2014) and the observations shared by local land-users as a part of this research highlight the cultural and socioeconomic dimensions of environmental change. Likewise, our broad-scale assessment of cumulative effects highlights patterns across the entire southern ISR and emphasizes trends that are not readily evident in interviews with individual harvesters.

Limitations and Future Research

In order to map such a wide range of disturbances across a large study area, we made a number of simplifying assumptions. Disturbances were weighted based on our assessment of their initial severity and their persistence on the landscape. There is no uniform standard for disturbance weighting, and the severity of environmental disturbance varies in relation to the ecosystem component(s) in question. It is likely that research concerned with a specific ecological variable would weight disturbances differently than a study focused on another ecosystem component. For example, cumulative effects studies focusing on specific wildlife species (Johnson et al. 2005, Gunn et al. 2011) will likely weight the impacts of oil exploration differently than research that focuses on geological and vegetation responses to oil development (Raynolds et al. 2014). During an internal review of my research by the Northwest Territories Cumulative Impacts Monitoring Program, several reviewers commented on this issue and suggested that future research could rely on an expert review panel to create consensus disturbance weights.

Our modeling of future disturbance scenarios was heavily influenced by changes in fire regimes, due to their larger spatial footprint than simulated human disturbances. Future studies in the ISR should assess potential scenarios where human disturbance is more widespread. This could be accomplished by modeling scenarios where natural gas reserves are developed for hydrocarbon extraction, and mapping the spatial footprint of required infrastructure, such as wells, well pads, roads, seismic lines, and other disturbances associated with natural resource extraction (Holroyd and Retzer 2005).

Our community-based research was characterized by highly local observations made by Inuvialuit hunters and trappers. Because interview responses varied based on the spatial extent of individual harvesting patterns, it is likely that our sample size does not capture the full range of impacts to wildlife harvesting in the study area. Additionally, our participant list is made up entirely by male land-users and our results are likely influenced by a strong gender bias. Inuvialuit observations are already incorporated into regional environmental monitoring (Bennett and Lantz 2014), but future research should build on this work to incorporate a fuller range of Inuvialuit observations on wildlife harvesting into cumulative effects monitoring. This may be accomplished through the expansion of interviews to female land-users and harvesters who access different regions, as well as formalizing the integration of Inuvialuit observation in the descriptions of environmental impacts.

My thesis results also suggest a need for additional research on the impacts of socioeconomic change on subsistence culture in the ISR. Many participants indicated that socioeconomic changes in the ISR have had major impacts on wildlife harvesting. While a full analysis of these changes is beyond the scope of this research, interview results clearly suggest that an increased cost of bush travel, a shift towards wage employment and life in permanent settlements, and a decreased interest in land-based activities impact wildlife harvesting in the region. While this is a new field of cumulative effects research, these conclusions are similar to ones made in socioeconomic research in the Arctic (Nelson 2013). Additional cumulative effects research should continue to develop methods for assessing the impact of development on social indicators such as poverty levels, the ability to participate in traditional activities, or the sense of place and control amongst community members (Mitchell and Parkins 2011).

Interview results also revealed a potential mismatch in scale between indigenous observation and the drivers of some types of environmental change. Many interviewees noted that they observed particular changes in wildlife harvesting, but did not always identify the cause of change. For example, many participants indicated that they experienced a decline in local caribou populations, but were unsure of the cause. This suggests that land-users are experiencing the effects of change that is beyond the scale of local observation. Future research should investigate this possibility in more detail to better understand the most effective use of indigenous knowledge in environmental monitoring, and identify additional circumstances where broad-scale scientific research can complement local knowledge.

Conclusion

My thesis emerged as a part of a collaboration between the Inuvialuit Joint Secretariat and the University of Victoria to create an environmental monitoring program based on Inuvialuit knowledge (Lantz et al. 2013, Bennett and Lantz 2014). Land-users who participated in my project clearly emphasized the importance of local ecosystems and the significance of environmental change. These insights are critical in gaining a detailed understanding of cumulative environmental impacts and their effect on subsistence harvesting culture. Spatial analysis identified regional patterns of environmental disturbance quantified its impact on the ability to conserve wildlife harvesting areas. The ability for these two types of research to inform one-another creates a more comprehensive assessment of cumulative effects. Ongoing environmental monitoring should involve continued dialogue between researchers, land-users, and land-managers to incorporate multiple perspectives in cumulative effects research and explore the wide-ranging impacts of Arctic environmental change.

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