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FOSTERING RESILIENCE AND ADAPTING TO CLIMATE CHANGE IN THE CANADIAN NORTH — IMPLICATIONS FOR INFRASTRUCTURE IN THE PROPOSED CANADIAN NORTHERN CORRIDOR

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FOREWORD

THE CANADIAN NORTHERN CORRIDOR RESEARCH PROGRAM PAPER SERIES

This paper is part of a special series in *The School of Public Policy Publications*, investigating a concept that would connect the nation's southern infrastructure to a new series of corridors across middle and northern Canada. This paper is an output of the Canadian Northern Corridor Research Program.

The Canadian Northern Corridor Research Program at The School of Public Policy, University of Calgary, is the leading platform for information and analysis on the feasibility, desirability, and acceptability of a connected series of infrastructure corridors throughout Canada. Endorsed by the Senate of Canada, this work responds to the Council of the Federation's July 2019 call for informed discussion of pan-Canadian economic corridors as a key input to strengthening growth across Canada and "a strong, sustainable and environmentally responsible economy." This Research Program will benefit all Canadians, providing recommendations to advance the infrastructure planning and development process in Canada.

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Program Director, Canadian Northern Corridor Research Program

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S. Jeff Birchall, Sarah Kehler and Nicole Bonnett

KEY MESSAGES

The key findings and recommendations of this review are:

- **Resilience of northern infrastructure is dependent on adaptation being done in an equitable way**. This means balancing environmental risk reduction through infrastructure measures and vulnerability reduction through socioeconomic stressor support.
- **Northern Canada is warming at double the global rate, which is already causing significant challenges for northern infrastructure.** The feasibility of expanding northern infrastructure is drastically reduced without capitalizing on the ability of adaptation and resilience planning to mitigate increased risks due to climate change.
- **Northern Canadian communities are considerably vulnerable to climate change.** Physical vulnerability due to remoteness, amplified warming and ecological fragility is compounded by systemic socioeconomic stressors, economic vulnerability and overwhelming adaptation and maintenance costs.
- **Climate change adaptation is projected to be exceedingly costly and increasingly necessary.** There is an urgent need to prepare communities for the worst, without putting them at an economic disadvantage or hindering their ability to function and thrive.
- **Misconceptions about the opportunities climate change will bring to northern Canada hinder effective adaptation.** Underestimating the severity and complexity of climate change and its effects can have unintended consequences, and therefore, the potential to drastically reduce the feasibility of expanding northern infrastructure.

- **Hard infrastructure adaptation measures are capital intensive, costly to maintain and carry a high risk of failure.** The costs and effectiveness of adaptation measures have limits in the face of unrestricted climate change and are constrained by sociopolitical factors that define a community's capacity to adapt.
- **Effective adaptation is integral to the sustainability of any proposed northern expansion.** Smart adaptation measures focused on reducing vulnerability through a place-based approach can be identified through public consultation and fostered through the respectful integration of non-Western knowledge systems. Intergovernmental co-operation is critical to facilitate implementation of low-risk, high-benefit policy.

SUMMARY

The Canadian Northern Corridor (CNC) has been proposed to overcome gaps in the northern transportation system that limit social and economic development in the Canadian North (Fellows et al. 2020). Intended to be a multimodal transportation right-of-way through Canada's North, the CNC seeks to capitalize on shifting global markets and increased access to northern resources (Pearce et al. 2020; Fellows et al. 2020). However, transportation infrastructure has remained constrained across northern Canada. Significant challenges exist for northern infrastructure due to isolation, restricted access and extraordinary environmental conditions — all of which climate change is projected to radically intensify (Palko and Lemmen 2017; Pearce et al. 2020).

Climate change drastically reduces the feasibility of expanding northern infrastructure. Significant increases in environmental risk threaten existing infrastructure and magnify maintenance costs. Adaptation in remote northern locations can be exceedingly difficult and costly (Palko and Lemmen 2017). Additional Arctic warming is guaranteed to have systemic effects and pose significant challenges for northern infrastructure: temperature and precipitation will continue to increase; permafrost thaw will be amplified through changes in seasonal snow cover and land ice; ice loss of mountain and polar glaciers is virtually certain; coastal impacts such as erosion and storm surges will be magnified by increasing sea level and extreme volatility; and Arctic sea ice extent will decline to the point of likely being practically ice free in September before 2050 (IPCC 2021). Determining how to facilitate long-term, effective climate change adaptation is critical to overcome these challenges.

Adaptation planning seeks to anticipate and mitigate the risks that result from climate change. This is done through two methods: hard and soft adaptation. Hard adaptations provide a physical barrier to the source of risk, such as a sea wall. In contrast, soft adaptations reduce risk by adjusting human behaviour through a variety of methods, including regulating development out of high-risk areas through land use bylaws or development permits, and fostering environmental stewardship to bolster ecosystem services, such as wetland preservation to reduce flooding (Bonnett and Birchall

2020). However, common misunderstandings about which adaptation initiatives are effective often disable adaptation planning (Kehler and Birchall 2021). This often results in maladaptation — when adaptation measures result in unintended negative consequences that further increase risks. Hard infrastructure adaptations intended to reduce physical risk, despite typically being used as the foundation of adaptation planning, magnify the risk of maladaptation when used alone (Bonnett and Birchall 2020). Due to the capital-intensive nature of hard measures, both upfront and in long-term maintenance, and their predisposition to environmental degradation, the need to go beyond hard measures to address vulnerability is well understood (Bonnett and Birchall 2020; Kehler and Birchall 2021; Naylor et al. 2020).

Adapting infrastructure to climate change in the Canadian North presents a formidable challenge. Limits and constraints to effective adaptation, such as lagging implementation, isolation, low population and limited tax base to fund local-level adaptation and infrastructure maintenance, result in significant challenges and limited capacity to overcome them (Bonnett and Birchall 2020; Birchall and Bonnett 2020; Birchall et al. 2021; Ford et al. 2015).

While climate change is perceived to have the potential to increase access to the North — allowing trade, tourism and transport of much-needed goods and services to northern communities — in reality, existing and new construction will be progressively vulnerable to unprecedented climatic effects and the resulting infrastructure maintenance will grow increasingly costly. This increase in vulnerability and costs is likely to restrict the anticipated socioeconomic boons of expanded connectivity and resource development, potentially straining already vulnerable communities and Indigenous Peoples. Considerable uncertainty requires a planning approach to infrastructure adaptation that focuses on mitigating risks of climate change while also bolstering community resilience. Infrastructure expansion such as the CNC necessitates adaptation planning that includes fostering economic diversity and infrastructure resilience. Increased disaster risk due to climate change could push communities already overwhelmed by maintenance and adaptation to being unable to cope, resulting in vulnerabilities across northern Canada.

Balancing hard adaptations with other forms of policy, such as soft adaptations intended to increase adaptive capacity and adaptation readiness, is critical to avoid maladaptation of infrastructure. Regardless of cost or feasibility, for infrastructure adaptation to be effective it must coincide with a reduction of socioeconomic stressors, and all decision making must be done through a localized, participatory and equitable process (IPCC 2014). Addressing adaptation and resilience for northern infrastructure requires exploring what is necessary to foster resilience, examining what avenues for adaptation are most effective and then maximizing the benefits of limited funding allocated toward these strategies.

Effective adaptation strategies focus on the reduction of vulnerability through place- and context-specific approaches, using low-risk, high-benefit policy measures that are supported through significant intergovernmental co-operation, public engagement and

integration of non-Western knowledge systems. By further understanding the pathways to achieve resilience, and through a holistic approach to adaptation, it is possible to balance the increased environmental risks of climate change with socioeconomic impacts, and to do so in a way that is economically sustainable long into the future.

1. INTRODUCTION

Canada is rich in natural resources; much of its history has been shaped by resource extraction and export, with many permanent settlements forming around dense resource stockpiles (Van Assche et al. 2016). However, transportation infrastructure across the Canadian North remains limited due to extraordinary environmental conditions and remote geography (Pearce et al. 2020), rendering considerable resource wealth inaccessible and limiting social and economic development in the Canadian North (Fellows et al. 2020).

The expansion of northern infrastructure has been proposed in response to these challenges. The Canadian Northern Corridor (CNC) — a proposed multimodal transportation right-of-way through Canada's North — aims to capitalize on shifting global markets and increased access to resources in the North due to accelerated polar warming, while seeking to include northern Canada in the south's prosperity (Pearce et al. 2020; Fellows et al. 2020).

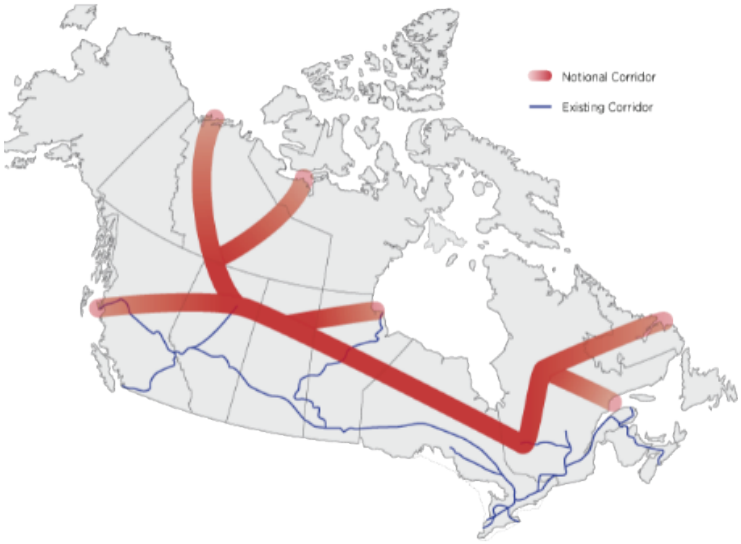

Figure 1: A possible route of the Canadian Northern Corridor proposed by the University of Calgary School of Public Policy (Pearce et al. 2020; Sulzenko and Fellows 2016).

However, as the Canadian North warms due to climate change (Environment and Climate Change Canada 2019), transportation infrastructure faces significant challenges (Palko and Lemmen 2017). In particular, thawing permafrost, flooding and wildfires threaten the stability and efficiency of northern transportation systems, rendering it critical to build infrastructure with these risks in mind (Palko and Lemmen 2017). As climate change impacts are worsening, there is growing urgency to assess the magnitude of risk to infrastructure in the Canadian North and identify adaptation strategies to increase the resilience of northern infrastructure. Climate change impacts are the result of changing environmental processes interacting with human systems — manifesting through vulnerability due to lack of preparedness and exposure to increasing risk. Across the globe, as climate change effects threaten communities, there is a significant need to address the following question: How can communities, and the

infrastructure that supports them, withstand the dramatic changes that are occurring in the warming climate? To answer this question, the field of urban and regional planning has undertaken an approach that bolsters community adaptation and resilience in the face of increasing environmental variability and extremes.

Adaptation to climate change is defined as the adjustment of human systems in order to moderate or avoid harm or exploit beneficial opportunities posed by climate change, while resilience to climate change refers to the capacity of these systems to cope with and adjust to hazardous events or stressors that result from a warming world (IPCC 2014). Climate change poses numerous challenges for the CNC, many of which would require extensive adaptation and have significant implications, both positive and negative, for the resilience of northern communities.

An urban and regional planning approach to infrastructure adaptation reveals several crucial considerations for the planning of northern transportation infrastructure. Climate change is a momentous threat to the livelihoods and critical infrastructure of isolated and vulnerable northern communities. Resilience is inherently complex, and vulnerability to climate change even more so. While adaptation seeks to reduce vulnerability and mitigate exposure to risk, to do so effectively goes beyond hard infrastructure measures alone and requires balancing the many interconnections between communities and the environment around them. In the Canadian North, this balance is substantially more precarious. To successfully adapt requires consciously balancing unique northern environmental considerations, such as increasing disaster risk and ecosystem fragility with ever-increasing adaptation costs and the needs of isolated vulnerable communities. Poor planning of adaptation initiatives could lead to unintended consequences that further degrade the resilience of northern communities. The complexity of climate change vulnerability and the uncertainty of its effects leave a significant margin for error. Maladaptation refers to adaptation strategies that fail in the face of this complexity, resulting in wasting limited funds while worsening the situation and further perpetuating vulnerability. Consequently, the CNC's impacts on the resilience and capacity for northern communities to adapt to climate change will need to be carefully considered when determining project feasibility.

1.1 PURPOSE AND METHODS

This paper is part of the Canadian Northern Corridor Research Program, which seeks to develop the information base, analysis and evaluation necessary to assess the feasibility and desirability of establishing permissible corridors across northern Canada. The purpose of this paper is to explore the implications of the proposed CNC on the resilience of northern infrastructure vulnerable to climate change. It has been conducted through a review of relevant literature and, most importantly, takes an urban and regional planning approach to climate adaptation and resilience.

In general, a planning approach is interdisciplinary, works within many spatial scales from urban to rural to regional, and is primarily concerned with optimizing how the varying elements within a given space — such as the local culture, economy and

transportation infrastructure — all work together. As a result, this approach offers a broader perspective of resilience that enables adaptation methods which recognize and leverage the value that each unique local context brings to the larger regional system. This approach is critical to understanding the complexity of the project itself and the implications it would have for the Canadian North. Increasingly, northern communities are relying on transportation infrastructure for delivery of basic necessities, yet there remain significant gaps throughout the northern transportation system (Palko and Lemmen 2017). A planning approach allows for analysis of the potential implications of expanding infrastructure on the resilience of northern communities and provides critical considerations for infrastructure adaptation to climate change. Consequently, this paper uses an urban and regional planning approach to review existing literature and explore the following questions:

1. What are current challenges and opportunities for northern Canadian infrastructure caused by climate change?
2. What are some of the strategies currently pursued to adapt to the impact of climate change on infrastructure?
3. Considering the impact of climate change on infrastructure, how can the Canadian Northern Corridor support the development of resilient infrastructure in the Canadian North?

First, this paper will summarize urban and regional planning, followed by an introduction of what it means to plan for climate change. Once this general understanding is reached, the implications of climate change in the Canadian North are reviewed, leading to an examination of the challenges facing northern adaptation planning. Following this context is a section devoted to exploring obstacles and unintended consequences in adaptation, supplemented by several case studies, which is intended to facilitate an understanding of the complexity of climate change in the Canadian North. Last, further considerations are recommended for the adaptation of northern infrastructure and the CNC, focusing on a holistic and dynamic approach that reinforces resilience. These strategies include hard and soft infrastructure adaptation measures to mitigate environmental risk, in addition to vulnerability reduction measures by addressing socioeconomic stressors and increasing the adaptive capacity of northern communities.

2. URBAN AND REGIONAL PLANNING

Urban and regional planners provide strategic recommendations to policy-makers to guide the effective use of land, resources, facilities and services within communities and across regions. As members of an accredited technical profession governed by a strict code of ethics, Canadian planners are first and foremost responsible to the public interest (Canadian Institute of Planners 2016). This responsibility demands planners act in good faith to secure the physical safety, economic efficiency and social well-being of the communities they serve. With awareness of each community's unique needs, planners are positioned to ensure impacts on social stressors are considered when implementing technical recommendations. In many ways, planning functions as a liaison between technical experts, community members and elected officials.

2.1 COMMUNITY PLANNING AND THE DESIGN OF LAND USE

Planning is largely a discipline of dynamic balance; planners must work to first determine the current needs of their local community, then forecast future needs and attempt to meet them, all while simultaneously considering the far-reaching implications of decisions. To do so successfully, planning relies heavily on participatory processes to determine the public interest, technical assessments to determine feasibility and makes recommendations to decision-makers such as elected officials/ city council. Through these processes, planning makes both local- and regional-scale recommendations through master plans and long-term strategic policies covering land use such as infrastructure placement and design. This has broad implications for the network of transportation connections within and between cities.

While planning is a technical accredited profession, planners are often interdisciplinary; rather than specializing in any one area, they are trained to grasp and analyze the intricacies of how all the parts of a city or region work together, then communicate the importance of these interconnections with other technical disciplines. On the local scale, planning makes recommendations about municipal infrastructure through community plans such as area redevelopment plans, municipal development plans and transportation master plans. These plans are built off the foundation of public participation. Through meaningful consultation with all community members affected by a decision, planners work to uphold democratic principles by facilitating an ongoing and inclusive dialogue throughout the decision-making process. Different levels of plans guide development and land use design; for example, master plans cover growth and redevelopment across an entire municipality, while area redevelopment plans consider redevelopment at a smaller, local community level. The recommendations set out in these official plans are then implemented through legislation such as bylaws and zoning codes that define, for example, use type, density, design or setbacks. However, planning is more than just zoning — planners are involved in the efficient and sustainable transportation of goods and services, the distribution of basic necessities such as housing and economic growth, and the development and maintenance of public infrastructure.

Finance is a key aspect of planning, particularly for infrastructure. Large infrastructure projects, like the CNC, usually derive their capital budget from a variety of high-level sources such as the federal government. Once completed, responsibility for the projects' maintenance costs shifts to lower levels of government. Municipal-level planning and maintenance of public infrastructure, such as transportation infrastructure, is funded primarily through property taxes; once a municipality has determined its yearly budget, this cost is distributed across all city properties as a percentage of property value dependent on use type. When property tax alone is inadequate for operation, these excess costs, if the maintenance is deemed critical, are funded through federal or provincial contributions. In contrast, on a regional level, provinces and territories receive revenue to fund infrastructure from a variety of sources, including income taxes, investments, non-renewable resource revenue and transfers from the federal government. As a result, a municipality has less diversity in sources of income compared to higher levels of government. Because the capacity for a municipality to pay for infrastructure maintenance is largely dependent on its property values, infrastructure development and maintenance are vulnerable to local economic fluctuations. So, while revenue for regional maintenance is obtained from a variety of sources and therefore less vulnerable, the municipal connections in between are vulnerable, despite being a vital part of the regional infrastructure system. This is critical when considering the cost of maintaining vital transportation connections between and within cities — infrastructure connections which define how basic necessities are distributed and facilitate economic growth.

While the intricacies of planning remain outside of the scope of this paper, this basic overview will facilitate the understanding of subsequent concepts.

2.2 PLANNING FOR CLIMATE CHANGE

Anthropogenic climate change is unequivocal (IPCC 2021). The consequent severe environmental changes continue to pose significant risks to vulnerable communities across the globe (Naylor et al. 2020; Pandey et al. 2017; Siders 2019). Consequently, adaptation and resilience planning continue to gain momentum among planners and policy-makers (Birchall and Bonnett 2021; Ford and King 2013; Siders 2019; Williams et al. 2020). Despite this increase in planning for climate change, the relationships between vulnerable communities and the infrastructure that supports them remain staggeringly complex (Eriksen et al. 2020; Meerow and Newell 2016; Naylor et al. 2020). It is well understood that adaptation to climate change is likely to be one of the costliest endeavours facing communities in the next century, rendering it essential to determine what adaptation strategies will remain effective and financially viable in the long term (IPCC 2014; OECD 2015; Suter et al. 2019).

Planning for climate change strives to reduce the current and future vulnerabilities that arise from a warming world. These efforts rely heavily on two concepts: adaptation and resilience. Adaptation and resilience do not exist separate from one another, but rather are complex and interconnected. On one hand, adaptation seeks to adjust human systems to climate change, while on the other, resilience facilitates flexibility

within these systems (IPCC 2014). Understanding the history and current planning theory behind these two concepts is critical to truly grasp the ways in which effective adaptation of infrastructure in the Canadian North can be achieved. Both concepts will be introduced individually here, while subsequent sections will explore how they interrelate.

2.2.1 ADAPTATION

Climate change is no longer avoidable. Unless drastic actions are taken, limiting warming to the 1.5°C agreed upon in the Paris Agreement is extremely unlikely (IPCC 2021). The need for adaptation planning is thus increasingly critical (Birchall and Bonnett 2021; Ford and King 2013; Williams et al. 2020). Climate change is likely to be one of the greatest economic disasters humanity will face (Andrew 2008; OECD 2015; Singh and Birchall 2019). While the upfront costs of addressing climate change are substantial, the long-term consequences loom much larger (Kehler and Birchall 2021; OECD 2015).

Planners, when considering the future of communities, need to anticipate local risks that may occur due to climate change and plan for them accordingly. This adjustment can consist of hard adaptations such as seawalls that provide a physical barrier, or soft adaptations such as altered land use or wetland preservation (Bonnett and Birchall 2020). Both hard and soft adaptations are critical to a community's overall resilience and come with benefits and drawbacks. The goal of any adaptation is to reduce risk by limiting exposure and vulnerability to climate extremes.

Despite the threat of climate change, adaptation planning remains in its infancy, with its effectiveness often disabled by common misunderstandings. Adaptation policy, across all levels of government, frequently focuses solely on hard measures which rely on engineering to modify infrastructure to mitigate disaster risk, or on the economic opportunities that a warmer climate will bring (Birchall and Bonnett 2020). Hard infrastructure adaptations, which are heavily relied on to reduce vulnerabilities, come with considerable drawbacks and carry a high risk of maladaptation: these measures are capital intensive, costly to maintain and often further degrade the northern environment (Bonnett and Birchall 2020). This high cost poses a considerable fiscal challenge and increasingly, the costs of adaptation and maintenance are downloaded from national governments to regional and local governments with limited financial capacity to adapt (Down and Birchall 2019; Singh and Birchall 2019). Because hard infrastructure adaptations provide a visible sense of security and are relatively quick to install, they give the illusion of protection. Yet, the potential for maladaptation is high; hard measures tend to be too costly in the long term and lack the flexibility necessary to provide adequate protection as climate change worsens (Bonnett and Birchall 2020). Consequently, the need to go beyond hard measures alone is well understood (Bonnett and Birchall 2020, Kehler and Birchall 2021; Naylor et al. 2020).

Given the risk of maladaptation due to an over-reliance on hard measures, soft adaptations intended to increase adaptive capacity and adaptation readiness are equally as critical. The adaptive capacity, or the potential of systems to adapt, defines the efficacy of any adaptation initiative — something which planners, through a holistic approach, can play a key role in strengthening (Birchall and Bonnett 2021; Dale et al. 2020; Ford and King 2013; Runhaar et al. 2018; Siders 2019; Williams et al. 2020).

Adaptive capacity is scale-dependent and goes beyond hard adaptation measures to consider the available economic resources, technology, information and skills, infrastructure and social institutions (Adger and Vincent 2005; Fitton et al. 2021; Ford and King 2013). Furthermore, adaptive capacity is a function of social structures such as the values and ethics of the local community and culture (Adger and Barnett 2009). Increasingly, the value of non-Western knowledge systems in adaptation is being recognized. Indigenous perspectives offer greater understanding of climatic changes and impacts, and increased flexibility and innovation in adaptation initiatives (Lede et al. 2021; Pearce et al. 2015; Tran et al 2021). It is therefore critical to understand the local context and integrate place-based knowledge into adaptation planning (Ramsey et al. 2019; Williams et al. 2020).

The significance of localized adaptation approaches becomes particularly relevant as adaptive readiness — the willingness for governments to implement adaptation — is often constrained by governance processes and lack of implementation in decision-making (Ford and King 2013; Ojwang et al. 2017). The interconnections between adaptive capacity and readiness further demonstrate the challenge faced when planning for climate change in northern communities: "Short-term economic and political priorities become meaningless when long-term climate impacts dismantle infrastructure systems" (Birchall, MacDonald and Slater 2021, 8). On one hand, climate policy often comes from higher levels of governance, yet remains ineffective at a local level; on the other, local governments are often best suited to address adaptation, yet face significant challenges in prioritizing adaptation while facing more immediate economic or political concerns (Birchall, MacDonald and Slater 2021). Collaboration and communication between levels of government on adaptation planning is critical in facing these challenges, facilitating proactive adaptation and helping to balance immediate interests with increasing risks due to climate change.

Considering the novel and unpredictable nature of climate change, the ability to plan for beneficial outcomes and possible risks has been drastically misunderstood (Dawson et al. 2018; Field 2018). As costs of adaptation mount and beneficial opportunities provided by climate change have proven extremely rare, both public and private organizations remain confounded as to who is responsible for this incredible expense (OECD 2015). Anticipatory planning that prioritizes incremental infrastructure upgrades can greatly facilitate cost-effective adaptation of infrastructure, while planning policy intended to increase adaptive capacity can ensure communities have the resources necessary to adapt.

Regardless of significant challenges, urban and regional planning allows for greater understanding of how to achieve adaptation through a wider lens that considers the unique context of each community, whether that be by mitigating disaster risk through incremental adaptation, or by increasing adaptive capacity through economic diversification and addressing socioeconomic inequities.

2.2.2 RESILIENT COMMUNITIES

Despite ongoing debate among academics about its true meaning, resilience continues to be adopted as a goal within adaptation plans (Davoudi et al. 2013; Meerow and Newell 2016). Consequently, for policy-makers and planners alike, resilience remains a necessary term for policy. Yet, what is resilience? The IPCC (2014) defines resilience as the capacity of social, economic and environmental systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining their capacity for adaptation, learning and transformation. Our understanding of resilience has changed substantially over time, particularly as climate change has forced researchers to revisit the concept and reframe it in a constantly changing world. As the effects of climate change become more severe, the importance of resilience to strategic planning is also becoming more apparent.

In essence, resilience is simply the propensity of a system to be flexible in the face of adversity and began as a concept used predominantly within engineering and ecology. Static engineering resilience refers to a system's ability to bounce back to its previous state, while dynamic ecological resilience focuses on a system maintaining key functions when perturbed (Holling 1996). These perspectives of resilience have had significant impact on how infrastructure resilience is thought of today. Soft adaptation initiatives address the physical impacts of disaster and facilitate effective recovery through design and land use decisions founded on the following key concepts: diversity, modularity, redundancy and connectivity (Allan and Bryant 2011). Infrastructure resilience requires a diversity of infrastructure that functions as a network with high modularity across all scales — this facilitates reorganization in the event of a failure in one aspect of the system (Allan and Bryant 2014; French et al. 2019). Resilient networks require alternative connections should one fail, which is only possible in a system deliberately planned to have high connectivity with adequate redundancy built in (French et al. 2019).

These earlier perspectives of resilience, however, rely on the notion of the system returning to a stable equilibrium — an equilibrium which cannot be defined for complex human systems within an unpredictably changing climate (Davoudi et al. 2013). To overcome this discrepancy, a new conceptual framework was developed called evolutionary resilience, which defines a community's capacity for resilience as a function of both socioeconomic stressors and environmental risk (Davoudi et al. 2013; IPCC 2014). This perspective of resilience acknowledges the complexity of adaptation and vulnerability to climate change, while underscoring the importance of strategic

planning for resilience (Davoudi et al. 2013). Planning is uniquely situated to increase communities' evolutionary resilience; its participatory methods and place-based theories offer a perspective of communities and their environment as a unique and interconnected socio-ecological system, enabling an approach to adaptation planning that considers both physical and social sources of vulnerability.

Tyler and Moench (2012) offer a framework through which urban planning can foster evolutionary resilience. By moving beyond a focus on only climate impacts, this framework seeks to integrate ecological, infrastructure, social and institutional factors to create a holistic perspective of resilience (Tyler and Moench 2012). Through this approach, planners can foster resilience by leveraging the benefits of shared learning and planning processes to build adaptive capacity, co-create knowledge and effectively prepare for climate change (Kehler and Birchall 2021; Tyler and Moench 2012). While resilience concepts such as connectivity or diversity are imperative to infrastructure resilience, the perspective of evolutionary resilience is critical in order to avoid maladaptation of critical infrastructure — infrastructure systems do not exist in isolation from the people and communities that use them (Tyler and Moench 2012). Adaptation plans focused solely on infrastructure resilience carry a high risk of failure as the dangers associated with only addressing hard measures are momentous (Birchall and Bonnett 2021; Osborne 2013; Siders 2019; Stoett and Omrow 2020).

Focusing on resilience holistically ensures that adaptation is effective and that limited funds are not needlessly exhausted; to do so effectively requires deliberate consultation with communities and deliberate fostering of resilience through policy measures (Kehler and Birchall 2021). While it is largely the participatory planning processes that facilitate effective adaptation, when it comes to resilience the steps are less intuitive. In fact, a lack of resilience greatly hinders the planning process, and as successful adaptation measures rely on increased co-operation between governments and communities vulnerable to climate change, it becomes clear that adaptation planning can only occur effectively in a resilient community (IPCC 2014; Johnson et al. 2015; Kehler and Birchall 2021). This further highlights the need to address both aspects of resilience — socioeconomic and environmental risk — through policy.

Planning is uniquely situated to grasp the complexities of resilience, from both a general and an evolutionary perspective. By focusing on the complex relationships between infrastructure and communities, it is possible to effectively plan for climate change.

3. CLIMATE CHANGE IN THE CANADIAN NORTH

The CNC project has significant unknowns. While each unknown continues to be analyzed by researchers through the Canadian Northern Corridor Research Program, the implications of climate change for such an extensive infrastructure project could render the project unattainable. In the face of such a complex issue as climate change, adaptation of infrastructure is simultaneously essential, uncertain and exceedingly costly (Suter et al. 2019; Val et al. 2019). Understanding the impact of adaptation on this project requires the following: first, a general grasp of climate change in the Canadian North and its consequences for the CNC, and second, an understanding of adaptation of critical northern infrastructure.

3.1 CLIMATE CHANGE IMPLICATIONS FOR NORTHERN CANADA

Climate change is projected to bring significant changes across the globe. Northern Canada is warming at more than double the global rate — a trend that is expected to increase significantly in the next several decades (Environment and Climate Change Canada 2019; IPCC 2021). While climatic effects across the Arctic have been studied time and again (Wan et al. 2019), the seriousness of such change has been highlighted most recently by the IPCC (2021). As northern Canada spans several biomes, a multitude of climate effects are expected to occur (Pearce et al. 2020), making it critical that adaptation measures reflect the diversity of Canada's northern landscapes. While the CNC research program has published the physical science implications of climate change for the northern corridor (Pearce et al. 2020), the relationship between the severity and unpredictability of these effects and adaptation considerations cannot be overstated. Therefore, the results are summarized below.

Pearce et al. (2020) found that climate change is already impacting northern infrastructure and that these impacts can be expected to intensify, putting both existing infrastructure and new projects at significant risk of damage. Since roughly 1950 the annual average temperature across northern Canada increased approximately 2.3°C, coinciding with a 20 per cent increase in precipitation (Pearce et al. 2020). Warmer temperatures continue to threaten northern systems through a multitude of interconnected pathways. As temperature and precipitation increase, the risks of disasters such as flooding and fires do, too (Pearce et al. 2020). Shifting precipitation patterns often result in heavy rainfall over short periods of time, causing overland flooding. Simultaneously, increases in temperatures result in more days with ideal conditions for high-intensity fires (Kirchmeier-Young et al. 2017).

In northern Canada, permafrost further compounds the impacts of increases in temperature and precipitation. Losses in snow cover and land ice due to warmer temperatures expedite melting in what was once permanently frozen ground, while increased frequency and severity of fires further warms the active layer, decreasing the bearing capacity of permafrost throughout the year (Pearce et al. 2020). Coastlines historically protected by sea ice and permafrost are now facing significant erosion due to sea level rise, increased wave intensity and extreme water levels and temperatures (Pearce et al. 2020).

Construction and maintenance of northern transportation infrastructure are likely to be dramatically affected: construction of new projects will require integration of climate change projections for both overall feasibility and civil engineering adaptations, while maintenance will need to be significantly more robust, responsive and well funded to prevent adverse impacts to or hindering of northern transportation (Pearce et al. 2020). The infrastructure adaptations necessary for "dynamic and increasingly extreme conditions" would carry increased costs, while, due to the unpredictable nature of warming effects, effects of intensifying risks would magnify beyond the corridor itself and into communities (Pearce et al. 2020).

3.2 PLANNING FOR CLIMATE CHANGE IN THE NORTH

While dramatic climate change effects are virtually certain to occur somewhere across the Arctic regions, the exact location or severity is difficult to identify (IPCC 2021; Suter et al. 2019). This uncertainty, paired with the complexity of the global climate system, underscores the urgency to prepare communities for the worst, without putting them at an economic disadvantage or hindering their ability to function and thrive. Despite this urgency, adaptation of northern communities presents a significant planning challenge. The capacity of adaptation to mitigate risk to the complex web of northern infrastructure is limited by remoteness and amplified climate change effects. Simultaneously, sociopolitical factors hinder adaptation initiatives — mindset barriers, lack of contextual understanding and lagging implementation, combined with exorbitant construction and maintenance costs perpetuate ineffective planning.

Acute climate impacts have already pushed some northern communities to begin deliberately planning for climate change. In Yukon, for example, Dawson City, Mayo and Whitehorse partnered with the Northern Climate Exchange (Yukon University, then Yukon College) to develop climate change adaptation plans (Hennessey et al. 2011, 2012; Hennessey and Streicker 2011). These plans intended to assess impacts and vulnerability, recommend adaptation actions and increase resilience in the long term. However, since being published in 2011, a lack of accountability and cohesiveness necessary to facilitate action have hindered the plans' implementation.

While adaptation planning in general frequently faces significant barriers, adaptation in the Canadian North remains constrained by exceptional circumstances. With amplified warming effects across the North, adaptation of the CNC is integral to the sustainability of the project; however, the cost and effectiveness of adaptation measures have limits in the face of unrestricted climate change and are constrained by sociopolitical factors that define a community's capacity to adapt (Adger and Barnett 2009; IPCC 2015).

3.2.1 LIMITS AND CONSTRAINTS FOR ADAPTATION IN THE CANADIAN NORTH

Adaptation measures in the Canadian North face significant limits and constraints. Lagging implementation, isolation and low population, and limited tax base to fund local-level adaptation, coupled with amplified warming, result in significant challenges and limited capacity to overcome them (Birchall and Bonnett 2021, 2020). To overcome these constraints requires planning that deliberately employs strategies to increase adaptive capacity and reduce the risk of maladaptation. However, substantial resources are required to facilitate adaptation. Isolation and remoteness of northern communities can result in restricted financial capacity and inadequate technical knowledge required to undertake anticipatory adaptation (Birchall and Bonnett 2020; Singh and Birchall 2019).

Adaptation needs and costs, particularly in remote northern locations, can be significant (Field 2018; Palko and Lemmen 2017; Suter et al. 2019). Local governments are responsible for local-level adaptation, yet their ability to do so is often constrained by a lack of financial support due to their limited tax base and inadequate levels of external support, resources or expertise (Birchall and Bonnett 2020; McNamara et al. 2017). How is it then that local governments are expected to adapt to climate change without adequate resources? Despite the critical need for external support, mindset barriers, conflict and lack of willingness to enact adaptation within multi-level governments all hinder critical northern adaptation planning (Birchall and Bonnett 2020; Ford and King 2013). Without multi-level governmental co-operation, top-down decision-making can render adaptation ineffective — political and economic priorities are misplaced due to misunderstandings about vulnerability and risk, consequently overshadowing the severity and urgency of climate change (Eriksen et al. 2021; Kehler and Birchall 2021; Mayer et al. 2017). For policy-makers who are undereducated about the reality of climate change, its complex nature leads to considerable misconceptions about the opportunities that a warmer climate will bring to the North (Dawson et al. 2018; Birchall and Bonnett 2020; Palko and Lemmen 2017). As a result, adaptation planning for northern communities is rife with maladaptation: scarcity of resources, over-reliance on hard measures and poor land use decisions result in decreased resilience, and as the climate changes communities are overwhelmed by reactionary measures, causing lagging adaptation implementation and further hindering their ability to anticipate and plan (Birchall and Bonnett 2020).

While the severity of climate change across northern communities continues to increase unabated and local governments are already overwhelmed, implementation of anticipatory adaptation is still possible. An effective adaptation plan is preceded by a deliberate effort to overcome constraining factors by building adaptive capacity and reducing vulnerability (IPCC 2014). Particularly within the northern context of the CNC — where accelerated climate change and dramatic vulnerability of infrastructure are compounded by limited adaptive capacity — addressing these barriers is urgent (Ford et al. 2015; MacDonald and Birchall 2019). For example, despite facing significant environmental risks, Lede et al. (2021) found that individuals living in northern communities felt that social stressors, such as housing shortages, food insecurity and overcrowding, far over-shadowed the physical impacts of climate change in their

daily lives. Such significant social stressors substantially limit resilience and adaptive capacity, yet are feasible to address (Kehler and Birchall 2021). Adaptation planning can foster resilience by improving maladapted infrastructure and addressing the lack of resources that limit adaptive capacity (Ford and King 2013; Ramsey et al. 2019; Williams et al. 2020).

Because local governments are best suited to provide context-based adaptation, yet do not have the necessary financial resources to achieve it, multi-level government collaboration and resource sharing are essential (Birchall, MacDonald and Slater 2021). Furthermore, when facing scarce or limited resources, resources available for adaptation should be used strategically to foster resilience through policy that meets socioeconomic needs and generates additional benefits through increased adaptive capacity (Birchall, MacDonald and Slater 2021; IPCC 2014). Strategic planning holds significant potential to foster resilience to climate change provided incremental adaptive measures are mainstreamed and agreed upon through a bottom-up participatory process (Kehler and Birchall 2021; MacDonald and Birchall 2019). To do so requires resources to be allocated equitably through multi-level government collaboration with local governments being given autonomy for effective place-based adaptation planning (Birchall, MacDonald and Slater 2021). The importance of this approach cannot be overstated: decisions about adaptation priorities must be made by those who experience impacts first-hand, fostering resilience through place-based planning, culturally appropriate methods and shared knowledge (Tran et al. 2021).

Resilience is a key aspect of northern infrastructure adaptation in the face of climate change; however, significant barriers persist. Infrastructure expansion has a high potential for maladaptation: Canada's massive scale and varying socioeconomic and environmental constraints increase the difficulty of identifying adaptation actions to foster resilience. Consequently, the effect of new infrastructure such as the CNC on wider resilience depends on the approach to adaptation and its risk of maladaptation. Poorly planned, such projects have the potential to increase the severity of socioeconomic stressors within northern communities and worsen the environmental risk. To address adaptation and resilience across the entire CNC project would require significant research into each local context, deliberate consideration of existing adaptation plans, a more robust economic analysis from a climate change perspective and intentional dialogue with affected communities to determine feasibility.

4. BALANCING THE CNC: OBSTACLES AND UNINTENDED CONSEQUENCES IN NORTHERN INFRASTRUCTURE

Despite the best intentions, planning decisions are often rife with unintended consequences (Adger and Vincent 2005; Axon and Morrissey 2020; Ramsey et al. 2019; Sandercock 1998). Given the complex relationships between socioeconomic factors and climate change vulnerabilities (Kehler and Birchall 2021; Naylor et al. 2020), adaptation of the CNC will need to consider the effects of expanded transportation networks on individual communities.

Planning, through its interdisciplinary and holistic perspective, offers unique insights into how the increasing need for adaptation will be challenged by the exceptional obstacles northern communities already face. The following exploration of case studies intends to exemplify some of the barriers to adaptation northern Canadian communities face, as well as unintended maladaptation resulting from planning decisions.

4.1 RESOURCE-BASED TOWNS

Canadian towns, particularly in northern Canada with its abundance of natural resources, tend to be reliant on one or two resources at a time (Van Assche et al. 2016). The CNC, which aims to expand the transportation network in order to facilitate the movement of natural resources and increase Canada's ability to compete in the international market (Fellows et al. 2020), is likely to encourage significant economic growth in natural resource extraction in communities along the corridor. While at first glance this seems beneficial, the reality is that in order to adapt to climate change, the resilience of the communities affected is critical, and unfortunately, relying heavily on one or two resources increases vulnerability to any change. Communities in any location will feel the effects of economic fluctuations; however, for resource-based towns the effects of boom-and-bust cycles can be dramatic, even potentially resulting in communities being abandoned (Van Assche et al. 2016). Economic diversification is a key aspect of effective adaptation; by relying on a variety of local economic activities, communities can facilitate resilience. There is robust evidence and high agreement that by supporting economic diversification, protecting vulnerable groups and providing financial support, governments can co-ordinate effective adaptation to climate change and mitigate the momentous financial burden of acting on adaptation too late (IPCC 2014).

Without conscious economic diversification, any affected community along the corridor would be at significant risk; however, this vulnerability intensifies as either (or both) the global market for emissions-producing resources decreases in response to the Paris Agreement or as the effects of climate change become increasingly severe. The long-term sustainability of the CNC project and the communities along it is dependent on economic diversification as an adaptation to climate change. For the CNC to be a low-risk endeavour, it should include local support for diversifying the economies of affected communities.

Case Study: Dawson City

Dawson City is arguably one of Canada's most iconic northern communities. To this day, the Klondike Gold Rush is a favourite legend among Canadians, despite the rush itself only lasting three years in the late 1800s (Clark 2011). However, is not commonly understood that the rush to resource extraction itself was a response to a financial recession in the United States, a global gold shortage and significant unemployment (Berton 2001; Morse 2003) — setting the stage for a long history of economic vulnerability for Dawson City and demonstrating the risks of northern development. As a result of boom-and-bust cycles, Dawson's population, and therefore the necessary infrastructure, fluctuated immensely. At the height of the rush, it is likely the town boasted nearly 100,000 people; however, once much of the gold had been extracted the population fell to 5,000 (Coates 1991). This had significant effects on community infrastructure. By 1914, abandoned homes, collapsing businesses and overgrown city lots were common (Morrison and Coates 1989). By 1952, the town was still struggling and attempted to branch out into tourism with the creation of the Klondike Tourist Bureau, which was largely unsuccessful at the time (Commonwealth Historic Resource Management Limited 2008). The expansion of Dawson's economy beyond gold really intensified as a response to flooding in 1979 (Benkert et al. 2015). Floodwaters reached nearly two metres deep and put much of the town's unique heritage infrastructure at significant risk, and in response, investment into heritage preservation soared and tourism quickly became the primary industry (Government of Yukon 2018). This transition diversified the local economy into a mix of gold mining, tourism, arts and culture, fostering resilience to fluctuations in the global economy. Dawson City in many ways is a northern resilience success story. Unfortunately, not all communities are able to weather economic vulnerability and expand their economies successfully. Despite Dawson's economic diversification and the subsequent increase in resilience, climate change, coupled with a lack of multi-level governmental co-operation, threatens this achievement.

Climate change is already affecting Dawson in many ways: river flows are increasingly variable, forest fires are increasing in frequency and, most notably, permafrost slumping rates are increasing, causing major issues for infrastructure (Benkert et al. 2015). As most of the townsite sits on a discontinuous permafrost zone, increased surface temperatures due to climate change lead to variation in snow cover depth, active-layer hydrology variations and infrastructure effects, posing upkeep challenges for building owners and the municipal government (Benkert et al. 2015). Heritage buildings, vital to Dawson's tourism industry, are particularly vulnerable to climate change effects. These historic sites have posed significant challenges for the municipality, as their upkeep is essential to the town's long-term economic sustainability (Parks Canada 2021). In the 1950s, Parks Canada began acquiring heritage properties and artifacts; the federal government now owns and operates many historic properties in the Dawson City area (Parks Canada 2018). Unfortunately, a significant portion of Dawson's historic downtown remains undeveloped and in disrepair due to disagreements between the federal government and the municipality about how to best adapt the city's historic buildings to the challenges posed by the changing northern climate, particularly permafrost thaw (City of Dawson 2018).

This case study illustrates the extreme challenges faced by northern communities and the need for a localized, holistic approach. While Dawson's diversified economy increases its adaptive capacity in the face of climate change, the city's resilience remains limited by inaction resulting from a lack of multi-level governmental co-operation.

4.2 RESILIENCE AND INCREASING DISASTER RISK

The consequences of unmitigated climate change are guaranteed to be severe (IPCC 2021). All communities and the natural systems on which they rely will have significant impacts as the frequency, intensity and duration of weather extremes intensify due to climate change (Environment and Climate Change Canada 2019). Canadians are already feeling the impacts of climate change; Canada is warming at double the global rate and its northern regions are warming at triple the global rate (Canada 2021). Canada is already seeing extreme effects: drought, flooding, cold extremes, heat waves and wildfires have become commonplace (Environment and Climate Change Canada 2019). Such events are costly, disrupt transportation, hinder economic growth and put communities at risk.

Northern communities, such as those that the CNC would impact, are in a difficult place. On one hand, such communities are resource-based, and the CNC would likely increase access to transportation and facilitate expansion and diversification of these industries; on the other hand, climate change will significantly increase disaster risk and result in increased adaptation costs. The potential economic prosperity granted by the CNC would be vulnerable to disasters, requiring significant consideration of how, or if, transportation infrastructure can be planned in a way that facilitates resilience as disaster risk increases.

Expanded transportation connections can have significant implications for disaster risk resilience. Increased disaster risk for northern Canadian communities due to climate change is nearly guaranteed and has the potential to render any hard adaptation measures ineffective. By encouraging development in a high-risk area without adequate modularity and redundancy of infrastructure, resilience of the local community is substantially hindered. However, if land use and transportation connections are considered from a holistic perspective of resilience, it may be possible to reduce maladaptation and complacency, ensuring that risk is lessened in the event of a disaster.

Case Study: Fort McMurray

Fort McMurray, a northern Alberta community, sits in the centre of the Athabasca oilsands. As the epicentre of oil and gas development in Canada, the local economy relies heavily on extraction and production of petroleum (Van Assche et al. 2016). Despite volatile global oil prices, Fort McMurray's population has remained quite stable and has consistently been growing since 2000 (Statistics Canada 2016). Despite this relative stability, in recent years Fort McMurray has experienced several natural disasters, the most notable being the 2016 wildfire which burned almost 600,000 ha, displaced over 80,000 people (Government of Alberta 2016) and caused $3.5 billion in losses (IBC 2016).

While there can be no direct correlation between climate change and the Fort McMurray fire, research has shown that climate change increases the likelihood of such events, and that in the future, as warming becomes more severe, this trend will continue. This increase in risk is due to longer fire seasons, increased fuel availability and more days with conditions suitable for spreading high-intensity fires (Kirchmeier-Young et al. 2017). While the Fort McMurray fire demonstrates the impacts of increasing disaster risk, what is most notable is the way the case highlights the extreme value of resilience in transportation infrastructure. The community is connected north and south by a single highway; from an emergency management perspective, this lack of redundancy and connectivity significantly reduces the community's resilience to a disaster. This was unfortunately demonstrated during the 2016 fire. On May 3, 2016, the wildfire cut off evacuees' route south, costing two people their lives (Public Safety Canada 2021).

This highlights the importance of considering emergency management while planning infrastructure expansion. Resilient community planning must account for increased disaster risk due to climate change. For Fort McMurray, the CNC could potentially facilitate more efficient east and west connections across Canada, likely increasing connectivity and positively impacting the community's resilience. However, increasing road connections alone do not guarantee the avoidance of complacency and maladaptation. To reduce this risk further, other soft adaptations for emergency management such as early warnings or evacuation schemes would need to go hand in hand with transportation infrastructure expansion.

4.3 MALADAPTATION AND MAINTENANCE COSTS

As climate change worsens and adaptation costs continue to increase, many infrastructure-related projects become unsustainable from a fiscal perspective. Climate change continues to threaten federal efforts to expand transportation infrastructure in the Canadian North, resulting in significant maladaptation — such as infrastructure failure due to melting permafrost and erosion, or food insecurity due to decreased operating windows and load capacities of winter roads — leading to significant vulnerabilities in the northern transportation system (Palko and Lemmen 2017). This is a particularly challenging issue for northern communities as infrastructure maintenance and, increasingly, incremental adaptation costs are being downloaded onto lower levels of government which lack the funds to pay for them. For northern communities, remote geographic locations and limited access restrict connectivity to southern Canada (Palko and Lemmen 2017), and this isolated nature perpetuates infrastructure vulnerability to climate change (Ford et al. 2015). While increasing connectivity is critical to resilience in the North, the momentous cost of maladapted infrastructure and subsequent disaster-related failures demand to be considered. The lack of multi-level governmental collaboration combined with misunderstandings about the opportunities and harsh realities of climate change in the Canadian North could lead to rampant

maladaptation along the proposed CNC. Due to permafrost thaw, sea level rise, wildfires and fragile ecosystems, climate change in the Arctic is complex and uncertain (Environment and Climate Change Canada 2019).

The costs and risks associated with conglomerating infrastructure on frozen ground in a location that is warming at three times the global rate could be massive. Permafrost thaw will necessitate increased maintenance and monitoring for all-weather roads that carry significant heavy traffic, while increasingly frequent forest fires will further destabilize permafrost (Palko and Lemmen 2017). Permafrost is inherently unstable and extremely sensitive to disruption. As warming increases the depth of the active layer that thaws during the summer, infrastructure constructed directly on the ground is more likely to thaw the permafrost beneath it. Additionally, in relation to transportation infrastructure, thawing is exacerbated by removal of continuous low vegetation and large construction vehicles can rupture protective vegetation, potentially causing water-filled linear depressions that further accelerate melting and can last for decades (Skinner et al. 1999).

While the CNC's potential route across Canada makes sense for moving goods to and from ports, much of the corridor's southern portion sits on sporadic permafrost — ground that is both challenging and extremely costly to build upon (Palko and Lemmen 2017). The impacts of climate change on the life-cycle replacement costs of Arctic infrastructure will be substantial: by 2059, due to environmental stressors, these costs are projected to increase by over 40 per cent for transportation infrastructure (Suter et al. 2019). The costs are already mounting; for example, in 2018, Russia spent six per cent of its total government budget on the infrastructure impacts of permafrost thaw alone (Suter et al. 2019). Regions of northern Canada are projected to require at least an additional one per cent of annual gross regional product to support existing infrastructure on permafrost due to the loss of load-bearing capacity and thaw subsidence (Suter et al. 2019). These compounding maintenance costs would fall to local governments, which are often poorly positioned to fund this responsibility due to isolation and economic vulnerability.

Northern communities are already overwhelmed by infrastructure maintenance because of climate change, and increased disaster risks could further undermine their efforts (Birchall and Bonnett 2020). While bottlenecks in the Trans-Canada corridor have been cited as a motivator for the CNC, northern infrastructure faces amplified risks for bottlenecks as a result of infrastructure failure and inefficiencies due to climate change (Fellows et al. 2020; Pearce et al. 2020). A single hazardous event can have significant cascading effects for vulnerable communities on isolated fringes of expanded transportation infrastructure. Consequently, it is likely that any minor disaster could disrupt transportation with significant effects; for example, without alternate routes in place, fires and floods along critical infrastructure on destabilized permafrost can be catastrophic. Without adequate planning for economic diversity and infrastructure resilience through redundancy and connectivity, increased disaster risk due to climate change could push communities from being overwhelmed by maintenance and adaptation to being unable to cope, resulting in vulnerabilities all along the CNC. From a planning perspective it would be strongly recommended to

create contingencies for the considerable maintenance costs and risks of disaster-related bottlenecks along the CNC.

Increases in repairs and maintenance that result from climate change are a significant burden for any transportation infrastructure built in the Canadian North (Palko and Lemmen 2017). The cost-prohibitive nature of maladaptation and unpredictability of climate change could create costly inefficiencies along the corridor.

4.4 INFRASTRUCTURE AND VULNERABLE COMMUNITIES

Northern communities are considerably vulnerable to climate change. Isolation, amplified warming, infrastructure sensitivity and limited adaptive capacity compound and perpetuate socioeconomic stressors and environmental risk, leading to decreased resilience (Birchall and Bonnett 2020; Ford et al. 2017; Davoudi et al. 2013; IPCC 2014). While environmental risk can be largely mitigated through adaptation infrastructure, socioeconomic stressors need to be addressed through other forms of policy. Consequently, successful adaptation of the CNC will remain contingent on balancing the risks and benefits of infrastructure expansion, and the implications this may have on the resilience of vulnerable communities.

Adaptation to climate change seeks to reduce the costs and risks associated with a warming world and understanding vulnerability to climate change is a critical aspect of our ability to reduce any negative consequences (IPCC 2014). However, the complexity of vulnerability continues to hinder infrastructure adaptation in the Canadian North; because both resilience and vulnerability to climate change are social and physical, an approach to adaptation that balances both aspects of vulnerability is necessary (Kehler and Birchall 2021; Naylor et al. 2020). Despite the dire need to understand it, exactly how to assess infrastructure vulnerability in northern Canada remains unclear, and the resulting gaps in understanding continue to prevent successful adaptation (Ford et al. 2015). Due to several considerable challenges, decision-making around adaptation for vulnerable communities is contentious: there are few collaborative efforts between social and technical disciplines to assess vulnerability to climate change and adequately inform decision-makers (Ford et al. 2015); ineffective stakeholder consultation results in decisions that perpetuate vulnerability (Johnson et al. 2015; MacDonald and Birchall 2019); inaccessibility of climate science hinders understanding for community members (Benevolenza and DeRigne 2018); and political and mindset barriers restrict the ability of climate adaptation to succeed (Birchall and Bonnett 2021). Such challenges present significant obstacles for new infrastructure such as the CNC. Effective adaptation plans require a clear understanding of what vulnerabilities will be perturbed, created or diminished.

In the face of such complex vulnerability, infrastructure expansion can have both benefits and unintended costs. While some costs for vulnerable communities are physical or economic, many are social, and the consequential reduction in resilience has the potential to destabilize any effort for adaptation. Socioeconomic stressors remain a critical, although under-represented aspect of adaptation: “If a community does not have the skills or resources to recover from or overcome the stresses of climate change,

then regardless of existing policies they will continue to be perpetually vulnerable" (Kehler and Birchall 2021, 472). Reduction of such stressors is best done through increasing access to public services such as education, housing, health services, sanitation or other basic needs (Kehler and Birchall 2021). However, in northern Canada, issues explored in the previous sections compound and reduce resilience substantially: economic vulnerability due to reliance on a single resource can cause systemic socioeconomic stressors in response to market fluctuations; warming continues to increase environmental risk; and the downloading of costly maintenance and adaptation to local governments further depletes resources needed for addressing ongoing issues and bolstering local resilience. Sulzenko and Fellows (2016) identified that there would be a difficult transition period in which communities along the corridor would struggle to provide public services in response to the expected economic activity and population growth; however, due to climate change, the resolution of this transition period is not guaranteed. Infrastructure adaptation is impossible if communities are not resilient, and resilience only occurs when there is adequate provision of public services to reduce socioeconomic stressors (IPCC 2014), making this transition period inherently vulnerable to market fluctuations or climate-related disasters.

While the CNC itself has the potential to better connect northern communities and increase Canada's play in the global economy, due to the complex vulnerability of northern communities to climate change, without adequate planning the project could just as likely have the opposite effect, burdening them with the costs of maladaptation and maintenance, or further isolating vulnerable communities due to disaster-related infrastructure failure. Approaching resilience of the CNC from a holistic and dynamic perspective, considering both environmental and socioeconomic risks and taking an interdisciplinary approach to vulnerability assessments could reduce these risks.

Case Study: Churchill, Manitoba

Churchill, Manitoba, a small town at the mouth of the Churchill River along the shoreline of Hudson Bay, provides unique insight into the significant risks of resource speculation, expanding infrastructure in the North and the cascading effects of high-risk economic endeavours. The town was initially a result of federal and provincial interest in a port city that could facilitate international trade routes in the 1930s. Still to this day, the town is connected to the rest of Canada by only one overland train route (Montsion 2015). Despite the difficulty of economic diversification for resource-based towns, Churchill was able to expand into eco-tourism, transportation and health-care services (Montsion 2015). However, climate change continues to threaten the town in several ways. For instance, receding Arctic sea ice has endangered belugas living in Hudson Bay and increased dangerous encounters with polar bears, to the detriment of the town's tourism industry and public safety (Wilder 2017; Smith et al. 2017). Most prominently, permafrost thaw has significantly impacted the community by causing disruptions to its overland rail connection.

The federal government completed the Hudson Bay Railway connecting Churchill to the south in 1929. CN Railway operated the lines until 1997, before being sold to privately owned OmniTRAX (Montsion 2015). Over time, due to increasing temperatures and subsequent permafrost thaw, maintenance grew increasingly costly, and in spring 2017 two unseasonably late winter storms resulted in flooding that washed out the rail line in more than 10 places (Porter 2017). The economic impacts to the town were substantial due to the disruption of tourism and access to supplies, resulting in a steep rise in the cost of living and an inability to provide critical health care to surrounding communities (Hoye 2017). Shockingly, despite the town's reliance on the rail line, significant cost meant that no public or private entity was willing to restore the line — both the federal government and OmniTRAX denied any responsibility for repairs and filed lawsuits against one another (CBC News 2018). After more than a year without rail service, through a public-private partnership spearheaded by First Nations groups and local governments, the line was purchased, repaired and finally resumed service in early December 2018 (Geary 2018).

Churchill illustrates the complexity of vulnerability that results as climate change increases risks. Churchill is vulnerable in a combination of ways: physically, due to permafrost thaw and other environmental risks; economically, as climate change threatens the diversity of its economy; socially, due to a minoritized population and high costs of living; and politically, due to the lack of collaboration and communication between levels of government. Regardless, Churchill is clearly resilient in other ways too, as demonstrated by its capacity to persevere and collaborate even in the face of the isolation caused by the rail line's failure. Not all vulnerable communities lack resilience, and fostering resilience through unconventional means, such as supporting strong social cohesion and internal networks, can help vulnerable communities adapt to climate change (Usamah et al. 2014).

5. ADAPTATION CONSIDERATIONS: RESILIENCE THROUGH A DYNAMIC APPROACH

Resilience in the Canadian North is complex. Resource-based economies, remote towns, marginalized populations and an unforgiving landscape amplify vulnerability to climate change and magnify the risks of costly maladaptation. Approaching adaptation of northern transportation infrastructure requires planning for the uncertainty and complexity of climate change by respecting the extraordinary circumstances northern communities face.

Planning for adaptation and resilience in the Canadian North faces hard limits and ample constraints. However, effective planning can facilitate flexibility. Adaptation is, first and foremost, local (Barnett et al. 2008; IPCC 2014; Siders 2019; Williams et al. 2020). The previous section highlighted the need for adaptation strategies to be context specific — meaning that, regardless of a similarity in risks or hazards, effective adaptation in any two communities will vary depending on local culture, values or socioeconomic processes — something that is even more relevant in northern communities (Tran et al. 2021; Van Assche, Birchall and Gruezmacher 2022). Van Assche, Birchall and Gruezmacher (2022) find that effective resilience planning for northern communities means having a vision of the future — founded through an inclusive process that values non-Western knowledge — a realistic and deliberate plan to achieve it, and the necessary governance tools to incite action. This approach relies on substantial co-operation across levels and domains of governance, local autonomy to implement detailed policy and an appreciation of local contexts (Bonnett and Birchall 2022; Van Assche, Birchall and Gruezmacher 2022).

The federal government has already commissioned hard adaptation practices focusing on engineering resilience for projects like the CNC (Palko and Lemmen 2017). However, limiting adaptation to hard measures alone would likely be ineffective. The IPCC (2014) identifies the following principles for effective adaptation: place- and context-specific approaches; significant intergovernmental co-operation; reduction of vulnerability; public engagement and integration of non-Western knowledge systems; and focus on low-risk, high-benefit policy measures that provide co-benefits for both adaptation and mitigation. In this case, an urban and regional planning approach can enable effective adaptation through policy directed toward increasing evolutionary resilience within communities by focusing on addressing vulnerability through environmental risk reduction and increasing adaptive capacity.

5.1 ENVIRONMENTAL RISK REDUCTION: INFRASTRUCTURE ADAPTATION

Reduction of environmental risk is a vital aspect of adaptation (Davoudi et al. 2013; Field 2018). This can be achieved through two complementary planning methods: hard infrastructure adaptations and non-structural, resilience-focused soft infrastructure adaptations. Currently, Canada's northern transportation system is ineffective due to gaps in connectivity (Palko and Lemmen 2017), leading to many isolated and vulnerable northern communities without reliable access to essential services. While expanding infrastructure can facilitate connectivity, as stated previously, the potential for maladaptation is high. Hard adaptation measures have limits, and in the face of unmitigated climate change these limits are sure to be exceeded. Soft adaptations, such as altered land use, diminish the risks of infrastructure failure associated with climate change.

Engineering of structural, hard adaptation measures are not the typical realm of adaptation planners. Given the complexity of adaptation for northern communities, in order to avoid maladaptation, a basic understanding of the physical challenges of Arctic infrastructure design is necessary. *Climate Risks and Adaptation Practices — For the Canadian Transportation Sector* details construction techniques and technologies for the adaptation of transportation infrastructure (Palko and Lemmen 2017). This includes permafrost-melt adaptation for all-season roads such as embankment thickening, geotextiles or thermosyphons, or for rail transportation, stone embankments or sun sheds. However, Palko and Lemmen (2017) stress that barriers such as costs, isolation and short construction seasons are likely to restrict adaptation initiatives across the North. Moreover, while opportunities due to climate change are often touted, in reality this is not the case for northern Canada. Climatic changes that are opening northern marine waters are also causing significant challenges for overland transportation: changes in operating windows and load capacities of winter roads are reducing access; permafrost degradation poses immediate and future risks to transportation infrastructure; and adaptation techniques are cost-prohibitive and rely on specialized equipment and materials (Palko and Lemmen 2017).

While hard adaptation alone has the potential to provide some benefit, it cannot be overstated that long-term effective adaptation also requires soft adaptation measures that focus on resilient community design (Van Assche, Birchall, and Gruezmacher 2022). Such measures focus on adjusting human behaviour and fostering resilience through planning (Bonnett and Birchall 2020). For northern communities, this may include planned relocation, altered land use and building controls, increased setbacks or effective emergency management (Bonnett and Birchall 2020). Building resilience into community design is critical for emergency management. Transportation networks that include redundancy, are well connected and have a high degree of modularity are able to facilitate recovery after a disaster (Allan and Bryant 2011; French et al. 2019).

5.2 SOCIOECONOMIC STRESSOR SUPPORT: SMART ADAPTATION AND ADAPTIVE CAPACITY

The reduction of socioeconomic stressors is simultaneously the most crucial and undervalued adaptation to climate change (Kehler and Birchall 2021); underestimating the complexity of adaptation as a social process can lead to misunderstandings about infrastructure adaptation (IPCC 2014). Smart adaptation uses policy to reduce vulnerability to climate change by addressing socioeconomic stressors and consists of low-risk policy choices that provide multiple benefits, such as reductions in GHG emissions and economic growth (Field 2018; IPCC 2014). Simultaneously, a community's adaptive capacity can be similarly supported by addressing local socioeconomic constraints stemming from limited economic resources, equity or access to technology or information (Adger and Barnett 2009; Ford and King 2013). Clearly, a place-based approach that considers socioeconomic stressors is critical to the feasibility of the CNC; yet this is threatened by governments' willingness to implement any adaptation at all, as short-term economic and political priorities consistently take precedence over necessary long-term resilience and adaptation goals (Birchall, MacDonald and Slater 2021; Ford and King 2013; Ojwang et al. 2017). Successful adaptation of the CNC, and likely the Canadian North in general, hinges on overcoming political barriers to effective adaptation and implementing the strategies outlined here.

When it comes to adaptation, priority should be given to reducing vulnerability and exposure to risk (IPCC 2014). While exposure to risk is generally reduced by infrastructure adaptation, vulnerability to climate change is significantly more complex and therefore requires a dynamic and flexible approach (Benevolenza and DeRigne 2018; Ford et al. 2015; Kehler and Birchall 2021; Naylor et al. 2020; Pandey et al. 2017). Smart adaptation seeks to mitigate risk through measures that are win-win, decreasing disaster vulnerability while also facilitating economic growth (Field 2018). These policy decisions include investments of public funds in strategies that are low economic risk and high adaptation benefit, such as poverty reduction, transportation networks or public health (IPCC 2015). Addressing socioeconomic stressors is increasingly recognized as a crucial element for adaptation to climate change to be economically sustainable (Kehler and Birchall 2021; OECD 2015). This approach reduces vulnerability in many ways while remaining flexible and effective over the long term by using low-risk policy measures that are established through a process grounded in public engagement and integration of non-Western knowledge systems (Field 2018; IPCC 2014).

Long-term vulnerability reduction strategies should include co-benefits for other objectives; this way, regardless of what climate change brings, funds and resources are not wasted. Smart adaptation strategies have significant potential to increase resilience of northern communities. Smart adaptation policy could increase local municipalities' ability to cope with maintenance costs, while boosting efficiency and reducing potential gaps in northern transportation infrastructure perpetuated by climate change. Because short-term outcomes tend to be the focus of policy decisions (Birchall, MacDonald and Slater 2021; Ford et al. 2017; IPCC 2014), in respect to the CNC, it will be critical to investigate the long-term opportunities and constraints of

infrastructure expansion. From this perspective, it is easy to see the value of multi-level governmental co-operation. Without support across all levels of government, such a complex approach is likely to fail.

For the CNC to avoid maladaptation and increases in vulnerability, considerable analysis is required to determine what policy measures are necessary to address the significant socioeconomic stressors present across northern Canada. Pearce et al. (2020) urge engaging local and Indigenous communities early and often to identify if a corridor is desirable and relevant to them; research here echoes this sentiment: in order for adaptation policy to be effective there must be sufficient public participation (IPCC 2014; Johnson et al. 2015; Kehler and Birchall 2021; Williams et al. 2020; MacDonald and Birchall 2019). However, if a community is not resilient, then participation in collaborative planning with decision-makers is impractical due to a fragmentation of perspectives (Johnson et al. 2015), further highlighting the critical need for smart adaptation policy that first and foremost reduces socioeconomic stressors preventing resilience. Furthermore, the IPCC (2014) identified that there is high confidence that Indigenous, local and traditional knowledge systems are a crucial resource to effective adaptation. Despite this knowledge, and to their detriment, adaptation initiatives across the Arctic consistently discount any integration of non-Western knowledge systems, despite offers of support from Canadian Indigenous leaders (Dene Nahjo et al. 2018; Tran et al. 2021).

Limited adaptive capacity, often due to a lack of smart adaptation policies and abundance of systemic socioeconomic stressors, significantly restricts the ability of northern communities to successfully adapt to climate change. Consequently, bolstering a community's adaptive capacity requires taking smart adaptation approaches built upon effective and equitable public participation. Reframing the value of public participation is critical to the CNC and adaptation of infrastructure to climate change in general. Northern communities cannot effectively participate in decision-making while plagued by socioeconomic stressors in a system that doesn't recognize the significant value of non-Western knowledge systems to adaptation. Rectifying these shortcomings is a crucial aspect of effective adaptation to climate change in the Canadian North.

6. CONCLUSION

This paper explores considerations for climate change adaptation of vulnerable northern infrastructure. By using an urban and regional planning approach to delve into the complex interrelations between adaptation and resilience, the potential implications of expanding northern transportation infrastructure are uncovered. In doing so, this paper highlights the need for a holistic and dynamic approach to adaptation and resilience and explores the consequences of failing to do so. The extent to which the CNC could enhance resilience of northern infrastructure remains unclear; however, due to the unpredictable and drastic effects of climate change, the potential for maladaptation and its resulting systemic repercussions remains significant. Resilience in northern Canada is a function of both environmental risk and the severity of socioeconomic stressors. Consequently, adequate consultation of local and Indigenous communities coupled with a critical analysis of the ways in which the project increases or decreases the severity of socioeconomic stressors and environmental risk remains at the forefront of adaptation for the corridor.

The feasibility of the CNC is drastically reduced due to climate change, as significant increases in environmental risk threaten existing infrastructure, magnify maintenance costs and push the limits of adaptation measures. To overcome these barriers would require a reimagining of Canada's northern transportation system. While the CNC offers the potential to reduce gaps in the transportation system and thereby improve access to essential services for isolated northern communities, the expansion of traditional transportation infrastructure does not necessarily incite long-term resilience in the face of climate change. For northern communities, existing systemic socioeconomic stressors reduce adaptive capacity and perpetuate physical vulnerability: resource-based economies result in economic vulnerability; overwhelming adaptation costs threaten the efficiency of critical infrastructure; ecological fragility and infrastructure sensitivity enlarge climatic impacts; and increasing disaster risk restricts access to basic goods and services.

The proposed CNC, if approached equitably, provides many opportunities for building resilience in the Canadian North and addressing systemic constraints in northern adaptation. Planning for resilience requires a community-oriented approach built on a foundation of sustainable theories and equitable methods. Sustainable planning theories include those such as smart growth, transit-oriented development or biophilic cities. However, these approaches are not always applicable or even possible for every community, particularly for small rural or northern locations. Determining what approaches can foster community resilience requires equitable planning methods, which strive to use public participation to investigate the needs and wants of community members and collaborate to co-produce adaptation plans. Unfortunately, participatory methods of adaptation planning continue to be a challenge across the globe. Social systems, power structures and resource hoarding limit equitable access to participation and can hinder the resilience of the entire community. Policy can address these challenges; examples include policy intended to foster sustainable local food networks, enhance basic services and infrastructure, bolster access to health systems or build accessible social safety nets. Constraints in northern adaptation, such

as lagging implementation, limited intergovernmental co-operation and increasing maladaptation risks, can be addressed through this approach to policy.

Further study would require significant research into each local context, deliberate consideration of existing adaptation plans across all levels of government, a more robust economic analysis from a climate change perspective and intentional dialogue with affected local and Indigenous communities to determine desirability and feasibility. Crucially, significant consideration will have to be given to the long-term, systemic effects of expanded transportation networks on individual communities and the resulting maintenance and adaptation costs, economic vulnerability and disaster risks.

For the Canadian Northern Corridor Research Program, future research directions on resilience and adaptation should include further academic review, empirical investigation and applied research:

1) Research best practices to engage with northern and Indigenous communities on infrastructure expansion while fostering equitable decision-making through collaboration across all levels of government, agency of local community members and integration of non-Western knowledge systems.

2) Robust economic analysis of increased capital and maintenance costs of the proposed infrastructure due to the effects of climate change, such as permafrost thaw, wildfire or overland flooding.

3) Further analysis, through empirical investigation, to identify existing gaps and barriers to adaptation in northern communities, such as limited intergovernmental co-operation, as well as best practices for addressing them.

4) Investigation of how to support sustainable and desirable economic diversification in northern communities through a community-based approach.

5) Review of specific soft adaptations to foster resilience in transportation infrastructure, such as land use decisions focused on diversity, connectivity, modularity and redundancy.

6) Capitalizing on the uncertainty of climate change and global decarbonization as an opportunity for Canada to spearhead the reimagination of northern transportation to means that are sustainable and flexible.

For the CNC to remain dynamic and durable in a warming climate, it is critical that the project is built upon a foundation of effective adaptation principles and good planning. This approach is grounded in the reduction of vulnerability through place- and context-specific approaches, with a foundation of public engagement and integration of non-Western knowledge systems. This requires significant intergovernmental co-operation, and a focus on low-risk, high-benefit policy measures that provide co-benefits for both adaptation and mitigation in the long term. In this way, the CNC may be a unique opportunity to spearhead reimagination of transportation infrastructure, foster collaboration across all levels of government, enable equity and reconciliation and promote resilience for all Canadians.

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