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Review

Barriers and limits to adaptation in the Arctic

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The Arctic is experiencing rapid environmental changes, adaptation challenges, and geopolitical competition. Indigenous Peoples inhabiting the Arctic particularly experience these impacts affecting livelihoods, culture, and the possibilities for long-term adaptation. This study examines the social barriers and limits to adaptation in the Arctic, highlighting the intricate relationship between different social factors. We showcase that these factors are not merely technical or isolated but are deeply political in nature, influenced by broader structural factors, power dynamics, and governance systems. Colonialism, global capitalism, and geopolitical interests intersect and affect resource extraction, Indigenous sovereignty, cultural continuity, and adaptation. We highlight how structural inequalities, exclusion, marginalisation, and systemic neglect impact Indigenous Peoples' adaptation. We examine how social norms, individual values, psychosocial factors, and governance systems shape adaptation outcomes, distinguishing between barriers and limits.

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Introduction

The Arctic is experiencing the fastest warming in the world, warming at a rate nearly four times faster than the global average, a phenomenon known as Arctic Amplification [••85], with potential impacts beyond its borders [••74]. Climate change is having widespread impacts on ecosystem services and communities, including sea ice loss, increasing risk of mass casualty incidents, rising temperature, thawing permafrost, food insecurity, and impacts on livelihoods and culture of Indigenous communities [••14,••2,66]. The Arctic has a population of approximately 4 million people, of whom approximately 10% are Indigenous, living in Alaska, Canada, Finland, Greenland, Norway, Russia, and Sweden [••65]. Indigenous Peoples have historically adapted through the combination of traditional knowledge, sharing networks, mobility, and technology [70] yet face significant constraints in a contemporary context [22].

Barriers are systemic obstacles that hamper progress towards effective adaptation but can be overcome [98]. *Limits* are thresholds, inherent restrictions, and points beyond which social or ecological systems cannot adapt without significant transformation or collapse or beyond which no more adaptation is possible [40,••45]. Barriers and limits to adaptation have largely been associated with a range of socioeconomic, cultural, institutional, and biophysical factors and are strongly influenced by the rates at which climate-influenced risks emerge and the pace at which adaptive changes can be made [••3,62,64,67,98].

Barriers and limits to adaptation in the Arctic are not entirely negative; while many restrict adaptation, others serve protective socioecological functions. Environmental limits, such as extreme cold, permafrost, and remoteness, discourage large-scale industrialisation and mass in-migration, sustaining Arctic ecosystems and Indigenous subsistence practices [49]. Regulatory barriers, like wildlife protection laws and fishing quotas, prevent overharvesting and support long-term ecological sustainability [105], though they can become restrictive when imposed without Indigenous input or community engagement.

While studies have extensively documented climate change impacts and adaptation strategies in the Arctic [18,27,34,36,49], less attention has been given to identifying barriers and limits to adaptation, particularly for Indigenous communities. This paper aims to fulfil this gap by identifying and characterising potential barriers and limits to adaptation for Indigenous Peoples in the Arctic. This study illustrates the significance of these barriers and limits through selected examples that highlight their diverse manifestations across Arctic

Table 1

Conceptual framework capturing key adaptation barriers and limits as they affect Indigenous Peoples in the Arctic (building on Refs. [98,4,78]).

Determinants	Barriers	Limits
Social norms [1,22,81]	• Marginalisation of Indigenous norms and practices in adaptation planning and erosion of communal practices. • Social stigmatisation of Indigenous knowledge as 'nonscientific' in policymaking and loss of traditional knowledge. • Limited access to education and job opportunities and gender biases in labour mobility and access to opportunities.	• Disruption of traditional hunting and fishing grounds and practices due to irreversible ecological changes (e.g. wildlife loss affecting food sharing) and loss of culturally significant wildlife (e.g. caribou decline). • Social expectations linked to rapid global cultural shifts are creating pressure to assimilate and leading to the loss of Indigenous languages. • Gendered societal expectations limiting participation in adaptation decision-making.
Individual values [25,27,76]	• Reliance on expensive technologies for hunting, fishing, and travelling. • Economic preferences driven by survival pressures (e.g. dependence on expensive store-bought food). • Young Indigenous women seeking education/ employment opportunities outside traditional Arctic communities.	• Diminished opportunities to sustain traditional livelihoods (e.g. herding, fishing) as conditions worsen and inability to access traditional foods due to environmental changes. • Economic thresholds beyond which adaptation becomes infeasible for communities reliant on traditional methods and inability to adapt due to financial constraints and poverty. • Regional variations in coping capacity (e.g. disparities between Scandinavian countries and Siberia).
Psychosocial factors [12,15,38]	• Cultural alienation from displacement undermining mental health and identity and mental health challenges due to climate-induced stress. • Reduced agency due to systemic inequities (e.g. limited access to education or resources) and increased food insecurity and health disparities. • Intergenerational disconnect in traditional knowledge transmission.	• Psychological stress from existential threats to cultural and ecological identity and increased vulnerability of older populations and youth. • Loss of community trust in institutions due to persistent inequities and neglect. • Loss of psychological resilience due to erosion of cultural practices and ties to ancestral lands.
Governance systems [32••,63,65••]	• Fragmented governance systems prioritising resource extraction over Indigenous rights (e.g. oil and gas exploitation) and sustainable practices. • Overlapping jurisdictions delaying adaptation policies. • Lack of equitable representation of Indigenous voices in decision-making processes and policies.	• Structural colonial legacies limiting long-term adaptive capacity (e.g. relocation policies reducing mobility) and historical and ongoing colonisation leading to land dispossession. • Inflexibility of governance systems to address transformation needs or account for regional differences (regional variations in coping capacity). • Geopolitical competition driving militarisation and diverting resources, limiting cooperative adaptation efforts.

regions. These examples illustrate the complexity of adaptation challenges, providing a framework for analysing barriers and limits in specific geographic and sociopolitical contexts. This paper examines how social norms, individual values, psychosocial factors, and governance systems create barriers and limits across Arctic regions, following the structure outlined in Table 1.

Social norms

The inherent challenges of living in the Arctic constrain human settlement, infrastructure, and economic activity. Extreme climatic conditions and short growing seasons render large-scale agriculture unviable, necessitating reliance on subsistence practices or imported food [22,46]. Sparse population and vast geographic expanses significantly limit the feasibility of shared infrastructure, such as extensive road networks and power grids, increasing the cost and logistical complexity of economic development [11]. However, these same conditions have historically provided ecological and cultural advantages for Indigenous communities. Sparse human populations relative to abundant fish and wildlife have sustained traditional subsistence economies, ensuring food security through hunting, fishing, and herding [23]. The vast, open landscapes have facilitated mobility, enabling seasonal resource access and fostering resilient adaptation strategies.

The loss of traditional knowledge is an important barrier to adaptation in the Arctic. External pressures such as globalisation cause resource extraction, displacement, and environmental degradation, impacting Indigenous knowledge systems, cultural practices, languages, and institutions [21], hence perpetuating epistemic injustice. Economic and environmental changes exacerbate this, causing generational discontinuities in the transfer of traditional knowledge to younger generations [81]. There is limited prioritisation of Indigenous Peoples in

adaptation policy development and support to respond to climate impacts [10,13]. The lack of engagement and exclusion of Indigenous Peoples, knowledge, and perspectives from policy formulations is a barrier that affects the implementation of effective culturally sensitive adaptation strategies and policies tailored and relevant to Indigenous Peoples [49,87].

Cultural practices such as sharing networks, communal hunting, oral traditions, storytelling, and connections to the land and ocean are affected by loss of traditional hunting grounds and wildlife due to climate change impacts [29], affecting food security and weakening community agency, cultural identity, resilience, and adaptive capacity. Indigenous knowledge systems are important for adaptation and are at risk due to cultural assimilation, modernisation, generational gaps, and transformative environmental changes [108,77]. This loss creates barriers, as it reduces adaptive capacity and coping mechanisms, undermining the ability of communities to respond effectively to changing climatic conditions. It reduces sustainable resource management and adaptive capacities and practices where communities could potentially lose critical insights that inform locally appropriate and culturally sensitive adaptation strategies [23,87].

In Scandinavia, Sami herding traditions, which involve adaptive rotational grazing to maintain reindeer populations, are often disregarded in conservation planning. Instead, policymakers prioritise European Union environmental regulations that enforce fixed grazing boundaries [100,68]. In Canadian Arctic, younger generations are increasingly disconnected from traditional hunting practices due to the influence of modern lifestyles, climate change, and the decline in wildlife populations [56,81]. This loss of traditional knowledge creates a barrier to adaptation, as communities lose the ability to respond effectively to changing environmental conditions.

The role of gendered labour norms acts as a barrier and plays a significant role in shaping adaptive capacity and decision-making. While men traditionally occupied roles as hunters, herders, and fishermen, climate change is altering these economic foundations, necessitating new employment opportunities [7]. In Sami communities, men's ability to continue reindeer herding is being undermined by shrinking pastures, forcing women into new economic roles [73]. In many Arctic communities, women are leaving for education and employment opportunities, which can both mitigate and exacerbate vulnerabilities [12]. While improved education and job access can enhance resilience, they may also lead to the outmigration of skilled individuals, further straining community cohesion and adaptive capacity. In Greenland, many Indigenous women are leaving their communities to seek education and employment in Denmark and urban areas, which provides economic empowerment but also weakens intergenerational knowledge transfer and community cohesion [54,82]. While these individual choices offer economic mobility, they weaken the transmission of traditional adaptation strategies, presenting both a barrier and a limit — a limit because the cultural shift away from subsistence practices is often irreversible.

Social norms tied to traditional subsistence practices are being fundamentally disrupted by climate change, leading to limits on adaptation. An important example of this limit is the loss of key wildlife species essential to Indigenous diets and cultural identity. The decline of caribou populations in the Canadian Arctic has reached a point where some communities can no longer rely on this culturally and nutritionally important species [8,93]. This represents a limit to adaptation, as the loss of caribou undermines food security, cultural identity, and traditional practices, significantly impacting Inuit communities. Conservation efforts, such as restricting caribou hunting, address ecological sustainability but force communities to abandon traditional food-sharing networks, important for survival and social cohesion [42]. In Greenland, Inuit hunters rely on sea ice for seal and whale hunting, which is economically and culturally significant. However, with sea ice loss accelerating, these traditional hunting grounds are disappearing [37]. This represents a limit — without ice, these practices cannot continue. This leads to both food insecurity and cultural erosion.

Individual values

Arctic Indigenous communities are not homogenous; individual values and economic preferences vary significantly across regions, influenced by local economic opportunities, cultural activities, state policies, and place/community-specific histories. While some communities remain deeply connected to subsistence economies — such as Nenets reindeer herders in Siberia or Iñupiaq whalers in Alaska — others, particularly younger generations, are transitioning towards wage-based employment, education, and urban employment [26,27]. Sami herders are increasingly using modern economic practices, such as using drones, GPS tracking, Geographic Information System, and market-based reindeer farming, helping them adapt to a changing climate [35,41]. In contrast, Siberian reindeer herders often lack access to such technologies due to economic disparities and centralised Russian governance, making adaptation difficult [48]. In Alaska, Indigenous women often face limited access to health, education, and employment opportunities, affecting community resilience [60,86]. This barrier is compounded by the outmigration of skilled individuals, further straining community

cohesion [60]. This migration trend, while individually beneficial, weakens the adaptive capacity of communities, as fewer young people remain to sustain traditional hunting, fishing, and herding practices.

As climate change alters the Arctic environment, many Indigenous communities are forced to shift away from traditional subsistence practices, leading to increased dependence on expensive technologies for food gathering, imported foods, and fuel [76]. The reliance on technologies such as high-efficiency snowmobiles and gasoline for transportation, advanced fishing equipment and boats for food gathering and travelling, and GPS systems and satellite phones for navigation has increased [••20,23,84]. However, buying these technologies is costly, imposing a significant social and financial strain on communities and creating social inequities. This is exacerbated by an increased reliance on expensive store-bought foods, a high cost of living, and dependence on global markets and price fluctuations [••65]. This economic shift presents a barrier for lower-income households that cannot afford adaptation costs, as well as a limit for communities that have surpassed economic feasibility thresholds.

Inability to adapt due to financial constraints presents a significant limit to adaptation. In Chukotka, Russia, many Indigenous communities live in poverty, with limited access to resources and infrastructure [53]. This financial constraint creates a limit to adaptation, as communities cannot afford the technologies or infrastructure needed to cope with climate change. The limited mobility due to fixed settlements acts as a limit. In Alaska, many Indigenous communities were forcibly relocated to fixed settlements. These settlements are now vulnerable to rising sea levels and permafrost thaw, limiting the ability of communities to adapt through traditional mobility practices [25,51].

Psychosocial factors

Psychosocial factors such as cultural alienation, mental health struggles, intergenerational disconnect, and loss of trust in institutions shape how Arctic Indigenous communities perceive, engage with, and respond to climate change. Indigenous communities face historical trauma of forced displacement and cultural alienation [88]. Many Indigenous communities are facing the threat of climate-induced relocation, as coastal erosion, permafrost thawing, and extreme weather events threaten settlements that have existed for generations [12,51]. However, relocation is not just a physical challenge — it represents a rupture in cultural continuity, identity, and psychological well-being. In Alaska, the communities of Shishmaref, Newtok, and Kivalina, are facing forced relocation due to rising sea levels and coastal erosion [25,9]. For many community members, this displacement represents more than just losing a home — it means losing a way of life, severing their spiritual and cultural ties to the land [71]. In Siberia, Indigenous Evenki and Nenets herders face disruptions to traditional migration routes due to industrial expansion and resource extraction [96]. These changes force some herders into fixed settlements, where they experience high levels of psychological distress and increased dependency on state welfare systems [52]. This psychological trauma represents an adaptation limit — once the connection to land is severed, a fundamental part of Indigenous identity is lost.

Socioeconomic inequalities, poverty, income disparities, and access to resources create barriers and lead to lower social well-being, affecting access to health care, food, housing, basic needs, education, and skill development in the Arctic [16,39,6,83]. Traditional livelihoods are increasingly becoming unsustainable and creating barriers for economically disadvantaged households dependent on them [80,89]. These inequities are exacerbated by systemic issues such as social marginalisation, inadequate infrastructure, and limited government support (at national to regional levels).

Climate change has affected social networks by impacting hunting and herding, availability of traditional foods, and high costs associated with accessing these foods [••38,50]. This has been complicated by a reduction in the number of wildlife that are culturally important to the communities. Food insecurity is a growing crisis in many Arctic regions, exacerbating mental health issues [56]. For example, the decline in the number of caribou in the Canadian Arctic has affected food security, traditional knowledge, mental health, cultural continuity, and the transmission of skills across the generations, compounded by the high costs of substitute foods [8]. This loss of communal food security creates chronic stress, anxiety, and depression, particularly for older generations who struggle to adjust to these shifts [72]. These mental health challenges act as a barrier to adaptation, as they reduce the capacity of individuals and communities to respond effectively to environmental changes. Indigenous communities face high rates of diabetes, cardiovascular disease, and mental health issues, largely due to nutritional transitions from traditional diets to processed store-bought foods and financial constraints [99,58]. These health issues reduce the adaptive capacity of individuals. This represents both a barrier and a limit. Food insecurity and health disparities that arise from climate-induced changes in wildlife availability represent limits, particularly for subsistence-dependent communities.

Many Indigenous Peoples experience a sense of loss, anxiety, and uncertainty about the future [56]. In the North American Arctic, the loss of sea ice has led to

'ecological grief', where individuals mourn the disappearance of traditional landscapes, loss of cultural practices, and uncertainty about their community's long-term survival [15]. This psychological burden represents an adaptation limit, as policy interventions cannot reverse existential grief tied to irreversible ecological loss.

Governance systems

The Arctic is governed by multiple overlapping regional, national, international, and Indigenous governance systems [91]. These fragmented and multiple governance jurisdictions lead to conflicting priorities, delays, and policy misalignment [75]. This fragmentation creates barriers to adaptation, as it hinders the development of cohesive and effective adaptation strategies. In Canada, Indigenous climate adaptation efforts are hindered by conflicts between federal, provincial, and Indigenous governance authorities. Inuit communities in Inuit Nunangat struggle with complicated land tenure systems, where decision-making power is split between the Canadian federal government, the territorial government, and local Inuit governments [106,61]. This can result in delays in implementing adaptation projects, uncertainty over land use rights, and limited control over natural resources [102,19]. While the Sami Parliament (*Sámediggi)* in Norway provides some level of self-determination and representation, it does not have exclusive lawmaking or fiscal powers, and final decision-making authority still rests with national legislators, often leading to delays or restrictions on herding practices that conflict with Indigenous knowledge [43]. These conflicts slow adaptation measures, reinforcing barriers that prevent communities from effectively responding to climate change. Governance creates a barrier to adaptation because governance systems are often slow to respond to emerging threats like climate change and have limited funds to invest where infrastructure is severely threatened [63].

Many national governments prioritise neoliberal development and resource extraction (mining, oil, and gas), while Indigenous governance systems advocate for sustainable resource management [103,••32,92]. In Norway, the government's focus on oil and gas development often conflicts with Indigenous demands for sustainable resource management [33]. This prioritisation of resource extraction over environmental and cultural preservation acts as a barrier to adaptation. In Russia, large-scale oil and gas projects — such as those in the Yamal Peninsula — have led to forced relocations of Nenets and Evenki reindeer herders, significantly reducing their ability to maintain traditional migration routes [107,44]. In Alaska and Canada, governments continue to grant resource extraction permits on Indigenous lands, despite widespread resistance from Indigenous communities [28,5]. The oil drilling Willow Project in Alaska, approved in 2023, has faced intense opposition from Indigenous activists who argue that it will increase environmental destruction, disrupt wildlife migration patterns, and accelerate permafrost thawing [31]. However, the project was still approved, highlighting how governance systems frequently privilege economic interests over Indigenous sovereignty and long-term climate resilience.

Indigenous communities are often marginalised in governance, decision-making processes, adaptation planning, and consultation in resource extraction and face challenges in asserting their rights and interests [103,97]. This exclusion creates significant barriers to adaptation, as policies that do not incorporate Indigenous perspectives often fail to address the realities of Arctic life.

Many of the governance failures in the Arctic are rooted in historical and ongoing colonialism, resulting in land dispossession and forced relocation, which have collectively impeded and, in certain cases, severed the important connections of Indigenous Peoples with their ancestral territories [47,••65]. In many cases, these colonial structures do not just act as barriers but as limits — where Indigenous communities have permanently lost land, mobility, and self-governance, making adaptation fundamentally more difficult. In Canada and Alaska, many Indigenous communities were forcibly relocated to permanent settlements, disrupting lifestyles, traditional hunting practices, and climate-adaptive mobility patterns [17,69]. These relocations have had lasting impacts on food security, mental health, and cultural preservation, creating a structural limit to adaptation [25].

Colonialism and injustice have evolved into government policies limiting access to resources such as small-scale Indigenous Peoples' fisheries and favouring offshore trawlers, resulting in historical and present-day inequities in the fishing sector [94]. Historical, interpersonal, epistemic, and systemic racism has created socioeconomic disparities, limiting access to health care, education, resources, and economic opportunities and affected the health and well-being of Indigenous Peoples [24,••59]. This presents a limit and undermines the adaptive capacity.

Colonisation has systematically turned the natural constraints in the Arctic into severe socioeconomic barriers by undermining Indigenous autonomy and severing traditional adaptation strategies [••65]. Forced sedentarisation, land dispossession, and restrictive resource governance have stripped Indigenous communities of their ability to flexibly respond to environmental challenges [104]. Colonial policies have reinforced the infrastructural limitations — investing in resource extraction rather than local development, leaving Indigenous communities with high costs of living, food insecurity, and limited access to essential services [55,90]. What were once manageable ecological limits have thus been compounded by imposed social,

political, and economic constraints, shaping the structural inequalities that define contemporary Arctic adaptation challenges.

Colonialism has created both barriers and limits to adaptation by forcibly relocating Indigenous communities to environmentally unsuitable and high-risk areas, where traditional hunting and fishing practices are no longer viable. While initially a barrier, this displacement has evolved into a structural limit, as these communities are now deeply established, making relocation impractical despite increasing climate risks. State-imposed wildlife regulations restrict Indigenous adaptive flexibility, preventing communities from adjusting their subsistence practices in response to environmental changes [22]. These policies, often designed without Indigenous input, reinforce colonial constraints on adaptation, further limiting the agency of Arctic Indigenous Peoples in navigating climate challenges.

The geopolitical competition among major powers such as the United States, Russia, Canada, and China; the escalation of military operations by Arctic nations; the expansion of commercial shipping routes through the Arctic; and the exploration of oil, gas, and mineral resources have emerged as important limits affecting Arctic governance and adaptation [30,79]. The geopolitics of the Arctic has gained global attention due to climate change, resulting in increased interest in commercial shipping and energy resources [95]. The reduction of sea ice has triggered a surge in human activities where countries and corporations vie for control over resources and shipping routes, diverting attention and resources for adaptation. This is exacerbated by increasing militarisation of the Arctic [101], affecting environmental and human sustainability and security and long-term adaptation planning. Russia has significantly expanded military bases in the Arctic, while the U.S. and NATO allies have increased defence spending [57]. This geopolitical tension reduces international cooperation on climate adaptation, as nations prioritise strategic control over adaptation funding and environmental protection. Geopolitical competition is a structural limit, as it shifts governance priorities away from climate resilience and human security and toward national security concerns.

Conclusion

Addressing barriers and limits to climate change adaptation requires transformative structural changes that recognise Indigenous rights, knowledge, and sovereignty, and a move towards inclusive governance. These changes can be achieved through targeted policies and frameworks, such as the Arctic Council's Sustainable Development Working Group, which facilitates collaboration on climate resilience strategies grounded in Indigenous knowledge. Initiatives like co-management agreements between Indigenous communities and national governments provide effective models for fostering inclusive decision-making. Investing in resilient infrastructure, promoting Indigenous knowledge systems, and ensuring social and economic equity are important steps toward enhancing adaptation capacity and long-term sustainability in the Arctic.

Author Contributions

Conceptualization: I.H.M., J.D.F.; Data curation: I.H.M.; Formal analysis: I.H.M., J.D.F.; Funding acquisition: I.H.M., J.D.F.; Investigation: I.H.M.; Methodology: I.H.M., J.D.F.; Project administration: J.D.F.; Resources: I.H.M., J.D.F.; Software: I.H.M.; Supervision: J.D.F.; Validation: I.H.M., J.D.F.; Visualisation: I.H.M.; Writing – original draft: I.H.M., J.D.F.; Writing – review & editing: I.H.M., J.D.F.

Data Availability

No data were used for the research described in the article.

Declaration of Competing Interest

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