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The adaptation challenge in the Arctic

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It is commonly asserted that human communities in the Arctic are highly vulnerable to climate change, with the magnitude of projected impacts limiting their ability to adapt. At the same time, an increasing number of field studies demonstrate significant adaptive capacity. Given this paradox, we review climate change adaptation, resilience and vulnerability research to identify and characterize the nature and magnitude of the adaptation challenge facing the Arctic. We find that the challenge of adaptation in the Arctic is formidable, but suggest that drivers of vulnerability and barriers to adaptation can be overcome, avoided or reduced by individual and collective efforts across scales for many, if not all, climate change risks.

The Arctic has been undergoing transformative change in climatic conditions for several decades[1]. The magnitude of warming is one such manifestation of this, with an Arctic-wide warming trend of 1.9 °C documented over the past 30 years; a rate three times the global average[2] (Tables 1 and 2). Climate models project that the Arctic will see the most rapid and extreme warming this century, at least double the global average[3], which is expected to have substantial impacts on biophysical and human systems[1] (see Supplementary Text Box). Climate policy is therefore of the utmost importance for Arctic regions.

There are conflicting views, however, on the nature of the challenge posed by climate change to the Arctic, and hence appropriate policy responses. On the one hand, Arctic populations have been identified as 'highly vulnerable' within global climate change discourse because of the rate and magnitude of climate change, which is viewed as limiting the ability to adapt[1,4–7]. This argument is commonly asserted in major scientific assessments[1,6,8], in regional studies[9,10] and by impacts-focused research approaches, and is typically used to underscore the need for global mitigation action[11]. Where adaptations are considered in studies of this nature, they tend to focus on responding to specific climate change projections with emphasis on techno-engineering adaptations. Conversely, social science and humanities research has demonstrated significant adaptive capacity among Arctic peoples themselves. This scholarship takes a bottom-up approach and starts with people in affected communities identifying what stresses (climate and non-climate related) are relevant and important to them, and what adaptations are realistic and feasible[12–14]. Human activity is highly localized, and impacts and responses are conditioned by local geography and a range of endogenous factors (for example, demographic trends, economic complexity and livelihoods), which result in some individuals and communities being better positioned to adapt than others. Although many potential barriers to adaptation have been identified, so have opportunities to overcome them and support adaptation needs[15–17].

To contribute to understanding the adaptation challenge in the Arctic, and more broadly inform circumpolar climate policy debates, here we assess peer-reviewed studies on climate change adaptation, resilience and vulnerability (ARV) that have been undertaken in the Arctic over the past decade (see Supplementary Methods and Supplementary Tables 1 and 2). Included articles (n = 135) were analysed using a framework based on Adger and Barnett's[18] four reasons for concern about adaptation, which summarize and capture the key challenges that have been articulated in the scholarship around the ability of human systems to adapt to climate change (Table 3 and Supplementary Results). We specifically focus on studies that examine how Arctic communities have experienced and responded to rapidly changing environmental conditions, and use this understanding to generate insights on the challenge of adapting to future climate change. This body of scholarship offers an alternative to the deterministic way in which climate change impacts and adaptations are often approached in impacts-based research[11], and provides understanding on the complex factors and interactions influencing how human systems in the circumpolar north respond to climate change[19–23].

Window for action on adaptation

The first reason for concern about adaptation is the scale, interconnectedness and speed of climate change, which is believed to create a limited window for action on adaptation. Studies reviewed here, however, describe high levels of adaptive capacity in Arctic communities of diverse sizes and socio-economic characteristics, with vulnerabilities often linked to how climate change interacts with non-climatic factors. Although this is not necessarily a new insight to the global scholarship, what is unique is the extent to which the literature demonstrates that even with pervasive and extensive environmental change associated with ~2 °C warming, it is non-climatic factors that primarily determine impacts, response options and barriers to adapting.

Non-climatic factors. Indigenous populations are the focus of the majority of the work reviewed here (81% of articles), with archaeological data revealing a long history of such communities adapting to environmental change[24]. For many indigenous knowledge systems, the Arctic environment is perceived as being in a constant state of flux, where surprise and change underpin daily survival, and knowledge of local environmental conditions, acknowledgement of uncertainty and unpredictability, flexibility in resource use, and social capital continue to underpin present-day adaptability[24–30]. Rapid climate change does not therefore necessarily pose insurmountable challenges for indigenous populations. Nowadays, however, climate change is not limited to biophysical change, but intersects with socio-economic and political factors, which influence adaptation and can amplify the consequences of climate change. Similarly, studies focusing on resource-based industries document climate change as one stress among many (for example, market prices), with climate change presenting both challenges and new opportunities for some industries (for example, the lengthening of some shipping seasons)[31]. The ability to exploit opportunities, however, is challenged by a variety of outside pressures including changing economic competitiveness, increasing costs and broader

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Table 1 | Observed climate change in the Arctic.

Arctic region (>64 °N)	Temperature increase (1981–2012)
Circumpolar	~1.9 °C (~0.60 °C per decade) (Global average ~0.5 °C (~0.17 °C per decade))
North America: Canada and USA (Alaska)	~1.7 °C (~0.54 °C per decade)
Greenland	~1.5 °C (~0.47 °C per decade)
Eurasian Arctic: Iceland, Norway, Sweden, Finland and Russia	~0.6 °C (~0.20 °C per decade)

policy changes[32–34]. It is such human determinants that shape the circumstances within which climate change is experienced, and the literature reveals a number of important drivers of vulnerability and adaptation to this end.

First, resource-use systems (for example, for hunting, fishing, herding, etc.) across the Arctic have evolved in the context of variable and unpredictable climates, where risk is managed through the sequential utilization of a large number of ecological or climatic niches, with resource-use rotationally switched. Such diversity and flexibility historically underpinned adaptability, and continues to do so, but depends on flexibility at individual, household and community levels to diversify, innovate and take advantage of different options[28,35]. Today, the success of such strategies is being constrained by societal changes, regulatory systems and competing land uses. Oil and gas development in the Yamalo-Nenets region of Siberia, for instance, is affecting the ability of reindeer herders to alter migration patterns in response to changing land access and snowfall patterns[25,36]. In North America, the settlement of indigenous peoples in permanent communities starting in the mid-twentieth century has circumscribed adaptations that involve mobility and flexibility[37,38]. Across Arctic regions, harvest regulations and quotas have reduced the ability to switch species harvested, or alter the timing and location of resource-use activities in response to changing conditions[24,30,37–41].

Second, traditional and local knowledge systems are being affected by socio-cultural change, resulting in a loss of location-specific knowledge on environmental conditions. This limits adaptive options and behaviour, and constrains the perception of change[42–46]. For indigenous populations, research has illustrated that enhanced dangers of travelling on the rapidly changing sea ice reflects reduced competency in land skills among younger generations as much as it does the impacts of climate change, a trend situated in the context of transformational changes in lifestyles in the twentieth century[41,47]. Similarly, in rural Alaska, Alessa *et al.*[48] document how desensitization to environmental conditions has resulted in many from the younger generations not being aware that climate change is impacting freshwater resources, thereby affecting the perceived need for adaptation.

Third, changing demographics are altering socio-cultural structures across many small communities, a number of which are characterized by rapid population growth. For example, in the low-lying coastal village of Barrow, Alaska, the population has more than tripled since the 1960s, significantly increasing infrastructural development in high-risk locations. Barrow's vulnerability would thus have been likely to increase whether the climate was changing or not[49]. Elsewhere in the Arctic, outmigration is a major challenge facing communities trying to maintain essential services and functioning institutions. In Greenland, many small settlements have an uncertain future, with investment and policy focus of the Home Rule Government channelled to major centres with their economic functions, affecting resources available for adapting to climate change and institutional interest[50]. An ageing and declining population of labourers in Nordic regions, meanwhile, has been identified as posing a challenge to the sustainability of natural-resource-based trades already struggling to cope with climate impacts[33].

Fourth, a common theme in much of the research reviewed here is limited decision-making control at local levels[25,36]. This is particularly problematic for communities in Nordic countries and Russia, where decisions regarding land use and development are often made by the private sector with limited input from local populations[33]. Keskitalo and Kulyasova[51], for example, demonstrate how small fishing communities in Finnmark, Norway and Archangelsk Oblast, Russia, have limited ability to take advantage of improved fish stocks with climate change, as quotas and boat size regulations favour large-scale fishers from other localities. In the Canadian Arctic, although decisions continue to be made outside of the Arctic region, the signing of land settlement agreements has increased the role of northern people in natural-resource-use decision-making and management, with potential positive impacts for adaptive capacity to future change[29,35].

Finally, countries with Arctic territory are characterized by high gross domestic product (GDP) and well-developed social, political and health systems, but there are often profound inequalities within and between northern regions. In many instances in the Canadian Arctic, Alaska and Greenland, indigenous populations are dealing with severe housing shortages and overcrowding, poverty and higher burdens of ill health[52,53]. These conditions act as underlying determinants of vulnerability, increasing sensitivity to climate change impacts and constraining adaptive capacity. Many of these social challenges can, in part, be linked to historical acts associated with colonization[15,16,54,55]. Such effects are longstanding and pervasive, although reconciliation efforts are being made in some countries and regions (for example, land claims agreements and the development of co-management regimes).

Rapid climate change. The primacy of non-climatic factors in shaping the ability to adapt is also evident in how the rate and magnitude of climate change has been observed to open up opportunities for renewal, reorganization and revitalization at various scales that otherwise may face more substantial barriers. At the international level, climate change seems to have focused the attention of high-level policy circles on Arctic issues, creating opportunities to revise and enhance governance systems that reflect the needs of those living in the north[56]. Climate change has created new spaces for lobbying and action by northern populations internationally, with a number of indigenous groups using international forums to highlight the risks posed by environmental change and to advocate for action on social issues (for example, in international media and at United Nations Framework Convention on Climate Change (UNFCCC) Conferences of the Parties)[57,58]. Domestically, too, climate change is leading to demands from local people to have greater political power to develop and implement local solutions, and is being used by some indigenous populations to mobilize politically to (re)assert their sovereignty, increase their decision-making power and revive traditional institutions and knowledge[7,57,59].

The directional nature of climate change being experienced in the Arctic, along with recurrent extremes, is increasingly becoming the norm and seems to have motivated adaptation in some contexts[27,60,61]. Many indigenous communities in Alaska and northern Canada have been observing changes in climate and noting unusual conditions since the 1980s. Here, studies highlight that the speed of change is encouraging adaptive learning among subsistence harvesters in some instances — who, through regular observation of and interaction with the environment, are developing and refining adaptive strategies to deal with problematic conditions[57,60,62–64]. As such, traditional environmental knowledge is far from a static set of facts that climate change is making obsolete, but a dynamic and evolving body of knowledge that is continually being updated and refined in light of changing conditions[14,65].

Table 2 | Impacts of and adaptations to climate change in the Arctic.

Biophysical impacts		Examples of impacts and adaptation	
Impacts	**Quantified consequences**	**Impacts and challenges**	**Adaptation**
Decreased sea ice extent	~37.9% reduction in summer ice minimum since 1979	Changes in ice extent, thickness and melt and freeze-up timing present new opportunities and challenges for accessing the Arctic	Development of the International Maritime Organization's International 'Polar Code' for governing Arctic shipping[99]
Decreased sea ice thickness	~1.8 m reduction in thickness since 1980		
Changing melt and freeze-up timing of sea ice	~18.8 more melt days since 1979		
Changing melt and freeze-up timing of river and lake ice	Poorly quantified, but widely observed		
Decreased snow cover extent	~7.2% reduction in Northern Hemisphere spring coverage since 1967; 52.7% reduction in summer coverage	Decreased snow cover extent has heightened land-use hazards and challenges associated with animal harvesting	Community-based education program about nutritional cooking with store foods to ameliorate projected declines in access to country food[110]
Accelerated permafrost thaw	Permafrost has warmed up to ~3 °C since the 1980s, increasing permafrost degradation	Permafrost thaw degrades Arctic transportation infrastructure (for example, ice roads), with implications for the mobility of residents and industry	Installation of heat exchangers in roadways to slow permafrost degradation[111]
Sea level rise	~3.2 mm yr^{-1} increase since 1993 — global average	Sea-level rise and coastal erosion threaten the viability of low-lying coastal communities, prompting forced migration or relocation	Building 'pioneer infrastructure' (for example, school buildings) away from exposed areas to promote new construction in safe zones[111]
Increased coastal erosion	Poorly quantified, but widely observed		
Increased weather intensity and variability	Poorly quantified, but widely observed	Weather-related changes increase risks associated with travel in the Arctic	Additional trip preparation, including carrying GPS units and bringing extra emergency equipment[62]
Changes in terrestrial, marine and freshwater flora and fauna distribution, abundance and health	For example: reduced sea ice extent affecting ice-dependent species, shifts in biomass production disrupting food webs, rising surface-water temperatures and changing discharge regimes altering the structure and function of aquatic ecosystems	Changes in Arctic ecology alter the abundance of, access to and quality of country foods	Development of co-management arrangements to understand and govern ecological change in ways that support conservation goals and culturally important harvesting activities[89]

However, the role of faster and more pronounced change in stimulating adaptive action is not uniform across regions: populations and communities who rely on a narrow resource base that is being undermined by climate change, where adaptation involves unacceptable loss of cultural and livelihood activities, or where the financial costs of adaptation are prohibitive, are examples where the speed of climate change presents a limit to adaptation (for example, see refs 66–70), where a 'limit' implies a level of adaptive capacity that cannot be surpassed[71]. For the Viliui Sakha people in north-eastern Siberia, for example, there are few alternative economic and cultural activities available to traditional cattle and horse breeding. These livelihoods are being undermined by changing weather, snow and temperatures, and in some instances have forced people to abandon their traditional livelihood with negative implications including loss of culture[67,68].

From adaptive capacity to adaptation

The second concern is that adaptive capacity will not necessarily translate into actual adaptation, with multiple barriers potentially impeding adaptations across sectors and scales. As noted above, human systems in the Arctic have demonstrated high adaptability historically as well as in the context of recent change, but new vulnerabilities are emerging that relate to ongoing societal and environmental changes. A number of conditions are consistently identified in the literature as hampering the ability of local peoples to adapt. Few of these barriers are being substantively addressed, and are likely to constrain future adaptation in the absence of targeted attention.

First, northern institutions often lack the mandate, time and funding to address climate change impacts. This is compounded by the nature of adaptation, which often crosses jurisdictions, and involves responding to future unknown risks for which mandates, laws and demands for action do not exist[35,72,73]. In these situations, political leadership is critical for initiating the process of adaptation, providing strategic direction and sustaining momentum over time[74,75]. There is evidence of such emerging leadership on adaptation in some regions, particularly in Canada and Alaska, although in most cases an absence of leadership has been identified as a major barrier to adaptation. In several instances, adaptation decision making and action is challenged by institutional fragmentation, understaffing and a lack of resources[15,37,76]. Studies, particularly from Russia and some Nordic regions, also report that the need to adapt is often contested or not perceived as being important, reflecting the presence of more immediate concerns, belief that climate change will bring benefits, and/or scepticism about the science of climate change[36,59,77].

Even in situations where the need to adapt is urgent, institutional barriers have often constrained adaptation. Many Alaskan native villages are threatened by erosion and flooding that is being accelerated by climate change. The need to relocate the most vulnerable communities has been recognized since the 1990s, including by the communities themselves, who have identified new settlement locations that would satisfy livelihood and cultural needs[37,78]. Various institutional barriers, however, have resulted in negligible progress on relocation, including the absence of a lead entity for adaptation, a lack of clear jurisdiction or protocols for

Table 3 | Adger and Barnett's[18] four reasons for concern about adaptation to climate change.

Concern	Nature of the concern
Limited window for action on adaptation	Temperature increase > 2 °C will be disruptive. We are running out of time to adapt.
The difference between adaptive capacity and adaptation	Barriers to adaptation are widespread. Adaptation is poorly embedded in planning. Is adaptation at this scale possible?
Maladaptation abounds	Maladaptation evident in diverse sectors. Absence of long-term proactive adaptation.
Integrating values into adaptation	Community values are neglected in determining the goals of adaptation. Adaptation will be challenging where there is irreversible loss (for example, relocation).

addressing the issue, and a focus of federal disaster response on rebuilding as opposed to risk-prevention activities[37,54,78,79]. The cost of relocation compounds these challenges: for the village of Kivalina in Alaska (population of 382) the cost of relocation is estimated at US$100–400m (ref. 80). No communities have yet relocated, with the government response to invest in infrastructural protection measures unlikely to be sufficient, given the risks posed by expected future climate change.

Secondly, many northern institutions and regulatory systems are slow or poorly prepared to respond to stochastic change[27,81–83]. Climate change has brought a multitude of challenges to regulatory regimes, including altering the health, availability and migration timing of fish species and wildlife utilized for subsistence and commercial uses, and affecting pest cycles and susceptibility to fire in forest stands[27]. A cohesive institutional response integrating climate change considerations has yet to develop[84], with resource management regimes often *ad hoc* and fragmented[82]. Chapin *et al.*[27,72], in their work in interior Alaska, document how formal state and federal institutions that manage ecosystem services remain focused on controlling a single resource as opposed to managing whole ecosystems for change. Similarly, national- and regional-level policies, including fishing, whaling and hunting quotas, have been documented as limiting the freedom of resource users to innovate and respond to change. One implication, as Berkes and Jolly[83] note in their work in northern Canada, is a timescale mismatch in responding to change, with communities responding rapidly to alter behaviour in light of observed conditions, but regulatory regimes being slow to change. In these cases, inflexible institutions have replaced informal mechanisms of local social control and obligation for managing variation in wildlife access and availability[28,82,85,86].

Not all forms of institutions necessarily inhibit adaptation — institutions can act as pathways for knowledge development and learning, thereby helping to enhance adaptive capacity[29,87]. Dawson *et al.*[88], for example, note how, in Greenland and Norway, where there is a long history of cruise tourism, there is a well-developed multilevel governance structure well-suited to managing new and emerging stresses with enhanced shipping activity. In northern Canada and Alaska, attempts to enhance regulatory management have also been documented. This has included the development of co-management regimes that integrate science, traditional knowledge and local needs into the management of wildlife stocks (for example, beluga monitoring in the Beaufort Sea)[86,89,90]. Evidence suggests that co-management has been effective at building capacity to manage climate change impacts by increasing the dialogue and interaction necessary for conflict resolution, enhancing the speed at which information flows across scales, and maintaining flexibility in resource systems[86,89]. However, success has not been uniform, with different power relations between stakeholders, and the conflict over the role of science and traditional knowledge evident, and continuing to compromise decision making. Particularly where the health of species and associated management in light of climate change impacts is in dispute, co-management arrangements have struggled to resolve conflicts, have been observed to perpetuate the marginalization of communities, or decisions have been compromised by policies at international scales (for example, the US ban on the importation of polar bear hides)[91,92]. Given the crosscutting nature of climate change, these situations may become more common in the future.

Maladaptation

The third reason for concern is the extent to which actions already in place are not sustainable, with maladaptation predicted to abound in multiple sectors. In an Arctic context, the literature indicates a number of processes that increase the potential for maladaptation, whereby actions taken to reduce vulnerability impact adversely on, or increases the vulnerability of, the system that is adapting, or other systems, sectors or social groups[93].

First, as noted above, the majority of documented adaptations taking place in the Arctic are autonomous in nature at the household/community scale, with limited evidence of strategic long-term planning or engagement of broader levels of government[84]. Although, in many instances, such responses are described in the literature as enhancing the capacity to deal with change, they may also increase the vulnerability of the system as a whole by displacing impacts to other locations or periods of time, particularly where ecosystem services are shared between communities or across regional/national boundaries. Working with Inuit communities, Ford *et al.*[62] argue that short-term coping mechanisms employed by communities to maintain harvesting activities in light of rapid climate change could increase vulnerability in the long term by representing overspecialized responses that reduce diversity in species use, exacerbate loss of land-based skills and concentrate harvesting pressures in limited locations.

Second, there is limited evidence of anticipatory thinking about future risks in adaptations taking place at household/community scales[84]. The literature reviewed here documents that many indigenous populations perceive the changes in climate that they are experiencing to be part of natural variability, and not reflecting directional change in the context of anthropogenic emissions[25,94–96]. This reflects beliefs about the sentience of the natural world and historic experience of climatic variability — indeed, thinking about the future in such terms is considered inappropriate in some cultures[95,97]. Reluctance to consider future societal and climate scenarios may limit opportunities for proactive adaptation, limit the engagement of local stakeholders in adaptation planning processes, or may perpetuate activities that are unsuitable for future conditions, which in turn could increase vulnerability to projected future climate stresses.

There is also limited evidence of proactive adaptation occurring within institutions or industries across the Arctic, particularly where new risks are emerging. Regarding higher levels of marine traffic with sea-ice decline, for example, concerns have been raised in Canadian waters over the lack of a central authority for governing the northern cruise ship industry, and a lack of guidelines for operations and management at a time when the industry is

expanding into new and largely uncharted regions[88,98]. The potential for maladaptation is particularly high where decisions create path dependency. For example, industrial and municipal infrastructure developed today will be exposed to different future climatic conditions. Despite this, the literature indicates very few examples where vulnerability assessments have informed such developments[84]. Without proper guidelines and regulations that anticipate the impact of future climate change on industrial development and resource use, local communities may become more vulnerable to changing conditions[99].

Third, given the magnitude of climate change risks faced in Arctic regions, some have argued that transformational adaptation will be required[100]. There is ample evidence of transformational adaptation historically in the Arctic, involving community reorganization and technological innovation in the face of environmental change[101]. However, there are few examples of this process currently in the Arctic, with the majority of adaptations being short-term, small-scale and incremental[84]. In Alaska and Canada, for example, in the face of coastal erosion, flooding and widespread recognition of the need to relocate high-risk settlements, the institutional response has been to invest in shoreline protection measures that may be effective in the short term but are unlikely to prevent long-term impacts and may increase vulnerability (for example, through the 'levee effect')[78,102]. In these circumstances, cost and institutional barriers have prevented action on the scale necessary for transformational adaptation to occur.

Fourth, an important prerequisite for developing effective long-term adaptation strategies is to remove or reduce the underlying structural determinants of vulnerability. These determinants are increasingly well characterized for indigenous populations and linked to long-term trajectories of disempowerment and colonization, yet rarely are they being addressed or recognized in adaptations that are being undertaken or proposed[37,55]. Even in cases where attempts have been made to enhance local decision making and control to better reflect local needs and knowledge systems (for example, co-management), this has rarely involved challenging existing bureaucratic systems that in many cases underpin vulnerability.

Integrating values

The fourth reason for concern relates to the focus on material well-being in adaptation, in which it is argued that community values and culture are often overlooked. The effectiveness, legitimacy and acceptability of adaptations can only be understood within particular social contexts, and adaptation can undermine resilience where cultural values are overlooked. For example, changing livelihood activities and relocation may be viewed as adaptation strategies by outsiders, but for communities this may represent the loss of important values[66]. Three perspectives on this concern emerge in the Arctic literature.

In the North American Arctic and, to a lesser extent, the Nordic countries, indigenous populations and leaders have been actively involved in research and policy debates[36]. This engagement builds on past mobilization for environmental issues in general among indigenous populations, beginning in the 1970s with international debates on wildlife conservation, continuing in the 1980s and 90s with persistent organic pollutants, and developing in a climate change context in the 2000s[57,58]. Contrary to Adger and Barnett's[18] fourth concern, in these regions, cultural values have helped shape the emerging adaptation landscape. This is evident in the substantial body of scholarship examining issues of direct relevance to communities in a changing climate, including land-based activities, resource management, culture and food systems. Organizations and communities have also initiated and led vulnerability and adaptation projects, and the integration of indigenous cultural values, traditional/local knowledge and community consultation are strongly emphasized in adaptation policy and practice. As Adger *et al.*[103] caution, however, dealing with the cultural impacts of climate change goes beyond community-led processes and engagement, the effectiveness of which can be constrained by higher-level political processes.

By comparison, the literature notes that Russia's Arctic population does not have the same level of political influence or engagement in research, with limited evidence of adaptation policy and practice. The studies reviewed here indicate widespread climate change scepticism among government, scientists and communities in northern Russia, where it is perceived either as an imposed Western construct or an issue of limited importance; as such, the need to adapt is both unrecognized and contested[36]. The literature examining human dimensions of climate change in Russia largely focuses on indigenous peoples in remote regions, and indicates significant resilience to observed climate change impacts, underpinned by flexibility in land use and maintenance of authority over local-level decision making[25,36,59,67,68]. Yet future climate change impacts and resource development could challenge these sources of resilience, and will occur in the context of limited dialogue between government institutions and indigenous peoples. There is an absence of power-sharing arrangements over resource management, with many land claims unresolved, thereby raising the potential for cultural loss[36,59].

Finally, across Arctic communities, but especially for indigenous populations, there is the potential for cultural values to be compromised if the process of responding to climate change involves the privileging of scientific knowledge over local/traditional knowledge and values, and/or an erosion of local power over decision making. There is a long history of policy interventions in the north advanced by outsiders in the name of beneficial outcomes, yet reflecting non-indigenous/local worldviews and notions of progress and planning, which have undermined cultural value systems and compromised well-being[97,104,105]. Although community-based approaches to adaptation research and policy development are increasingly the norm in research in northern regions, and community leadership on adaptation is evident, adaptation discourse nevertheless has the potential to further perpetuate this legitimization of outside intervention and control, entrench unequal power relations, and may be selectively used by powerful staekholders to advance particular development pathways and political agendas[55,61].

Discussion

This Review analyses Arctic-focused ARV research, and demonstrates a strong emphasis on the scholarship on indigenous populations, particularly those in North America and to a lesser extent Russia and the Nordic countries. This reflects the fact that such populations are likely to be disproportionately sensitive to climate change impacts, given their reliance on land-based and resource-dependent activities[106]. An emerging body of scholarship on non-indigenous resource-based communities has also developed, with little evidence of research focusing on larger urban areas, underpinning the need for greater geographic and sectorial diversity in Arctic-focused ARV scholarship. The key conclusions we draw from the analysis reflect these biases.

Even in the context of rapid climate change, societies are adaptable. For many Arctic populations, this adaptive capacity is underpinned by several factors: an acceptance of change and uncertainty; the diversity and flexibility of resource-use systems, which facilitates reorganization and renewal in the face of change; traditional and local knowledge systems; social learning, in which direct experience with climate change is altering human–environment interactions to be better suited to the new climate; and self-organization, where climate change is being used to advocate for enhanced governance systems that reflect the needs of those living in the Arctic.

Despite this adaptability, vulnerabilities are emerging in light of a rapidly changing climate. Limits to adaptation are also evident in

some of the studies reviewed here, typically cases characterized by high susceptibility to climate change impacts (for example, low-lying communities) or which have limited socio-economic diversity (for example, single-industry settlements). In the majority of cases reviewed, however, limits were not identified, with vulnerability rooted in underlying conditions linked to long-term social, economic and political processes and changes that are undermining adaptive capacity and increasing sensitivity to climate change impacts. Climate change acts as a trigger on these root causes. Research in other regions globally has similarly identified the importance of non-climatic drivers of vulnerability and constraints to adaptation, yet rarely has this work done so based on empirical evidence of responses to rapid climate change. What is unique here is the primacy of non-climatic determinants in light of what some would characterize as transformational climate change being observed in the Arctic[107]. As such, the Arctic is not only a bellwether of climate change to come at lower latitudes, but can provide empirically grounded insights for understanding the challenges to adaptation.

Viewing vulnerability as a problem of society rather than a problem for society shifts attention from focusing exclusively on the magnitude and speed of projected climate change[108] (as embodied in Adger and Barnett's[18] first reason for concern and much of the general debate on Arctic climate change) to considering how climate change plays out in specific societal contexts[109]. As such, adaptation needs to enhance generic capacities to manage change and stress, which involves addressing underlying causes of vulnerability that are rooted in marginalization, disempowerment and colonization. The resolution of these conditions has been a focus of government and community action in some regions, to which climate change brings renewed emphasis. Adaptation will also require specific capacity to adapt, in the form of tools, programs and actions for reducing the risk of climate impacts[108]. Building on traditional and local knowledge systems, integrating climate change considerations into ongoing policy processes, and proactively planning for future impacts will be necessary herein. Although Arctic societies have demonstrated significant adaptability to environmental variability and past episodes of change, the institutional response has been minimal. Many institutional barriers to adaptation are reported in the work reviewed here — and, left unaddressed, will limit the capacity to adapt to projected change. As such, Adger and Barnett's[18] second and third reasons for concern are substantiated in the work reviewed here in an Arctic context.

The challenge of adaptation in the Arctic is formidable, but the reviewed studies indicate that many of these challenges can be overcome, avoided or reduced by individual or collective effort, creative management, changed ways of thinking, political will, institutional change and financial support. Indeed, northerners are already active agents in responding to climate change at multiple levels, and adaptations are already taking place at household and community scales. Although these local responses represent important developments, adapting to future change will require broader-level action to address both generic and specific capacities to adapt in the context of ongoing social, economic, political, demographic and environmental change. There is evidence of this happening in some locations, although a coherent vision and framework for approaching adaptation is largely absent. The Arctic Council's current work on adaptation is thus of significant importance for catalysing the attention of northern policymakers.

This Review also demonstrates that there is substantial knowledge — varying by region, population and risk — on climate change adaptation, resilience and vulnerability. Yet there are also gaps in current understanding. Further studies on how climate change interacts with the root causes of vulnerability are needed, specifically research integrating projections of future climatic and socio-economic change. A profitable line of enquiry would also be to examine why particular communities have successfully adapted and others have not, both across and within regions, to further enhance our understanding of drivers of vulnerability, and locate barriers and limits to adaptation. Finally, few studies have comprehensively evaluated opportunities for adaptation, or examined the effectiveness, desirability, feasibility, urgency and durability of adaptations. Developing such knowledge needs to be a priority for future work.

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J.D.F. conceptualized the project, analysed the data and wrote the paper; G.M. led data collection and helped write the paper; and T.P. helped write the paper.

Competing financial interests

The authors declare no competing financial interests.