CHAPTER 31

Arctic Climate Change: Local Impacts, Global Consequences, and Policy Implications

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Introduction

The Arctic is warming at rates that are more than twice the global average, with pronounced effects on sea ice, landscapes, northern infrastructure, and ecosystems. This amplified warming will continue over this century and will result in perturbations that may severely disrupt Arctic food webs and the well-being of Arctic communities. The Paris Agreement target to limit warming to +1.5°C is predicted to translate into greater than 3°C warming in the Arctic, while "business-as-usual" scenarios project Arctic temperature increases in the range 8 to 12°C. The full impacts of such large-scale warming are difficult to predict; however, they are foreshadowed by changes that are already being experienced across the Arctic. These changes have begun to affect policy decisions at all levels, from local development and conservation plans, to shipping routes and safety provisions.

Arctic climate change has implications for policy makers that extend well beyond the North Polar Region. The Arctic contains large storehouses of ice, notably the Greenland Ice Sheet that if fully melted would raise global sea levels by up to seven meters. Arctic warming is likely to alter mid-latitude weather patterns and to increase the likelihood of extreme storms and droughts. The amplified warming in the Arctic and its associated impacts such as sea ice loss,

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ice shelf collapse, and northern coastline erosion provide striking visual evidence that the global environment is changing rapidly, and that large changes lie ahead throughout the world. Some nations and industries see these changes in the North as opportunities for improved access to markets and resources, and warmer conditions could open up possibilities, as yet uncertain, for northern agriculture, fisheries, and tourism.

Given the potential magnitude of these global as well as local impacts, many nations are now heavily investing in Arctic climate research, including European and Asian countries that lie well outside the circumpolar region. Knowledge about the northern climate and its effects on ecosystems is therefore expanding rapidly and provides opportunities for policy makers to recommend science-based actions. This essay first introduces some of the recent findings from Arctic climate change science and then examines the associated policy implications within four themes: adaptation, conservation, mitigation, and knowledge exchange.

Faster Warming in the Arctic

The more rapid warming of the Arctic relative to the rest of the world is termed "Arctic amplification" and has been highlighted in each of the Intergovernmental Panel on Climate Change (IPCC) reports. For example, comparison of the decade 2006–2015 with a pre-industrial reference period (1850–1900) shows that the global average temperatures rose by 0.87°C over this timespan, while the measured Arctic temperature rise was two to three times higher, and with large differences among different parts of the Arctic (IPCC 2018). The IPCC climate models predict that this trend will continue: a 2°C rise by 2100 at a global scale is projected to result in a 4 to 7°C rise in Arctic temperatures, while if all current national commitments for carbon reduction can be adhered to, a mean global increase of 3°C is projected, translating to 7 to 11°C in the Arctic (mean night-time temperatures; IPCC 2018). Global fossil fuel emissions rose by 1.7% in 2017 and by around 2.7% in 2018 (Le Quéré et al. 2018), indicating that the Arctic continues to be on a rapid warming trajectory toward +10°C or above by the end of this century.

Arctic amplification is the result of several feedback effects that are important in snow and ice environments (Holland and Bitz 2003). The loss of highly reflective ("high albedo") snow or ice cover on the land or sea means that less solar energy is reflected back into the atmosphere, and more goes into heating and melting, with yet more loss of albedo, thereby causing a vicious circle of continued thawing and increased warmth. Warmer air also holds more water vapor, itself a greenhouse gas, and this further amplifies the warming effect. Recent climate modeling indicates that one of the most important feedback mechanisms may simply be the transfer of heat from the increasingly open Arctic Ocean to the atmosphere (Dai et al. 2019).

Arctic Sensitivity to Warming

In addition to amplified warming, the Arctic is unusually sensitive to the impacts of climate change. This is because snow and ice are major features of the northern environment, and small increases in temperature across the melting point can cause massive changes. At lower latitudes, a shift of ground temperatures from say 20 to 22°C may have little perceptible effect, at least in the short term, but a shift of the same two degree magnitude from −1 to +1°C causes a transformation of solid ice to liquid water, and totally transforms the landscape and seascape. This abrupt threshold effect is dramatically illustrated each summer as the Arctic goes through its seasonal transition of snow melting and ice break-up. When thawing occurs over the summer, the region converts to a state that looks and functions in ways that differ strikingly from winter. Currently, this seasonal thaw is kept in check by the vast storehouses of ice that are contained in permanent snowbanks, permafrost (ground that remains frozen for two or more years), thick multiyear sea ice, glaciers, and the Greenland Ice Sheet. These deep-frozen stores are legacies from past cold climates and they dampen the effects of seasonal warming, but progressively warmer summers are depleting these legacies and buffers against change.

The impacts of human-induced climate warming are now apparent across all ice-containing environments in the Arctic and Subarctic. Sea ice volume and extent have decreased persistently over the last few decades, with the area of multiyear sea ice now 60% below that observed in the 1980s, and minimum summer sea ice volume now 75% reduced relative to 1979 (Overland et al. 2018). The total areal extent of sea ice in September has dropped by 45% over the last 30 years, with more than 90% loss in some areas such as Hudson Bay, the Kara Sea and the Chukchi Sea (Stroeve and Notz 2018). Full loss of summer sea ice is expected over the next few decades, accompanied by increasing extension of ice-free conditions into autumn (Lebrun et al. 2019). The thickest marine-derived ice on Arctic seas occurred in the form of ice shelves along the northern coast of Ellesmere Island, Canada that formed over a period of several thousand years. These substantially collapsed throughout the twentieth century, with loss of the largest ice shelf in 2012 (Copland et al. 2018). Only one remains intact, the Milne Ice Shelf that retains a unique lake ecosystem, but there is evidence of ongoing thinning and imminent break-up (Hamilton et al. 2017).

Glaciers are melting rapidly throughout the Arctic, with large differences among regions. An analysis of records from the Cryosat satellite showed that average rates of ice loss during the period 2011 to 2017 ranged from 2 billion tons (Gt) per year in Iceland to 59 Gt per year in Arctic Canada (Richter-Menge et al. 2018). In the Canadian Arctic Archipelago (CAA), a long-term mass balance analysis showed that the glaciers and ice caps contracted at much faster rates over the last two decades, particularly in the southern region (Baffin Island) of the archipelago where the ice caps have recently lost their protective layer of perennial snow cover (Noël et al. 2018).

Recent changes in surface features are also resulting in a more rapid melting and loss of ice from Greenland's ice caps and glaciers, which currently account for around 43% of global sea level rise. The areas that are most sensitive to warming are the peripheral glaciers and ice caps, which may lose up to 28% of their mass over the next century. Like the glaciers of the CAA, these ice features appear to have passed through a tipping point in 1997, with major loss of their surface refreezing capacity at that time (Noël et al. 2017). Rainfall events on the Greenland Ice Sheet are becoming increasingly common, and this liquid water is hastening the melting of the ice (Oltmanns et al. 2019). This process is further accelerated by pigmented microbes that grow in the surface meltwater. The microbial communities, in combination with the deposition of soot and other dust materials, darken the surface of ice and increase the extent of sunlight absorption, heating, and meltwater production (Kintisch 2017).

Arctic lakes and rivers are also showing evidence of dramatic change. Canada's most northern freshwater ecosystem, Ward Hunt Lake in Quttinirpaaq National Park (QUNP), had 4.3 m of perennial ice in the 1950s, but from 2008 onwards the ice rapidly thinned, and the lake experienced open water conditions in summer 2011 (Paquette et al. 2015), perhaps for the first time in millennia. These warm conditions in northern Canada also had an impact on Lake Hazen, a deep lake further to the south in QUNP, which showed a transition toward increased likelihood of summer ice-free conditions and evidence of concomitant biological shifts (Lehnherr et al. 2018). Arctic warming is intensifying the water cycle over northern lands, and there is an increase in river discharge to the Arctic Ocean, with potential dampening effects on marine productivity and food webs (Li et al. 2009).

Ecological Impacts of Declining Sea Ice

Loss of sea ice has a direct impact on many species that live on, in and near the ice, and that are intimately connected in ice-dependent food webs (Vincent et al. 2011). A variety of cold-adapted algae live within the saltwater channels that permeate the ice, with highest abundance at the ice-water interface. These ice algae are a food source for microscopic animals including zooplankton. Once the seasonal ice melts, the algae rapidly sink to the bottom of the sea where they are used by benthic (bottom-dwelling) animals such as clams, in turn eaten by walrus and other diving marine mammals and birds. The open waters of the ocean at the edge of the ice zone are sites of elevated algal production by phytoplankton, which are also fed on by the zooplankton at the bottom of the planktonic food web, providing food for seabirds such as auklets, and fish, including Arctic cod. The latter is fed on by seals and beluga whales, with seals as the main prey for polar bears. The zooplankton and the algae in both habitats are rich in energy and high-quality nutrients, in particular polyunsaturated fatty acids (PUFAs). The PUFAs are passed up the food web and contribute to the health of Inuit and other local and Indigenous peoples who depend on the sea for subsistence hunting and fishing. The ice is also used as a platform for calving seals and polar bears, and as a diving platform needed by walrus to reach their benthic food. In areas of major loss of sea ice, there is evidence of a shift away from walrus as the top of the food chain to an ecosystem based more on open water plankton and fish (Grebmeier et al. 2006).

Narwhals and bowheads are highly specialized for pack ice conditions and are therefore negatively affected by sea ice loss, while other whale species that have more generalist feeding habits such as belugas may be able to adjust more readily to such losses. Sea ice loss has resulted in the northern expansion of orcas that prey on the young of other whales, resulting in additional pressure on Arctic specialized species. Polar bears are especially vulnerable to declining sea ice conditions, and large reductions are predicted in their populations, including complete loss from certain areas where they are presently common. Certain terrestrial animals that use sea ice as a foraging habitat (e.g., Arctic fox, snowy owls) or as migration routes will also be adversely affected. For example, Peary caribou depend on the sea ice between islands of the CAA for migration in spring and early winter, which ensures both genetic exchange between populations and an ability to recolonize habitats; the ongoing loss of sea ice will thereby jeopardize the survival of this species (Mallory and Boyce 2019).

Sea ice decline also has broader, indirect effects, including by influencing the temperature and precipitation over land (Macias-Fauria and Post 2018). For example, open water conditions increase the likelihood of rainfall events, which can result in ice crusts on snow that prevent reindeer and other animals from feeding. Open waters around the Yamal Peninsula in northwestern Siberia and a resultant rain-on-snow event caused massive mortalities of the reindeer population, with long-term socioeconomic impacts on the Nenets herders whose livelihoods and well-being depend on these animals (Forbes et al. 2016). Although increased open water may result in increased moisture during some seasons, the warmer temperatures can also dry out the land. This drying effect may account for the measured decline in shrub growth in coastal Greenland and Svalbard (Forchhammer 2017). Sea ice loss experienced in the late twentieth century in Hudson Bay has also been implicated in the rapid warming of adjacent lands in northern Quebec (Bhiry et al. 2011) and the Hudson Bay Lowlands (Rühland et al. 2013), with associated changes in vegetation and lake ecology.

Impacts on Indigenous People and Cultures

People have lived in the perennially cold regions of the North for millennia. Many of their cultural practices require free movement across the ice on rivers, lakes, and the sea for subsistence hunting and fishing, and there is a vital sense of connectedness to the wildlife, plant life, and other natural features of the Arctic environment. These Indigenous cultures have shown enormous resilience to past and present changes, but climate warming compounded by other stressors such as rapid development and health issues is now severely testing that resilience.

Arctic climate change is affecting northern communities in multiple ways (Pearce et al. 2015). For example, the changing ice and weather conditions are causing increased travel risks, including via traditional routes over river ice and coastal sea ice. The shifting ice patterns are also affecting food security by limiting access to certain hunting and fishing resources, and decreasing the availability of important wildlife species for subsistence. These reduced ice conditions also favor rapid economic development in some locations, with associated ship traffic and possible social as well as environmental impacts. Finally, the effects of flooding and loss of permafrost stability are causing increasing challenges for the construction and maintenance of municipal infrastructure.

The combination of climate-related stresses can also elicit strong emotional reactions such as anger, sadness, frustration, anxiety, depression and despair, which Cunsolo and Ellis (2018) describe as an expression of grief for ecological loss, or "ecological grief." In a comparison of two communities affected by climate change, an Inuit community in northern Canada and family farmers in the Australian Wheatbelt, they found similar experiences of ecological grief across three categories: physical ecological losses, loss of traditional environmental knowledge, and anticipated future losses. Indigenous organizations at all levels, from municipalities to national and international bodies, recognize the need to develop and implement policies that strengthen local resilience in the face of these ever-mounting challenges. An essential starting point for these policies is recognition of the intertwined and co-evolving nature of the social, ecological, and biophysical features of the Arctic and their connections to the rest of the world (Arctic Council 2016).

Vulnerability of Northern Infrastructure

Much of the engineered infrastructure of the North was built during the twentieth century when permafrost was considered a solid concrete-like foundation for homes, roads, bridges, railways, runways, pipelines, communication towers, waste containments, and other facilities. Permafrost is warming throughout the world, with fastest rates in the Arctic (by around +0.39°C over the decade 2007–2016: Biskaborn et al. 2019), accompanied by a deepening of the seasonally thawed "active layer." As a consequence, the stability of northern permafrost lands is no longer a dependable ecosystem service, and built infrastructure is increasingly at risk (Vincent et al. 2017). Arctic coastal communities are especially vulnerable because of coastline erosion by permafrost thaw and the greater wave exposure caused by extensive open water conditions (Fritz et al. 2017).

Total precipitation on average will continue to increase over the Arctic, but with transition toward increased rainfall rather than snowfall (Bintanja and Andry 2017). This greater delivery of liquid water will speed up land erosion and snow melt, and thereby create further hazards for northern infrastructure due to flooding and permafrost subsidence. In Alaska, the financial costs of climate-related damage to public infrastructure are estimated as 4 to 5.5 billion US$ for the period 2015 to 2099, with the largest source of damage due to road flooding followed by building damage caused by thawing permafrost (Melvin et al. 2017). An analysis for one northern region of Canada (the Inuvialuit Settlement Region) has estimated that the adaptation costs for building foundations would be in excess of 100 million CAD$, and questions remain as to who would pay for such work (Pearce et al. 2015).

Arctic soils with high concentrations of ice in fine sediments are particularly susceptible to thawing and subsidence. A recent analysis has shown that one-third of infrastructure across the circumpolar North lies in such high-risk regions and will be subject to thaw instability over the next four decades. This includes 1590 km of the Eastern Siberia–Pacific Ocean (ESPO) oil pipeline, 1260 km of gas pipelines that originate in the Yamal-Nenets region and 550 km of the Trans-Alaska Pipeline System, along with more than 13,000 km of roads and more than 100 airports. The pipeline vulnerability is of special concern given the prospect of major oil spills and the impacts on energy delivery (including to Europe) and thus on economic activity and national security (Hjort et al. 2018).

Increased Northern Shipping

The diminishing sea ice is opening up new opportunities for marine transport. The most notable example is the "Polar Silk Road," a component of China's Belt and Road Initiative that involves the development of the Northern Sea route along the Siberian coast in cooperation with Russia. A subsidiary of China's largest shipping company started regular use of this route in summer 2017, and the resultant transport activity is growing rapidly: cargo shipping on the Northern Sea Route rose to 18 million tons in 2018, an increase of 80% over 2017 and 360% over 2013 (Humpert 2019). These shipping tonnages are still very small in scale relative to the rest of the world, and need to be placed in global perspective (Holroyd 2019). Furthermore, ice conditions will likely remain unpredictable and dangerous well into the future, and Arctic shipping ventures have considerable operational and commercial risks (Lasserre 2018). These factors will continue to dampen interest, and transpolar shipping across the central Arctic Ocean is unlikely in the near term. Nevertheless, the current and projected shipping activities across the region are large relative to previous transport in the Arctic, and the risk of accidents is increasing. This increased shipping and tourist activity heightens the need for improvements in Arctic marine disaster and response policies (Mileski et al. 2018).

Implications of Arctic Climate Change Outside the Region

Many countries are now paying close attention to Arctic climate impacts, and to the global influence of the changing Arctic. China's Arctic policy, for example, begins by underscoring both aspects:

> *Global warming in recent years has accelerated the melting of ice and snow in the Arctic region. As economic globalization and regional integration further develops and deepens, the Arctic is gaining global significance for its rising strategic, economic values and those relating to scientific research, environmental protection, sea*

> *passages, and natural resources. The Arctic situation now goes beyond its original inter-Arctic States or regional nature, having a vital bearing on the interests of States outside the region and the interests of the international community as a whole, as well as on the survival, the development, and the shared future for mankind. It is an issue with global implications and international impacts.* (People's Republic of China 2018, para. 1)

As noted above, China has a special interest in the maritime transport opportunities opened up by Arctic warming and sea ice loss, with improved access to markets as well as to energy supplies from Russia. This has reconfigured international security issues (including military), providing Russia with a vast Asian market for its western Siberian gas reserves, and China with a trade route to Europe outside the influence of the United States (Liu 2018).

Similarly, the United States in its release of the funding program "Navigating the new Arctic," draws attention to the changing Arctic and its global significance:

> *Arctic change will fundamentally alter climate, weather and ecosystems globally in ways that we do not yet understand but that will have profound impacts on the world's economy and security. Rapid loss of Arctic sea ice and other changes will also bring new access to the Arctic's natural resources such as fossil fuels, minerals, and new fisheries, and this new access is already attracting international attention from industry and nations seeking new resources.* (NSF 2018, para. 2)

The influence of the Arctic on weather patterns further to the south is currently a subject of intense research and ongoing scientific discussion (Overland et al. 2018). Noting the "expanding footprint of Arctic change" via global sea level rise, coastal erosion, permafrost carbon release, storm impacts, and ocean-atmosphere warming, Moon et al. (2019) conclude that Arctic sea ice loss may already be causing extreme weather events that are manifested in mid-latitudes across the Northern Hemisphere. Unusually cold winter weather in North America has been attributed to the increased waviness of the Polar Front, the circumpolar jet stream that separates cold Arctic air from warmer air to the south. There is evidence that this is related to warming of the North Polar Region, which weakens the north-south temperature gradients, slows the flow of the jet stream, and allows cold Arctic air to penetrate southwards. Similarly, release of summer heat from the increasingly ice-free Arctic Ocean north of Alaska may have contributed to drought conditions in California.

The conspicuous changes taking place in the Arctic provide a clear early warning that severe climate impacts are to be expected throughout the rest of the world if we continue on the current emissions trajectory, and they also raise moral issues for our global society. In her landmark volume "The Right to be Cold," Inuit leader Sheila Watt-Cloutier presents the view that the effects of climate change on northerners constitute a violation of international human rights, including the rights of Inuk hunters on the snow and ice (Watt-Cloutier 2015). The eminent philosopher Thomas De Koninck and his colleagues argue that the degradation of the Arctic associated with climate change is an ethical failure by all humankind to respect the fundamental notion of "oikos" and the dignity of our existence. They suggest that Kant's definition of dignity as "inner worth" provides a unifying principle to address the "*complex and evolving problems of the North*" and to respect the beauty of all human beings and the natural world (De Koninck and de Raymond 2019, 52).

Adaptation Policies

The Arctic is changing so rapidly that local policy decisions are urgently needed to address the present and near-future challenges posed by climate warming. For example, in their analysis of northern infrastructure on permafrost, Hjort et al. (2018) conclude that the risks will remain high up to 2050 even if there are substantial cuts to greenhouse gas emissions, and that community and regional adaptation policies to minimize and manage these contingencies must be put in place as soon as possible. A broad sweep of adaptation policies are now in development throughout the North led by local, national, or in some cases international initiatives in response to the increasing impacts of Arctic climate change.

In the Canadian North, construction engineers are placing increasing attention toward "designing for change" in which the long-term stability of the environment is no longer taken for granted (Vincent et al. 2017). This involves engineering practices and designs that may be more expensive in the short term than conventional practices, but that are economical in the longer term. Discussions with northern communities, engineers, and permafrost specialists have culminated in a set of national standards for geotechnical surveys before construction on permafrost, with additional standards for drainage systems in northern communities on thawing permafrost landscapes and for thermosiphons (permafrost cooling systems), building foundations, and snow loading in the changing Arctic climate.

Climate adaptation strategies are in rapid development within specific national regions. Integrated Regional Impact Studies across the Inuit territories of Canada have included community-specific analyses of vulnerability, defined as the susceptibility to harm relative to the capacity to adapt (Ford and Smit 2004), and the production of permafrost risk maps to define areas safe for building in certain villages (Allard and Lemay 2012). Attention is also being put toward improved surveillance methods to monitor, communicate, and respond to changes, for example, by the use of satellite remote sensing to warn of unsafe river and sea ice conditions, and multi-kilometer long, fiber optic sensors to warn of localized thaw and collapse of roads and runways. Similarly, there is a need for increased surveillance and prevention policies for aquatic ecosystems. The warming climate combined with increased transfer of invasive species may prompt harmful algal blooms in coastal regions, making shellfish dangerous to eat; some toxins in harmful algae are passed up the food chain and have direct effects on the health and reproduction of marine mammals, and inshore environments need to be monitored. For drinking water supplies, adequate surveillance and advisories are also critical to ensure water quality and safety. Protection of these essential resources requires integrated freshwater management policies, including consideration of alternate water sources as traditional supplies change in quantity or quality.

At a broader multinational level, the Arctic Monitoring and Assessment Program (AMAP) was tasked by the Arctic Council to "produce information to assist local decision makers and stakeholders in three pilot regions in developing adaptation tools and strategies to better deal with climate change" (AMAP 2017a, 4), and the resultant work has culminated in a set of reports with ongoing updates for the Barents Region (AMAP 2017a), Baffin Bay Davis Strait Region (AMAP 2018), and the Bering/Chukchi/Beaufort Region (AMAP 2017b). These reports have identified specific tools to aid local adaptation, including models, scenarios, and narratives. The detailed exploration of alternate scenarios may be especially useful given the uncertainties inherent in climate prediction, as well as in global carbon emission trajectories. For example, Walsh et al. (2018) made downscaled estimates of air temperature and precipitation for more than 4000 communities in Alaska and western Canada. They found that ongoing climate change is inevitable over the next few decades, underscoring the pressing need for adaptation strategies, and that beyond 2050 the choice of emissions trajectory made a large difference in the future climate of each community.

Conservation Policies

Regional parks, wildlife refuges, marine protected areas, and other conservation zones play a key role in protecting northern species and ecosystems from additional stresses superimposed on the rapidly warming climate, and they are now more important than ever. Arctic ecosystems have a lower diversity of plants and animals than in the temperate zone, and loss of only one or a few species may completely disrupt their food webs. These ecosystems are underpinned by a remarkable variety of microscopic life that has unusual adaptations to the polar environment (e.g., Tsuji et al. 2019). With continued warming, many species of plants, animals, and microbes will be pushed to the upper limit of their thermal tolerances, which will increase their sensitivity to other stressors. These effects are compounded by the increasing human presence in the Arctic, the associated increase in roads, shipping, aircraft movements, and increased likelihood of arrival of invasive species and their rapid dispersal.

New and existing protection zones require ongoing policy support at all scales, from catchment conservation to safeguard local water supplies, to the creation of large wilderness areas to protect Arctic ecosystems and their migratory animals. The existing protected areas of the Arctic have been created through traditional conservation policies of protecting ecosystems, habitats, and biodiversity, before the impacts of Arctic climate change were a matter of discussion or concern. However, these lie in areas that are now experiencing increasing climate impacts, and climate-related arguments could be incorporated within their strategic conservation plans and their rationale for protection.

For example, after considerable pressure by Indigenous, research and other groups, the borders of Tursujuq Park, the largest park in the northern Quebec territory of Nunavik, were extended to incorporate and preserve a large catchment that had been previously excluded because of its great interest to the hydroelectricity industry. This extension thereby protected a unique population of freshwater seals as well as striking landscapes and ecosystems. This area lies in the discontinuous permafrost region that is now experiencing rapid thawing and landscape changes (Allard and Lemay 2012), and the park offers an important refuge against the large human presence and road-building that would accompany hydroelectric development and industrialization. Similarly, in one of the largest northern conservation zones in Canada, Quttinirpaaq National Park, studies over the last two decades have shown that the land, lake, and fjord environments are responding strongly to the current trend of accelerated warming at these extreme high latitudes (82–83°N), leading to the perturbation or even complete loss of certain ecosystem types (Copland et al. 2018). In both of these cases, the parks provide refuges from additional stressors during this period of increasing climate perturbation.

Northern parks and other protected areas are likely to come under increasing economic and political pressure as the drive to extract resources from the Arctic continues to accelerate, along with improvements in access. Ongoing vigilance is required to maintain long-term conservation policies in the face of this pressure. A disturbing example is the current precarious state of the Arctic National Wildlife Refuge (ANWR) in Alaska. This vast, undeveloped wilderness is unusually rich in species diversity, including 42 fish and over 200 bird species. It also contains many mammal species such as caribou that are culturally important to the Inupiat and Gwich'in people. This refuge was opened up for oil and gas drilling under the terms of the "Tax Cuts and Jobs Act" of 2017, which allows certain areas to be leased for oil and gas exploration, and other areas to be identified for land easements that will give oil and drilling companies the legal right to use the land.

Climate change is also resulting in larger scale regional policies on conservation. Recognizing that sea ice is diminishing rapidly and putting Arctic marine wildlife at risk, the Word Wildlife Fund initiated planning for a localized "Last Ice Area" in the far North, where the diminishing ice may still be in place in 2050 and could provide a refuge for ice-dependent marine species. This area extends from across the Canadian Arctic Archipelago to northern Greenland, and it includes several areas that are already protected such as Northeast Greenland National Park (the largest national park in the world), Quttinirpaaq National Park in northern Ellesmere Island, and a Canadian marine conservation area that is now in advanced planning, Tallurutiup Imanga, at the eastern end of the Northwest Passage (WWF 2018). In March 2016, the United States and Canada issued a joint leaders' statement in which the two nations agreed to join forces in meeting the challenges in the Arctic region, with recognition that it is on the *frontline of climate change* (The White House 2016). As part of this agreement, Canada stated its intention to launch a "new process with Northern and Indigenous partners to explore options to protect the 'last ice area' within Canadian waters, in a way that benefits communities and ecosystems" (Prime Minister of Canada 2016), including evaluation of a new conservation area in the far North called Tuvaijuittuq ("the ice never melts" in Inuktitut).

Following the US-Canada Joint Statement of Arctic Leaders, the United States in December 2016 established the Northern Bering Sea Climate Resilience Area protecting the cultural and subsistence resources of over 80 tribes and a major migratory corridor for marine animals. Russia's Arctic policy also refers explicitly to climate change as factor motivating their creation of national conservation areas:

> *In the sphere of environmental security it is necessary: to ensure preservation of the biological diversity of the Arctic flora and fauna, including by expansion of a network of especially protected natural territories and water areas, taking into account national interests of the Russian Federation, necessity of preservation of the natural environment in the conditions of expansion of economic activities and global climate changes.* (Russian Federation 2008, para. IV 8c)

The central Arctic Ocean currently lies outside territorial boundaries and is an important focus of policy discussions concerning international conservation. The prospect of this area opening up to exploitation in the future has led to a binding agreement among many nations to prevent unregulated fisheries in this 2.8 million square kilometer region. This area has never been fished commercially, but the moratorium was agreed upon as the best precautionary approach to fisheries management "*given the changing conditions of the Arctic Ocean*" (European Union 2018, para. 2). There are calls for this international conservation policy to be extended more broadly into shipping activities in general. With the increased likelihood of a transpolar sea route through the high seas of the Arctic Ocean by the end of this century and concerns about oil spillage, noise, and pollution, this area could be designated as a "Particularly Sensitive Sea Area" under international law as a precautionary shipping measure (Stevenson et al. 2019).

Mitigation Policies

Climate mitigation policies that limit emissions from human activities have the potential to make a massive difference in lessening the severity of impacts on the Arctic and throughout the world. Recent analyses of records from the past show how the present trajectory may lead to a gross perturbation of our planetary environment, including the Arctic. Business-as-usual emissions would lead to a climate that has not been experienced since the early Eocene, some 50 million years ago, and would unwind the long-term cooling trend of tens of millions of years in less than two centuries. It seems unlikely that current ecosystems throughout the world could sustain this unprecedented speed of change (Burke et al. 2018). The same business-as-usual scenario predicts warming in the upper ocean in the range 35–50% of that experienced 250 million years ago. That warming is believed to have been responsible for a 96% loss of all marine species on Earth because of oxygen depletion, with the greatest effects at high latitudes (Penn et al. 2018).

The Greenland Ice Cap is known to have been unstable over much shorter time scales of warming. There is evidence that sea levels rose by six meters over 1000 years during the last interglacial period around 100,000 years ago, and that near-complete deglaciation of southern Greenland occurred in the interglacial around 400,000 years ago (Fischer et al. 2018). The IPCC (2018) analysis concluded that irreversible loss of the Greenland ice sheet could be triggered at around 1.5 to 2°C, indicating the urgent need to reduce emissions. Similarly, the probability of a sea ice-free Arctic Ocean during summer is substantially lower with global warming of 1.5°C compared to 2°C. The report also points out that the 1.5 rather than 2°C temperature target would make a large difference in the amount of human suffering that will be imposed by global warming, including through sea level rise, heat-related mortality, forest fires, impacts on food supplies, ecosystem services, and limits to adaptive capacities, and that the Arctic is especially vulnerable to the additional 0.5°C in global temperature. The engineering risk analysis for Arctic infrastructure by Hjort et al. (2018, 3) shows that while large impacts are to be expected over the next few decades irrespective of emissions control, reducing the extent of warming to the Paris Agreement's aspirational target of +1.5°C "would make a clear difference in terms of potential damage to infrastructure."

Arctic permafrost soils contain vast quantities of carbon, which if fully mobilized by complete thawing and decomposition could more than double atmospheric carbon dioxide levels. In many areas of the North, some of this soil carbon is being converted to the more powerful greenhouse gas methane via microbial processes in permafrost-derived lakes, ponds, and wetlands (Vincent et al. 2017). An analysis of moderate warming conditions, within the range of the Paris Agreement, during the last interglacial period 400,000 years ago indicates that a runaway mobilization of these reserves did not occur, and nor does it seem that there was a release of marine methane hydrates at that time. Greater warming, however, is a serious concern for release of this carbon and the associated feedback effects (Fischer et al. 2018). A modeling comparison of greenhouse gas emission trajectories shows that a business-as-usual scenario could shift northern permafrost lands from being a net sink to net source of carbon beyond the year 2100, indicating the importance of mitigation actions to attenuate this permafrost feedback effect on climate (McGuire et al. 2018). New factors are also coming to light that could accelerate permafrost thawing and methane production, for example, warm rainfall events in spring (Neumann et al. 2019).

The implementation of the Paris Agreement requires an urgent stepping up of national policies in three areas: energy efficiency, alternative energy sources, and climate frameworks concerning mitigation and adaptation. In an analysis of data from 18 nations that showed consistently decreasing CO_2 emissions over the period 2005–2015, Le Quéré et al. (2019) found that there was a positive correlation between the rate of decline in emissions and the number of policies passed by law in each of these categories. The urgency of such polices was underscored in the IPCC (2018) report, which concludes that overshoot of the 1.5°C target can only be avoided if global CO_2 emissions start to decline before 2030. Similarly, a recent analysis of millions of policy scenarios shows that immediate global abatement of greenhouse gas emissions is required to assure a tolerable climate for future generations (Lamontagne et al. 2019). The recovery from overshoots of the Paris Agreement target would require a geo-engineering approach such as large-scale carbon dioxide reduction (CDR) or induced changes in atmospheric reflectivity, involving technologies that are currently not feasible at a global scale and that carry huge risks for the future of humanity and the biosphere.

Knowledge Policies

The Arctic is changing rapidly, and the short-term and especially long-term security of its residents and ecosystems requires climate policies at all scales, from local to global. The setting and implementation of such policies can only occur if people and their governing representatives understand the nature of climate-related problems and the need for action. This requires ongoing studies to not only define the current state and functioning of Arctic, but also fundamental and applied research to address uncertainties in projections and to find new solutions toward effective adaptation, conservation and mitigation measures. It also requires policies to promote knowledge exchange at all levels, from disseminating locally relevant information (for example, explaining to northern residents, municipalities, and developers the science behind "building for change" and risk assessment maps, and linking this to Indigenous Knowledge), to effectively communicating the most recent scientific insights about Arctic change and its global implications to government policy makers and the public throughout the world.

The Arctic is now a focus of unprecedented attention by research agencies and scientists. The International Arctic Science Committee (IASC), the umbrella organization for coordinating Arctic research, was made up of eight Arctic nations at its inception in 1990, but today is composed of government nominated delegates from 23 nations, including strong representation from Asia and Europe (Rogne et al. 2015). A number of large-scale initiatives are in progress under the auspices of IASC, for example, the "Multidisciplinary drifting Observatory for the Study of Arctic Climate" (MOSAiC 2018), an over-wintering mission in the central Arctic Ocean that involves 600 science personnel supported by five ice breakers, aircraft, and satellite remote sensing to examine the causes and consequences of sea ice decline. This has given rise to the related IASC study "Terrestrial Multidisciplinary distributed Observatories for the Study of Arctic Connections" (T-MOSAiC 2018) that involves more than 100 land-based stations around the Arctic to examine the effects of Arctic sea ice and climate change on landscapes, land-based ecosystems, and people in the circumpolar North. In an analysis of Japan's Arctic Policy, Ikeshima (2016, 460) notes that an "urgent requirement is the construction of a new icebreaker or an ice-strengthened vessel" for Japan to participate more fully in Arctic climate change research given the implications for future maritime transport and the opportunities for "collaboration and cooperation between the Arctic and non-Arctic states." All of this expanding research activity and collaboration will have the most societal value if the scientific information can reach "policy makers and other people with influence" in a timely and accessible manner (Ditchley Foundation 2017).

Indigenous experience and understanding provide a knowledge stream that has enormous value for incorporation into climate-related policies. In the context of Arctic climate change, Gilligan et al. (2006) recognize three types of knowledge systems: Traditional Knowledge defined as that based on tradition and passed from generation to generation, Local Knowledge that is generated by a community based on first-hand experience, and Scientific Knowledge based on the Western or European approach toward observation and data analysis. They note that combining information from these three sources is essential, but with respectful attention to the holders of Indigenous Knowledge (Traditional and Local) and the use of such information. There are national and international calls for closer partnerships between local communities and research programs, including Indigenous-led research. The Arctic Science Ministerial (2018, 3) declared that "*Indigenous Peoples should be involved as appropriate—as they are in this Ministerial discussion—in the assessment and definition of Arctic research priorities*" and that there is "*the necessity for all States and the European Union conducting research in this region to work together, in collaboration with Arctic Indigenous Peoples and local communities.*" The increasing involvement of northern communities in research will favor the trend toward incorporating Indigenous Knowledge in Arctic policies.

There is overwhelming scientific evidence that our planetary climate is changing rapidly as a result of human activities, and the IPCC has made a clear statement that urgent action is needed to reduce greenhouse gas emissions and concentrations, and thereby prevent the ecological crisis and human suffering throughout the world that our present trajectory is leading toward (IPCC 2018). The increased frequency of wildfires, storms, and heat waves, along with declining biodiversity, decreased crop yields, rising sea levels, and coastal flooding has meant that the reality of climate change has begun to penetrate human consciousness at a global level, as witnessed by the remarkable consensus of 196 nations in the Paris Agreement. However, the urgency expressed in the IPCC (2018) report is not widely understood or accepted, with nations weakening their commitment to mitigation or (in the case of the United States) withdrawing from the Agreement. Even the Arctic Science Ministerial (2018, 6), while noting how the Arctic is "*one of the most sensitive areas to climate change on Earth*," made no reference to mitigation.

There are hopeful trends in the level of public awareness about global climate change, but much more work needs to be done in science education and outreach. A recent survey of the American public found that the majority believe it is very likely that climate change is happening (73% in December 2018, the highest since the survey began in 2008) and is mostly human-induced (62%); however, only 22% agreed that most climate scientists have concluded that human-caused climate warming is occurring (Leiserowitz et al. 2019), despite clear statements to this effect from the IPCC, national assessments, and professional scientist associations. Arctic research has a key role to play in this knowledge communication process, with its compelling visual messages that Earth's climate is changing rapidly, and that the future well-being of the Arctic, and the world, depends on urgent climate policy actions at a global scale.

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