Birchall, SJ., MacDonald, S, (2019). Climate Change Impacts and Resilience: An Arctic Case Study . In WL. Filho, PG. Özuyar, PJ. Pace, U. Azeiteiro and L. Brandli (Eds.), *Climate Action, Encyclopedia of the UN Sustainable Development Goals*. London: Springer. https://doi:10.1007/978-3-319-71063-1_79-1.

Climate Change Impacts and Resilience: *An Arctic Case Study*

S. Jeff Birchall, PhD
Assistant Professor, Coastal Community Climate Resilience Research Group
School of Urban and Regional Planning
Department of Earth and Atmospheric Sciences
University of Alberta
Edmonton, Canada
jeff.birchall@ualberta.ca

Seghan MacDonald, BA
Researcher, Coastal Community Climate Resilience Research Group
School of Urban and Regional Planning
Department of Earth and Atmospheric Sciences
University of Alberta
Edmonton, Canada
seghan@ualberta.ca

Definitions

Climate change is defined by the Intergovernmental Panel on Climate Change (IPCC) as an observable change in the state of the climate taking place over an extended period of time, that may be caused by natural processes (i.e. volcanic eruptions) or external forces (i.e. anthropogenic changes to atmospheric composition, land use) (IPCC 2014). The United Nations Framework Convention on Climate Change (UNFCCC) takes a different approach, defining climate change as a change in climate that can be attributed directly or indirectly to anthropogenic activity, and that changes the composition of Earth's atmosphere. According to the UNFCCC this change is in addition to observed natural climate variability over a similar period of time (United Nations 1992).

Earth's climate has naturally fluctuated over the course of history due to internal forces such as variations in ocean currents, volcanic eruptions, and atmospheric circulation. However, since the post-industrial era, anthropogenic activities have led to a large increase in the concentrations of greenhouse gases (GHG) such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in the earth's atmosphere (IPCC 2014). These GHG emissions (largely due to the burning of fossil fuels, deforestation, and agriculture) have resulted in an increase in global average temperatures.

Climate change impacts: Climate change can manifest in a variety of ways, with impacts ranging in occurrence and severity. Globally, a number of climate change impacts have been observed:

- Earth's land and ocean surface temperature increased 0.85°C between 1850 and 2012, with each of the last three decades successively warmer than any preceding decade since 1850 (IPCC 2014).

- Thermal monitoring in northern Canada indicates that warming of permafrost has occurred in recent years, with summer thaw penetration increasing as early as the 1990s (Prowse et al. 2009). Approximately half of the permafrost in Canada is at risk of disappearing under projected global warming (Prowse et al. 2009). Warming and thawing of permafrost is causing engineering concerns related to infrastructure stability, for example increased creep of foundations and frost heave on pilings (Instanes 2005).

- The extent of sea ice in the Arctic has decreased in every season and in every successive decade since 1979 (IPCC 2014). The annual maximum ice area has reduced by about 2% per decade and the annual minimum ice area has declined by about 5.6% per decade (Prowse et al. 2009). Variations in sea ice thickness and extent put a strain on indigenous communities in the Arctic who rely on safe travel over the ice for successful hunting expeditions (Ford 2017).

- Ice sheets in Greenland and Antarctica have been losing mass over the last two decades, with the rate of ice mass loss from both ice sheets increasing substantially over the period from 1992 to 2011 (IPCC 2014). Melting of land-based ice sheets along with thermal expansion of the warming oceans contribute to sea level rise globally (IPCC 2014).

- Global mean sea level rose by 1.7mm/year from 1901 to 2010 with that figure nearly doubling between 1993 and 2010 (IPCC 2014). Approximately 75% of observed global mean sea level rise since the early 1970s can be attributed to thermal expansion of the world's oceans and increased melting rates of glaciers and ice caps due to warming (IPCC 2014). Reef islands such as the Maldives with elevations of only 1 – 2 m above mean sea level are at risk of disappearing within this century if climate induced sea level rise continues (Woodworth 2005).

- Storm surges, defined by the IPCC as a temporary increase in the height of the sea in excess of the expected level of tidal variation in a particular location, have increased since 1970 (IPCC 2014). Studies show that there could be a larger number of intense storms due to climate change, with mid-latitude oceans in particular projected to experience increases in extreme wave height (Hallegatte 2011). Storm surges associated with climate change can lead to the flooding and erosion of coastal areas, stressing urban development and tourism industries in coastal communities (Toubes et al. 2017).

- Increased coastline exposure to waves and storms will lead to greater coastal erosion throughout the 21st century (IPCC 2014). In the Arctic, thawing of permafrost leads to hydrologic and geomorphic change making coastal areas more vulnerable to erosion (Chapin et al. 2006). Coastal erosion in Alaska has led to a loss of terrestrial habitat, causing some communities to relocate to safer areas (USGCRP 2018).

- As sea levels rise, saltwater is pushed further inland through rivers, deltas, and coastal aquifers (Hall et al. 2013). Saltwater intrusion is the infiltration of saline water into fresh groundwater aquifers in coastal areas (Werner and Simmons 2009). High demand for groundwater during the summer and fall months in California can result in saltwater intrusion as aquifers are depleted (Hall et al. 2013). Saltwater intrusion into coastal aquifers can threaten drinking water supplies, infrastructure, and coastal and estuarine ecosystems (USGCRP 2018).

- Low elevation delta regions, such as those in heavily populated areas in South Asia are at a high risk of flooding as sea levels rise and precipitation patterns change (McGranahan et al. 2007). Future climate scenarios suggest that an increase in the frequency, magnitude, and extent of flooding in South Asia can be expected (Mirza 2011). Densely populated cities in South Asia tend to have heavily developed delta regions. These flood-prone areas are often populated by vulnerable communities without the means to relocate (McGranahan et al. 2007).

- Changing temperatures and shifts in the timing and magnitude of precipitation events are leading to increasingly large and destructive wildfires around the world. In California, for instance, wildfire frequency, size, and overall burned area annually are collectively increasing (Miller et al. 2009). The increased frequency and intensity of wildfires leads to increased risk to property and lives and a rising economic cost of fire suppression efforts (USGCRP 2018).

- As anthropogenic climate change progresses there is a risk of increased frequency, intensity, and duration of droughts (Kiem and Austin 2013). Southeastern Australia for example, has been experiencing an extended period of drought since the mid-1990s (Sherval and Askew 2011). Persisting drought leads to low financial returns in agricultural sectors, quickly spreading to associated industries and economies (Kiem and Austin 2013).

Resilience comes from the Latin root *resi-lire*, meaning to "spring back" (Davoudi et al. 2012). Multiple definitions of the term have since evolved, beginning in 1973 when C.S. Holling defined the difference between engineering and ecological resilience. Holling defined engineering resilience, or stability, as the ability of a system to return to an equilibrium state following a disturbance. The rate at which a system returns to equilibrium, along with its resistance to fluctuation, dictates how stable or resilient it is (Holling 1973).

Ecological resilience on the other hand is a measure of the persistence of a system despite an added stressor. It measures the magnitude of a disturbance that a system can absorb while still maintaining the same fundamental function and structure (Holling 1996). Ecological resilience allows for a system to change, and acknowledges the presence of multiple states of equilibria with a greater focus on the ability to persist and adapt (Adger 2003).

Evolutionary resilience is a more recent iteration of the concept. In this view, natural and social systems are considered non-linear (Folke et al. 2002). Evolutionary resilience therefore places a greater importance on the ability of a system to change, adapt, and transform in response to stressors (Walker et al. 2004). The IPCC, when defining resilience, takes the evolutionary approach. It places an emphasis on the capacity of social, economic, and environmental systems to manage a hazardous event, trend, or disturbance and to respond in ways that maintain the system's essential function and structure while also fostering the capacity for adaptation, learning, and transformation (IPCC 2014).

Introduction

Climate Change Impacts

Anthropogenic contributions of GHG emissions into the atmosphere through the burning of fossil fuels, deforestation, and agriculture have been shown to cause increases in global temperature (IPCC 2014). Global climate, over the last six decades, has been changing rapidly when compared to natural variations that have occurred throughout Earth's history (USGCRP 2017). As of 2018, human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels (IPCC 2018). However, changes in climate can vary drastically across the planet with some regions experiencing warming greater than the global average and, at the same time, lower average temperature changes over the ocean than over land (IPCC 2018). There has also been a significant decrease in total precipitation (rainfall) in southern Europe, China, and southwestern Australia, while precipitation has increased in much of Canada, northern Europe, and Scandinavia (Dore 2005). The annual extent of snow-cover in the northern hemisphere has been steadily decreasing due to increased spring and summer melt, yet the United States, Canada, and Russia have all experienced an increase in annual snowfall (Dore 2005).

Historic emissions commit Earth to some degree of future warming regardless of efforts to mitigate climate change. Indeed, models suggest that global temperatures could increase by 1.5°C to 2°C by 2100 (IPCC 2014). Mitigation efforts, largely via emissions trading schemes and carbon markets, have been the primary focus of climate change policy (e.g. Birchall et al. 2015, Birchall 2014). Yet GHG emissions continue unabated throughout much of the world. With extreme climate impacts rising temporally and spatially, the need for adaptation is becoming increasingly important. Recent reports released by the IPCC and the United States National Climate Assessment (NCA) show growing evidence that climate change impacts will have a significant effect on both natural and human systems globally. Addressing issues of vulnerability will be crucial to the resilience of communities and urban centers across the globe, and will require radical social and economic shifts (Carter et al. 2015).

Vulnerability to Climate Change

Sources of anthropogenic GHG emissions have historically been concentrated in a small number of developed countries, while many of the populations that are most vulnerable to the impacts of climate change have contributed little to global GHG emissions (IPCC 2014). Climate change is not limited geographically, and GHG emissions from one country or region can lead to global changes in climate. Urban areas with high population density and infrastructure development are especially vulnerable to the impacts of climate change (Carter et al. 2015).

According to the United Nations, more than 50 percent of the world's population currently lives in urban areas (United Nations 2018). This figure is expected to rise to more than 60 percent over the next three decades, with most future urban population growth expected to occur in developing countries (Wilby 2007). As urban populations increase globally, cities and their elected officials will be important actors in future direction and decision-making on climate change. Not only do cities account for more than 40 percent of global GHG emissions, they are also uniquely vulnerable to the effects of climate change (Rosenzweig et al. 2011). Due to high concentration of land development in urban areas, cities experience unique micro-climates that can magnify the effects of climate change. The urban heat island effect, which causes urban areas to be warmer than the surrounding countryside, can be exacerbated by more frequent heat waves associated with climate change (Rosenzweig et al. 2011). Further, replacement of vegetated surfaces with impervious built surfaces leads to reduced infiltration of rainwater runoff, which will cause a higher risk of flooding with projected variations in the frequency and intensity of precipitation (Carter 2015).

Vulnerability to climate change is not solely determined by climate impacts, it is also largely subject to various non-climate related elements, including socio-economic factors, demographic shifts and trends, and resource accessibility (Baker et al. 2012). In developing countries urbanization is occurring more rapidly, with the challenges described above exacerbate pronounced stressors such as ageing infrastructure, improper land use, and income inequality.

Pressure on land in developing countries often leads to development of vulnerable spaces such as flood-prone areas, with the poorest of the population living in these locations (Nicholls 1995). Climate change impacts tend to have a greater effect on vulnerable populations such as the elderly or those with low income. Inequities among socio-economic groups are projected to become even more pronounced as climate change progresses (Rosenzweig et al. 2011).

Poverty, gender, ethnicity, and age have all been documented as factors that affect vulnerability of urban populations to climate hazards (Tyler and Moench 2012). These social elements, when combined with the physical processes of climate change impacts can lead to various, potentially poorly understood, secondary effects such as displacement of vulnerable populations (Carter et al. 2015). Moreover, populations that do not have the resources to adapt to climate change impacts will experience higher exposure to extreme weather events. This is particularly true for low income populations in developing countries, and also remote locations such as the Arctic (IPCC 2014). Arctic communities are often located in isolated areas with limited seasonal accessibility and experience greater social, health, and economic disparities, compared to communities in more populated regions. These disparities, along with a strong dependence on the environment, make Arctic communities especially vulnerable to climate change impacts (Larsen et al. 2014).

Climate change impacts have the potential to affect communities globally, disproportionately impacting low-income and socially vulnerable populations. Adaptation programs are thus becoming increasingly necessary to address vulnerabilities and build resilient communities.

Restrictions to Adaptation

While communities around the world are developing adaptation programs, efforts remain largely uncoordinated and inconsistent (Wallace 2017). There is often a deficit in local, relevant, and easily-accessible research to support the development of adaptation plans (Baker et al. 2012). If the public and local government decision-makers are not well educated on the impacts of climate change, barriers can arise that impede policy action and implementation. Many adaptation policies and plans involve expensive investments and long-term commitments, which can be financially restrictive. Indeed, uncertainty surrounding the timing and severity of climate-related impacts, combined with limited resources and funding, and conflicting objectives among interest groups, can lead governments to prioritize more concrete and short-term issues over climate change adaptation (Baker et al. 2012, O'Brien et al. 2006). Even when a community and local government are engaged and supportive of adaptation policies, implementation can be hindered by jurisdictional conflicts over who can or must take action on a particular initiative (Rosenzweig et al. 2011). Inconsistencies in legislation across state and federal levels of government and even amongst local governmental departments can form constraints on policy development and execution (Wallace 2017).

Improving Urban Resilience to Climate Change

Mitigation, through management of anthropogenic contributions to GHG emissions, has been the primary approach when responding to climate change; however, with projections committing Earth to at least some degree of warming, the need for adaptation is becoming increasingly apparent (Wallace 2017). Community resilience to climate change can be seen as the basis for increasing adaptive capacity (Bulkeley and Tuts 2013). Determining the adaptive capacity of a community requires considering the potential impacts of climate change in the context of social, physical, and governing structures already in-place. Stressors such as resource scarcity can affect a community's resilience and capacity to adapt to future climate hazards (Bulkeley and Tuts 2013).

Creating resilient communities prepares them for future known and unknown impacts of climate change. A more resilient community is able to absorb larger climate stressors without changing in fundamental ways. If and when massive transformation occurs, a resilient community will be able to successfully reorganize (Folke et al. 2010).

Climate Science

Reliable research is essential in supporting successful adaptation planning and policy. Uncertainty with regards to local climate change projections, however, has the potential to form barriers to action (Ford 2017). Policy-makers and stakeholders need access to data on regional- and local-scale climate change impacts and vulnerabilities in order to effectively plan long-term adaptation responses (Carter et al. 2015). Despite the prevalence of large-scale climate models and data, there is often a lack of relevant research on local scale climate impacts. This makes it difficult to project how climate change will affect individual communities, which hinders decision-makers' ability to negotiate and assemble resources for local adaptation policy (Baker et al. 2012, Picketts 2016). Improved knowledge, covering a range of disciplines is essential to support government action in developing effective adaptation responses to climate change (Nicholls 1995, Baker et al. 2012).

Political Leadership

Political leadership is critical for climate change adaptation and resilience. However, there are often various limiting factors in developing successful government adaptation policies. As mentioned above, a lack of reliable research paired with the inherent variability associated with climate change impacts can make it difficult to gain political buy-in for adaptation. Further, local governments are often dealing with limited resources and tend to focus on more immediate and short-term issues; planning for future and uncertain climate change impacts can be overwhelming (Baker et al. 2012, Wallace 2017).

Research suggests that mainstreaming of climate change policies so that they are integrated into existing procedures and policy-goals can help to enhance community resilience to longer-term climate impacts, while still dealing with present-day issues (O'Brien et al. 2006, Ford et al. 2007, Wallace 2017). In order to increase effectiveness, developing comprehensive and achievable climate change adaptation policies requires consideration of, and integration with current government policies (and coordinated across governance scales). Additionally, the process of developing policy should be consistently re-visited and improved as experience grows; a successful adaptation policy will remain responsive to changing conditions and human requirements (Nicholls 1995).

The sharing of information and resources is crucial to identifying and implementing successful policies (Baker et al. 2012, Bulkely and Tuts 2013, Carter et al. 2015). Climate adaptation policies should be supported by consistent legislation at all levels of government with additional collaboration and engagement amongst various public and private stakeholders in the community (Baker et al. 2012, Bulkeley and Tuts 2013, Picketts 2016, Wallace 2017). Local governments, while critical players in adaptation planning, cannot act fully independently of external forces. Often, a community's adaptive capacity is tied to global and regional economic, technological, and environmental trends (IPCC 2014). At the same time, policies established at higher-levels of government without consultation with local governments or institutions can lead to unforeseen consequences down the line (Baker et al. 2012, IPCC 2014). To improve efficiency, standards for climate adaptation plans should be coordinated by national governments, while consulting local governments and acknowledging the highly variable context of different communities (Baker et al. 2012, IPCC 2014). National governments can also facilitate local government efforts through ongoing funding to help enable long-term planning around climate change preparedness (Baker et al. 2012).

In order to be successful, resilience-building processes must be inclusive, allowing participation and involvement by all invested parties including vulnerable community members most affected by climate change (Tyler and Moench 2012, Bulkeley and Tuts 2013).

Adaptive Measures

Adaptive measures that build resilience to climate change can take many forms depending on the specific vulnerabilities of a community. They can come in the form of institutional, educational, and behavioral change; development of early warning and proactive planning information systems; physical infrastructure development; integrated natural resources management etc. (IPCC 2014).

Harman et al. 2015 discusses three main categories of adaptation to climate change: planned retreat, accommodation measures, and protective measures. *Planned retreat* involves organized withdrawal or regulated restrictions on development in hazardous coastal areas affected by sea level rise, erosion, storm surges, etc. (Harman et al. 2015).

Accommodation measures consist of revised building codes and changes to urban design, allowing populations to continue to develop and live in areas affected by climate change impacts while reducing sensitivity and/or exposure to those impacts (Harman et al. 2015). Increasing green space in developed urban areas is considered a valuable accommodation response, as green spaces can mitigate the urban heat island effect by re-radiating less heat than built surfaces and providing cooling through evapotranspiration while also creating attractive spaces within urban centers (Carter et al. 2015).

Protective measures can be used to shield coastal communities from the impacts of climate change. These can be implemented through hard defenses such as dikes or sea walls, or soft defenses such as beach nourishment or coastline naturalization (Harman et al. 2015). As sea levels rise and the potential severity and frequency of storm surges increases, hard defenses can prevent flooding and reduce coastal erosion (Harman et al. 2015). Coastline naturalization can help to protect developed areas from the impacts of climate change (Harman et al. 2015; McDougall 2017). Allowing a coastline to either remain in or return to its natural state can reduce the risk of flooding associated with sea level rise and storm surges while also providing a form of erosion control (Cormier-Salem and Panfili 2016).

Successful implementation of adaptive measures should involve public disclosure at all stages. Open communication with at-risk populations allows the public to be involved in adaptation planning while also making them aware of any hazards associated with climate change in their community (Bulkeley and Tuts 2013, Harman et al. 2015).

A Case Study of the Arctic

Vulnerability in Arctic Communities

The Arctic is warming at a rate two to three times that of the global average (IPCC 2018). Since the 1950s, average annual temperatures in the Arctic have risen by about 2°C to 3°C and in the winter by up to 4°C (ACIA 2005). The effects of climate change in the north are not going unnoticed; communities, governments, and indigenous organizations in the Arctic have all expressed concern over the risks associated with climate change, and the urgency for appropriate action (Ford et al. 2007).

Climate variability in the Arctic has always affected the way of life of northern populations. High winds, fog, and ice break-up in the summer and extremely low temperatures and blizzards in the winters, heavily influence daily activities (ACIA 2005). In recent years, seasons have become less consistent, with shorter spans of extremely low temperatures and an increasing daily temperature variation (ACIA 2005). As the climate continues to change in the north, warmer seasonal temperatures have led to increased unpredictability of sea-ice conditions, melting permafrost, and subsequently, coastal erosion (Ford et al. 2006). These changes are impacting infrastructure, food systems, livelihoods, and human health and well-being (Ford 2017). Thawing permafrost and coastal erosion have already damaged infrastructure and heritage sites along the Beaufort Sea coast and caused planned retreat and relocation of entire coastal communities in Alaska (Shaw et al. 1998, Bronin and Chapin 2013). Reductions in the extent, stability, and seasonal duration of sea ice, along with less predictable weather patterns, have affected traditional hunting and subsistence activities of Arctic indigenous groups (Krupnik and Jolly 2002).

Both indigenous and non-indigenous peoples in the Arctic have traditionally been quite resilient to climate variability. For instance, hunters will adjust their hunting trails, the timing of their excursions, and even the animals they hunt in an effort to cope with large seasonal and inter-annual fluctuations in weather patterns and natural resources availability (Chapin et al. 2006, Ford et al. 2007, Larsen et al. 2014). However, with more extreme projected climate impacts, the resilience of northern communities will depend heavily on successful implementation of strategic long-term adaptation policy.

In Canada for example, most of the funding allocated to adaptation by the federal government is used for climate research with very few examples of the research translating over to concrete implementation of adaptation policy (Ford 2017). In order to develop adaptation programs and strategies that build a community that is resilient to both the physical and socio-economic impacts of climate change, it is imperative that policy makers and local leaders focus on understanding the nature and scale of climate impacts on their local community.

Resilience and Adaptation in the Arctic

Arctic communities, with small populations and limited industrial activity, contribute little to global GHG emissions (Ford et al. 2007). However, these communities are especially vulnerable to the effects of climate change due to their strong cultural ties to the environment and a heavy dependence on hunting and fishing to support their way of life (Larsen et al. 2014). As the climate in the Arctic becomes increasingly variable and extreme, adaptation is quickly becoming a necessity for building and maintaining resilience in these communities.

Coastal erosion caused by a combination of sea level rise, increased storm surges, and changing winter sea-ice patterns affects a large number of coastal communities in the Arctic. In fact, the US Government Accountability Office found that flooding and erosion affect 184 of the 213 Alaska Indigenous villages. Thirty-one of these villages are imminently threatened, and 12 communities are planning to relocate (Bronen and Chapin 2013).

As coastal communities experience increasingly devastating effects, local governments find themselves allocating greater resources to infrastructure repairs and shoreline defenses such as sea walls. In the past, sea ice protected coastal communities by creating a barrier to storm-related waves and surges; however, the intensity of storms combined with changing sea-ice conditions have resulted in elevated rates of coastal erosion and significantly damaged engineered defenses (ACIA 2005, Bronen and Chapin 2013).

Determining appropriate adaptive responses requires on-going assessment of a community's vulnerability and its capacity to adapt through protection in place, managed retreat of at-risk structures, or community-wide relocation (Bronen and Chapin 2013). In the United States, for example, erosion control and flood protection efforts have not been sufficient to eliminate risk in some communities, despite significant state and federal resource expenditures (Bronen and Chapin 2013). When engineered controls are no longer feasible, many communities are forced to relocate to areas of lower risk. Relocation and managed retreat can be extremely costly as infrastructure, housing, and livelihoods must be re-built (Bronen and Chapin 2013).

As climate change progresses, it is important to create a governance framework to help communities faced with relocation to understand how they can access funding or technical assistance to support adaptation (Albert et al. 2018). Government should be able to dynamically respond to communities faced with coastal climate change impacts, and provide support through post-disaster recovery, protection in place, hazard mitigation, and relocation while considering the humanitarian needs (Bronen and Chapin 2013).

For many Arctic indigenous groups more than just their homes and infrastructure are affected by climate change. Traditional daily activities such as hunting and fishing are almost entirely dictated by environmental conditions such as sea-ice thickness, snow depth, and winter storms (ACIA 2005). Financial limitations can restrict hunters from purchasing equipment such as GPS devices, immersion suits and personal locator beacons needed to keep them safe in unpredictable conditions (Ford et al. 2007). Economic and institutional support through government funding and public programs can help to build resilience in Arctic communities where there are often high levels of unemployment and limited job opportunities, and where much of the population is reliant upon hunting as a source of income or subsistence (Ford et al. 2007). The small equipment fund from Nunavut Tunnagavik Incorporated and the disaster compensation fund from the Government of Nunavut are examples of programs that provide hunters with the means to purchase safety equipment, to help better prepare for climate variability (Ford et al. 2007).

Communities throughout the Arctic, depending on their geography, infrastructure, and economic drivers, will experience vulnerability to climate change in different ways. This discrepancy highlights the need for local stakeholder engagement when planning adaptation policies in the Arctic. Engaging with local communities throughout the planning process allows the most vulnerable individuals to have a voice. Stakeholder engagement is especially important in Arctic communities due to the ongoing value placed on Inuit traditional knowledge, or Inuit Quajimajatuqangit (Ford 2017). The high adaptive capacity of northern indigenous peoples in the past has been largely attributed to the dynamic nature of traditional knowledge (Larsen et al. 2014). The long-term success and implementation of climate adaptation plans in the Arctic is more likely if policies are closely tied to indigenous cultural values and historical knowledge (Ford et al. 2007). Policy-makers should engage local community members and elders throughout the planning and development process to ensure policies appropriately address vulnerabilities and cultural values.

Climate change research in the Arctic has become increasingly widespread as the region has been recognized as an early warning opportunity to understand how climate change may impact other areas around the globe (Ford et al. 2012). While a majority of climate research conducted in the Arctic is related to physical climate change impacts, research on the human dimensions of climate change in the Canadian Arctic is on the rise (Birchall and Bonnett 2018, Birchall 2019). Research has also begun to focus on the importance of indigenous traditional knowledge and the impacts that climate change is having on human interactions with the environment (Ford et al. 2012). Despite these increases, there are still geographic disparities limiting local research across the widely dispersed communities and regions of the Arctic (Ford et al. 2007). Due to the significant differences in vulnerability and adaptive capacity between regions, geographic disparities in research can lead to large knowledge gaps that may then affect local policy-makers' ability to develop successful adaptation policies. Remote Arctic communities often struggle with a lack of access to reliable, up-to-date research and climate projections (Ford 2017). Increasing the geographic scope of climate research in the Arctic will help to improve access to accurate and reliable climate data and projections.

With climate change impacts already influencing communities in the Arctic, indigenous peoples have begun to implement their own adaptation strategies (Larsen et al. 2014). Indeed, hunters have adapted their activities to account for environmental change, including changing the timing and location of hunting and fishing areas, combining new technologies with traditional knowledge, taking more supplies while hunting, and constructing permanent shelters on land as refuge from storms (Larsen et al. 2014). Communities in the Arctic are well equipped with a long history of resilience and adaptation to change. However, with environmental variability exacerbated by current (and projected) climate change, historical adaptation methods may no longer be sufficient. Proper government funding and support along with continued scientific research will be needed to supplement traditional knowledge and foster ongoing resilience in future generations.

Opportunities

As the Arctic continues to warm, some changes in the physical environment will eventually provide new opportunities and benefits to industries such as agriculture, biofuels, forestry, and shipping (ACIA 2005, Callaghan 2006). Warmer summer months and longer growing seasons will increase the productivity of many crops in the Arctic, allowing for development of agricultural industries. In Iceland, for instance, the production of grain has increased over the last two decades (Larsen et al. 2014).

Warmer seasonal temperatures open up the Arctic Ocean to longer shipping seasons and additional shipping routes. A decrease in sea ice thickness will positively affect shipping operations by reducing the need for ice breakers and thereby reduce overall shipping costs. An increase in shipping in the Arctic Ocean could also enhance economic trade of natural resources in the region. With improved transportation conditions to bring products to market, industries like mining and agriculture will be much easier to sustain and develop (ACIA 2005).

While most opportunities arising from climate change in the Arctic tend to benefit commercial industries, there will be some benefits to traditional practices as well. Increased prevalence of storm surges, for example, can benefit some hunting and harvesting activities: late season storm surges wash clams onto beaches, making it easier to harvest them; whitefish can be trapped up-rivers behind sand dams formed by the storm surges. In addition, later freeze-ups can provide hunters with a longer period to use boats to hunt spotted seals and caribou; however, this does come with increased risk as hunters must face increasingly variable weather. Storm surges and late season high water also provide remote communities with a source of fuel in the form of logs that wash up on mud flats (ACIA 2005).

Despite the benefits to small communities and indigenous peoples in the Arctic, the negative impacts are likely to outweigh the opportunities. Moreover, positive development for commercial industries in the Arctic may result in future conflict with smaller communities and indigenous groups.

Future Directions

The degree of future climate change is dependent upon both anthropogenic and natural responses. Mitigation strategies along with the response of ecosystems to the changing climate, will dictate the extent of global warming and climate change impacts (Carter et al. 2015). How urban areas and communities adapt to these changes in climate is largely in the hands of government decision-makers and stakeholders, and their action in the coming years.

Programs to enhance resilience to climate change are emerging. The Building Adaptive & Resilient Communities (BARC) program, for instance, was designed by ICLEI (Canada) to help local communities to respond to the impacts of climate change by developing and implementing adaptation plans[1]. The 100 Resilient Cities program, launched by the Rockefeller Foundation, provides cities from across the globe with the resources necessary to adopt and incorporate resilience planning into their government processes. The long-term goal of 100 Resilient Cities is to build a practice of resilience among governments, organizations, and individuals around the globe[2].

The 2014 IPCC Fifth Assessment Report on climate change warns that the ongoing emission of GHG's will lead to continued warming and long-lasting changes in all components of the climate system. These changes increase the likelihood of severe, pervasive, and irreversible impacts for people and ecosystems (IPCC 2014). Building resilient communities around the world is crucial to maintaining the well-being of human and natural ecosystems in the face of a changing climate. Increasing the inherent capacity of a community to manage future unknown stresses and shocks through strategic preparation, will facilitate a more resilient system better able to deal with unforeseen hazards (Tyler and Moench 2012).

Cross References

- Adaptation (Wandera)
- Climate change adaptation (CCA) (Barinova and Roka)
- Climate change and anthropogenic impacts (Vieira)
- Climate change effects natural and human systems (Frederik)

[1] http://www.icleicanada.org/programs/adaptation/barc
[2] http://www.100resilientcities.org/

- Climate change impacts (Gasbarro)
- Climate change planning (Down and Birchall)
- Climate resilient communities (Roka)
- Community planning opportunities (Heang and Birchall)
- Immediate climate vulnerabilities (Macdonald and Birchall)
- The green climate fund (Al-Saidi)
- Vulnerability (Ribeiro)
- Vulnerable communities (Bonnett and Birchall)

References

ACIA. 2005. Arctic Climate Impact Assessment. Cambridge University Press, Cambridge, 1042.

Albert, S., Bronen, R., Tooler, N., Leon, J., Yee, D., Ash, J., & Grinham, A. (2018). Heading for the hills: climate-driven community relocations in the Solomon Islands and Alaska provide insight for a 1.5°C future. *Regional Environmental Change*, 18(8), 2261-2272.

Baker, I., Peterson, A., Brown, G., & McAlpine, C. (2012). Local government response to the impacts of climate change: An evaluation of local climate adaptation plans. *Landscape and urban planning*, *107*(2), 127-136.

Birchall, S. J. (2019). Coastal climate adaptation planning and evolutionary governance: Insights from Alaska. *Marine Policy, Land and Sea Interaction Special Issue*.

Birchall, S. J. (2014). New Zealand's abandonment of the Carbon Neutral Public Service program. *Climate Policy*, 14(4), 525-535.

Birchall, S. J., & Bonnett, N. (2018). Local-scale climate change stressors and policy response: The case of Homer, Alaska. *Environmental Planning and Management*. https://doi.org/10.1080/09640568.2018.1537975.

Birchall, S. J., Murphy, M., Milne, M. (2015). Evolution of the New Zealand voluntary carbon market: An analysis of CarboNZero client disclosures. *Social and Environmental Accountability Journal,* 35(3), 142-156.

Bronen, R., & Chapin, F. S. (2013). Adaptive governance and institutional strategies for climate-induced community relocations in Alaska. *Proceedings of the National Academy of Sciences*, *110*(23), 9320-9325.

Bulkeley, H., & Tuts, R. (2013). Understanding urban vulnerability, adaptation and resilience in the context of climate change. *Local environment*, *18*(6), 646-662.

Carter, J. G., Cavan, G., Connelly, A., Guy, S., Handley, J., & Kazmierczak, A. (2015). Climate change and the city: Building capacity for urban adaptation. *Progress in Planning*, *95*, 1-66.

Chapin III, F. S., Hoel, M., Carpenter, S. R., Lubchenco, J., Walker, B., Callaghan, T. V., ... & Barrett, S. (2006). Building resilience and adaptation to manage Arctic change. *AMBIO: A Journal of the Human Environment*, *35*(4), 198-202.

Cormier-Salem, M. C., & Panfili, J. (2016). Mangrove reforestation: greening or grabbing coastal zones and deltas? Case studies in Senegal. *African journal of aquatic science*, *41*(1), 89-98.

Davoudi, S., Shaw, K., Haider, L. J., Quinlan, A. E., Peterson, G. D., Wilkinson, C., ... & Davoudi, S. (2012). Resilience: a bridging concept or a dead end?"Reframing" resilience: challenges for planning theory and practice interacting traps: resilience assessment of a pasture management system in Northern Afghanistan urban resilience: what does it mean in planning practice? Resilience as a useful concept for climate change adaptation? The politics of resilience for planning: a cautionary note: edited by Simin Davoudi and Libby Porter. *Planning theory & practice*, *13*(2), 299-333.

Dore, M. H. (2005). Climate change and changes in global precipitation patterns: what do we know?. *Environment international*, *31*(8), 1167-1181.

Folke, C., Carpenter, S., Elmqvist, T., Gunderson, L., Holling, C. S., & Walker, B. (2002). Resilience and sustainable development: building adaptive capacity in a world of transformations. *AMBIO: A journal of the human environment*, *31*(5), 437-440.

Folke, C., Carpenter, S. R., Walker, B., Scheffer, M., Chapin, T., & Rockström, J. (2010). Resilience thinking: integrating resilience, adaptability and transformability. *Ecology and society*, *15*(4).

Ford, J., Pearce, T., Smit, B., Wandel, J., Allurut, M., Shappa, K., Ittusujurat, H., & Qrunnut, K. (2007). Reducing vulnerability to climate change in the Arctic: the case of Nunavut, Canada. *Arctic*, 150-166.

Ford, J. D., Smit, B., Wandel, J., Allurut, M., Shappa, K., Ittusarjuat, H., & Qrunnut, K. (2008). Climate change in the Arctic: current and future vulnerability in two Inuit communities in Canada. *Geographical Journal*, *174*(1), 45-62.

Ford, J. D., Bolton, K., Shirley, J., Pearce, T., Tremblay, M., & Westlake, M. (2012). Mapping human dimensions of climate change research in the Canadian Arctic. *Ambia, 41(8),* 808-822.

Ford, J. D., Labbé, J., Flynn, M., Araos, M., & IHACC Research Team. (2017). Readiness for climate change adaptation in the Arctic: a case study from Nunavut, Canada. *Climatic Change*, *145*(1-2), 85-100.

Hall, N. D., Stuntz, B. B., & Abrams, R. H. (2008). Climate change and freshwater resources. *Natural Resources & Environment*, *22*(3), 30-35.

Hallegatte, S., Ranger, N., Mestre, O. et al. Climatic Change (2011) 104: 113

Harman, B. P., Heyenga, S., Taylor, B. M., & Fletcher, C. S. (2015). Global lessons for adapting coastal communities to protect against storm surge inundation. *Journal of Coastal Research*, *31*(4), 790-801.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual review of ecology and systematics*, *4*(1), 1-23.

Holling, C. S. (1996). Engineering resilience versus ecological resilience. *Engineering within ecological constraints*, *31*(1996), 32.

Instanes, A., Anisimov, O., Brigham, L., Goering, D., Khrustalev, L. N., Ladanyi, B., & Larsen, J. O. (2005). Infrastructure: buildings, support systems, and industrial facilities. *Arctic Climate Impact Assessment.*

IPCC. (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L. A. Meyers (eds.)]. IPCC, Geneva, Switzerland, 151.

IPCC. (2018). Summary for Policymakers. In: Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32.

Kiem, A. S., & Austin, E. K. (2013). Drought and the future of rural communities: opportunities and challenges for climate change adaptation in regional Victoria, Australia. *Global Environmental Change*, *23*(5), 1307-1316.

Krupnik, I., & Jolly, D. (2002). *The Earth Is Faster Now: Indigenous Observations of Arctic Environmental Change. Frontiers in Polar Social Science*. Arctic Research Consortium of the United States, 3535 College Road, Suite 101, Fairbanks, AK 99709.

Larsen, J. N., Anisimov, O. A., Constable, A., Hollowed, A. B., Maynard, N., Prestrud, P., Prowse, T.D., & Stone, J. M. R. (2014). Polar regions. *Climate change 2014: Impacts Adaptation and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press. 1567-1612.

McDougall, C. (2017). Erosion and the beaches of Negril. *Ocean & Coastal Management*, *148*, 204-213.

McGranahan, G., Balk, D., & Anderson, B. (2007). The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment and urbanization*, *19*(1), 17-37.

Miller, J. D., Safford, H. D., Crimmins, M., & Thode, A. E. (2009). Quantitative evidence for increasing forest fire severity in the Sierra Nevada and southern Cascade Mountains, California and Nevada, USA. *Ecosystems*, *12*(1), 16-32.

Mirza, M. M. Q. (2011). Climate change, flooding in South Asia and implications. *Regional Environmental Change*, *11*(1), 95-107.

Prowse, T. D., Furgal, C., Melling, H., & Smith, S. L. (2009). Implications of climate change for northern Canada: The physical environment. *AMBIO: A Journal of the Human Environment*, *38*(5), 266-271.

Nicholls, R. J. (1995). Coastal megacities and climate change. *GeoJournal*, *37*(3), 369-379.

O'Brien, K., Eriksen, S., Sygna, L., & Naess, L. O. (2006). Questioning complacency: climate change impacts, vulnerability, and adaptation in Norway. *AMBIO: A Journal of the Human Environment*, *35*(2), 50-56.

Picketts, I. M., Andrey, J., Matthews, L., Déry, S. J., & Tighe, S. (2016). Climate change adaptation strategies for transportation infrastructure in Prince George, Canada. *Regional environmental change*, *16*(4), 1109-1120.

Shaw, J., Taylor, R. B., Solomon, S., Christian, H. A., & Forbes, D. L. (1998). Potential impacts of global sea-level rise on Canadian coasts. *Canadian Geographer/Le Géographe canadien*, *42*(4), 365-379.

Sherval, M., & Askew, L. E. (2012). Experiencing 'drought and more': local responses from rural Victoria, Australia. *Population and environment*, *33*(4), 347-364.

Smith, J. B., Schneider, S. H., Oppenheimer, M., Yohe, G. W., Hare, W., Mastrandrea, M. D., & Füssel, H. M. (2009). Assessing dangerous climate change through an update of the Intergovernmental Panel on Climate Change (IPCC)"reasons for concern". *Proceedings of the national Academy of Sciences*, *106*(11), 4133-4137.

Toubes, D.R., Gossling, S., Hall, C.M., & Scott, D. (2017). Vulnerability of Coastal Beach Tourism to Flooding: A Case Study of Galicia Spain. *Environments 4(83)*, 1-23.

Tyler, S., & Moench, M. (2012). A framework for urban climate resilience. *Climate and development*, *4*(4), 311-326.

United Nations. (2018). https://population.un.org/wup/Publications/Files/WUP2018-KeyFacts.pdf

United Nations & Canada. (1992). *United Nations Framework Convention on Climate Change*. New York: United Nations, General Assembly

USGCRP. (2017). Climate Science Special Report: Forth National Climate Assessment, *Volume I* [Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, 470 pp.

USGCRP (2018) Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, *Volume II* [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA. doi: 10.7930/NCA4.2018.

Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (2004). Resilience, adaptability and transformability in social–ecological systems. *Ecology and society*, *9*(2).

Wallace, B. (2017). A framework for adapting to climate change risk in coastal cities, Environmental Hazards, 16:2, 149-164.

Werner, A. D., & Simmons, C. T. (2009). Impact of sea-level rise on sea water intrusion in coastal aquifers. *Groundwater*, *47*(2), 197-204.

Wilby, R. L. (2007). A review of climate change impacts on the built environment. *Built Environment*, *33*(1), 31-45.

Woodworth, P. L. (2005). Have there been large recent sea level changes in the Maldive Islands?. *Global and Planetary Change*, *49*(1-2), 1-18.