The state of climate change adaptation in the Arctic

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Abstract
The Arctic climate is rapidly changing, with wide ranging impacts on natural and social systems. A variety of adaptation policies, programs and practices have been adopted to this end, yet our understanding of if, how, and where adaptation is occurring is limited. In response, this paper develops a systematic approach to characterize the current state of adaptation in the Arctic. Using reported adaptations in the English language peer reviewed literature as our data source, we document 157 discrete adaptation initiatives between 2003 and 2013. Results indicate large variations in adaptation by region and sector, dominated by reporting from North America, particularly with regards to subsistence harvesting by Inuit communities. Few adaptations were documented in the European and Russian Arctic, or have a focus on the business and economy, or infrastructure sectors. Adaptations are being motivated primarily by the combination of climatic and non-climatic factors, have a strong emphasis on reducing current vulnerability involving incremental changes to existing risk management processes, and are primarily initiated and led at the individual/community level. There is limited evidence of trans-boundary adaptations or initiatives considering potential cross-scale/sector impacts.

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1. Introduction
The Arctic is undergoing transformative change in climatic conditions [1]. The magnitude of warming is one manifestation of this, with circumpolar temperatures increasing ~0.60 °C per decade over the last 30 years [2]. Many of the resultant impacts are significant: sea ice extent in the Arctic Ocean for example, has decreased in all months and virtually all regions over the last 30 years, and has been accompanied by a reduction in ice thickness, later ice freeze up and earlier break up [3, 4]. The loss of sea ice is affecting marine and terrestrial ecological dynamics, with the implications of a changing climate already affecting the health, abundance, and migration timing of a variety of wildlife species. In turn, this has affected commercial harvesting and subsistence based livelihoods common among the Arctic’s Indigenous populations [5–8]. In addition to impacts on wildlife, changing weather conditions and ice dynamics are increasing the difficulties of land based travel and transportation (e.g. ice road access to communities and mine sites is becoming more unpredictable and difficult); thawing permafrost, coastal erosion, and sea level rise are affecting municipal and industrial infrastructure (e.g. water supply, airstrips, housing, pipelines); while warming temperatures are altering the prevalence and incidence of waterborne, foodborne, zoonotic and vector-borne diseases, and affecting economic sectors including forestry and agriculture via a longer growing season but with increased exposure to pests [1, 5] (for current and project impacts of climate change in the Arctic see [9–12]).

Projections indicate that warming will continue to be amplified in the Arctic [13]. The potential negative impacts of
climate change are significant, yet new economic opportunities associated with resource development and enhanced shipping access are also expected to arise [1]. However, if northerners are to take advantage of these new opportunities while minimizing negative impacts, adaptation will be needed [14–18]. Northern societies have not been passive in the face of a rapidly changing climate, with a variety of adaptation policies, programmes and practices evident. In Canada for instance, adaptation has been recognized as an essential component of northern climate policy since the early 2000s, and has been prioritized with the creation of adaptation plans for many northern communities [14, 19, 20]. Similarly, in Alaska, adaptation figures strongly in the State’s climate change strategy, and at a circumpolar level adaptation is emerging as a priority issue for the Arctic Council (e.g. adaptation actions for a changing Arctic program).

Despite the increasing importance of adaptation in the Arctic, we only have limited systematic understanding of if, how, and where adaptation is occurring, in response to what stresses, and by whom? IPCC AR5 for example, profiles examples of adaptation in polar regions [1], as does the Arctic resilience report [5], regional climate assessments [21], and a number of adaptation focused websites (e.g. Many Strong Voices), yet it is unclear to what extent these adaptations are representative of broader trends, and the selection criteria by which adaptations are selected to be profiled are rarely provided. The absence of such examination constrains our ability to characterize the current status of adaptation, to assess the types of adaptation taking place, to monitor progress over time, and to assess the adequacy of adaptations taking place, and is part of a broader deficit globally examining if/how adaptation is taking place [22–25].

This paper responds to this deficit, posing the question: what is the current state of climate change adaptation in the Arctic? Using a systematic adaptation tracking approach, we identify, describe, characterize, and compare adaptations being undertaken in the circumpolar north. The intent of the work is to generalize and quantify adaptation trends to generate board level insights on the current state of adaptation, and to provide a basis for assessing progress over time.

2. Methodology

We develop a systematic review methodology to examine the current status of adaptation based on adaptation reporting in the English language peer reviewed literature, building upon and refining in an Arctic context an approach developed in work on adaptation tracking at the global and regional scale [26–29].

2.1. Data source

We use reported adaptations documented in the English language peer reviewed literature between 15 November 2003 and 15 November 2013 as our data source. While recognizing that many adaptations are documented outside this body of literature, peer reviewed articles provide a widely accepted and scientifically rigorous source of data for rapid and standardized analyses, and have been used for similar adaptation tracking studies, where adaptations reported in articles function as a proxy for actual adaptations [27, 28, 30, 31].

A search-string was developed to locate relevant work and was designed to identify those articles that report or discuss intentional human adaptations to experienced or anticipated effects of climate change in the Arctic (see supplementary materials, available at stacks.iop.org/ERL/9/104005/mmedia). Our demarcation of the Arctic followed the Arctic human development report [32] (figure 1) to include Alaska, Canada North of 60°N together with northern Quebec and Labrador, all of Greenland, the Faroe Islands, Iceland, the northernmost counties of Norway, Sweden and Finland, and in Russian the Murmansk Oblast, the Nenets, Yamalo- Nenets, Taimyr, and Chukotka autonomous okrugs, Vorkuta City in the Komi Republic, Norilsk and Igorsk in Krasnoyarsky Kray, and those parts of the Sakha Republic whose boundaries lie closest to the Arctic Circle. The area included encompasses >40 million km² and is home to approximately 4 m people [32], of whom between 400 000 and 1.3 million are Indigenous persons [1]. Although many Arctic residents remain involved in subsistence-based livelihoods, mixed cash-subsistence and extractive industry-related activities comprise a growing proportion of Arctic socio-economic activity [5]. Adaptation was defined consistent with the IPCC, as adjustments in human systems in response to actual or expected climatic stimuli or their effects, which moderate harm or exploit beneficial opportunities. Searches were performed in ISI Web of Knowledge, Scopus, PubMed, PAIS International, Environmental Sciences and Pollution Management, and CINAHL to ensure a wide coverage of adaptation being reported in the scientific/technical, socio-economic/political, and health literature.

An initial search produced 1618 potentially relevant articles. After importing results into endnote, duplicate returns were deleted and the titles of the remaining 1043 articles were scanned, and irrelevant returns were removed. Abstracts for the remaining 373 articles were read in relation to the inclusion/exclusion criteria to determine relevance (table 1). Seventy-five articles for full review were obtained from the initial search; these articles were then used as the basis for backward and forward citation-tracking search, which located 18 additional articles for full review. Finally, to cross-check the robustness of the study’s search syntax, a broadened key word search using the terms climate change, global warming, adaptation, and resilience was conducted using the native search functions of the journals Arctic and Polar Research, with no additional articles identified. Combined, 93 articles were selected for full review; however, 21 of these were removed when evidence for exclusion was identified during full review (final n = 72).

2.2. Analysis

A coding scheme was developed to standardize the collection and analysis of adaptations, with analysis focusing on individual adaptations, or what have been termed ‘discrete
adaptation initiatives’ [26]. As such, multiple adaptations within single articles could be coded. Data were extracted for article information as well as adaptation characteristics including adaptation type, stage, the country and region where the adaptation was occurring, what sectors were adapting, and who was leading adaptations (codebook in supplementary materials). Following Lesnikowski et al [26], adaptations were also coded by stage: groundwork actions are considered first steps necessary to inform and prepare for adaptation, but do not explicitly indicate tangible changes in policy or programming that improves resilience; adaptation actions involve changes made to built environments, the delivery of government services, regulations etc in response to predicted or experienced impacts of climate change. Data from reviewed articles were entered into excel, where descriptive statistics were used to characterize and quantify information about adaptation across the Arctic.

3. Results

3.1. Reporting on adaptation initiatives has increased since 2003, but is geographically constrained to North America with a strong focus on Indigenous populations

Seventy two journal articles were retained as documenting adaptation initiatives (see supplementary materials), with the majority of articles initially identified in the review excluded due an exclusive focus on natural systems, or reporting on...
adaptation initiatives. Climate change was reported to be the sole driver of 22% of motivations for adaptation. Permafrost degradation (24%) and sea level rise/coastal erosion (19%) were also cited as notable drivers. For 46% of adaptation initiatives (n = 72), climate change was a primary motivator in combination with other factors, and for 31% (n = 48) non-climatic stressors were of equal or greater importance than climate in motivating adaptation. Important non-climatic stressors included challenges stemming from cultural changes (34%), such as subsistence to mixed cash/subsistence livelihood transitions; economic stresses (31%); health related factors (16%), such as concerns about hunter safety; and resource development activities (13%), which present both opportunities and risks. Examples of adaptations occurring in the Arctic are outlined in table 2.

3.3. Hunting and subsistence is the dominant focus of adaptation initiatives

Of the 157 documented adaptation initiatives, 48% (n = 76) were undertaken in the hunting and subsistence harvesting sector, primarily reflecting adaptations documented in a Canadian Indigenous context. Twenty five percent of adaptation initiatives were documented in the context of institutional and resource management (e.g. climate-related policy development among governmental and or inter-governmental agencies), with the other sectors accounting for less than 20% of adaptation initiatives. Sectors underrepresented in this review but facing significant vulnerabilities to climate change, included health and well-being, where initiatives such as the Climate Change and Health Adaptation Program for Northern First Nations and Inuit in Canada are promoting novel approaches to northern health research and funding to address vulnerabilities related to a changing climate (n = 24, 15%) [34]; infrastructure and transportation, where logging companies are constructing roads with more durable surfaces to overcome access challenges related to transportation networks undermined by thawing (n = 30, 19%) [11]; and business and economy, where extensive geological surveys to identify mineral and hydrocarbon resources are becoming more common (n = 24, 15%) [34, 35].

3.4. Adaptation initiatives are primarily behavioral in nature, reactive, and taking place at the individual / household level

The majority of documented adaptations occurred reactively in response to observed change in climatic conditions (n = 101, 64%), were initiated at the individual/household level (n = 91, 58%), and involved behavioral changes (50%). This profile reflects the dominance of adaptations documented in the subsistence sector, where altered harvesting behavior and the utilization of new equipment have been widely documented among small North American Indigenous communities in response to climate change impacts. Those focused on surveillance and monitoring (34%); infrastructure, technology, and innovation (28%); and organizational development (15%) were also documented. Such adaptations...
### Table 2. Illustrative adaptations from Arctic regions.

| Arctic region | Adaptation                                                                 | Stressors                                                                                           | Publication |
|---------------|----------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------|-------------|
| Alaska        | Construction a new school in sheltered location away from settlement. Road to school provides an evacuation route during extreme weather; school may serves as pioneer infrastructure for community relocation. | Sea level rise and coastal erosion, extreme events                                                 | (Bronen and Chapin 2013) |
| Northwest Territories | The Women’s Community Kitchen project—effort to educate about nutritional cooking with store foods to ameliorate projected declines in country food availability | Changing sea ice dynamics, decreasing snowfall, food insecurity                                       | (Pearce et al 2012) |
| Yukon         | The Whitehorse Community Adaptation Project—multi partner project to develop scenarios for planning in the context of climatic and social change. | General climate-related concern, changing socio-economic conditions                                 | (Hennessey 2010) |
| Nunavut       | Altering location and timing of hunting; additional preparation, including GPS, monitoring weather forecasts, extra emergency equipment | Changing sea ice dynamics, environmental conditions uncertainty, weather uncertainty, economic stress | (Ford et al 2013) |
| Nunatsiavut   | Changing climate, changing health, changing stories—participatory approach to understanding and promoting human health in the context of complex social and ecological interactions | Rising temperatures, seasonality change, weather uncertainty, decreasing rainfall, changes in wildlife, health related concerns, cultural change | (Harper et al 2012) |
| Lapland       | Constructing more weather resistant roads into logging areas to overcome access challenges related to thawing roads | Rising temperatures, weather uncertainty, environmental conditions uncertainty, economic stress | (Keskitalo 2008) |
| Fennoscandia  | Moving reindeer by truck due to poor land conditions, supplementary winter feeding due to frozen pasture | Rising temperatures, seasonality change, environmental conditions uncertainty, economic stress | (Furberg et al 2011) |
| Greenland     | Altering location and timing of hunting; additional preparation, including GPS, monitoring weather forecasts, extra emergency equipment; women’s employment playing a larger role in finance hunting activities | Changing sea ice dynamics, weather uncertainty, changing wildlife distributions, rigid wildlife management programs, economic stress | (Ford and Goldhar 2012) |
| Siberia       | Changing livestock grazing patterns, decreasing heard size to promote flexibility | Vegetation change, rain on snow events, environmental conditions uncertainty, resource development related concerns, marginalization | (Forbes et al 2009) |
| Beringia      | State and federally funded coastal erosion control efforts | Sea level rise and coastal erosion, extreme events,                                                 | (Marino 2012) |
| Pan-Arctic    | The development of the International Maritime Organization’s International ‘Polar Code’ for Arctic shipping | Changing sea ice dynamics, resource development related concerns, increased shipping in Arctic waters | (Hoivelsrud et al 2011) |

Included efforts to increase understanding of change in Arctic socio-ecological systems [36], the adoption of new tools by Indigenous land-users such as GPS to aid in navigating a less predictable northern environment [37], and the development of polices to manage increased economic activity and geopolitical concerns in the circumpolar north [38].

Most adaptations were led by individuals, families, or community residents (58%), although local (14%), regional (23%), and national (22%) governments also play a significant role. Half of the adaptations documented take place at the individual/household scale (52%). However, community- (22%) and regional-scale (12%) adaptations were also common. National and pan-Arctic scale adaptations represent only 4% and 10% of reported initiatives, respectively. Although there is a correlation between the actor leading an adaptation and the scale at which an adaptation occurs, this is not always the case (e.g. state led community relocation programs). A smaller proportion of adaptation initiatives focused on public awareness and outreach (11%), resource and financial transfers (10%), regulatory responses to climate change (9%), and performance reviews (4%).

3.5. A mix of adaptation actions and groundwork action are reported, varying by region and sector

Sixty-three percent of adaptations were classified as actual adaptation actions, with the remainder constituting groundwork. The proportion of adaptations classifiable as adaptation...
actions was highest in Greenland (100%), Russia (88%), and Canada (81%); adaptation groundwork dominates in the United States (74%) and among adaptations at the pan-Arctic scale (100%). Regionally, Lapland (100%), Siberia (88%), Nunavut (88%), and the Northwest Territories (76%) had the highest proportion of adaptation actions. From a sectorial perspective, adaptation actions are dominated by activities in the hunting and subsistence harvesting (95%) and culture and education (53%) sectors, with groundwork representing at least half of the adaptations in all other sectors.

No evidence of adaptations being formally evaluated was documented. Three percent of adaptation initiatives were classified as clearly transformative, where adaptation is adopted at a much larger scale or intensity; is new to a particular region or resource system; or is transformative of a place-based human environment system, including a shift of such systems to other locations [39]. This included the climate-induced relocations of coastal communities in northern Alaska [40]. Four percent of adaptations were classified as clearly mal-adaptive, where adaptations impact adversely on, or increases the vulnerability of the adapting actor(s) or other sectors, social groups, or systems (including ecosystems) [41], and included, for example, responses to climate change and external socio-economic stresses by modifying eating patterns in ways that compromising nutritional intake and have adverse health implications [42]. For many initiatives, such categorization was not possible, due to a lack of information and/or temporal perspective.

4. Discussion

With the increasing importance of adaptation in climate policy, creation of specific adaptation programs, and commitment of adaptation funds, the characterization and monitoring of adaptation actions has become a priority [22]. Efforts to track adaptation however, have been complicated by an absence of common reference metrics and debate about what actually constitutes ‘adaptation’ [23, 43–45]. Consequently, the nascent, yet rapidly developing, adaptation tracking field is characterized by a diversity of approaches, each applied at different scales, for different purposes, and using different metrics [44]. Using Ford et al.’s [25] typology, the work reported here utilizes an ‘action based approach,’ using reported adaptation initiatives to develop a general understanding on the status and characteristics of adaptation across the circumglobal north. The approach is suited for making comparative analysis between and across regions and sectors, for identifying general trends and patterns, and for monitoring progress over time [25, 46–48]. Yet caution is also required when interpreting the results. Many adaptations are undocumented, particularly in the peer reviewed scholarship, with likely under-representation of industry and town-planning focused adaptations which are more commonly documented in the grey literature. This potential bias has significant implications for the documentation of adaptations taking place in Russia and Fennoscandia, in particular, which have a more urbanized and non-Indigenous Arctic population.

Adaptations will also have taken place outside the sample timeframe, and the level of detail provided on adaptations can vary significantly by article. In view of these limitations and biases, we underscore the study as a proxy or snapshot of adaptations being undertaken.

The results hold several broad level insights on the current state of adaptation in the Arctic. Firstly, there is limited reporting on adaptation initiatives, and while the number of initiatives reported has increased over time, peaks in 2009 and 2011 have not been sustained. Of the 1618 articles initially reviewed, only 72 were included for analysis documenting 157 adaptations. While it is not possible to make judgments on the state of adaptation solely on number of reported initiatives, it nevertheless supports assertions made elsewhere that adaptation remains in its infancy in the Arctic, with adaptation deserving increased attention [49]. Similarly, other studies examining national level adaptation in developed countries with Arctic territory [26, 50, 51]. There is also a large variation in adaptation by region, with adaptations primarily reported in a North American context, and a quarter of Arctic nations having no adaptations documented in the English language peer-reviewed scholarship.

Second, examination of how adaptation is taking place reveals a predominance of autonomous adaptations being undertaken in the subsistence harvesting sector, mostly among Inuit communities in Canada and Alaska. These adaptations are indicative of the inherent resilience of subsistence activities, and will be the primary way through which subsistence households respond to future impacts [52–56]. These responses however, are largely reactive in nature, taking place and initiated at the individual/household level and seeking to maintain livelihood activities in-light of experienced changes. As such, they may not involve strategic long term planning or evaluation of the impacts of adaptation actions, with a recent study suggesting that some responses could be maladaptive, reducing adaptive capacity in the long-term, and may also displace impacts to other communities/time periods in-light of a rapidly changing climate [37].

Other sectors and populations are significantly under-represented in the documented adaptations. Climate change presents numerous opportunities to resource development and tourism sectors, for example, yet there are few examples of documented adaptations seeking to maximize benefits and minimize negative impacts of such developments [57, 58]. Similarly, urban areas and industrial settlements are home to the majority of the Arctic’s population, face a number of risks from changing landscape hazards, yet are largely absent in reporting on adaptation. We believe that the harvesting and Inuit focus reflects a number of factors, including a historic interest of research on ‘traditional’ ways of life, the importance of harvesting to northern livelihoods and significant sensitivity to climate change impacts, and lobbying by Inuit political actors to establish climate change as a human rights issue (e.g. [59, 60]). Other sectors however, also have significant vulnerabilities: in Alaska for example, Larsen et al [61] project that climate change could add $5.6–$7.6 bn to future costs for public infrastructure from now to 2080, with
some coastal communities already becoming unlivable because of damage to critical infrastructure. The northern European forestry sector is also affected by climatic stressors that influence, among other things, stand productivity and disease exposure, yet understanding of adaptations in this sector to take advantage of increased productivity while minimizing harm related to changes in stand health remains nascent [11, 62].

Thirdly, the majority of adaptation initiatives reviewed are being led and initiated at the community and household level, particularly in North America. This reflects the focus of many research programs and policy initiatives at the community level, which is also recognized as a key scale for adaptation for the purpose of engaging stakeholders in the development of adaptations, incorporating local and traditional knowledge, targeting responses to local context, and ensuring actions are locally appropriate [18, 49, 63]. However, local scale actions may be constrained or rendered maladaptive by broader scale policies and wider processes of social, economic, and political change, they may displace impacts to other communities or regions, or they may require broader level support to be possible [16, 64–67]. Despite this, there is limited explicit recognition in documented initiatives of the need for adaptations at the national and international level, consideration of which adaptations are optimal across sectors and regions, or examination of how local adaptations may be contained by broader scale processes. This deficit is pertinent for wildlife management where numerous climate-sensitive populations span national/regional boundaries and are managed under different regulations (e.g. polar bear and narwhal in Baffin Bay). In these instances, adaptation in one jurisdiction to maintain harvesting may displace impacts or increase vulnerability of the system as a whole. Similarly, oil and gas projects initiated in response to changing sea ice conditions present socio-economic opportunities, risks, and tradeoffs that are often conceptualized as highly local, yet non-local policies and market dynamics will dictate many of the locally rendered socio-economic conditions stemming from climate-related adaptations in the industrial sector [68].

Fourthly, adaptation is taking place in response to multiple stimuli not just climate change, with non-climatic factors functioning as co-stressors in the majority of cases, and many adaptation initiatives are not targeting climate change explicitly. The benefits of such mainstreaming are widely known [49, 69], and in an Arctic context are particularly pertinent given immediate priorities concerning economic development, education, social issues, and constrained institutional capacity in many regions [18, 54, 70–72]. However, given the magnitude of climate change and associated impacts projected for the Arctic this century, specific interventions targeted at future change will also be required to prepare and effectively respond [1, 5]. Integrating projections of future change is important to this end, although the lack of downscaled projections remains barrier to model-informed adaptation in an Arctic context [1].

The need for transformative adaptation has also been recognized in the Arctic, including the need to develop novel Arctic governance systems that are both flexible across issues and adaptable over time [39, 73]. The majority of documented adaptation initiatives however, are based on accommodating change and involve incremental responses based on an extension of existing actions and behaviors to manage climate-related risks. Such responses may be effective in the short-term, but may not be sufficient in-light of future climate change, and may increase vulnerability [74]. In a resource development context, for example, McDowell and Ford [68] have argued that Greenlandic hydrocarbon development plans do not adequately account for anticipated trajectories of environmental change, leading to the initiation of activities that are believed to be within acceptable margins of safety, but actually have uncertain risk portfolios vis-à-vis the future Arctic environment.

Finally, there are a number of key areas that are not being reported on. Integration of vulnerable groups into documented adaptations is limited, aside from the predominance of adaptations taking place within Indigenous populations. The effectiveness of reported adaptations is unclear, with no examples of monitoring and evaluation (M and E). M and E is important for developing an evidence base on adaptation, and ensuring effectiveness of policy programming. There are also few examples of adaptations to capitalize on the benefits of climate change. While it is commonly assumed that the private sector will autonomously take advantage of opportunities of climate change, there are significant institutional, regulatory, and infrastructural barriers in an Arctic context [1].

5. Conclusion

This paper develops a baseline characterization of the current status of adaptation in the Arctic. The use of a systematic methodology and Arctic focus differs the work from national and regionally focused climate assessments, with the profile of adaptation generated providing a baseline from which to monitor change over time. The paper demonstrates that adaptation remains in its infancy in Arctic regions, with significant gaps and regional differences in the risks being addressed and nature of adaptations being undertaken. We have much to learn from what is and is not being done on adaptation, and this study further emphasizes the importance of future assessments on adaptation tracking in the Arctic. Specifically, there is need for future work to use multiple data sources to build up a more comprehensive profile of Arctic adaptation, including reporting on adaptation in the ‘grey literature’ (i.e. government and consultant reports, websites, national assessments, climate change plans etc) which is more likely to be focused on the actual policy aspects of adaptation. As the adaptation tracking field further develops, there is also a need for longitudinal studies which assess adaptation progress over time and across regions in the Arctic, for research that examines the success/effectiveness of adaptations taking place, and for comparison of the status of adaptation in the Arctic with other regions globally.
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