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Looking back while moving forward: How past responses to climate change can inform future adaptation and mitigation strategies in the Arctic

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ABSTRACT

Modern Arctic Indigenous peoples face many interconnected pressures, not the least of which is anthropogenic climate change, which is emerging as one of the most dramatic drivers of social and economic change in recent memory. In this paper, we investigate whether or not insights into premodern strategies for coping with climate change—and especially the "deeper histories" of traditional ways-of-knowing—can play a useful role in future planning, management and mitigation efforts. We do this in two ways. First, we assess this special issue's 17 archaeological case studies, in order to determine whether they are conducted within a framework that is consistent with approaches to resilience in studies of modern Arctic communities. Second, we focus on three climate-driven challenges faced by Canadian Arctic Inuit: safe travel, food security and food safety. For each, we identify specific ways in which studies of past social-ecological systems intersect with modern climate adaptation. We conclude that since archaeological insights highlight the operation of decision-making processes within long-term culture-adaptive trajectories, they can offer unique insights into the much shorter-term processes currently underway. While we highlight many potential directions for productive collaboration, much more work is required in local and regional settings to demonstrate the full potential of archaeology for future-oriented planning and mitigation efforts.

1. Introduction

Indigenous peoples in the Arctic face many inter-connected social and economic pressures—all of which amplify the multiple challenges of everyday life in the region. Understanding how global changes affect the Arctic, and finding sustainable solutions to these challenges, is particularly important for hunter-gatherer-fishers and reindeer pastoralists, who have traditionally relied heavily on climate-sensitive food webs, both wild and domestic. But for all these communities, climate change is arguably the most substantial and pervasive driver of change, impacting the sustainability of food-webs, landscapes and environments, and generating an avalanche of existential challenges. In an effort to understand the ongoing transformation of indigenous communities and ecosystems across the Circumpolar North the Arctic Council commissioned the comprehensive *Arctic Resilience Report* (*ARR*) (Arctic Council, 2016). The goal was to understand current cultural and ecological dynamics and assess risks and opportunities for sustainable development in the north; a key argument was that understanding and responding to these threats requires a systemic approach integrating both cultural and natural dynamics (Arctic Council 2016).

The 'point of departure' of the *ARR* is the concept that while global climate change generates both challenges *and* opportunities for social-ecological systems (SES) worldwide, nowhere is change more rapid and perilous for human populations than in the Arctic. The report also underlines the importance of Indigenous knowledge systems in informing and mediating how local communities respond to these challenges and opportunities, and highlights the importance of long-term perspectives that acknowledge the fact that many eco-adaptive strategies in the Arctic have deep cultural ancestry. While climate simulation studies can play an important role in understanding drivers and consequences of evolving systems, they have tended to focus on ecological and climatic datasets, whereas use of societal data has been minimal, and use of datasets that have a longer time depth largely absent. Many current strategies are based around future scenario planning, which has become a popular tool in place-based environmental research for identifying and evaluating alternative future scenarios for local and regional SES.

In this paper, we argue that fuller integration of longer-term cultural

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and ecological datasets can play a vital role in improving understanding of how Arctic SES's have evolved and changed under the pressures of past climate change, and that these insights need to be better incorporated into future-oriented conservation, management, mitigation and planning processes. We start by summarizing current practice—-with a focus on future scenario planning, and highlight the gaps and lost opportunities generated by use of exclusively short-term cultural and ecological datasets. We then draw on the suite of papers presented in this special issue of *Quaternary International*, summarizing the range of insights offered by archaeological and paleo-ecological studies of past social-ecological systems. Next, we explore how such insights can be deployed to address three major challenges that confront Arctic communities on a daily basis: safe travel, food security and food safety. We conclude that improved understanding of long-term cultural responses to Arctic climate change can be used to inform, strengthen and invigorate the evolution—and critical evaluation—of new strategies that better equip Arctic communities for challenging and uncertain futures.

2. Current approaches to planning and mitigation efforts

Important to this discussion is the heuristic concept of the "social-ecological system" (SES), based on the argument that humans and their environments are intimately interconnected, and that these close interrelationships are constantly co-evolving. The fundamental challenge for sustainability science is the identification and evaluation of the various pathways that particular SES's may eventually take; the ultimate goal is to generate understanding and insight into how they might be steered into more sustainable and socially- and environmentally-desirable directions. Several planning tools are commonly used to generate insights into the evolution of systems, improve knowledge and formulate intervention strategies.

Many resilience studies are regionally focused, and begin by assessing existing cultural and environmental conditions in order to identify how a specific SES is evolving. The next step is to define which of these uncertainties are critical, and then develop a limited number of plausible future scenarios (i.e., the different directions that current developmental trajectories could potentially lead to). This approach, known as "participatory scenario planning" (Arctic Council, 2016: 196–197; Flynn et al., 2018), allows planning and mitigation strategies to be generated, evaluated and implemented, ideally through close engagement between local and other stakeholders. One potential problem with this approach is that it often relies on contemporary or recent-historic baselines, both cultural and ecological. Thus, many such studies lack greater time depth, and they risk missing out on identifying a wider range of possible future scenarios, and also generate a restricted set of potential response, planning and mitigation strategies.

While every SES is in some way unique, and will have its own dynamic complexity, most remain shaped by a relatively limited number of variables. Identifying and investigating relationships between key variables can reduce the level of apparent complexity of a particular SES to generate useful scientific and also practical management and mitigation strategies. Computer simulation models are often exploratory, stimulate debate and encourage innovation in that they project how particular combinations of variables generate cumulative outcomes. (In other words, they produce *projections* rather than *predictions*.) In the Arctic, the widest application of modelling has been in the study of natural systems in the biological and ecological sciences. However, the use of modelling has rarely combined both social and ecological datasets to explore future scenarios and inform policy and mitigation efforts; this, despite the fact that use of agent-based SES models may be able to identify critical thresholds, so-called "slow" variables (see Crépin, 2007; Walker et al., 2012), nonlinearities and unexpected sources or fragility or resilience. A particular problem is the presumed lack of diachronic, or "deep-time", datasets on the cumulative effects of human decision-making meant to mitigate—or take advantage of—local environmental change.

Also crucial to any consideration of human-environment relationships is traditional Indigenous knowledge, and its capacity to help groups identify problems and facilitate behavioural flexibility in responding to them. Social scientists and environmental historians now widely acknowledge the importance and relevance of locally-based knowledge systems. Moreover, both Arctic and non-Arctic Indigenous peoples are culturally, emotionally and spiritually committed to maintaining sustainable lifestyles (see Jiao et al., 2012; Norgaard and Reed, 2017; Gould et al., 2019 among others). This commitment is often deeply felt, and can serve as a moral catalyst that supports resilience in the face of evolving challenges. Such traditions affect how the environment and its resources are used and understood, and provide a knowledge base that can be crucial for adapting to changing environmental conditions. At the same time, such traditions are dynamic and flexible, often building on centuries of history (Arctic Council, 2016: 42, 100).

One of the most important challenges is understanding what triggers sudden, major and permanent changes in Arctic SES's (Arctic Council, 2016: 193–4). In resilience theory, such rapid changes are known as "regime shifts", defined as momentous, abrupt and persistent changes in the structure and function of systems. They are commonly researched and understood using mathematical modelling of diverse terrestrial and aquatic systems, but investigation of SES's has been more limited, primarily due to a reported lack of *long-term* data (see Palmer and Smith, 2014; Dawson, 2016 for an Arctic archaeological example). We consider this a dramatic oversight, considering the Arctic archaeological and environmental record is rife with examples of systems undergoing both abrupt and gradual regime shifts.

3. Adapting to climate change in the Arctic: an enduring challenge

Change and transformation are not new phenomena in the Arctic; cultures and ecosystems in the region have never been "stable" in the sense of being static. In fact, cultural and ecological baselines have undergone sometimes-significant shifts, with repeated cycles of climatic and environmental change being a central feature of Arctic cultural development for millennia. These include the massive reorganization of biogeographical zones at the end of the Pleistocene and beginning of the warmer Holocene, but also more gradual warming and cooling trends, the most recent being the Medieval Warm Period (ca. 1000 to 700 BP) and the Little Ice Age (ca. 675/650 to 150/100 BP). In addition to these, there have also been several shorter climatic "shocks", such as the 8.2 cal BP event and others (see Desjardins and Jordan, 2019).

While their often-rich archaeological presence in the Arctic attests to a history of successful adaptation by Indigenous peoples to these pressures, modern climate change is posing new challenges, not only in its rapid onset, but also its projected intensity—with temperature increases perhaps as high as 6–7 °C by 2100 (CNRS, 2019). Still, long-term perspectives are vital in that they remind researchers, and also Indigenous communities, that contemporary assumptions of "normal" or "traditional" human and environmental responses and actions in Arctic SES's are prone to shifting baselines. A critical question is the role played by human decision-making processes—informed by traditional knowledge systems—in devising and adjusting strategies in the face of risk, uncertainty and changing climatic conditions. It is clear that adaptations to past change cannot simply be "cut" out from the past and "pasted" onto contemporary communities to ensure future sustainability; they do, however, represent human-scale evidence of local impacts and responses to climate change, how groups of various levels of social organization dealt with uncertainty, and where potential socio-cultural limits to adaptation may lie (Jackson et al., 2018; see also Hardesty, 2007; Van de Noort, 2011; Hudson et al., 2012). In short, these "palaeosocietal" archives can be used to run "natural experiments in history to learn from the past" (Riede, 2014; Van de Noort, 2011).

Such an "experiment" could proceed as follows:

(a) Identify and document various cultural and ecological baselines, and examine how they have evolved and changed over time;
(b) Improve understanding of what triggered transformation in past SES's (which could be beneficial for future-oriented scenario planning exercises); and
(c) Inspire and refine agent-based simulation studies that draw on a broader and better-informed set of cultural variables and relationships in order to understand past decision-making processes.

At present, however, all these records remain an underused resource in Arctic climate-adaptation research, whose potential use is acknowledged but not yet harnessed (Arctic Council, 2016: 47; Riede, 2014).

Finally, the evolution and refinement of traditional Indigenous knowledge about the environment can also be placed in a longer-term historical context. Modern Inuit of Inuit Nunangat (the parts of northern Canada traditionally occupied by Inuit) are the direct cultural and genetic descendants of Thule Inuit populations (ca. 820-350 BP) that already survived major episodes of climate change in the past, including the Little Ice Age and Medieval Warm Period (see Desjardins and Jordan, 2019). Many modern Inuit are well versed in *Inuit qaujimajatuqangit* (*IQ*; Inuktitut for 'things long known to Inuit'), which draws from and builds on past experiences, to inform contemporary life and aid in planning for the future. However, dramatic new social and environmental stressors (e.g., the combined effects of Euro-Canadian colonialism and modern climate change) *may* be pushing *IQ* to its operative limit in terms of its ability to inform responses to some human-environment relationships.

4. Can archaeological studies contribute to an understanding of contemporary resilience?

This brings us to the central concern of this paper, and the special issue of which it is a part: How can past SES's, and more specifically changes within these systems relating to past climatic shifts, contribute to current discussions of adaptation and mitigation? There are many sources of relevant "palaeo" data, though all have limitations. For example, there is a great volume of purely paleoenvironmental work being performed using a variety of proxies such as pollen, diatoms and chironomids to reconstruct past climates (e.g., Finkelstein, 2016). In some instances, such studies have recovered direct evidence for changing adaptations among human populations—as, for example, when lake cores adjacent to Thule Inuit archaeological sites revealed evidence for hunting of bowhead whales (Douglas et al., 2004). Written records, including formal ethnographies as well as historical records of whalers, traders, missionaries, and other colonial agents, also provide a wealth of information for specific times and places. However, these records are uneven, and restricted in most circumpolar regions to the last few centuries at most.

As a result, archaeology emerges as a critical source for understanding long-term patterns in the resilience of Arctic SES's in the face of climate change. This article is not the place to provide an in-depth review of the entire literature on circumpolar prehistory (see Friesen and Mason, 2016 and Mason and Friesen, 2017 for recent overviews). Instead, our coverage will rely mainly on the 17 case studies in this special issue, as these comprise a representative selection of current work in the region. Chronologically, they run from the late Pleistocene through to the recent past, with many focusing in particular on the impacts of and adaptions to the MWP and especially the LIA.

One of our primary goals is to explore the integration of these long-term Palaeo records with trans-disciplinary studies of resilience in modern SES's, particularly as they are outlined in the *ARR*. In order to do this, we will explicitly examine the case studies in this special issue in reference to resilience concepts. First, to improve clarity and ensure communication and compatibility between the *ARR* and these archaeological case-studies, we provide a short review of key terms in "resilience studies" in Table 1. These definitions are largely self-explanatory, and provide concepts for characterizing the different categories of past human responses to climate change as they have been referenced in the case studies.

In Table 2, we present a summary of the ways in which the 17 papers in this special issue articulate with the major issues relating to resilience, as outlined in Table 1. Our purpose is not to explore the themes within each individual paper, but rather to comment on their aggregate approaches and outcomes. In the first category, "baselines", it is noteworthy that a great majority of papers deal explicitly with both ecological and cultural baseline data sets (Table 2, columns 2.1.1 and 2.1.2). This is a key requirement for advancement of the field – that is, we need to reduce the "siloing" of research and publication in cultural *or* environmental realms. By bringing together these threads in the context of research teams with expertise across both, outcomes are expected to improve due to factors such as the resolution of terminological differences between disciplines, and the likelihood of better project design if the concerns of multiple disciplines are considered during the planning phase (Izdebski et al., 2016).

The second category of aggregate information in Table 2 relates to patterns and processes of change in SES's. Here, a few key observations are in order. The first relates to the concept of transformations or regime shifts - that is, instances in which major reorganizations are inferred for the SES (Table 2, column 2.2.1). For those cases to which this category applies, a great majority do indeed see major shifts in, for example, subsistence, technology or regions occupied by past societies. We suggest that this high level of attention to regime shifts results in large part from the fact that they have high visibility in the archaeological record. Continuous human occupations with relatively stable SES do not offer easily identifiable "events" that might be considered in relation to changing climates. Importantly, this can lead to circularity: if attempts to understand linkages between climates and SES are only explored in relation to periods when the SES undergoes radical change, we may miss case studies in which the SES is resilient enough to "ride out" climatic and linked ecological changes or fluctuations. We note the same phenomenon in the next category, focussed on thresholds and tipping points (Table 2, column 2.2.2). As should be expected, these values largely mirror those in the previous column; that is, for those case studies in which regime shifts were identified, these are commonly linked to threshold conditions or tipping points that lead to abrupt change. Finally, in terms of the main drivers of observed changes in SES (Table 2, column 2.2.3), for most case studies a direct connection is drawn between changing climate and changing SES. This should not be taken to indicate the presence of "climatic determinism", since these studies explore a range of ways in which human societies reacted to these changing climates. However, we do believe that as the field matures, there will be more "space" to consider other causal factors for observed changes, including those relating to social organization, politics, technological change, and the role of agency. A final important point relates to the fact that it is not only cooling temperatures that can act as forcing mechanisms for SES; warming temperatures can also have negative effects, for example in relation to marine productivity (Mason and Barber, 2003).

The third major category consists of features and capacities of SES in the case studies. Not surprisingly, virtually all of the case studies rely on some consideration of the role of ecosystem services in the consideration of climate-culture interactions (Table 2, column 2.3.1). Given that the case studies in this special issue relate largely to hunting-gathering-fishing societies, there is a very direct relationship between resource abundances resulting from local ecosystem variables and the resilience of the SES in question. If climates change enough to impact ecosystems in a significant way, it is in this realm that they will potentially force a reaction on the part of human decision-makers. Similarly, most case studies also deal directly or indirectly with the concepts of adaptive capacities (Table 2, column 2.3.2) and resilience (Table 2, column 2.3.3). In seeking to understand how climate may have impacted past SES which are observed to have undergone significant change, it is

Table 1
Resilience in Arctic social-ecological systems: Key term and concepts (adapted from Arctic Council, 2016).

"Baselines"	
Ecological	An **ecological baseline** is a body of data on a given ecosystem, over a particular period of time, against which development, climate change and other impacts on the system are measured.
Cultural	A **cultural baseline** refers to an evaluation of a people's social and economic system—including their relationship with the natural-environmental features comprising the local ecological baseline—at a given moment or period in time.
Transformation of Arctic SES's	
Transformation / Regime shift	**Transformation** is fundamental change to the coupled SES, and occurs when ecological, social or economic conditions become unsustainable. Such change can be unintended or actively initiated (see "agency", below). A **regime shift** is a possibly-sudden, substantial and enduring reorganization of an SES.
Threshold / Tipping point	A **threshold** is an abrupt dividing point, or boundary, between alternate states of an SES; often, a small change in one variable produces a large change in the structure, function and feedbacks of the system. A **tipping point** is a specific kind of threshold characterized by bifurcation in an SES system.
Driver of change	A **driver of change** is a natural or human-induced factor that results in change in an SES.
Ecosystem services	**Ecosystem services** are the various benefits to human societies originating in the natural environment; "provisioning" ecosystem services consist of food (including "country foods"), fuel, fresh water and other such resources.
Adaptive capacity / Adaptive trajectory	**Adaptive capacity** refers to the ability of an SES to adjust to changing conditions or recover from the impacts of change. Such capacity is determined by the structures and processes that enable or constrain choices for action and that shape people's ability to anticipate and plan for future change. An **adaptive trajectory** is the path along which an SES evolves.
Resilience	**Resilience** refers to the capacity of an SES to cope with stressors and shocks—both external and internal—by responding or reorganizing in ways that maintain essential identity, function and structure; it includes the capacity to navigate and shape change, including transformational change.
Agency / Innovation	Human **agency** is the capacity for people to make choices and take actions to affect their situation. For our purposes, the primary consideration is *why* individuals in the past made specific decisions and developed specific adaptive strategies. **Innovation** is the development or adoption of new technologies, activities, social structures and beliefs ultimately leading to increased capacity for resilience.

Table 2
Overview of "palaeo" insights into circumpolar social-ecological systems. (* See Quaternary International Special Issue, Long-Term Perspectives on Circumpolar Social-Ecological Systems; ** See Table 1, the main text, as well as the Arctic Resilience Assessment [Arctic Council 2016: xvii] for further explanation.) Case studies: Alvarez et al., 2020, Anderson et al., 2020, Blankholm, 2020, Damm et al., 2020, Desjardins, 2020, Fernaandez et al., 2020, Forbes et al., 2020, Friesen et al., 2020, Jorgensen, 2020, Landry et al., 2020, Mason et al., 2020, Masson-MacLean et al., 2020, Panagitakopulua et al., 2020, Pavlova and Pitulko, 2020, Tallavaara and Pesonen, 2020, Wren et al., 2020, Blankholm et al., 2020

1. Case-Study Details (source: Desjardins and Jordan 2020)*				2. Inventory of "Palaeo" Insights**								
				2.1 (Pre) Historic "Baselines"		2.2 Patterns and Processes of SES Change			2.3 Features / Capacities of SES			
Region	Case-Study Author(s)	Coverage	General Research Theme	2.1.1 Ecological	2.1.2 Cultural	2.2.1 Transformation / Regime Shift	2.2.2. Thresholds / Tipping Points	2.2.3 Main Driver(s)	2.3.1. (Provisioning) Ecosystem Services	2.3.2. Adaptive Capacity	2.3.3 SES Resilience	2.3.4. Agency / Innovation
A. Arctic Eurasia												
NE Asia	Pavlova & Pitulko 2020	50 cal BP - Present	Human-enviroment interactions	Yes	Yes	Yes	Yes	Climate (warmer/colder)	Hunting (some FG)	Yes	Yes (?)	Innovations in technology, subsistence, mobility
Coastal Finland	Tallavaara & Pesonen 2020	10 - 2 cal BP	Human-enviroment interactions	Yes	Yes	Yes	Yes	Climate (warmer/colder)	Coastal HFG	Limited	No	Appear to be limited
Arctic Norway	Jørgensen 2020	11.5 - 1.5 cal BP	Paleodemographic-climate interactions	Yes	Yes	Yes	Yes	Climate (warmer/colder)	Coastal HFG	Limited	No(?)	Appear to be limited
Western Finnmark	Damm, et al. 2020	11.5 - 2 cal BP	Human-enviroment interactions	Yes	Yes	Yes	Yes (?)	Mixed climate / culture	Coastal / Inland HFG	Yes	Yes	Innovations in technology, subsistence, mobility
Eastern Finnmark	Blankholm 2020	8.3 - 8.1 cal BP	Combined tsunami / 8.2K impacts	N/A	Yes	No	No	N/A	Coastal HFG	N/A	Yes	No (SES absorbs these two immediate "shocks")
Eastern Finnmark	Blankholm, et al. 2020	6.1 - 3.5 cal BP	Climate change / toxic foods	Yes	Yes	N/A	N/A	Climate (warmer)	Coastal HFG	Unclear	Unclear	Unknown (long-term effects of toxic food unclear)
B. Arctic North America and Greenland												
NW Alaska	Anderson, et al. 2020	5 - 0.2 cal BP	Human-enviroment interactions	Yes	Yes	Yes	Yes	Mixed climate / storminess	Coastal HFG	N/A	N/A	N/A (refines culture-environment chronologies)
NW Alaska	Mason, et al. 2020	AD 400 - 1100	Reconstruction of storm intensities	Yes	Yes	Yes	Yes	Increased storminess	Coastal HFG	Yes	Yes	Innovation in technology, (marine) subsistence, migration
SW Alaska	Forbes, et al. 2020	AD 1450 - 1850	Palaeoclimate reconstructions	Yes	N/A	N/A	N/A	Climate (colder)	N/A	N/A	N/A	N/A
SW Alaska	Masson-MacLean, et al. 2020	AD 1500 - 1600	Human-enviroment interactions	Yes	Yes	No	No	Climate (colder)	Coastal HFG	Yes	Yes	Flexibility in subsistence and technology
Canadian Arctic	Friesen, et al. 2020	AD 800 - 1800	Climate-migration interactions	Yes	Yes	Yes	Yes	Mixed climate / culture	Coastal / Inland HFG	Limited	Limited	Innovation in subsistence and settlement (migration)
Baffin Island, Canada	Landry, et al. 2020	6 - 2 cal BP	Human-enviroment interactions	No	Yes	No	No	N/A	Coastal / Inland HFG	Yes	Yes	Flexibility in subsistence and mobility
Foxe Bain, Canada	Desjardins 2020	AD 1250 - Present	Human-enviroment interactions	Yes	Yes	Yes	Yes (?)	Climate (colder)	Coastal HFG	Yes	Yes	Innovations in subsistence, technology, storage strategies
SW Greenland	Panagiotakopulu, et al. 2020	AD 1400 - 1700	Palaeoenvironmental reconstructions	Yes	Yes	N/A	N/A	Climate (colder)	Yes	N/A	N/A	N/A
James Bay, Canada	Wren, et al. 2020	4.2 cal BP - Present	Settlement Strategies	Yes	Yes	No	No	General Deglaciation / Upli	Yes	Yes	Yes	Agency (location of habitation sites "works with" evolving landscape)
C. Subantarctic South America												
Fuegian Archipelago	Álvarez, et al. 2020	1.3 - 0.2 cal BP	Human-enviroment interactions	Yes	Yes	No	No	Climate (warmer/colder)	Yes	Yes	Yes	Flexibility in subsistence and technology
Fuegian Archipelago	Fernández, et al. 2020	6 - 0.3 cal BP	Human-enviroment interactions	Yes	Yes	Yes	Yes	Climate (warmer/colder)	Yes	Yes	Yes	Flexibility in subsistence and technology

inevitable that researchers look at impacts on the resilience of the subsistence adaptation, at least initially. Not surprisingly, it is in the final category, centered on the role of agency and innovation, that we see the greatest range of interpretative frameworks deployed (Table 2, column 2.3.4). When faced with risks imposed by changing environments, human societies are faced with a broad array of constraints, and an equally broad range of potential solutions including development of new technologies, intensification and other alteration of subsistence economies, or migration to areas perceived as preferable. Ultimately, these changes result from decisions made by individual actors based on existing knowledge and their social frameworks in relation to other individuals, families, and interest groups; as such, the process can be difficult to reconstruct from the archaeological record.

Based on this meta-analysis of multiple studies relating to climate change and SES in the Arctic past, it is clear that there is significant common ground between these studies and the *ARR*, which characterizes resilience in *modern* societies. Most of the same elements are present, and even emphasized – it appears that researchers in these two often-separate research areas actually *think* along the same lines. This bodes well for the next, and significant, challenge: bringing the data and models from the past into the arena of modern resilience.

5. Three contemporary challenges

In this section, we review three of the most direct and common impacts of climate change on modern Arctic communities, especially of Indigenous peoples: safe mobility, food security, and food safety. All impact the *resilience* of modern communities, in terms of economics, health and general well-being, as represented by connections to the land and opportunities for intergenerational transfers of knowledge. These impacts are described as they affect Inuit communities in Arctic North America, but they are broadly relevant to communities across the circumpolar North. In each case, the modern issues are interwoven with consideration of their past manifestations as understood from traditional knowledge, ethnohistory or archaeology.

5.1. Sea ice and safe mobility

Perhaps no single environmental feature plays a more decisive role in the well-being of Indigenous peoples in Arctic North America than sea ice, the conditions of which determine how people are able to move freely across sometimes-vast distances in search of both marine and terrestrial resources (see papers in Krupnik et al., 2010). Climate change is the primary driver of serious and lasting changes in sea ice conditions and seasonal ice coverage in the Arctic. Both real-time and projected climate impacts affect local travel by leading to increasingly unpredictable sea ice formation, and generate new risks to traditional Inuit lifeways across Inuit Nunangat and Greenland. Aporta (2002, 2004, 2009, 2011) has examined how Canadian Inuit understand and utilize ice, in part to facilitate movement for multiple purposes, from hunting to maintaining social contacts. From the perspective of a traveller, the surface of "safe" land-fast ice and large ice floes can feel as sturdy and capable of supporting the weight of a dog team or snow machine as solid ground. In the past, the safety of this ice environment has traditionally been at least somewhat knowable and predictable from one season to the next, with periods of real uncertainty about ice conditions generally being limited to the annual breakup and build-up of landfast ice. These were relatively brief spans that could be planned for and adapted to.

Today, warmer temperatures are creating new and more variable freeze/thaw patterns, thereby increasing periods of uncertainty. Surveying members of three northern Canadian communities, Ford et al. (2008: 654) found that "ice is taking longer to reach a thickness capable of supporting travel." While it is difficult to see a silver lining in the lack of predictability, less ice coverage for at least part of the year may have some benefits to northern residents. Longer periods of open water reduce travel times by allowing for more (and faster) boat travel (Ford et al., 2008: 654–655). Additionally, marine-mammal hunters and fishers acquiring prey in open water will have longer access to these resources.

Just as motorized boats have significantly changed the way in which the waters are navigated, so too have snow machines changed human relationships with ice, making winter overland and over-ice travel faster, if arguably less safe; unlike dogs, snow machines cannot intuitively detect and avoid dangers, such as thin ice, fissures or leads (Ford et al., 2008: 655), and accidents involving snow machines and thin ice are not uncommon (Ford et al., 2009). It is likely that among many Indigenous peoples, the various traditional means of forecasting for safe travel are under pressure from climatic volatility (Downing and Cuerrier, 2011); for example, traditional means of gauging ice safety are often no longer tenable due to changes in weather, wind and prevailing currents. Inuit of the island community of Igloolik (Iglulik), Nunavut, rely on their knowledge of seasonal sea-ice and open water dynamics to travel safely to and from their community to visit friends and family in nearby communities, as well as to hunt. Ford et al. (2008) found Igloolik residents were acutely aware of "the increased potential for loss of life and injury, and increasing stress" of traveling upon ice at particular times of the year (2008: 653).

Insights from archaeology can shed light on how past episodes of climatic instability—and associated uncertainty among, and adaptive responses by, local human populations—were manifested. For example, both Grønnow et al. (2011) and Desjardins (2018) have found that Thule Inuit populations in northeast Greenland and northern Foxe Basin, respectively, likely capitalized on increased duration and extent of sea ice during the Little Ice Age. Such adaptation may require changes in where village sites are situated, which prey species are focused upon and the technology used to acquire and process them. In Inuit Nunangat, new technologies (e.g., rifles, motorized boats and GPS technology) have long been embraced—especially by hunters—in the struggle to adapt to changing social and economic circumstances, as well as evolving standards for personal risk and what constitutes "safe" travel on land, sea and ice. Satellite phones and GPS tracking devices, such as "SPOT", are regularly used by hunters and others as a means of added security when traveling outside communities. Increased connectivity is facilitating safe travel through cellular data (3G and 4G/LTE) communication networks. In 2019, the Nunavut-based Arctic Eider Society has launched a free mobile and desktop app called Siku (Inuktitut for "ice") (https://siku.org), which enables users to view and record local ice conditions and *IQ* of traditional hunting locales (see Fig. 1). The use of new technologies and innovation represents one point of continuity between past and present adaptation to changing climates.

5.2. Food security

In the premodern past and today, travel away from residential locales was and is necessary for acquiring animal prey that may migrate widely—in predictable ways, seasonally, but also in unpredictable and novel ways due to climate change. If these changes are too rapid, traditionally-informed understanding (i.e., through *IQ* and other forms of traditional knowledge) may not be able to keep up. Even relatively minor changes in climatic conditions can have severe impacts on delicate food webs. For example, warmer Arctic summers and late freeze-ups can result in fewer nutrients in sea ice and meltwater; this affects ice-borne algae, algae-feeding fish, piscivorous mammals and birds, and ultimately, Indigenous hunters (Ferris, 2013: 8).

Importantly, terrestrial biomes can also be affected. According to Downing and Cuerrier (2011:64), "warming and cooling or freezing rain can cause a food shortage (lichens) for caribou (*Rangifer tarandus*) herds as it becomes inaccessible under a layer of ice and snow"; fewer caribou during autumn could force many Inuit toward other country food species, or less healthy store-bought foods. A similar domino effect can be seen in the longstanding and important relationship between ringed seals (*Pusa hispida*) and Indigenous peoples across the Arctic. At Thule and historic Inuit archaeological sites across Inuit Nunangat and Greenland, zooarchaeological evidence indicates the bulk of the diet in many regions of consisted of small seals, such as ringed seals (see Desjardins, 2018; Murray, 2008), which require a balance of snow and heavy ice to productively forage for food and reproduce. Ferguson et al. (2005) have shown that in western Hudson Bay, Canada, warmer temperatures are resulting in less overall snow cover, and an earlier-than-usual breakup of sea ice leads to lower survival rates of seal pups, and ultimately, fewer seals for Inuit to hunt.

Over the past 50–70 years, people of Inuit Nunangat have undergone an arguably traumatic dietary shift from consuming primarily wild harvested "country foods" to a mix of less healthy store-bought foods and country foods—the latter depending upon availability (Wenzel, 1991). It is important to note that unequal access to food is likely not new; relative "wealth" among hunting-gathering-fishing populations may in fact have been largely based upon the relative food security of one's family—a matter of existential importance in a volatile environment with low species richness, such as the Arctic. While the real risk of starvation for Canada's Inuit due to local ecological crashes may have subsided over the past half-century, nearly 46.8% of Nunavut households—and 60% of children—still regularly experience food insecurity (Tarasuk et al., 2016). The historic Inuit dietary transformation has also likely weakened social networks based on group hunting and food sharing, though further research in this area is needed. It is clear that Indigenous food insecurity can be exacerbated by social factors particularly, social and economic marginalization, as well as contamination/alteration of local ecosystems through industrial pollution and commercial harvesting. It is likely climate change has the capacity

Fig. 1. A screenshot of the Siku desktop app, showing dangerous ice conditions (first-hand observations and linked satellite imagery) near Sanikiluaq, Nunavut (https://siku.org/#/press-kit).

to increase the impacts of these negative phenomena, as well as to create entirely new stresses on Indigenous life related specifically to uncertainty. For example, among Inuit of Labrador, Canada, Durkalec et al. (2015) found that there may be significant mental and emotional health repercussions from the loss of sea-ice—and the implied loss of access to food resources—due to climate change. (This may have been the case for Inuit in premodern times as well; after all, mental health is not a facet of wellbeing relevant only in modern times.)

In premodern times, one of the most common and practical means of adapting to local episodes of climate change for hunting-gathering-fishing populations was to alter their seasonal rounds; in more extreme cases of food insecurity, groups in Inuit Nunangat, such as Dorset Paleo-Inuit (Tuniit) even periodically abandoned large parts of the Arctic for centuries at a time—presumably because of resource stress (Friesen, 2017). Even when climate change was not an existential issue for Inuit, groups in historic times would often vacate areas that had been occupied too long. According to Igloolik elder Herve Paniaq, the long occupation of the well-known historic Inuit campsite Avvajja in northern Foxe Basin finally ended in the 1950s when camp leader Ittuqsarjuaq declared that "the land was too 'hot'" and must be left to allow it to cool down (pers. comm. 2018) (Fig. 2). The implication of this is that staying in one place too long is inherently unhealthy—both for the land and the people on it. The external pressures on Inuit in the early-to-mid 20th century toward year-round sedentism, as seen most clearly in settlement in "modern" permanent communities, has prevented them from taking drastic measures, such as moving to temporarily allow (a) the land to "cool," (b) local resources to rebound, and (c) struggling and food-insecure Inuit to seek out "greener pastures" for a time.

5.3. Food safety

Beyond the availability of and safe access to country foods, climate change may also affect the safety of these foods for human consumption. The first consideration is the health of living animals commonly acquired as food by Inuit; if these species have difficulty in adapting to changing conditions, they may become less physically well, making them vulnerable to a diverse range of zoonotic pathogens that can harm people. The possible susceptibility of animals to such infections is unclear, and requires more study. What *is* clear is that the remains of commonly-hunted animal species in the Arctic can become vectors for parasites (e.g., *Toxoplasma gondii* and *Trichinella* spp.), bacteria (e.g., *Clostridium botulinum*, *Salmonella* spp. and *Mycoplasma* spp.) and possibly even viruses (Tryland et al., 2014).

Epidemiological and public health research on the relationship between country food safety and climate change in the Arctic is compelling; the issue is of key importance at lower latitudes, where the effects may already be manifesting. Subsistence hunting in Nunavik (the Inuit territory of northern Quebec) is partly illustrative of the new intersections emerging between climate change, foodborne illness and traditional foods. Traditional foods derived from seals and walruses in Nunavik are particularly susceptible to *C. botulinum* type E (causing botulism) (Leclair et al., 2013; Leclair et al., 2017) and *Trichinella nativa* (causing trichinellosis) (MacLean et al., 1989; Larrat et al., 2012). An analysis of epidemiological data by Leclair et al. (2013) revealed that the average incidence rate for botulism outbreaks "among the [primarily Inuit] population of Nunavik, where type E botulism linked to aged marine mammal products is endemic, is > 1600 times higher than for the rest of Canada (0.03/100,000 population for Canada versus 50.5/100,000 population for Nunavik). Outbreaks of botulism associated with Native foods in Canada account for 83.5% of all outbreaks" (2013: 966). In response to a 2017 botulism outbreak in Nunavik linked to beluga meat, the region's Director of Public Health, Dr. Francoise Bouchard, noted, "[W]ith the climate getting warmer in our communities every year, there's a need to be more careful now in conservation

Fig. 2. Igloolik elder Herve Paniaq (fourth from the right) describes the early-to-mid 20th century occupation of Avvajja, northern Foxe Basin, Nunavut, to author S. P. A. Desjardins (third from the right), 2018. Photo by S. Rufolo (Canadian Museum of Nature/*Musée canadien de la nature*).

and preservation of those traditional foods" (CBC, 2017).

As Inuit learn to hunt and negotiate their natural environments, they are taught that traditional ways of doing things are not only the most productive, but also the safest. Among Igloolik Inuit and their ancestors, a long and innovative tradition of caching walrus meat in beach-gravel caches may have provided local populations with a far greater degree of food security during the Little Ice Age than Inuit elsewhere experienced (see Desjardins, 2018). The caching process—and the butchery preceding it—is laborious; *IQ* demands it be carried out in relatively precise and ordered steps. These provisions (including the depth and capacity of caches, grade of the beach gravel, approximate timing of each step, etc.) likely evolved at least in part to ensure the resulting meat—excavated and consumed months later—was not only tasty, but also safe to eat. Over time, the logic of following these provisions is clear: they have kept generations of Inuit safely fed for centuries.

However, as the effects of climate change begin to be felt in earnest by those at higher and higher latitudes, the flexibility of *IQ* may be tested as never before; indeed, it may not be the straying from traditional knowledge, but rather the "textual" adherence to it that is the greater potential danger when change occurs quickly. The great respect many young Inuit maintain for tradition and the knowledge of Elders may complicate efforts to modify such practices to rapidly changing environmental conditions. One experienced Inuit hunter from Igloolik, Nunavut, explained to author Desjardins in 2011 that some younger hunters caching walrus meat were adhering too rigidly to traditional provisions as they learned them. *IQ* demands meat be cached immediately, or very soon after, returning to shore with a walrus catch. However, since the early-to-mid 20th century, use of motorized boats has reduced the duration of walrus hunts from several days to several hours, meaning that meat cached after a hunt is often still warm when placed in the ground upon permafrost—the active layers of which are sure to be affected by climate change in the coming years. All of this may negatively impact the taste and/or the safety of the meat (pers. comm. 2011).

6. Discussion: decision-making, traditional knowledge and dynamic adaptation

One of the most important themes to emerge from this review of three aspects of modern and past resilience is the dynamic nature of traditional knowledge, and its capacity to equip Inuit for rapidly-changing climates. It highlights (a) agency—how people make choices and take action; (b) innovation in the development and adoption of new practices and technologies; and (c) occasional inefficiency and even unsustainability. Cultural transformation and development are constant features of the Arctic archaeological record, but not all shifts resulting in observable changes in the record would have been simple, "natural" or painless, for either individuals or communities.

It is our understanding that *IQ* is not a set of rules that can be neatly codified, but rather a suite of skills—inherently adaptive—meant to provide people with the capacity to understand and productively (and safely) negotiate the world around them. One possible explanation for any overreliance on the "letter" over the "spirit" of traditional knowledge systems, such as *IQ*, by recent Indigenous generations is the emphasis on empiricism in Western education—now a mainstay in most Inuit communities. The dominant social and economic system—-relatively recently imposed upon Inuit—demands they negotiate two often complementary and parallel, but sometimes starkly different and conflicting ways-of-knowing and ways-of-organizing information. While efforts are underway to bring these together, often under the rubric of "Two-Eyed Seeing" (e.g., Bartlett et al., 2012), the process remains challenging. In Nunavut, efforts at the territorial and community level have aimed to bolster *IQ* and promote traditional activities among Inuit youth by facilitating inter-generational knowledge transfer with experienced hunters and Elders, not only in a classroom setting, but on the land, sea and ice. In a similar vein, we believe learning about past resilience in the face of climate change—such as the Thule Inuit caching regime during the Little Ice Age—can also help strengthen an understanding of the adaptive power of *IQ*. This can be accomplished through Elder- and archaeologist-led visits to the well-preserved archaeological sites themselves.

Likewise, the utility in such insights is not the promise of fixed rules or neat packages of ancient strategies that can be applied uncritically to the challenges of the present. Instead, the power of traditional knowledge, such as *IQ* among Inuit, for addressing the relationship between past and present climate change may lie in its capacity to bestow wisdom about *how* and *why* decisions were made, as well as to consider the consequences such actions had for people, communities and environments. A compelling example of this is the way in which communities in the Wemindji Cree Territory continue to select habitation sites that make the best of new ecological situations created by ongoing post-glacial uplift (Wren et al., this issue).

A renewed focus on how people and communities make decisions when confronted with pressures of climate change will be central to future planning and mitigation efforts as the world confronts a period of accelerating warming and retreating sea ice. The uneasy truth is that Arctic archaeology—and the frozen archaeosocial and archaeoecological "archives" that are Arctic archaeological sites—rarely provide obvious or straightforward solutions to past episodes of climate change, let alone solutions that would be immediately applicable to contemporary warming. However, the field does provide information and insights into earlier decisions, strategies and outcomes. When integrated with other "tools" and "technologies" such as participatory scenario planning, agent-based simulation studies and the co-creation of new approaches drawing upon traditional knowledge, an improved understanding of long-term cultural responses to Arctic climate change can inform, strengthen and invigorate new strategies to better equip Arctic communities for facing future challenges.

7. Conclusions and outlook

This paper has been about bringing together two similar, but often isolated, subjects: adaptation of Arctic communities in the face of modern climate change, and studies of past climate-culture interactions. We have demonstrated that the two can be linked through the common framework and language of resilience studies, and that for three major sets of challenges facing modern communities, there are past analogues that can provide insight and context. However, this should not be taken to imply that bringing the two together is without obstacles. For example, archaeological data are often of low resolution and do not allow reconstruction of all types of human activities equally. Thus, even when archaeologists can clearly infer that changes have occurred, they may not have data appropriate for understanding the role of individual agency, or for disentangling the relative impacts of multiple causal factors in the past ("equifinality"). Traditional knowledge systems, such as *IQ*, ethnographic observations and historical data are finer-grained, but are much more limited in time and space. Other obstacles include separate publishing cultures in the different disciplines, and emphasis on very different data sets during the conduct of research projects.

Contemporary warming in Arctic ecosystems impacts directly on local Indigenous communities—many of whom rely upon hunted resources (country foods) to help stave off food insecurity, as well as practical and spiritual engagements with Arctic landscapes in relation to health, wellbeing and cultural identity. While climate-driven challenges for Arctic SES's are not new—across the circumpolar Arctic, survival has always demanded an ability to cope with high-risk, unpredictable resources and environmental change—they generate fundamental questions about how best to design future-oriented management, planning and mitigation efforts. We believe such strategies can and should be designed through local engagement, and incorporating traditional knowledge systems, such as *IQ*; they should also contribute to and make progress toward more general, global ambitions, such as the United Nations Sustainable Development Goals (SDGs). (The most relevant challenges for Arctic communities are those pertaining to food security [SDG2], health [SDG 3], and sustainable stewardship of the Arctic's marine [SDG 14] and terrestrial ecosystems [SDG 15].)

The International Arctic Science Committee report, *Integrating Arctic Research – a Roadmap for the Future* (IASC, 2015) argued that much more interdisciplinary research is needed to better understand long-term human responses to Arctic change, especially in the area of food security. We believe increased attention to "premodern" insights on climate change has much to offer, including fuller integration of ethnographic, historic and especially archaeological and palaeoecological datasets, which add centuries, and in many cases millennia, to understandings of Arctic adaptions and transformations. We also accept that working with archaeological data to address these issues has inherent challenges pertaining to scale, resolution and the causality of culture change. Despite the challenges, premodern insights can contribute in three key areas:

(a) The detailed reconstruction of past cultural and ecological "baselines", including cumulative human impacts on Arctic species and ecosystems (this, in turn, can inform future management and conservation efforts);
(b) The addition of greater time depth and a wider range of examples of long-term human-environment interaction; and
(c) The consideration of longer-range social, cultural and ecological datasets that can be integrated into simulation studies, especially those employing agent-based approaches.

Perhaps most importantly, these combined archaeological insights highlight the operation of human decision-making processes over multiple generations.

There are many potential directions for productive multi-, inter- and transdisciplinary research on this topic. Researchers have previously argued for the usefulness of archaeological and historical data in future mitigation strategies due to their ability to contribute human-scale data to the analysis of climate-adaptation dynamics over multi-generational timescales (Riede, 2014; Jackson et al., 2018; Fitzhugh et al., 2018). We concur, and suggest the best results will be achieved in places such as Inuit Nunangat and Greenland, where there remains a deep and abiding cultural persistence in subsistence, culture and identity that serves to bridge past and present lifeways.

Declaration of competing interest

We, the authors, affirm that we are aware of no conflicts of interest held by us in relation to the information presented in the article we have submitted.

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