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Food and water security in a changing arctic climate

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Abstract
In the Arctic, permafrost extends up to 500 m below the ground surface, and it is generally just the top metre that thaws in summer. Lakes, rivers, and wetlands on the arctic landscape are normally not connected with groundwater in the same way that they are in temperate regions. When the surface is frozen in winter, only lakes deeper than 2 m and rivers with significant flow retain liquid water. Surface water is largely abundant in summer, when it serves as a breeding ground for fish, birds, and mammals. In winter, many mammals and birds are forced to migrate out of the Arctic. Fish must seek out lakes or rivers deep enough to provide good overwintering habitat.

Humans in the Arctic rely on surface water in many ways. Surface water meets domestic needs such as drinking, cooking, and cleaning as well as subsistence and industrial demands. Indigenous communities depend on sea ice and waterways for transportation across the landscape and access to traditional country foods. The minerals, mining, and oil and gas industries also use large quantities of surface water during winter to build ice roads and maintain infrastructure. As demand for this limited, but heavily-relied-upon resource continues to increase, it is now more critical than ever to understand the impacts of climate change on food and water security in the Arctic.

Keywords: surface water, lakes, Arctic, climate change, subsistence

1. Surface water in a changing climate

The potential impacts of climate change in the Arctic are well documented in the Arctic Climate Impact Assessment (ACIA 2005) and other review documents (Hinzman *et al* 2005, Overpeck *et al* 1997, Serreze *et al* 2000). Surface air temperature is perhaps the most basic and tangible aspect of climate change. From the instrumental records, it is clear that the air temperature has increased (Hinzman *et al* 2005), warming 0.6 °C since the early 20th century (Overpeck *et al* 1997). Although peak 20th century temperatures actually occurred around 1945, followed by a cooling period, the surface air temperature began rising again in the 1970s. Temperature change is spatially and seasonally variable (Serreze *et al* 2000).

Precipitation is a climate parameter that is difficult to measure in the Arctic and complex to predict. ACIA (2005) suggests that a 1% increase in precipitation per decade was probable over the last century. Most of the climate stations reported by Hinzman *et al* (2005) showed an increase in annual precipitation over the length of their record (since the late 19th century or more recent), yet the summer surface water balance (precipitation minus potential evapotranspiration, P-PET) measured in Alaskan North Slope villages decreased since 1960. Seasonal distribution of precipitation is important to consider as winter precipitation has increased since the 1970s, and because arctic winter precipitation is projected to increase with continuing climate change (Serreze *et al* 2000). Other weather variables have been changing at northern locations, including an increase in wind since the 1960s (Hinzman *et al* 2005) and increased cyclone activity (Serreze *et al* 2000).

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Ecosystem changes resulting from climate change have also been observed, with many more expected. A longer growing season (Sturm *et al* 2003) favors a possible northward expansion of agriculture, as well as northward shifts in natural plant and animal distributions. Some observed land cover changes include the expansion of shrubs in the tundra (Sturm *et al* 2001, Hinzman *et al* 2005), and a northward drift of the arctic tree line (Serreze *et al* 2000). The continuation of these trends would increase the water loss due to evapotranspiration, which suggests drier conditions in the future for the Arctic.

1.1. Hydrologic changes

Permafrost warming, degradation, and the retreat and disappearance of glaciers are surface water issues of critical importance to the Arctic. Permafrost temperatures at 20 m depth have been rising on the North Slope of Alaska since the 1980s, and a rise of 2–4 °C in borehole permafrost temperatures has been observed in the last 50–100 years (Hinzman *et al* 2005). As the permafrost degrades, thermokarst processes can result in the draining of ponds. In continuous permafrost, lakes have increased in area and number, as a result of thermokarst geomorphology, but in discontinuous permafrost, lakes have shrunk and drained. This has been observed in Siberia and the Seward Peninsula of Alaska (Smith *et al* 2005, Yoshikawa and Hinzman 2003). In Siberia, lakes in continuous permafrost increased in size and number since 1972, while those in discontinuous permafrost shrank and disappeared (Smith *et al* 2005). Likewise, tundra ponds near Council, Alaska, an area of discontinuous permafrost, have decreased in area and disappeared over the last 50 years (Yoshikawa and Hinzman 2003). River discharge changes have also been observed, with increasing runoff in basins having major glacial input (due to glacial melting) and decreased runoff in non-glacial watersheds (due to increased evapotranspiration); however, increased discharge has been observed in three non-glaciated Alaskan rivers (Hinzman *et al* 2005). Siberian rivers have also increased in winter discharge, even in non-dammed tributaries (Hinzman *et al* 2005).

2. Surface water demand

What makes a good water source depends to some extent on the social institutions, technology and infrastructure available for managing access, quality control, and distribution. In the northern climates, the continued degradation of permafrost could have a significant impact on water quality and availability for both rural and urban northern communities as well as high-latitude industry.

The loss of surface water sources may significantly impact communities lacking an adequate groundwater aquifer. To mitigate such impacts, some communities have attempted drilling wells, only to find aquifers frozen, dry, impacted by saltwater intrusion, or otherwise unsuitable for drinking or irrigation.

Climate models predict variable changes in precipitation, increasing in some places while decreasing in others, and changing in the timing/season of precipitation. On the Seward Peninsula, for example, precipitation is expected to increase in some areas and to decrease in others. Changing lakes on the arctic landscape will also impact oil and minerals exploration and development. If insufficient water is available for ice roads, the cost of harvesting natural resources will increase dramatically. Although industrial need for water is significant, here we discuss the need for water from the perspective of food security for arctic people.

3. Surface water and food security

Though we have only begun to study the short-term and long-term effects of the ongoing hydrological changes described above, we do know that there is a network of heavily interconnected consequences relevant to the food and water security of indigenous communities who continue to make their livelihoods from the land and from the use of wild resources. Indigenous livelihoods are strongly connected to climate, weather, ecosystems, cultures and economic systems, with responses to change in each domain both complex and multifaceted (Krupnik and Jolly 2002, Paci *et al* 2004). Water is a foundational aspect of these relationships: communities tend to aggregate along the coast or up and down major rivers, making the watershed or seascape the context within which traditional 'country' foods are collected, e.g. moose, caribou, waterfowl, salmon, whitefish, whale, seal, walrus, etc. Rural communities need both a reliable and safe water and food supply, with implied implications for availability, access and distribution of those resources. Reliable transportation and access to resources are required so that traditional foods can be harvested in sufficient quantity to be consumed, shared amongst family and friends, and stored for the harsh winter months. Any unexpected changes in hydrology have the potential to significantly confound the already-complicated circumstances of living a 'subsistence' lifestyle.

In order to accurately measure the impacts of changes in surface water on the food security of arctic communities, it is useful to consider both the direct and indirect pathways along which such changes can influence subsistence activities. Recent trends in ecosystems and weather are manifest in new and unpredictable conditions relating to surface water, requiring that indigenous peoples alter their harvesting strategies in new ways, and quickly enough to prevent seasonal and yearly country-food shortfalls. The environmental cues that hunters once used to predict the weather and behavior of animals have become less effective predictors, and where political, economic and resource management regimes are not in step with or responsive to these new ecological conditions, the direct impacts of ecological variability will interact synergistically with these institutions in negative ways. Some federal and state resource management regimes make it difficult for hunters to effectively adapt and alter harvesting strategies (Gerlach *et al* 2007, Natcher and Davis 2007). For many communities there is no guarantee that enough wild food can be harvested to satisfy immediate needs, or that enough can be processed and put into storage to provide for either food or nutritional security through the long winters.

Though market foods are becoming increasingly available to indigenous communities, even in the most remote locations, we cannot measure food security based on availability alone. The nutritional quality and socio-cultural relevance of commercial food is often far inferior to fresh, locally harvested or produced food (Receveur *et al* 1997). Village health care costs rise when the contribution of industrial food relative to country food increases in the diet, and with the decreased activity and exercise levels associated with reliance on store-bought foods (Kuhnlein *et al* 2004). In contrast, the harvesting of wild fish and game provides nutritious and high-quality food, and promotes individual and community health through shared work and harvesting activities (Bersamin *et al* 2007, Grivetti and Ogle 2000), with seasonal family fish camps as just one example. Food security exists not only where people have physical and economic access to food, but also when there is a secure supply of safe and nutritious food that meets both food preference and dietary requirements in order to maintain an active and healthy life (WFS 1996).

3.1. Water, transportation and harvest success

Seasonal changes in surface water have impacts on arctic food systems at multiple scales. Changes in precipitation, the timing of break-up and freeze-up, fire regime and hydrological changes, individually and in tandem, create terrestrial changes that impact both the country-food harvest as well as overall community viability. This includes transportation across landscapes, from safety concerns regarding movement across the land and waterways, difficulties accessing traditional harvest areas because of water levels, coastal or river bank erosion, and further complications for barge travel that connects rural communities to urban service-hubs for food, fuel, commodities and material supplies (Beltaos and Burrell 2003). Lower water levels, for instance, will affect both the timing of salmon runs and their spawning success (Fleener and Thomas 2003, NRC 2004, Schindler 2001), as well as the feasibility of access via river-travel to traditional harvest areas (Gerlach *et al* 2007). Similarly, the timing and duration of break-up can cause ice-dams and significant flooding. Should a season bring sustained periods of drying, the magnitude and frequency of forest fires are likely to increase, further cutting off access to both harvest areas and supply networks (Chapin *et al* 2006a).

These hydrological and ecological constraints on transportation and access are often magnified by imposed obstacles to land access and mobility; regions such as Alaska are characterized by a patchwork of state, federal, private and tribal land ownership, and an institutional and regulatory framework that provides these federal and state agencies with control over much of the land and most of the fish and game (Gerlach *et al* 2007). As mentioned above, many regulatory systems are slow or unprepared to respond to fast, often stochastic changes. In such cases, changes to landscape, fire, migratory patterns, and seasonal variation, are all compounded rather than mitigated by federal or state policies, which regularly include fairly rigid fishing and hunting quotas as well as intermittent closures of entire traditional hunting grounds. Communities faced with meeting short-term food security needs therefore opt to purchase market foods as a more consistent but imperfect substitution for country foods. This dependence on market foods results in more time spent earning wages instead of time spent on the land harvesting country foods as well as trends of village out-migration by youth, which converge to create a positive feedback whereby the knowledge and practice of traditional subsistence activities are increasingly undermined (Huskey *et al* 2004, Poppel *et al* 2007).

4. Conclusion

Although projections of future climate change carry considerable uncertainties, evidence of change is already being observed in the Arctic. Both observed and anticipated changes in seasonal temperature and precipitation, along with consequent changes to permafrost and hydrology, highlight the need to better understand the potential impacts of such changes. Potential climate impacts require a detailed understanding of how climate is integrated with environmental, cultural and economic conditions at the community scale. Moreover, even though future climate projections vary, this uncertainty can be used together with impact analysis to develop climate change risk assessments that aid community planning and preparedness.

In order to assure food security for arctic communities, especially in the face of the rapid and often unpredictable ecological trends like those presented in this paper, communities need both the freedom to innovate and adapt, and access to quality climate and weather information so that they might predict water and landscape conditions and make the best decisions about where and when to hunt and fish in times of uncertainty (Chapin *et al* 2004, Paci *et al* 2004). Successful country-food harvests must be well tuned with the flow of the seasons, and anything that disrupts seasonality may well disrupt the flow of human activities (Glantz 2006). Communication between scientists and rural communities is improving with mutual awareness through collaboration, although more work is still needed from both sides before it will be possible to correlate and integrate spatial, temporal and observational scales. Subsistence harvests are daily and seasonal, whereas climate models are often based on decades and/or millennia, and do not always provide the high-quality weather information needed on a seasonal basis (Raynor and Malone 1998, Guyette 1996, Harris *et al* 2001, Dickson 2003). There is a need to synthesize and communicate climate change information to both institutions and local communities. For planning purposes it will be useful when fine-grained local and regional climate and seasonal weather information is integrated with community-based knowledge through hunter experimentation and testing in the field (Aporta 2002, Krupnik and Jolly 2002, Duerden 2004, Ford and Smit 2004, Ford *et al* 2006). Above all, new paradigms for more effective linkages between institutional and local responses to change need to be explored by resource managers, so that communities are empowered to make local decisions regarding resource management and use based on the highest-quality local and scientific knowledge and observations (Chapin *et al* 2006b, Irvine and Kaplan 2001).

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