ARCTIC WINTER COLLEGE
VOLUME IV

COMMUNITY WELLBEING IN THE
NORTH AMERICAN ARCTIC

MIGRATION IN HARMONY
Research Coordination Network

ABOUT THE SERIES

The briefers included in this volume are presented as part of the Arctic Winter College of 2021.

The Arctic Winter College brought together 60 emerging leaders and experts for 10 weeks in a free series of web-based seminars. The program builds a lasting, policy-oriented network of Arctic professionals to strengthen communication between peoples and nations, scientific disciplines, policy areas, and across the science-policy interface to improve collaborations, research, and decision-making in the Arctic.

Weekly webinars focused on the theme “Arctic on the Move.” Urbanization, globalization, and the impacts of climate change are activating the simultaneous migrations of species, ecosystems, settlements, and cultures across Arctic coastlines in new and unpredictable ways. Each of these intersecting mobilities challenge the quality of life, sustainable development, and environmental health of the circumpolar north. Participants engaged with Arctic researchers, traditional knowledge holders, and practitioners in a variety of fields related to movement.

ABOUT THE AUTHORS

Susana Hancock, DPhil

Susana Hancock specializes in global risk as a result of the polar climate crisis and works to shape this on the international agenda. Outside of work, she is President of APECS International, where she initiates global projects on science diplomacy and the climate crisis. She is an expert reviewer for the Intergovernmental Panel on Climate Change and an ECR chair with IOC-UNESCO. Native to an Arctic state, Susana has grown up living throughout the Arctic and has completed three polar expeditions. She speaks five languages and has a varied background, having studied astrophysics, linguistics, and anthropology at the graduate level. She graduated from the University of Oxford with three degrees. Susana can be reached at hancocksusana@gmail.com.

Katherine Janoski

Katherine Janoski, is the Emergency Manager at the University of Alaska Fairbanks in Fairbanks, Alaska. Katherine plans, develops, schedules, and evaluates scenario exercises to measure campus emergency response and preparedness capacities. She also organizes and conducts community outreach to inform and educate University staff, faculty, and students on disaster and individual preparedness. She is the International Association of Emergency Managers Region X representative for Alaska and the Alaska Emergency Management Association Director for the Interior. She holds a bachelor's degree in Emergency Management and a Masters in Disaster and Security Management from the University of Alaska Fairbanks (UAF). She is currently working on a Master of Arts in Environmental Policy at UAF's Arctic and Northern Studies Program. Katherine can be reached at kajanoski@alaska.edu.

ABOUT THE AUTHORS

Chloe Nunn

Chloe Nunn is a marine ecologist and social scientist currently working as a consultant. Her research interests range from deep-sea ecology to community resilience. Nunn was awarded a National Geographic Early Career Grant to fund her master's dissertation fieldwork in Uummannaq, Greenland, where she researched social-ecological system resilience to local disruptions. She hopes to pursue a Ph.D. in seaweed ecology, services, and harvest techniques from a coastal community lens, giving particular space to Indigenous knowledge and ecological stewardship. She is also passionate about science communication and educational outreach, which she has pursued as the U.K. Polar Network's festival coordinator and the Society for Women in Marine Science's communication lead.

Audrey E. Reinert, Ph.D.

Audrey E. Reinert is a Research Engineer specializing in human guided data analytics in geospatial intelligence applications. She previously worked as Postdoctoral Researcher at the University of Oklahoma's Data Science Institute for Societal Challenges (DISC Center). She holds a Ph.D. in Industrial Engineering from Purdue University (2019), a master's in human- Computer Interaction from the Georgia Institute of Technology (2015), and a Bachelors in Cognitive Neuropsychology from the University of California, San Diego (2012). Her research interests lie at the intersection of human-centered computing and visual analytics for solving complex spatial problems. She is a member of IEEE, HFES, and the AGU and can be reached at crcreiner@gmail.com.

Sasha Leidman

Sasha Leidman is a Ph.D. candidate in the Department of Geography at Rutgers, The State University of New Jersey, USA. His research focuses primarily on arctic hydrologic systems, especially regarding Greenland and climate change. Specifically, his work centered around analyzing supraglacial stream networks on the Greenland Ice Sheet to determine the impact of climate change on the albedo of the ablation zone. Sasha is a recipient of the National Science Foundation Graduate Research Fellowship, the CUAHSI Pathfinder Fellowship, the American Association of Geographers RS Tarr Award, and the American Geophysical Union Cryosphere Innovation Award. He is also a member of the IARPC Code of Conduct Committee and the ARCUS Membership Development Committee. Sasha received his bachelor's degree in Geology with a minor in Watershed Sciences and Geographic Information Systems from the University of California at Davis. Sasha can be reached at szl9@scarletmail.rutgers.edu

ABOUT MIGRATION IN HARMONY

Learn more at migrationinharmony.org

The Migration in Harmony Research Coordination Network is three-year international, cross-disciplinary network of Arctic migration researchers funded by a National Science Foundation grant to Georgetown University, under the direction of Dr. Victoria Herrmann, Assistant Research Professor and Managing Director of The Arctic Institute. We are traditional knowledge holders, natural scientists, engineers, students, humanities scholars, economists, social scientists, storytellers, engineers, health professionals, practitioners, and educators working on the many dimensions of Arctic migration.

MIGRATION IN HARMONY
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CONTENTS

CLIMATE CHANGE IS DRASTICALLY IMPACTING THE ARCTIC BY ALTERING ITS LANDSCAPE AND DISRUPTING ENVIRONMENTAL SYSTEMS. THESE CHANGES AFFECT COMMUNITY WELL-BEING, FOOD SECURITY, AND INFRASTRUCTURE IN THE NORTH AMERICAN ARCTIC REGION AND MAKE THE RESIDENTS MORE VULNERABLE TO DISASTERS AND LONG-TERM ADVERSE EFFECTS. AREAS ADVERSELY AFFECTED INCLUDE MEDICAL INFRASTRUCTURE, CYBERSECURITY, MARINE ECOLOGICAL SUSTAINABILITY, FOOD AND HEALTH SERVICES, FISHERIES, AND EXISTING INFRASTRUCTURE, PRIMARILY LOW-LYING, FLOOD-PRONE INFRASTRUCTURE. THIS POLICY BRIEFER WILL EXPLORE THESE SUBJECTS; CLIMATE CHANGE IMPACTS, HOW COMMUNITIES WILL NEED TO ADAPT TO THE GROWING THREAT OF A CHANGING ARCTIC AND MAKE BROAD RECOMMENDATIONS FOR REDUCING RISKS.

SUMMARY

Introduction

Communities[1] in the Arctic rely on the natural landscape to maintain their way of life. The well-being of these communities depends on how they can adapt their lifestyles to the changing landscape and develop infrastructure that mitigates the impact of natural disasters caused by climate change. These include bolstering human health programs, securing vital food systems, assessing and planning natural disasters, and incorporating technologies that increase security, foster social cohesion, and facilitate research and development. Community well-being in the Arctic requires addressing challenges associated with the area's unique environmental, social, and political characteristics. This is done through incorporating multidisciplinary perspectives, hearing from all stakeholders, and recognizing the harrowing history of colonization experienced by Indigenous peoples. By studying the changing landscape, bringing together communities to plan for future risks, and developing assessment and emergency response strategies, the Arctic can function sustainably with nature to build vibrant communities and support rich ecosystems.

Unfortunately, literature tackling multidisciplinary approaches to community well-being in the Arctic is sparse. Further research is needed to determine the factors that put Arctic community wellbeing at risk of predominantly climate-driven impacts and the appropriate planning strategies to mitigate harm. This article aims to outline some of the major factors that need to be considered moving forward to address how the natural and built environment of the Arctic is already changing and will continue to change into the near future.

We discuss five key topics: marine ecosystems, rescue infrastructure, flooding, telehealth, and artificial intelligence. These topics are highly interrelated and vital for community well-being in the Arctic. Maintaining ecosystems in the Arctic can reduce coastal flooding risks, increase nutritious foods' availability, thereby increasing community health, and inspire innovation in sustainable fishing techniques. The increase of coastal and inland flooding due to climate change can threaten marine ecosystems, lead to increased exposure to pollutants, putting pressure on health systems, and require emergency rescue for residents far from critical resources. Artificial intelligence can inform decision-making to allocate better marine ecosystem management resources, flood mitigation measures, cyber infrastructure development, and provide healthcare to the community. As such, all these areas of research are interconnected and inform decisions about each other. Taking a systems approach can improve the data we collect and our analysis to reduce communities' risks and create more equitable government structures. Understanding how these systems interact and planning for their potential limitations and risks is vital for bolstering community resilience and ensuring that the Arctic is prepared for unexpected hazards.

[1] Community definition: Groups of individuals living within a shared space within the Arctic or sub-Arctic. This includes individuals within incorporated and unincorporated cities, municipalities, tribal groups, and cultural groups within permanent or transient localities.

Arctic Seaweeds and Community Wellbeing

Chloe Nunn

Seaweeds, like other major ecosystem cornerstones, are integral to the health of both a given ecosystem and also the wider social-ecological system of the Arctic. They do this by providing a food source to communities, absorbing CO_2 and excess nutrients, creating habitat for other species and physically protecting coastlines from erosion. Safeguarding and promoting sustainable use of seaweeds is important for community wellbeing but will require the development of a deeper understanding at the system level and careful management of the resource.

Seaweed: Macroalgae (seaweed) are multicellular, photosynthesizing marine organisms and can be found in the entire ocean. Typically found in coastal and surface waters, seaweeds harbors biodiverse marine populations and are among the most productive and resilient ecosystems on Earth.[2] While not known for its green growth, the Arctic is home to hundreds of seaweed species;[3] however, only a few occur endemically.[4] As the dominant intertidal organism, macroalgae begins its annual growth cycle with sea ice break-up in the Arctic, which occurs with increasing solar radiation.[5] Polar macroalgae can withstand low light levels making them highly efficient photosynthesizers[6] and well-adapted to their environment, experiencing up to 4 months of complete darkness a year. Beyond extreme light exposure and temperatures, macroalgae are resilient to physical disturbances in the ocean as well.[7]

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[2] UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment"; Gundersen et al., "Ecosystem Services."
[3] Stekoll, "The Seaweed Resources of Alaska"; Diehl, Karsten, and Bischof, "Impacts of Combined Temperature and Salinity Stress on the Endemic Arctic Brown Seaweed Laminaria Solidungula J. Agardh."
[4] Wiencke and Amsler, "Seaweeds and Their Communities in Polar Regions."
[5] Wiencke and Amsler.
[6] Wiencke and Amsler.
[7] Gundersen et al., "Ecosystem Services."

Ecosystem Services and Community Wellbeing: Humans cannot survive and thrive without the environments around us, and the well-being we receive from these local and global systems breaks down into 'ecosystem services,' which can be direct or indirect.[8] Macroalgae ecosystems perform many of these services at a proximate coastal level and at a global level.

Seaweed has been used as food, medicine, trade, and gift items by Indigenous coastal communities around the world for centuries.[9] Seaweed is predominantly a food source, with the largest harvests in Asia but burgeoning markets elsewhere. Macroalgae also provide nursery grounds and food for many other marine organisms like fish.[10] This supports humans as we rely on biodiversity and general ecosystem health to protect marine fisheries. Macroalgae play a role in the global carbon cycle through photosynthesis which can then transfer CO_2 to the deep ocean and sediments via dead organic matter.[11] Tourism and recreation,[12] enjoyment of foraging,[13] and spiritual and physical connection[14] are three ways in which macroalgae intersects with human culture. Further examples are found in Table 1.

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[8] TEEB, "The Economics of Ecosystems and Biodiversity"; Gundersen et al., "Ecosystem Services."

[9] Turner, "The Ethnobotany of Edible Seaweed (Porphyra Abbottae and Related Species; Rhodophyta: Bangiales) and Its Use by First Nations on the Pacific Coast of Canada"; O'Connell-Milne and Hepburn, "A Harvest Method Informed by Traditional Knowledge Maximises Yield and Regeneration Post Harvest for Karengo (Bangiaceae)"; Mac Monagail et al., "Sustainable Harvesting of Wild Seaweed Resources"; Kobluk, "Temperature, Size, and Harvest Method Drive Recovery in an Indigenous Kelp Fishery"; Thurstan et al., "Aboriginal Uses of Seaweeds in Temperate Australia: An Archival Assessment."

[10] Ugarte and Sharp, "A New Approach to Seaweed Management in Eastern Canada: The Case of Ascophyllum Nodosum"; UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment"; Gundersen et al., "Ecosystem Services."

[11] Wiencke and Amsler, "Seaweeds and Their Communities in Polar Regions"; Duarte et al., "Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation?"; Gundersen et al., "Ecosystem Services"; Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."

[12] UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment"; Gundersen et al., "Ecosystem Services"; Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."

[13] Gundersen et al., "Ecosystem Services."

[14] Thurstan et al., "Aboriginal Uses of Seaweeds in Temperate Australia: An Archival Assessment"; Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."

Provisioning	**Supporting**	**Regulating**	**Cultural**
• Food[15] • Medicines[16] and pharmaceuticals[17] • Animal Feed[18] Supplementary food for reindeer[19] and Arctic fox[20]	• Biochemical cycling[23] • Nutrient cycling and fertility[24] • Habitat production for other species: juvenile fish, otters, and benthic organisms[25] • Non-synthetic agricultural fertilizer[26] • Water purification[27]	• Flood/storm protection[28] • Combat eutrophication via nutrient uptake[29] • Carbon sequestration[30] • Desiccation protection to other species[31]	• Recreation[32] and ecotourism[33] • Education, research, and cultural amenities[34] • Spiritual & physical connection for

[15] UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment"; Duarte et al., "Will the Oceans Help Feed Humanity?"; Monagail et al., "Sustainable Harvesting of Wild Seaweed Resources"; Thurstan et al., "Aboriginal Uses of Seaweeds in Temperate Australia: An Archival Assessment."

[16] UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment."

[17] Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."

[18] Monagail et al., "Sustainable Harvesting of Wild Seaweed Resources."

[19] Hansen and Aanes, "Kelp and Seaweed Feeding by High-Arctic Wild Reindeer under Extreme Winter Conditions."

[20] Kapel, "Diet of Arctic Foxes (Alopex Lagopus) in Greenland."

[23] UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment."

[24] UNEP.

[25] Ugarte and Sharp, "A New Approach to Seaweed Management in Eastern Canada: The Case of Ascophyllum Nodosum."

[26] Monagail et al., "Sustainable Harvesting of Wild Seaweed Resources"; Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."

[27] Bricknell et al., "Resilience of Cold Water Aquaculture: A Review of Likely Scenarios as Climate Changes in the Gulf of Maine."

[28] UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment"; Chapin, Kofinas, and Folke, "Principles of Ecosystem Stewardship: Resilience-Based Natural Resource Management in a Changing World"; Mac Monagail et al., "Sustainable Harvesting of Wild Seaweed Resources"; Tunón, "Biodiversity and Ecosystem Services in Nordic Coastal Ecosystems – an IPBES-like Assessment."; Bricknell et al., "Resilience of Cold Water Aquaculture: A Review of Likely Scenarios as Climate Changes in the Gulf of Maine."

[29] Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."

[30] Wiencke and Amsler, "Seaweeds and Their Communities in Polar Regions"; Duarte et al., "Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation?"; Gundersen et al., "Ecosystem Services"; Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."

[31] Mac Monagail et al., "Sustainable Harvesting of Wild Seaweed Resources."

[32] UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment"; Gundersen et al., "Ecosystem Services."

[33] Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."

[34] UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment."

• Biofuels[21] • Texturizing agents[22]			traditional custodians[35]
Table 1: Ecosystem services are categorized as supporting, provisioning, regulating, and cultural[36]			

While some of the ecosystem services provided by seaweeds may be understated in the Arctic (for example, providing clean ecosystems for scuba diving may not be as important in colder climates), seaweed is important in areas such as Disko Bay, Greenland where nature and marine biodiversity are foundational components of Indigenous culture.[37]

Marine ecosystems support not only the well-being of coastal communities but all human society.[38] This is most easily seen by looking at how marine ecosystems support the broader system of food security in the Arctic. Healthy food is a vital component of community well-being; however, the limited availability of imported goods can make food security precarious, especially for Arctic Indigenous communities.[39] Indigenous use of seaweeds in Alaska and especially their use for herring spawn[40] are important ways in which communities can protect traditional and non-traditional food stocks. Arctic Indigenous diets have received a lot of attention due to food insecurity, toxin levels, and import affordability.[41] While not currently a major food source in the Arctic, seaweeds contain abundant levels of nutrients, such as omega 3, as well as comparable levels of protein and fiber in relation to marine and terrestrial foods,[42] which could allow them to aid in Arctic food security.

Macroalgal ecosystems are fish hatcheries and nurseries feeding into fisheries that support incomes within communities experiencing disproportionate levels of poverty.[43] Healthy ecosystems are crucial for economically poorer communities where well-being is more

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[21] Monagail et al., "Sustainable Harvesting of Wild Seaweed Resources"; Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."
[22] Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."
[35] Thurstan et al., "Aboriginal Uses of Seaweeds in Temperate Australia: An Archival Assessment"; Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."
[36] World Resources Institute, *Ecosystems and Human Well-Being: Wetlands and Water Synthesis*; Gundersen et al., "Ecosystem Services."
[37] Tunón, "Biodiversity and Ecosystem Services in Nordic Coastal Ecosystems – an IPBES-like Assessment."
[38] Gundersen et al., "Ecosystem Services."
[39] Turner and Turner, "Where Our Women Used to Get the Food: Cumulative Effects and Loss of Ethnobotanical Knowledge and Practice; Case Study from Coastal British Columbia"; Kuhnlein et al., "Indigenous Peoples' Food Systems & Well-Being: Interventions & Policies for Healthy Communities"; Kobluk, "Temperature, Size, and Harvest Method Drive Recovery in an Indigenous Kelp Fishery."
[40] Stekoll, "The Seaweed Resources of Alaska."
[41] Kuhnlein et al., "Vitamins A, D, and E in Canadian Arctic Traditional Food and Adult Diets."
[42] Macartain et al., "Nutritional Value of Edible Seaweeds"; Roleda et al., "Chemical Profiling of the Arctic Sea Lettuce Ulva Lactuca (Chlorophyta) Mass-Cultivated on Land under Controlled Conditions for Food Applications."
[43] United Nations, "State of the World's Indigenous Peoples."

intrinsically linked to direct ecosystem services[44]. Beyond food supply, seaweed can also be sold to the biofuel industry, to agricultural farmers as non-synthetic fertilizer,[45] and to the pharmacological industry.[46]

Aquaculture, or marine farming, of seaweed in coastal environments can further some of its positive impacts on community well-being in the Arctic, such as supplemental income. There are also many co-benefits of aquaculture when combined with other development, such as integrating with coastal erosion protection,[47] a service offered by seaweed naturally.[48] Combining macroalgae aquaculture with finfish farming ensures healthier fish, reduced marine pollution, and halting the consequent eutrophication.[49] Seaweed aquaculture and wild harvest have also provided opportunities to progress gender equity,[50] as women continue to play pivotal roles in the activity around the world.[51]

Threats and Opportunities: Despite the benefits from Arctic seaweed ecosystems, there are many threats to Arctic macroalgae and human communities. Impacts of climate change are more visible in Arctic regions compared to most non-polar regions. As such, coastal habitats, including seaweed systems, are disproportionately threatened by anthropogenic warming as well as other activities such as land-use change, overfishing, eutrophication from nutrient influx, increased demand for food, and a shift in food preferences.[52] Fisheries trawling in some parts of the Arctic is a particular threat to local ecosystems, many of which are seaweed-dominated and important for supporting subsistence fisheries.[53] Polluted marine ecosystems are also associated with health issues in human communities due to the proliferation of waterborne diseases and those passed on through food.[54]

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[44] Abunge, Coulthard, and Daw, "Connecting Marine Ecosystem Services to Human Well-Being: Insights from Participatory Well-Being Assessment in Kenya."

[45] Gundersen et al., "Ecosystem Services."

[46] Bogolitsyn et al., "Biological activity of a polyphenolic complex of Arctic brown algae"

[47] UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment."

[48] Chapin, Kofinas, and Folke, "Principles of Ecosystem Stewardship: Resilience-Based Natural Resource Management in a Changing World"; Gundersen et al., "Ecosystem Services"; Bricknell et al., "Resilience of Cold Water Aquaculture: A Review of Likely Scenarios as Climate Changes in the Gulf of Maine."

[49] Gundersen et al., "Ecosystem Services"; Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."

[50] Rebours et al., "Seaweeds: An Opportunity for Wealth and Sustainable Livelihood for Coastal Communities"; Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."

[51] Mac Monagail et al., "Sustainable Harvesting of Wild Seaweed Resources."

[52] UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment."

[53] Tunón, "Biodiversity and Ecosystem Services in Nordic Coastal Ecosystems – an IPBES-like Assessment."

[54] UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment."

Climate change impacts in the Arctic such as warming waters, decreased salinity,[55] acidification, sea-level rise and fall, migration of foreign species into new territories, and increased storm frequency and intensity impact seaweed growth and resilience,[56] with warming being of particular concern. Bricknell et al.[57] found that sub-Arctic seaweed species were retreating north, which may diversify Arctic macroalgae systems.[58] Climate change may also cause some Arctic seaweed species to disappear.[59]

While many of the other threats to seaweed are not yet well understood, seaweed growth has been found to reduce localized ocean acidification, alleviating its impact on calcifying organisms like clams,[60] indicating that, in general, macroalgae ecosystems are resilient to climate change. Seaweed is estimated to sequester 173 teragrams of carbon per year, exporting organic matter to the deep sea and burying it in sediments; even accounting for harvested seaweed, 60% of the carbon it takes up via photosynthesis is released back into the water column as dissolved organic carbon with the potential of being sequestered.[61] Although there are some uncertainties about carbon sequestration, seaweed still has a positive impact on water quality.[62]

Impacts such as sea-level rise threaten accessibility to seaweed by people, affecting traditional harvesting in Alaska of both the macroalgae itself and other harbored resources like fish eggs lain on kelp blades.[63] Harvesting of seaweed can be a good supplemental income to offset threats to fish catches,[64] especially with the growth rate of the seaweed industry at 8% per year.[65] Additionally, threats to food security can be allayed through seaweed harvesting, which reduces reliance on land-based agriculture known to degrade the environment and industry, which will not keep pace with a growing population.[66] Sea urchins and ice scour are two main ecological

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[55] Diehl, Karsten, and Bischof, "Impacts of Combined Temperature and Salinity Stress on the Endemic Arctic Brown Seaweed Laminaria Solidungula J. Agardh."
[56] Müller et al., "Impact of Oceanic Warming on the Distribution of Seaweeds in Polar and Cold-Temperate Waters"; Bricknell et al., "Resilience of Cold Water Aquaculture: A Review of Likely Scenarios as Climate Changes in the Gulf of Maine"; Diehl, Karsten, and Bischof, "Impacts of Combined Temperature and Salinity Stress on the Endemic Arctic Brown Seaweed Laminaria Solidungula J. Agardh."
[57] Bricknell et al., "Resilience of Cold Water Aquaculture: A Review of Likely Scenarios as Climate Changes in the Gulf of Maine."
[58] Jueterbock et al., "The Fate of the Arctic Seaweed Fucus Distichus under Climate Change: An Ecological Niche Modeling Approach."
[59] Diehl, Karsten, and Bischof, "Impacts of Combined Temperature and Salinity Stress on the Endemic Arctic Brown Seaweed Laminaria Solidungula J. Agardh."
[60] Xiao et al., "Seaweed Farms Provide Refugia from Ocean Acidification."
[61] Duarte et al., "Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation?"; Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."
[62] Gundersen et al., "Ecosystem Services."
[63] Johnson et al., "Impacts of Submerging and Emerging Shorelines on Various Biota and Indigenous Alaskan Harvesting Patterns."
[64] Rebours et al., "Seaweeds: An Opportunity for Wealth and Sustainable Livelihood for Coastal Communities"; Mac Monagail et al., "Sustainable Harvesting of Wild Seaweed Resources."
[65] FAO Fisheries & Aquaculture, "FishStat Plus"; Duarte et al., "Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation?"
[66] Duarte et al., "Will the Oceans Help Feed Humanity?"

stressors on macroalgae, but human harvesting in unrestricted ways or with damaging tools can also be detrimental to macroalgae populations, potentially requiring decades of recovery time.[67]

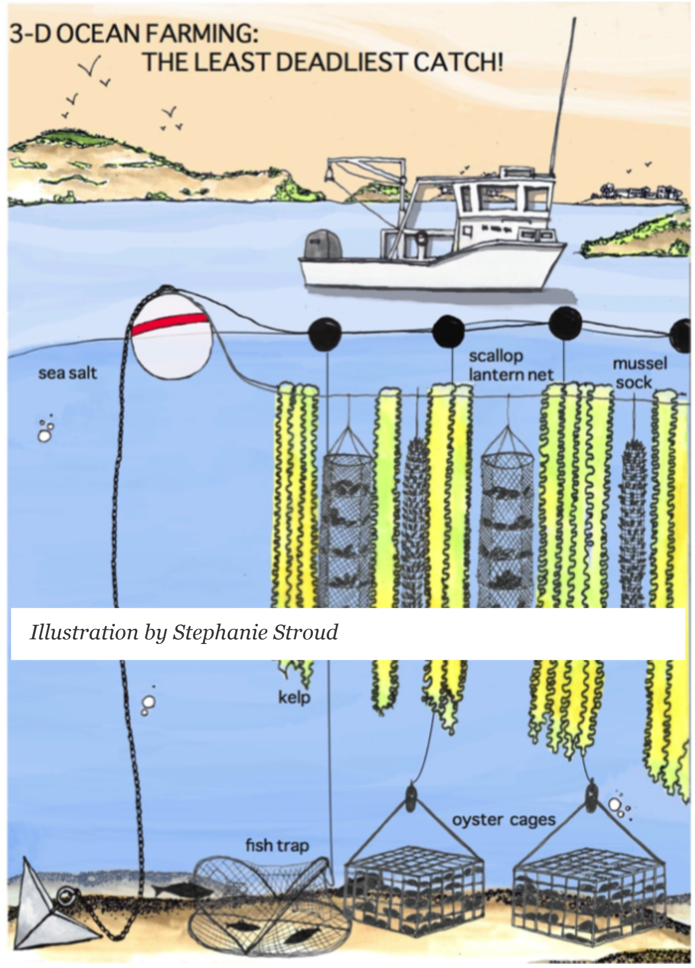

Illustration by Stephanie Stroud

Management: While seaweed harvesting can be a major economic benefit to Arctic communities,[68] extensive and/or unregulated harvesting can threaten macroalgae. Farming of lower trophic level organisms like macroalgae increases the sustainability of aqua- and agri- culture and reduces hazards associated with pollutants from fertilizer in run-off, for example.[69] While the Arctic is low in land-based agriculture, it does have areas of increased nutrients causing eutrophication which can also be mitigated by macroalgae.[70] Seaweed aquaculture would increase the CO2 drawdown from the atmosphere and provide well-being benefits via food, income, and broader ecosystem services,[71] and in a warming Arctic, is increasingly viable. However, many factors such as scale, positioning, management structures, and pre-existing ecosystem conditions must be considered when implementing seaweed aquaculture,[72] and a multispecies, ecosystem approach to management is vital.[73]

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[67] Mac Monagail et al., "Sustainable Harvesting of Wild Seaweed Resources."
[68] Rebours et al., "Seaweeds: An Opportunity for Wealth and Sustainable Livelihood for Coastal Communities"; Mac Monagail et al., "Sustainable Harvesting of Wild Seaweed Resources."
[69] Duarte et al., "Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation?"
[70] Ardyna M, Gosselin M, Michel C, Poulin M, Tremblay JÉ., "Environmental forcing of phytoplankton community structure and function in the Canadian High Arctic: contrasting oligotrophic and eutrophic regions"
[71] Sondak et al., "Carbon Dioxide Mitigation Potential of Seaweed Aquaculture Beds (SABs)"; Duarte et al., "Can Seaweed Farming Play a Role in Climate Change Mitigation and Adaptation?"
[72] Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."
[73] Ugarte and Sharp, "A New Approach to Seaweed Management in Eastern Canada: The Case of Ascophyllum Nodosum."

The concept that coastal waters are "commons" for all to use[74] can result in vying stakeholders over space for their developments, disregard of ecosystem health,[75] and disputes over access.[76] Knowledge gaps of wild seaweed standing stock,[77] climate spurred species migration, seaweed genetic diversity,[78] nutrient cycling, and long-term/large-area ecological processes[79] need to be addressed to ensure macroalgal resources are not overexploited as demand rises in the Arctic and globally.[80]

The monetary value of marine and coastal ecosystem services globally is estimated to be around $50 tr. USD per year,[81] but values are in decline,[82] and costs of destruction do not typically appear on accounting forms.[83] To push ecosystem services as sustainable resource priorities, there is a need to standardize their valuation[84]. A monetary evaluation has its drawbacks but is complementary to alternatives that take integrated approaches.[85]

Developing multidisciplinary indicators, such as community reliance on fisheries, would help to alleviate deficiencies in monitoring and understanding of coastal ecosystems[86] while demonstrating how ecosystems are important to human well-being.[87].= Abunge, Coulthard, and Daw[88] suggest that self-determination supports community well-being by offering communities ownership over their resources and highlighting the importance of community-based management. Ecology should not come at the cost of Indigenous governance, resource management, and traditional proprietorship,[89] especially when Indigenous stewardship

[74] UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment"; Mac Monagail et al., "Sustainable Harvesting of Wild Seaweed Resources."
[75] Duarte et al., "Will the Oceans Help Feed Humanity?"
[76] Mac Monagail et al., "Sustainable Harvesting of Wild Seaweed Resources."
[77] Mac Monagail et al.
[78] Bricknell et al., "Resilience of Cold Water Aquaculture: A Review of Likely Scenarios as Climate Changes in the Gulf of Maine."
[79] UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment."
[80] Gundersen et al., "Ecosystem Services"; Mac Monagail et al., "Sustainable Harvesting of Wild Seaweed Resources."
[81] Costanza et al., "Changes in the Global Value of Ecosystem Services"; Alleway et al., "The Ecosystem Services of Marine Aquaculture: Valuing Benefits to People and Nature."
[82] Costanza et al., "Changes in the Global Value of Ecosystem Services"; Costanza, "Twenty Years of Ecosystem Services: How Far Have We Come and How Far Do We Still Need to Go?"
[83] Gundersen et al., "Ecosyst. Serv."
[84] Abunge, Coulthard, and Daw, "Connecting Marine Ecosystem Services to Human Well-Being: Insights from Participatory Well-Being Assessment in Kenya."
[85] Kubiszewski et al., "The Future Value of Ecosystem Services: Global Scenarios and National Implications."
[86] UNEP, "Marine and Coastal Ecosystems and Human Well-Being: Synthesis: A Synthesis Report Based on the Findings of the Millenium Ecosystem Assessment."
[87] Gundersen et al., "Ecosyst. Serv."
[88] Abunge, Coulthard, and Daw, "Connecting Marine Ecosystem Services to Human Well-Being: Insights from Participatory Well-Being Assessment in Kenya."
[89] Ban et al., "Incorporate Indigenous Perspectives for Impactful Research and Effective Management."

principles have previously been found to support sustainable harvesting techniques of macroalgae, as on the coasts of Haíłzaqv (Heiltsuk) Nation in British Columbia.[90]

Ultimately, by safeguarding Arctic seaweed ecosystem services and promoting their sustainable use, sources of food, income, coastal protection, cultural significance, and many other components of community well-being are not just protected but bolstered in the face of unprecedented change.

[90] Kobluk, "Temperature, Size, and Harvest Method Drive Recovery in an Indigenous Kelp Fishery."

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Mercury, Diabetes and Climate Change: searching for food sovereignty in Greenland.

Susana Hancock, DPhil

Climate change presents many challenges for public health by threatening the food sovereignty of Arctic residents. One area of particular interest due to its confluence of environmental and geopolitical factors is the rise of agriculture within contemporary Greenlandic society. Marine mammals, once a mainstay of a healthy diet, are now laden with carcinogenic toxins.[91] Melting glaciers imperil traditional hunting practices[92] and threaten the future of Inuit culture. A rising reliance on imported food is bringing new diseases.[93] Each significant on its own, together these issues present a catastrophic, multilateral overload of the nation's public health system.

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[91] AMAP. *AMAP Assessment 2015: Human Health in the Arctic*. Oslo: Arctic Monitoring and Assessment Programme (AMAP). 2015. 90-94.
[92] M Nuttall. "Anticipation, climate change, and movement in Greenland". *Études/Inuit/Studies* 34/1. 2010. 28.
[93] C Jeppesen, P Bjerregaard and ME Jorgensen. "Dietary patterns in Greenland and their relationship with type 2 diabetes mellitus and glucose intolerance". *Public Health Nutrition*. 17/2. 2014.

While a successful farming industry is still a nascent development in Greenland,[94] this is an area of rapidly growing locally-driven interest and thus in need of funding and research. Currently, agriculture remains under-explored compared with more established industries like fishing. This briefer will examine four leading mechanisms of addressing food security: imports, fishing, terrestrial hunting, and agriculture, each with direct cultural implications. In terms of long-term investment strategy and public health, Greenland should invest in augmenting its agriculture sector in order to minimize public health concerns while maximizing national sovereignty and cultural cohesion.

Climate change in Greenland and its impact on food systems

If climate change is, as the U.N. Secretary-General has called it, an "existential threat" to humanity,[95] the Arctic is the canary in the coal mine. According to measurements by the GRACE-FO satellite system, Greenland lost a record 532±58 gigatons of ice in 2019.[96] Record heat waves are consistently broken with new daily highs.[97,98] A transition away from a cryosphere-dominated ecosystem is already well underway.[99] Despite these statistics, Greenland's own ministry of health claims it has yet to undertake an analysis of the societal health risks of climate change.[100]

The U.N. Food and Agriculture Organization identifies food security as having "physical, social and economic access to sufficient, safe, and nutritious food [meeting the] dietary needs and food preferences for an active and healthy life."[101] Greenlanders have traditionally been a food-insecure culture. This means that their supply of food is dependent upon its procurement (e.g., the success of hunting). Although many Greenlandic residents continue to meet the FAO criteria to be food insecure, their needs extend beyond the U.N.'s pillars of availability, accessibility, utilization, and stability of food[102] and relate to greater issues of autonomy, self-reliance, and culture.[103] For example, this reliance on imports hinders autonomy from the Danish Crown in

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94 MH Bojesen and A Olsen (eds.). "Agriculture in Greenland: Possibilities and needs for future development and research". *Synthesis Report for Greenland Agricultural Initiative (GRAIN) in cooperation with Greenland Perspective*. 2019.

95 "Climate change: An 'existential threat' to humanity, UN chief warns global summit". *UN News*. Vienna, 2018. https://news.un.org/en/story/2018/05/1009782.

96 I Sasgen, B Wouters, AS Gardner et al. "Return to rapid ice loss in Greenland and record loss in 2019 detected by the GRACE-FO satellites". *Communications Earth & Environment* 1/8 2020.

97 C Harvey. "An Arctic heat wave ushered in the start of the melt season two weeks earlier than average". *Scientific American*. 2020.

98 JE Overland and M Wang. "The 2020 Siberian heat wave". *International Journal of Climatology* 41 2021.

99 L Landrum and MM Holland. "Extremes become routine in emerging new Arctic". *Nature Climate Change* 10. 2020. 1114.

100 Climate Greenland. "Health". Accessed 12 March 2021 from http://climategreenland.gl/en/citizen/society-and -health/health.

101 FAO. "Draft declaration of the world summit on food security". In *Proceedings of the World Summit on Food Security*, Rome. November 2009.

102 FAO. "An Introduction to the Basic Concepts of Food Security". *FAO Food Security Programme*. 2008.

103 See B Panikkar and B Lemmond, "Being on Land".

Greenland's quest to be a fully sovereign state.[104] To achieve the nexus of food sovereignty and self-governance, decisions need to center around Indigenous Knowledge and Inuit practices[105] and necessarily position Inuit in the management of the resources on which they depend. Inuit Circumpolar Council Alaska has identified numerous points of tension concerning food sovereignty throughout the greater Inuit region, ranging from management and cultural considerations to shipping and subsidies, and all impact the current and future Greenland foodscape.[106]

Food choice in Greenland

One direct consequence of a melting Greenland is the loss of reliable access to traditional foods, notably marine mammals. The seals, walrus, and whales that comprise traditional Inuit fare are high in protein, micronutrients, and healthy fats. Although fresh and healthy, these meats are also increasingly high in heavy metals and POPs,[107] which bioaccumulate in flesh and fat and are transferred to humans at toxic levels.[108,109] Despite concerns about toxins, Greenland was notably absent among the 130 signatories of the U.N. Minamata Convention on Mercury until February 2021.[110] Dependence on marine mammals in Greenlandic diets is also becoming a growing problem as hunting becomes increasingly dangerous as ice floes are less predictable, yet Inuit food remains culturally significant. The Greenlandic Board of Food and Environment has pushed a compromise: a local diet comprising lean fish, land mammals, and agricultural goods.[111,112] This compromise, however, does not necessarily reflect the needs of Greenlandic Inuit. For example, when eaten whole (that is, with bones, internal organs, and skin), fish such as capelin provide an ample supply of calcium and other micronutrients that are lacking when the meat is processed. Thus, when purchased from a market shelf, the same capelin no longer is a sufficient source of micronutrients, like calcium. Focusing on the market diet, the Greenlandic Nutrition Council advises families to feed children ½ liter of milk daily, which along with a slice of cheese, will provide 90% of the child's calcium needs.[113] One issue: the majority of

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[104] Although sovereignty from Denmark is frequently understood as a political ambition, it is also critical to self-health.

[105] Inuit Circumpolar Council Alaska. *Food Sovereignty and Self-Governance: Inuit Role in Managing Arctic Marine Resources*. Anchorage: ICC. 2020. 119.

[106] Inuit Circumpolar Council Alaska's *Food Sovereignty and Self-Governance*. 2020. 65.

[107] These toxins are primarily through pollution. This is discussed in P Johansen and K Rydahl "Grønlandsk kost er sundt".

[108] Currently, 70% of Greenland's population exceeds the US EPA recommended blood methylmercury levels whereas 98% exceeds the recommended PCBs levels (See AMAP, "Human Health". 116.).

[109] These pollutants have a range of impacts on the human body but most commonly affect the neurobehavioral, endocrine, immunological, cardiovascular and reproductive systems. Many are also carcinogenic. For discussion on the impact of these pollutants, see Yurdakök 2015, Weihe et al 2016, Timmermann et al 2019.

[110] United Nations Treaty Collection. "Reference: C.N.61.2021.TREATIES-XXVII.17 (Depositary Notification)". 2021.

[111] AMAP, "Human Health". 118.

[112] B Adlard, SG Donaldson, JO Odland et al. "Future directions for monitoring and human health research for the Arctic Monitoring and Assessment Programme". *Global Health Action* 11. 2018.

[113] Ernæringsrådet. *Sunde råd: mad til små børn 0-3 år samt gravide og ammende*. 2012. 10.

Greenlandic Inuit are lactose intolerant. While replacing the calcium from fish bones with that from dairy might be numerically equivalent, the solution is out of context with the local needs.

Although beyond the scope of this paper, the approach by the European Union to block the trade of seal products has significantly reduced the European market for seal skins over the past fifty years (Inuit were exempt from the ban but harmed through anti-seal campaigning).[114] While seal meat remains commercially available throughout Greenland, the foreign trade of seal skins heavily financed hunting expenses, including ammunition and fuel.[115] Therefore, although the meat might be available, accessing it is prohibitively expensive for many hunters. This is an example in which foreign policy has impacted local food patterns, triggering a shift away from locally sourced meat to imported products.[116]

Imported food: Warnings from the Pacific Islands

By 2013, nearly 80% of energy consumed by Greenlanders came from abroad.[117] Over the past decade, this percentage has steadily risen, with the ratio of traditional food to imported food reaching 14:86 by 2021.[118] The majority of food and produce in Greenland's markets is imported from Denmark.[119] Towns and villages are very remote and rely on domestic shipping (97%) and, to a much lesser degree, air (3%) transport.[120] This transport increases the price of food, adds to the carbon footprint, makes shipments vulnerable to extreme weather, and threatens local sovereignty. Food imported from Denmark averages 36% more expensive in a Nuuk grocery market than in one in Copenhagen.[121] The carbon footprint of either ringed or harp seal is at best 1.7kg CO2e/kg (at worst, 4.5kg CO2e/kg), whereas Danish pork measures 7.6kg CO2e/kg.[122] The range for the seal reflects the use of ammunition and hunting methods (using motorboats is increasingly common as ice melts), as well as distance traveled. In addition to those associated with transport, the majority of the emissions associated with the pig relates to the soil and manure management in the farming process.[123]

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[114] European Commission. "EU Regulation 2015/1775. Amending Regulations EC 1007/2009 on Trade in Seal Products, and Repealing Regulation 737/2020". European Commission: Brussels. 2015.
[115] F Ziegler, K Nilsson, N Levermann, M Dorph, et al. "Local Seal or Imported Meat?" 2.
[116] F Ziegler, K Nilsson, N Levermann, M Dorph, et al. "Local Seal or Imported Meat?" 2.
[117] G Mulvad. "Food security in Greenland". In H Exner-Pirot, B Norbye and L Butler (eds.), *Northern and Indigenous Health and Health Care*. Saskatoon: University of Saskatchewan. 2018.
[118] M Wielsøe, D Berthelsen, G Mulvad, S Isidor, M Long, EC Bonefeld-Jørgensen. "Dietary habits among men and women in West Greenland: follow-up on the ACCEPT birth cohort". *BMC Public Health* 21. 2021.
[119] T Pars, M Osler and P Bjerregaard. "Contemporary Use of Traditional and Imported Food among Greenlandic Inuit". *Arctic* 54:1. 2001.
[120] F Ziegler, K Nilsson, N Levermann, M Dorph, B Lyberth, AA Jessen, G Desportes. "Local Seal or Imported Meat? Sustainability Evaluation of Food Choices in Greenland, Based on Life Cycle Assessment". *Foods* 10. 2021. 9.
[121] The Arctic Journal. "Report finds Greenland consumer prices higher than Europe". *Arctic Today*. 2017.
[122] F Ziegler, K Nilsson, N Levermann, M Dorph, et al. "Local Seal or Imported Meat?" 6.
[123] F Ziegler, K Nilsson, N Levermann, M Dorph, et al. "Local Seal or Imported Meat?" 6.

Given that nearly everything is processed to be shelf-stable, the nutritional value is poor. Fresh vegetables are routinely available in larger towns during the summer months but are often non-existent in more remote communities or during extended spells of inclement weather. Traditional diets in these communities did not include many fruits and vegetables.[124] Apart from the current heavy metals and POPs, there are no signs that this diet is detrimental to health or shy of minerals and vitamins.[125]

Relying on imports is myopic. Poor nutrition is the leading cause of disease in the world.[126] In Pacific island communities, up to 80% of all deaths are attributed directly to the nations' allegiance to processed food[127,128] and 40% of hospitalizations are related to diabetes.[129] These foods are poor in nutrients and high in calories, sugar, trans-fats, and salt, which are associated with high rates of non-communicable diseases, such as diabetes, cardiovascular disease, and obesity. Higher rates of disease associated with processed foods may also relate to the food's loss of microbial diversity. For instance, initial research in Greenland suggests the same calcium-rich capelin mentioned earlier are high in propionate, a short-chain fatty acid, which triggers feelings of satiation. However, the levels of propionate are higher when the food is dried locally than when industrially prepared, meaning that individuals relying on processed food are more likely to consume more calories.[130,131] In addition to disease and premature death, poor diet unleashes additional burdens by exacerbating poverty, impacting the social structure and regional development, and leading to disability, the loss of employment, and financial insecurity.

In the Pacific, imported foods have saturated the domestic market so that the demand for developing local products is low.[132] A similar process is underway in Greenland and is bringing with it the same health risks. In the mid-1960s, diabetes throughout the Arctic island was exceedingly rare.[133] Within 50 years, 16% of the adult population was diabetic (Jørgensen and

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[124] "Aviaja Hauptmann on Traditional Inuit Animal-Based Diets & Fighting the Plant-Based Agenda". *Peak Human Podcast* 90. 2020. https://www.peak-human.com/post/aviaja-hauptmann-on-traditional-inuit-a
nimal-based-diets-fighting-the-plant-based-agenda.

[125] See also SM Andersen. "Vitamins and minerals in the traditional Greenland diet". NERI Technical Report, No, 528. *National Environmental Research Institute*. 2005.

[126] A Afshin, P Sur, KA Fay et al. "Health effects of dietary risks in 195 countries, 1990-2017: a systematic analysis for the Global Burden of Disease study 2017". Lancet. 393/10184. 2019.

[127] N Pollock, "These Roots", discusses the impact of colonization on local diet, a process that is very similar to Greenland's history under Danish rule.

[128] See NL Hawley and ST McGarvey, "Obesity"; A Afshin, P Sur, KA Fay et al. "Health".

[129] The International Diabetes Federation estimates that the disease costs the Fijian government $24.4 million US annually (Turaga, "USD$24.4million".). This funding is money that could otherwise be invested in sustainable development.

[130] The Arctic Institute. Indigenous Perspective on Microbial Research with Aviaja Lyberth Hauptmann [Video]. YouTube. https://www.youtube.com/watch?v=RTzabF9mv6c&t=23s. 2021.

[131] Some Inuit report supplementing processed foods with microbiota, including propionate capsules, to increase its health effects.

[132] R Hughes. *Diet, food supply and obesity in the Pacific*. Manila: World Health Organization Regional Office for the Western Pacific. 2003.

[133] U Sagild, J Littauer, CS Jespersen et al. "Epidemiological studies in Greenland 1962–1964: Diabetes mellitus in Eskimos. *Acta Medica Scandinavica* 179. 1966. 29-39.

Pedersen 2018). Among Inuit men, obesity (BMI ≥ 30) has risen from 16% in 1994 to 25.4% between 2005-2010. For Inuit women, these percentages are 31.3% and 54.2%, respectively. In addition to the change in diet, the rise in obesity is also attributed to an increase in the sedentary lifestyles associated with an imported food diet.

Fishing in Greenland

Initially, for subsistence and later for commerce, Greenland's coastal communities have relied on a steady source of fish. Greenland first exported fish to the European Union in 1985, and although it experienced a few tumultuous years involving fluctuating revenue and unstable markets, by 2014, its fishery comprised more than 95% of Greenland's total foreign merchandise trade.[134] Greenland further benefits from its fish stocks by selling catch rights to the E.U. Updated in 2021, the E.U. can catch 32,000 tons of fish annually at the cost of €16,500,000, of which just under €3 million is earmarked to support the domestic fishing industry.

In some regions, such as near Ilulissat or Nuup Kangerlua, melting glaciers are temporarily feeding this fishing boon. Both sites are sources of marine-terminating glaciers. With marine-terminating glaciers, the nutrient-poor meltwater creates an upwelling of the nutrient-rich bottom layers of the ocean, which enables phytoplankton to photosynthesize and stimulate the entire aquatic food chain.[135] In Ilulissat, the inshore annual halibut catch averages 5,000-6,000 tons over several square kilometers, far exceeding the open ocean catch over a comparable area.[136] However, these high numbers present false ideas about the health of the inshore ecosystem.[137] The retreat of glaciers throughout Greenland is accelerating. Between 1992 and 2017, Greenland's marine-terminating glaciers lost 3,536 gigatons of mass,[138] and they are retreating toward land and will eventually cease to calve into the ocean entirely. Meltwater from land-terminating glaciers does not mix into the nutrient-rich ocean water as they inject water higher into the water column and fail to have enough force to break the thermocline and create upwelling.[139] Land-terminating glaciers are also associated with increased surficial sediment plumes, which decrease the albedo of the water, consequently reducing the available energy for photosynthesis.[140] For these reasons, regions of land-terminating glaciers are thus associated with relatively poor fishing stocks.[141] Therefore, while melting marine-terminating glaciers may create a temporary increase in fish stocks, it may be followed by more barren seas as these

[134] *FAO*. "Fishery and Agriculture Country Profiles: Greenland". 2016. 2.
[135] M Lorenz, JJ Mortensen, P Meire, et al. "Marine-terminating glaciers sustain high productivity in Greenland fjords". *Global Change Biology* 23. 2017.
[136] PB Christensen. "Melting glaciers may reduce Greenland fishery". Arctic Research Centre. Aarhus University. 2019. https://arctic.au.dk/news-and-events/news/show/artikel/melting-glaciers-may-reduce-greenland-fishery.
[137] *Pinngortitaleriffik*, Grønlands Naturinstitut. "Sammendrag af den biologiske rådgivning for 2019 om fiskebestande behandlet i NAFO-regi." Nuuk: *Pinngortitaleriffik*. 2018.
[138] M Wood, E Rignot, I Fenty et al. "Ocean forcing drives glacier retreat in Greenland". *Science Advances* 7:1. 2021.
[139] PB Christensen, "Melting glaciers".
[140] T Bianchi, S Arndt, WEN Austin e et al. "Fjords as Aquatic Critical Zones (ACZs)". *Earth-Science Reviews* 203/103145 (2020). 10.
[141] *Pinngortitaleriffik*, "Sammendrag".

glaciers continue to retreat. Greenland does not currently support algaculture, although there may be new markets to open, including those for sea cucumber, urchin, and seaweeds.[142,143] However, these potential markets are also associated with the same issues associated with glacial retreat.

Land mammals

Land mammals, such as muskox and reindeer, and sea birds like little auk and ptarmigan have always been a component of the traditional Inuit diet. However, as toxins have increased in marine mammals and fish, these land-dwellers have had a larger place on the dinner plate. As mentioned earlier, this shift has been supported by the Greenlandic Board of Food and Environment to reduce dietary toxin intake.[144,145]

Land mammals and seabirds are also among the species struggling to adapt to climate change, which makes them a vulnerable population on which to rely for subsistence. Climate change impacts phenology, changing niche migration patterns, winter icing, summer fires, and available food quality.[146] Species such as reindeer are also targeted by new predators as climate change drives polar bears and summer insects into wider ranges.[147,148,149] Although hunting land mammals may supplant the cultural vacancy left by imported foods, these animals are also under threat due to climate change, and their numbers fluctuate in response to food.[150] Furthermore, rapid changes in the environment mean that Greenland's hunting seasons no longer correlate with animal migration patterns. Hunting seasons and quotas have been instituted by the government without consultation with local knowledge holders and limit the efficacy of hunting to meet community caloric needs.[151]

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142 FAO. “Fishery”. 10.

143 For interest, please refer to “Arctic Seaweeds and Community Wellbeing” by C Nunn in this edition.

144 B Adlard, SG Donaldson, JO Odland et al. “Future”.

145 Studies have found smaller amounts of heavy metals and chemicals in land-based mammals (P Aastrup F Riget, R Dietz et al, “Lead”; H Bjermo, S Sand, C Nälsén, et al, “Lead”.). Additionally, hunting with lead bullets may contribute to a noted increase in lead (AMAP “Human Health”. 52.).

146 CD Mallory and MS Boyce “Observed” discuss this in relation to the global depletion of reindeer, which comprise a significant source of Arctic protein. J Berger, C Hartway, A Gruzdev et al, “Climate” show that increasingly common climate events, such as new ground icing, have dramatic effects on the sustainability of species, such as muskoxen.

147 S Sharma, S Couturier and SD Côté. “Impacts of climate change on the seasonal distribution of migratory caribou”. *Global Change Biology* 15. 2009.

148 K Joly, DR Klein, DL Verbyla et al. “Linkages between large-scale climate patterns and the dynamics of Arctic caribou populations”. *Ecography* 34. 2009.

149 M Le Corre, C Dussault and SD Côté. “Weather conditions and variation in timing of spring and fall migrations of migratory caribou”. *Journal of Mammalogy* 98/1. 2017.

150 C Cuyler. “West Greenland caribou explosion: What happened? What about the future?” *Rangifer*, *27*/4. 2007.

151 C Goldhar, JD Ford and L Berrang-Ford. “Prevalence of food insecurity in a Greenlandic community and the importance of social, economic and environmental stressors”. *International Journal of Circumpolar Health* 69/3. 2010. 277.

Focused largely in the south, Greenland also has a history of animal husbandry dating back to the Vikings of 985 CE.[152] This will be addressed in the following section on agriculture.

Agriculture in Greenland

Modern agriculture has a relatively recent history in Greenland, dating only to 1906, although the Vikings cultivated crops and raised cattle, goats, and sheep from 985 CE-1500 CE.[153,154] Earlier climate adaptation models suggested Greenlanders might transition naturally to agricultural farming for subsistence as climate change imperiled their reliance on marine mammals. However, increased drought and unpredictable weather patterns have been less conducive to farming.

This section is primarily concerned with agriculture as it extends to crop cultivation rather than animal husbandry. Contemporary Greenland's history of animal husbandry, mostly sheep farming, has remained an uncertain economy, delicately balanced between shifting climate patterns and weather fluctuations.[155] Feilberg and Høegh provide a thorough introduction to land use in Greenland for sheep husbandry.[156]

Lehmann et al. state that the vast majority of cultivated land is for sheep fodder, and still, much of it needs to be imported or supplemented with fishmeal to meet winter needs.[157] The nutritional quality of local fodder has not been analyzed, although the Neqi slaughterhouse near Narsaq has correlated the health and size of lambs to the available resources during their development, suggesting there is varied land health.[158][159] Greenland does not have regulations on imported plant material, meaning that quality is not standardized and that the nation is vulnerable to potential new pests. This is an area in need of regulation regardless of future investment in agriculture. Furthermore, poor soil quality reduces gas exchange and hydration

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[152] See TH McGovern. "Cows, Harp Seals, and Churchbells: Adaptation and Extinction in Norse Greenland". *Human Ecology* 8/3. 1980. 245-275.

[153] V Bichet, E Gauthier, C Massa et al. "The history and impacts of farming activities in south Greenland: An insight from lake deposits". *Polar Record* 49/50. 2013.

[154] PS Henriksen. "Norse agriculture in Greenland? Framing in a remote medieval landscape". *Ruralia* X. 2016.

[155] See CH Rose, P Nansen, RJ Jørgensen and DE Jacobs. "Sheep farming in Greenland. Its history, managemental practices and disease problems". *Nordisk veterinaermedicin* 36/3-4. 1984. 65-76.

[156] J Feilberg and K Høegh. "Greenland". In G Austrheim, L-J Asheim, G Bjarnason, J Feilberg, AM Fosaa, Ø Holand, K Høegh, IS Jónsdóttir, B Magnússon, LE Mortensen (eds.), *Sheep grazing in the North-Atlantic region– A long term perspective on management, resource economy and ecology*. NTNU: Rapport zoologisk. 2008.

[157] JO Lehmann, B Sharif, C Kjeldsen et al. "Nunalerinermik inuussutissarsiuteqarnermi silap pissusianut naleqqussarnissamut periarfissat". Aarhus: Aarhus University. 2017.

[158] Lehmann, JO, MV Odgaard and T Kristensen. "Carcass weight of Greenlandic lambs in relation to grazing area biomass". *Open Agriculture* 5/1. 2019.

[159] Experiments to increase soil productivity through fertilizers, including seaweed, manure, liming and glacial rock flour are underway and thus far positive (See MH Bojesen and A Olsen (eds.). "Agriculture".

and consequently requires increased territory to ensure sufficient yield compared with other regions.[160]

Despite these challenges, agriculture is worth the investment. Beyond fodder and potatoes, commercial crops in Greenland are still in their infancy. However, local greens and fruits are now regularly available at small farmers' markets, and small-scale merchants see success blossom inside insulated greenhouses.[161] With growing seasons expected to increase dramatically,[162] agriculture has the potential to have an increasing role in the future of the Greenlandic food system. Currently, a variety of hearty vegetables, including cabbages, brussels sprouts, cauliflower, carrots, turnips, and potatoes, are increasingly available. Although there is local knowledge about plant use in Greenland, much of the agriculture-specific knowledge needs to be cultivated. Both the Upernaviarsuk agricultural research station and Greenland Institute of Natural Resources are positioned well to analyze and tailor foreign framing practices to the domestic environment. Successful transfers of knowledge have already proven successful through the development of seaweed fertilizers, crop rotation, and the use of the Icelandic sheep breeding program, Fjárvis.[163]

A 2017 report outlines future opportunities for agriculture as the climate warms and highlights some of the ground-breaking research at Upernaviarsuk agricultural research center in Qaqortoq, which is experimenting with different crops and incentives to develop a successful vege-table economy.[164] This involves developing ventilated and insulated storage systems to enable crops to overwinter as well as greenhouses that support seasonal growth. Despite the extensive expertise of Inuit cold climate storage systems to preserve meat, Greenlanders have not traditionally practiced the long conservation of vegetables, such as through pitting root vegetables as done elsewhere in northern Europe and Canada.[165] Storerooms, which may be insulated locally by sheep's wool, also support crop rotation and the cultivation of additional foods, such as the fodder radish, which can buffer against pests and diseases but have not been able to overwinter in the past. Greenhouses and agricultural food co-ops also have several social benefits: they support homegrown sources, develop local jobs, reduce reliance on Denmark and foreign aid, and have the potential to develop into community centers, which may supplant some of the social losses associated with traditional hunting. This last point has already been successful in at least one community in which a greenhouse has developed into a community hub, bringing people together for *kaffemiks* and social gatherings.[166]

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[160] For example, the average yield of potatoes is 16-20 tons per hectare, whereas in Denmark a similar expanse might yield 40 tons (MH Bojesen and A Olsen [eds.], “Agriculture”. 15.).
[161] Personal correspondence. 2021.
[162] Christensen states a temperature rise of 1.8-3.9°C would correlate to a season extended by 27-127 days (PB Christensen, “Melting glaciers”.).
[163] Landbrugskommisionen. “Landbrugskommisionens betænkning februar 2014”. Nuuk: Naalakkersuisut. 2014.
[164] JO Lehmann, B Sharif, C Kjeldsen, et al, “Nunalerinermik”.
[165] MH Bojesen and A Olsen (eds.), “Agriculture”. 17.
[166] Personal correspondence. 2020.

Conclusions

Whether in the Pacific or in the Arctic, diet is rarely an individual's choice but rather is the result of supply chains dictated by global food networks and trade patterns combined with availability and disposable income. This means that diet is shaped by external forces and does not necessarily align with local culture. Policy, therefore, needs to address the wider supply chain issues and ensure funding is allocated appropriately to meet the dietary needs of Greenland's populations in a healthy and affordable manner.

What is clear is that an imported, processed food diet is harmful to the health of all Greenlanders. Despite the escalating toxins in marine mammals, the Greenland Board of Nutrition has determined that the adverse health effects related to obesity are greater than those associated with bioaccumulated contaminant exposure.[167,168] To that extent, the government needs to ensure traditional food systems remain supported and must facilitate the transfer of Indigenous knowledge of sustainable hunting practices to younger generations. This will necessarily involve appropriate research and funding to support subsistence hunting, whether in the form of an intergenerational training program or financial subsidies, as the climate becomes increasingly less predictable.

However, when considering rapid climate changes and ice unpredictability, crop-based agriculture is a strong option to supply the nation's energy needs in a sustainable manner that does not have the same climate liabilities and negative health consequences associated with fishing, hunting, and imports. Farming practices need to be developed in-country, informed through research, and by local knowledge. Although gut microbiota is determined largely by diet, there is little indication that a transfer of diet would cause digestive challenges even among Inuit not relying on a non-traditional diet.[169]

Currently, most of Greenland's population faces a daily choice: expensive food with high levels of toxic pollutants or very expensive food with little nutritional value and a wealth of public health impacts.[170] New ideas in farming can change this paradigm by providing safe, nutritionally sound food at affordable prices while also renewing social cohesion.

Developing a strong agricultural sector will also support Greenland's infrastructure goals and its project finance development. While such developments are necessary to enable the transfer of fresh produce more readily, Greenland's plans are not unchallenged. Currently, key proposals

[167] P Bjerregaard and G Mulvad, "The best".
[168] There are additional dangers associated with marine mammals that affect lifespan and health, such as those inherent in working on ice floes. For example, as the climate becomes warmer and less predictable, hunters are at increased risk for falling through the ice.
[169] S Sharma, X Cao, C Roache et al. "Assessing dietary intake in a population undergoing a rapid transition in diet and lifestyle: the Arctic Inuit in Nunavut, Canada". *British Journal of Nutrition* 103/05. 2010.
[170] The current assumption is that obesity is more harmful than a diet high in contaminants due to the importance of identity (See P Bjerregaard and G Mulvad, "The best".).

include highly controversial requests for new airports[171] and roadways,[172] which threaten significant ecological damage and invite carbon-heavy industries.[173] In addition to supporting community growth and nutritional health, agriculture has the capacity to decrease the rise in non-communicable diseases associated with poor diet and increase food sovereignty, which is important as Greenland continues to assert its home rule and Danish decolonization.

The problem of food sovereignty in Greenland will increase if long-term solutions are not developed. The imported foods that currently dominate the market are linked to high levels of non-communicable disease and colonialism, and fishing and hunting will continue to be threatened by climate change. Although agriculture is not yet a completely viable source of long-term sustenance and will require upfront investments, it has demonstrated the capacity to thrive throughout Greenland when developed and supported properly. Moreover, in addition to providing the necessary calories, agriculture can support public health, community cohesion, and national identity, all of which are suffering as Greenland increasingly relies upon Danish imports in place of subsistence hunting. Greenland can choose to invest in a future of sustainable health, or it will see an escalating social cost associated with its reliance on imported foods and the loss of culture.

[171] Greenland is currently proposing three new airports in Nuuk, Ilulissat and Qaqartoq. However, it is worth noting that this proposal is met with great controversy, in part due to its incentivizing high carbon-emitting business practices. Moreover, regarding the Nuuk site, there are concerns associated with the high cost, turbulent weather and impracticality of the terrain to support a large airstrip.

[172] Qeqqata Kommunia. "Kontrakt for anlæggelse af ATV spor fra Kangerlussuaq mod Kangerluarsuk Tulleq (første fjord) er indgået". Accessed 04 April 2012 from https://www.qeqqata.gl/Nyheder/2020/07/Kontrakt_ATVspor?sc_lang=da. 2020.

[173] KN Rud, M Hørmann, V Hammervold et al. "Energy in the West Nordics and the Arctic". Nordic Council of Ministers. 2018.

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Arctic Flood Risk

Sasha Leidman

Alaska-Stewart Highway Flood of 2011. Image courtesy of B.C. Ministry of Transportation and Infrastructure

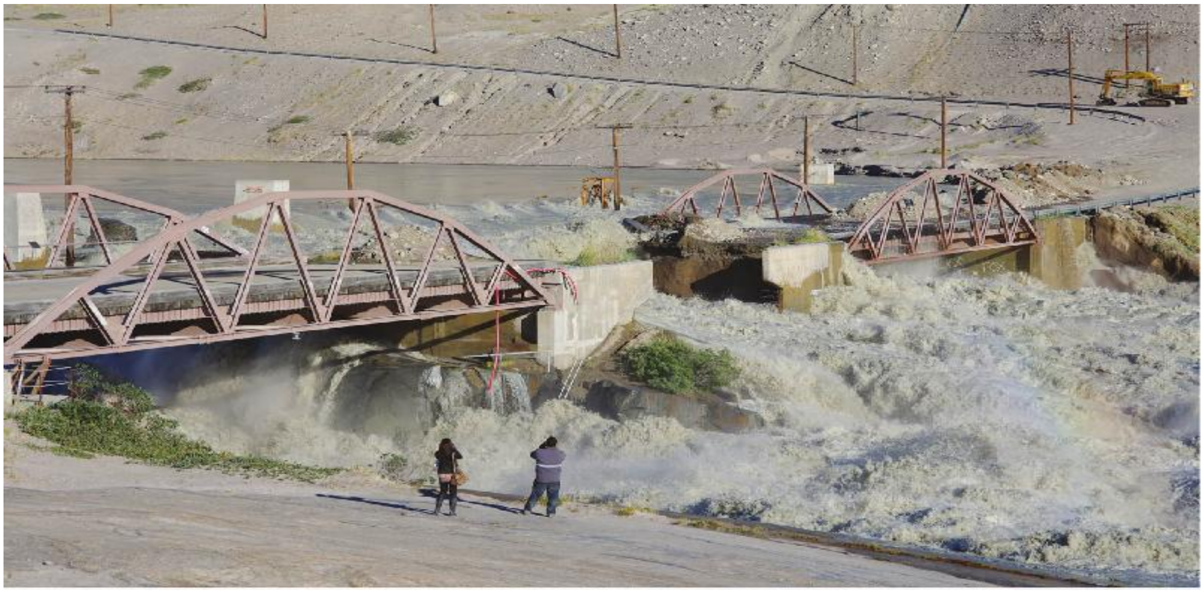
Flooding is a major concern to coastal and riverine communities in the Arctic. A vicious dichotomy exists where communities depend on water resources for food, drinking water, transportation, and other essential services; yet this dependence leaves them exposed and vulnerable to major flood events. Many Arctic communities also have small populations and are located far from federal or state emergency services and transportation infrastructure. As such, they lack reliable means for obtaining outside assistance when flooding occurs. Consequently, special attention needs to be made to plan for flooding events and assess the impact of climate change on flood frequency and magnitude. A more in-depth look at the climatological as well as policy decisions that exacerbate flooding impacts is key to minimizing future damages and increasing community sustainability.

Arctic residents have a long history of flood exposure. Of the 305 towns in Alaska that have a population over 40, 88% are located on the coast, and 77% are located along a National Hydrography Dataset major river.[174] As a result, these towns are vulnerable to erosion and flooding caused by sea-level rise, decreasing ice cover, and changing precipitation patterns. This proximity to the ocean or rivers results in 13% of Alaskan towns with populations between 40-500 experiencing spring flooding.[175] This is in addition to the communities that frequently experience ice-jam floods (flooding that occurs upstream of an accumulation of ice). These floods have manifested in extreme events such as the 1967 flood of the Tanana River in Alaska

[174] Major Alaskan rivers, according to the USGS, are defined as rivers visible in satellite imagery with a spatial scale of 1:63,360. More information can be found at https://www.usgs.gov/core-science-systems/ngp/national-hydrography

[175] Kontar et al., 2018

that caused over 7000 residents to seek refuge due to rainfall rates that were three times the annual average over the course of a month,[176] as well as the 2012 Kangerlussuaq flood caused by extreme glacial melt.



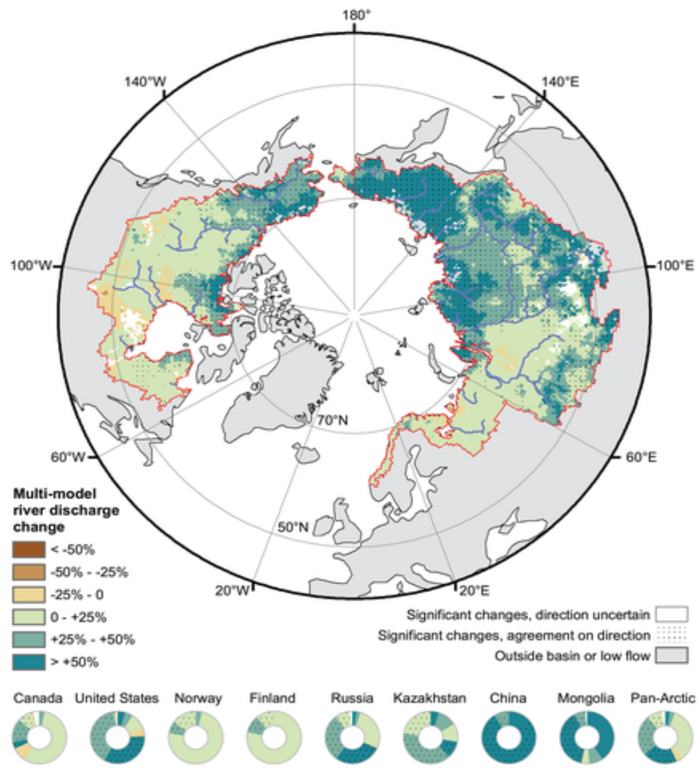
2012 Flood of the Watson River in Kangerlussuaq, Greenland. Image courtesy of Jens Christiansson.

Coastal Flooding

Arctic coastal communities are particularly vulnerable to flooding as climate change increasingly threatens coastlines. The Arctic is warming at a rate 1.9 to 2.5 times faster than the global average.[177] This warming has caused Arctic Sea ice extent to decrease by nearly 5% every decade since 1980,[178] and even under the most optimistic projections, the Arctic will likely be completely ice-free in September by 2050.[179] This decline in sea ice, especially shore fast ice,[180] has a large effect on coastal flooding. Exposed coastlines are subject to increased erosion rates, especially as climate change causes increased storm intensity and storm surge in the Arctic.[181] The impacts of this coastal flooding can be seen in communities such as Shishmaref, Alaska, where residents were forced to relocate after continued climate-driven erosion.[182] The Alaskan Arctic coastline has been receding at 0.4 m/yr on average, while the Canadian arctic coast has receded at 1.1 m/yr; however, these rates are highly variable and can be on the order of several meters per year in highly exposed areas.[183] Coastal communities located near a delta system may also experience increased sea ice loss and therefore increased erosion rates as heat is

[176] Yarie et al, 1998
[177] Winton, 2006, Stjern et al., 2019, Previdi et al., 2020
[178] Yadav et al., 2020
[179] Notz, 2020
[180] Shorefast ice is defined by the National Snow and Ice Data Center as sea ice that is anchored to the shore or ocean bottom, typically over shallow ocean shelves resulting in ice that does not move with the wind or currents.
[181] Vermaire et al., 2013
[182] Marino and Lazrus, 2015
[183] Federick et al., 2016

transported from the river system into coastal waters.[184] These hazards are likely going to increase in the near future[185] resulting in damages to infrastructure on the order of $6 billion.[186] The financial and public health risks associated with flooding in coastal Arctic communities, therefore, necessitate planning for increased infrastructure investment to increase resilience as well as emergency management policies and building codes that recognize the accelerating hazard.



Reprint of Fig. 3 of Bring et al., 2017, showing the projected change in Arctic river discharge from 1961–1990 to 2061–2090.

Inland Flooding

Inland flooding is also a major concern along riparian corridors. Inland flooding can be influenced by several factors. The majority of rivers in the Arctic are snowmelt-fed; however, rain, groundwater, and glacial meltwater also play a major component in river discharge. Non-glacierized basins generally depend on snowmelt during the spring, followed by groundwater-driven flows into the summer.[187] This summer, groundwater flux is exacerbated by increases in Arctic permafrost degradation,[188] resulting in increased river discharge. Permafrost degradation also contributes to the development of sinkholes which affects land subsidence, accelerating the lateral migration of river bends to areas of the community with permanent structures or roads.

[184] Park et al., 2020
[185] Radosavljevic et al., 2016
[186] Federick et al., 2016
[187] Blaen et al., 2013
[188] Rowland et al., 2010

While unlikely, permafrost degradation can potentially expose communities to pathogens as viruses and bacteria frozen within the ice are melted out.[189]
Climate change has had a significant effect on the amount of water flowing through inland river systems. Arctic river discharge has increased due to negative glacier mass balances, increased evaporation, and precipitation due to sea ice loss, and changing snowmelt regimes. As a result, annual discharge from Arctic rivers has increased by 10% since 1977.[190] This increased flow, as well as the Arctic shifting from predominantly rainfall driven instead of snowfall driven, will likely lead to more intense flooding events.[191] By the end of the century, much of Alaska, central Canada, and Russia will have increased their river discharge by over 25% over the course of 100 years,[192] suggesting that inland flooding will continue to exacerbate with further climate change. One instance where this might not be the case, however, are areas with frequent ice-jam floods. Ice-jam floods occur when a natural barrier (such as a sharp river curve) or a manmade impedance (such as a dam) causes the accumulation of ice that decreases streamflow.[193] Ice-jams are more common as you move further north, however as temperatures increase (especially in winter) and more precipitation falls as rain, riverine ice cover will likely thin and break up more easily, resulting in a nearly 4-fold decrease in arctic ice-jam floods by the end of the century.[194] Considering that the most severe instances of these floods can cause hundreds of millions of dollars in damages,[195] this decreased risk of early spring flooding will be a significant relief to communities affected by ice-jam floods, although it is unclear if summer increases in flood frequency and severity will compensate for these decreased ice-jam flood risks. These complex interactions between climate change and riparian flooding show that communities will need to work with state and federal agencies to fund, implement, and enforce more comprehensive flood prevention and mitigation strategies that reduce the impact of these changing hazards.

Community Awareness and Preparedness

While climate change is altering the frequency and intensity of flooding in the Arctic, the impact on communities depends on the decisions of community leaders to recognize the risks and take steps to reduce vulnerability. Many arctic communities were established in locations due to their military usefulness or proximity to mineral extraction sites and, as a result, are situated in areas of frequent flooding. Indigenous communities historically recognized the risks of flooding and established settlements predominantly along lakes instead of rivers when not along the coast.[196] The dispersion of Indigenous communities into more urban communities due to both fleeing climate impacts and forced colonial migration[197] has resulted in communities losing connections to these traditional cultural practices and, as a result, an increased vulnerability to flooding. In

[189] Parkinsen et al., 2009
[190] Déry et al., 2016; Overeem and Syvitski, 2010; Petersen et al., 2002
[191] Bintanja and Andry, 2017
[192] Bring et al., 2016
[193] Kontar et al., 2018
[194] Beltaos et al., 2006
[195] Lindenschmidt et al., 2016
[196] Kontar et al., 2018
[197] Bronen,, 2010

locations such as Alaska, however, community knowledge of flood risk can be informed due to a large portion of the population growing up in areas with more frequent flooding and more stringent flood mitigation policies. As these individuals move to Arctic communities, they bring with them knowledge of how to prevent flood damage as well as how to seek property that has limited flood exposure.[198]

Effective flood mitigation and preparedness require that residents are aware of the dangers associated with floods and how climate change may compound those risks. This awareness is best developed through coordinated public education campaigns and regulations. Efforts need to be made to make sure that all regulatory and emergency response agencies collaborate and share information from local district flood managers to state officials to federal agencies such as FEMA. This type of coordination can aid groups in making sure that community members are not incentivized to rebuild in flood-prone areas, and that flood maps are updated with the most recent reliable data. These preemptive measures can reduce the impacts of floods, better prepare emergency responders, and foster social interactions between communities. Flood impacts are always a counterbalance between the cost of preventative measures and the cost of damages; however, taking steps to prepare residents and conducting research to model future flood extents can save lives and substantially promote community well-being in the Arctic.

[198] personal communications, Nancy Durham, 2021

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Expanding Access to Medical Care via Telehealth in Rural Alaska via Broadband Internet

Katherine Janoski

Access to adequate healthcare is challenging in rural communities across the Arctic. These challenges are due to a lack of local medical professionals and facilities and the complex logistics of traveling to a city to provide necessary medical resources. Telehealth has demonstrated benefits for patients by improving care continuity, access to specialty care, and health outcomes[199]. Medical care delivered via telehealth has been practiced in rural and remote regions for several years.[200] Treatment via telemedicine has varied from treating suicide and alcohol-related disorders to oncology, otolaryngology, and diabetes treatment.[201] Telehealthcare is delivered through various telecommunication methods, including video conferencing, the internet, store/data forwarding, and telephone communication. These methods provide clinical services through face-to-face communication and can improve access to care in rural or urban areas with scarce health care resources.[202]

The COVID-19 pandemic has forced most professions to change how they operate and adapt due to customers' and employees' need to maintain safe distances to prevent the virus's spread. This is no different for those in the medical profession. Most have turned to online communications platforms to continue patient care.[203] The expanded development of telemedicine due to the

[199] Ching-Ching Claire Lin et al., "Telehealth in health centers: key adoption factors, barriers, and opportunities," *Health Affairs* 37, no. 12 (2018).
[200] Samantha J Achenbach, "Telemedicine: Benefits, Challenges, and Its Great Potential," *Health L. & Pol'y Brief* 14 (2020).
[201] Ethan Stephens, "Rural Telemedicine in Alaska: A Look at Healthcare Through Telecommunications," (2012).3
[202] Ching-Ching Claire Lin et al., "Telehealth in health centers: key adoption factors, barriers, and opportunities," *Health Affairs* 37, no. 12 (2018).
[203] David A Hoffman, "Increasing access to care: telehealth during COVID-19," *Journal of Law and the Biosciences* 7, no. 1 (2020).

pandemic has shown that distance working is possible, and employees can effectively work from home as they were from an office. Expanded telemedicine practice has increased during this emergency and provided a continuity of healthcare for communities with limited access to services, including rural and underserved areas. Despite these advances, efforts are still needed to provide service to communities with limited internet broadband service and whose residents may have less access to other telehealth technologies such as smartphones.[204]

Limited Access to Medical Care

The Arctic is sparsely populated, and, as a result, medical care can be extremely hard to access. While some larger communities have internet access through fiber broadband installed along highways and the pipeline, many Arctic communities have communications services exclusively by satellite. Satellite-delivered communication services include telephone, internet, radio, television reception, and interactive services for telehealth and education.[205] With limited communication infrastructure, Alaska also has challenges providing health care access in remote communities. Most villages are not accessible by road and can be reached only by airplane or boat in the summer and by plane or snow machine in the winter.[206] This limited access to health care is concerning because chronic diseases disproportionately affect racial and ethnic minority populations in remote communities.[207] With limited options for rural Alaskans to travel for advanced, non-urgent medical care, it can be difficult and expensive. The ability to communicate with a doctor for non-emergent treatment and care without traveling for an in-person appointment saves time, resources, and money.[208] For patients, traveling from their homes is a potential barrier, even when insurance covers travel costs such as airfare, hotel stays, and meals. Also, not traveling to medical appointments increased medical access and decreased wait times for patients versus waiting for physicians and specialists to travel to their rural communities to provide care.[209]

Benefits of Telehealthcare

Telemedicine has been shown to be cost-effective and positively impact various scenarios such as therapeutic effects, health care services efficiencies, and technical usability.[210] To realize these

[204] David A Hoffman, "Increasing access to care: telehealth during COVID-19," *Journal of Law and the Biosciences* 7, no. 1 (2020).2
[205] Heather Hudson, "5G Mobile Broadband: Spectrum Challenges for Rural Regions," *Available at SSRN 3427548* (2019).5
[206] Christine Golnick et al., "Innovative primary care delivery in rural Alaska: a review of patient encounters seen by community health aides," *International journal of circumpolar health* 71, no. 1 (2012).2
[207] Hiratsuka et al., "Patient and provider perspectives on using telemedicine for chronic disease management among Native Hawaiian and Alaska Native people."1
[208] Vanessa Hiratsuka et al., "Patient and provider perspectives on using telemedicine for chronic disease management among Native Hawaiian and Alaska Native people," *International journal of circumpolar health* 72, no. 1 (2013).1
[209] Hiratsuka et al., "Patient and provider perspectives on using telemedicine for chronic disease management among Native Hawaiian and Alaska Native people."3
[210] Woldaregay, Ashenafi Zebene, Ståle Walderhaug, and Gunnar Hartvigsen. "Telemedicine Services for the Arctic: A Systematic Review". *JMIR Medical Informatics* 5, no. 2 (2017)

benefits, providers need to deploy the necessary technology to communities that currently lack broadband internet access and the use of smartphones. This broad use of the technology will create more diverse data to produce better telehealth implementations over time. The increased use of the technology will also help extend healthcare services to rural areas and underserved urban communities. Communities that are underserved with healthcare services may also have limited access to reliable broadband internet service and the understanding of how to deploy telehealth technology.[211] Within state borders, telemedicine can expand the geographic area that a doctor and hospital can serve. Patients living in rural areas would not need to travel for routine consultations with primary-care physicians or specialists. Telehealth services supplementing in-person care can provide more frequent access to care than in-person visits.[212]

Limitations to Adopting Telemedicine

Increased demand for telemedicine access in rural communities will likely increase pressure on broadband internet providers; however, the extent to which current infrastructure will be stressed is still unclear. Rural communities with the least access to medical care typically have the least access to broadband internet and lower health insurance coverage rates. It is therefore unclear whether installing more broadband internet infrastructure will lead to increased telehealth use.[213] Before the COVID-19 outbreak, telehealth and integrated A.I. were common, though not the prevailing practice.[214] In the Arctic, patients and medical personnel are faced with availability challenges imposed by bad weather, absence of communication networks, and absence of Arctic-enhanced telemedicine equipment.[215] Medical facility standard practices and regulations governing the healthcare system have largely not responded to the increased use of telemedicine. Until recently, telehealth use has primarily been limited, stifled by the ambiguous and often changing regulations on doctors and licensure reimbursement, especially across state lines. State and federal barriers in the use of Telehealth and A.I. have served as hindrances to the launch of its full capabilities, particularly those laws that present a patchwork of accepted and non-eligible costs and services.[216] Also, differences in the forms of technology and connections between a provider's clinical settings and remote clinical sites influenced their perceptions of telemedicine's value, where some providers had experienced decent connectivity and clear images and considered telemedicine technologies a useful "tool" while others

[211] Hoffman, "Increasing access to care: telehealth during COVID-19."12
[212] Nicol Turner Lee and Roberts, "Removing regulatory barriers to telehealth before and after COVID-19."9-10
[213] Brian E Humphreys, "Demand for broadband in rural areas: Implications for universal access," *CRS Report* 46108 (2019).19
[214] Jack Karsten Nicol Turner Lee and Jordan Roberts, "Removing regulatory barriers to telehealth before and after COVID-19," *Brookings Institution* (2020).
[215] Woldaregay, Ashenafi Zebene, Ståle Walderhaug, and Gunnar Hartvigsen. "Telemedicine Services for the Arctic: A Systematic Review". *JMIR Medical Informatics* 5, no. 2 (2017)
[216] Jack Karsten Nicol Turner Lee and Jordan Roberts, "Removing regulatory barriers to telehealth before and after COVID-19," *Brookings Institution* (2020).2

experienced suboptimal image clarity, poor or unreliable internet connections, and delays from technical difficulties leading to unfavorable impressions.[217]

Recommendations

There are already plans to bring broadband internet to remote Arctic regions. Although telemedicine options are available in some areas, increasing internet availability would allow for more medical access. The unique impacts of the COVID-19 public health emergency have created an unprecedented number of regulatory changes for telehealth, helping to address the current crisis and provide an opportunity to improve health outcomes and lower costs.[218] Connecting rural residents allows them to participate in broader society, both virtually and physically, by expanding healthcare access via telemedicine. State government agencies and legislators have current and proposed legislation and plan to expand rural broadband access; however, federal investment is needed to ensure digital equity for all. In May 2020, U.S. lawmakers introduced the Universal Broadband Act in Congress, which proposed a plan to label broadband internet as a Universal Service, which expands service to rural and underserved areas providing a solid foundation for the future vitality of rural communities.[219]

[217] Hiratsuka et al., "Patient and provider perspectives on using telemedicine for chronic disease management among Native Hawaiian and Alaska Native people."3
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Developing resilient, sustainable, and equitable A.I. for addressing disparities in temporal and geospatial sampling in the Arctic

A.E. Reinert

Analyzing and predicting the short- and long-term environmental, social, and security risks posed by climate change has become an increasingly pressing concern for national, tribal, and local governments, policymakers, and stakeholders in the Arctic. Given the complex and pervasive nature of climate change, it is difficult for communities and individuals to fully contextualize how this risk affects the numerous choices they must make to ensure reliable access to sustainable and healthy food and water resources. Artificial Intelligence (A.I.) and machine learning (ML) are powerful tools that allow stakeholders to explore and analyze complex, multi-dimensional datasets to uncover new insights and interactions. However, the datasets used by these algorithms may contain disparities in temporal and geospatial location sampling that inherently produce outcomes biased against under-sampled regions. Addressing this disparity is necessary to ensure sustainable and equitable food and infrastructure security that benefits all Arctic residents.

Problem Context and Definitions

The use of Artificial Intelligence (A.I.) and Machine Learning (ML) allows researchers to derive, model, and understand complex, nonlinear dynamics in large datasets [Niu et al. 2016; Twala 2009; Ceccaroni et al. 2018; Castelli, Vanneschi, and Popovič 2015]. These tools can be leveraged to uncover new insights and relationships that humans may not immediately detect. A structural limitation of these systems is that the predictions and models made using these tools can and do produce biased or inaccurate outcomes [Mehrabi et al. 2019; Mitchell 1980]. There are multiple sources of bias, as documented in [Cabrera et al. 2019; Mehrabi et al. 2019; Wexler et al. 2019], but for the purpose of this briefer, the focus will be on temporal or geospatial disparities.

While A.I. and ML models can provide highly accurate and detailed insights about conditions in the Arctic, the accuracy of these models is dependent on the quality and quantity of the data used to build them. A model built using a dataset where a few locations are overrepresented will more accurately describe or predict conditions in those locations compared to other underrepresented regions. This can lead to solutions that inherently favor one region to the detriment of another.

Why AI and ML Matter for Arctic Research

The scientific community has long recognized that the changes emanating from climate change pose an existential threat to earth's ecosystems and to human civilization. The Arctic region is already experiencing many of these changes. Given the complex and pervasive nature of climate change, it can be difficult to fully contextualize how these different risks affect policy choices. Moreover, the nonlinear dynamics of climate-linked phenomena, the local spatial variation, and the underlying seasonal to sub-seasonal (S2S) variations in weather patterns are often difficult to comprehend in real-time.

One of the issues we face when discussing an issue so complex in nature and pervasive in scope is an inability to fully contextualize and comprehend how these changes affect daily life. This does not mean it is impossible to assess certain categories of risk. Some of the risks posed by climate change include increased instance rates and spreads of infectious diseases [Ebi et al. 2013; Ma et al. 2019; Waits et al. 2018], permafrost degradation [Hjort et al. 2018], and changes to regional human and animal migration patterns [Hamilton and Stampone 2013; Kelman and Næss 2019; Olmos et al. 2019; Wauchope et al. 2017; Zurell et al. 2018].

Artificial Intelligence and Machine Learning research represent powerful tools to understanding the complex, nonlinear dynamics connecting these issues while presenting actionable solutions. The following two case studies demonstrate why investments in Artificial Intelligence and Machine Learning Research, and data collection infrastructure are necessary to secure and maintain community well-being in the arctic.

Case Study 1: Addressing Sampling Bias

A primary cause of bias in the datasets used to train and test A.L. and ML systems is sampling bias. Sampling bias occurs when some members of a population - or geographic regions - are systematically more likely to be sampled than others. There are two reasons sampling bias limits the effectiveness of A.I. and ML systems in Arctic research. First, the solutions and recommendations produced by these systems will inherently benefit the oversampled group. This can reinforce unequal policy outcomes. Second, sampling bias can skew individual, community, and stakeholder perceptions.

The impact of sampling bias is best explained through two examples: one centered on community health and the other coastal management.

Community Health

Sampling bias is a well-documented problem in community health and most often takes the form of under coverage. Under coverage occurs when some elements of the population or geospatial locations are inadequately represented. A broad consequence of under coverage is that
policy solutions will discount the unique needs and experiences of the underrepresented group. It should be noted that the areas and people most likely to be under covered are individuals in remote, rural communities and Indigenous populations [Amaya et al. 2021].

Under coverage has specific impacts on the use of A.I. and ML systems to determine where to develop new community health infrastructure and/or deploy community health interventions. A direct consequence of under coverage is that the medical needs of rural, remote regions are minimized or overlooked—these compound existing disparities in medical treatment between urbanized centers and rural communities. A secondary consequence of this disparity is that preventable deaths and diseases will be more prevalent in those rural regions because of a lack of healthcare. Another direct consequence is that A.I. and ML-enabled models of disease spread, and dispersion will misrepresent the resiliency of remote Arctic communities. This is especially pressing as warming permafrost, and changes in weather patterns are causing a resurgence of communicable diseases [Dighe, 2020; Hofmeister, 2021].

A.L. and ML systems can identify areas or populations that are likely to be under covered. However, this identification process requires access to reliable streams of data and necessitates human supervision. If both are present, a human-computer team can identify areas where under coverage is likely to occur and propose a series of solutions to remedy said under coverage.

Unfortunately, there are times when bias is unavoidable. Many locations in the Arctic are inaccessible during certain times of the year, and environmental factors can damage data collection equipment. Damage to these instruments can blind analysts to environmental changes in remote regions for months at a time and can be expensive to repair and replace. Remote communities may be difficult to access, limiting the number of opportunities for collecting updated data. However, one possible means to close this data gap is through active regional level investments in the creation of village-based networks of data collectors inspired in part by citizen science techniques [Danielsen 2018].

While satellite, aerial surveillance, and other forms of remote sensing data can help fill in the gaps, collecting data using these methods introduces additional challenges. First, each of these methods requires the use of expensive equipment and infrastructure such as satellite ground stations or airfields. Second, remote sensing data needs to be validated against other data sources to ensure the data is both accurate and reliable [Badou, Diekkrueger, and Montzka 2018; Kraehenmann et al. 2013; Ferrelli et al. 2015; Colon-Robles et al. 2018].

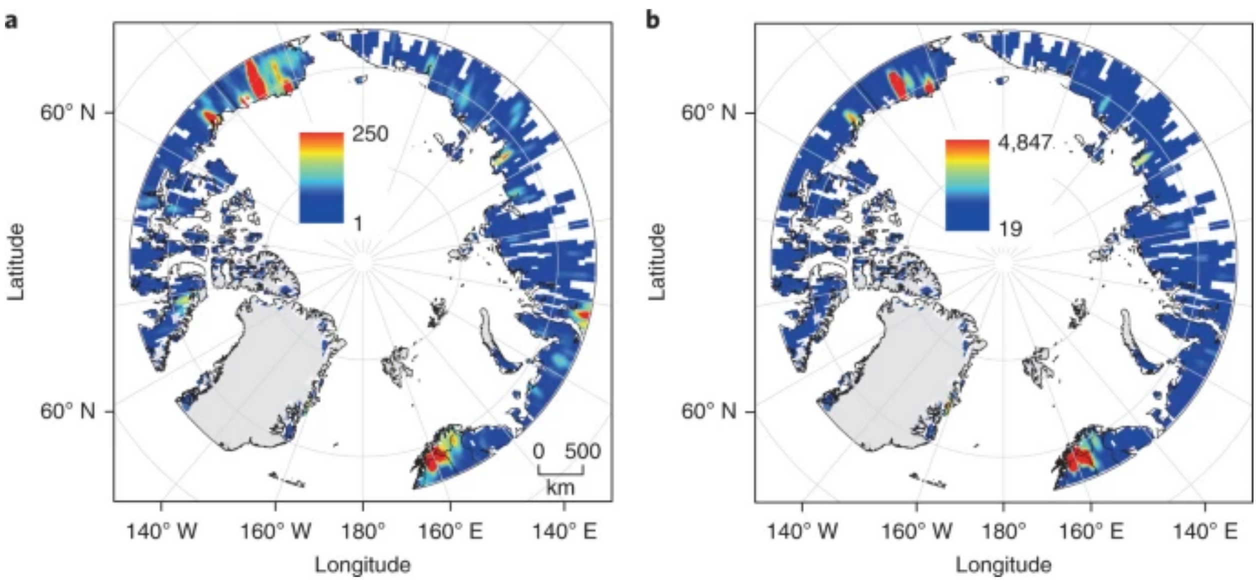
Case Study 2: Food, Water, and Medical Security

A classic challenge facing community stakeholders in any context is access to clean, sustainable sources of food and water. However, warming in the Arctic has caused previously inaccessible areas to become viable locations for extractive industries to operate (Bench 2003; Adam, Owen, and Kemp 2015; Nightingale et al. 2017). This has resulted in the creation of boomtowns (Archbold 2015; Ruddell 2017)**.** While boomtowns do bring employment to the regions, the creation of a boomtown strains local food, water, and medical infrastructure while introducing other deleterious outcomes, such as the introduction of heavy metals into the ecosystem. Further, there are unique operational and logistical constraints that must be accounted for that influence regional planning.

A.I. and ML research, in conjunction with both local and Traditional knowledge, is needed to increase the stability of these communities. A.I. and ML can evaluate a range of sensor data to help regional planners make informed decisions about food and water availability. In turn, this information can be used to assess where investments in critical infrastructures - such as transportation networks, medical facilities, and social services- would have the maximal impact on the community. Further, advances in A.I. and ML can predict changes in land use, flood risk, and fire risk while helping local communities become resilient [Sun 2018; Harfouche et al. 2019].

It should be noted that physical computing infrastructure will be needed to perform these computations, and this infrastructure can prove costly to install and maintain. However, the data processing infrastructure need not be co-located so long as a stable telecommunications connection exists.

Addressing Sampling Disparities



While the above case studies demonstrate how A.I. can be used to improve community well-being, A.I. can also aid in scientific research conducted in the Arctic by addressing issues of geospatial and temporal sampling disparities. First, AI systems can be trained to identify locations that are under-sampled relative to other areas. This information would help regional planners determine where additional physical infrastructure would be needed in order to ensure equal coverage across the Arctic. Alternatively, this information can be used by policymakers to plan future interventions in underserved communities. An example of this would be the use of A.I. in order to determine the ideal location of a weather station to improve climate model predictions as described in (Metcalfe et al. 2018).

Moving Forward

Investments in the development of resilient, sustainable, and equitable A.I. to address these disparities in temporal and geospatial sampling would benefit a wide range of stakeholders in the Arctic. These investments would take many forms ranging from physical data collection infrastructure to support citizen-supported science to developing low-cost aerial sensor platforms. Such investment would directly benefit Arctic and non-Arctic stakeholders through the development of improved weather and climate forecasting models, refined disease prediction and intervention models, and ecosystem models.

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Conclusion

Community well-being in the Arctic requires a systemic approach to assess potential hazards. Planning for these hazards can avoid serious risks associated with climate change and disasters. This planning should incorporate all stakeholders and be aided by scientific research pertinent to the area. The Arctic poses unique challenges that can complicate this process, such as the diversity and interests of residents, increased warming due to Arctic amplification, and the remoteness of communities from necessary resources and services. Additionally, the evolving nature of climate change necessitates that this planning process is conducted in a way that can be flexible to unforeseen changes to environmental conditions. Through this process, risk management can allow for the creation of equitable, sustainable, and inclusive policies that bolster Arctic communities and strengthen responses to extreme events.

Through a detailed look into several key components of community well-being, we highlight important considerations when assessing risk and demonstrate how system-oriented solutions facilitate resilient community structures. Communities must recognize that living sustainably in a changing Arctic requires working alongside the environment and preparing for hazards. This includes conducting research on marine ecosystems and potentially incorporating seaweed harvesting, conservation, and management practices to the cultural lexicon to increase food security, reduce flood risks, increase water quality, and mitigate climate change. These measures will bolster not only coastal communities but also inland communities that face similar yet different challenges such as ice-jam flooding and changes in water supply. Climate change will have measurable impacts on community health, not just from the increase in disasters such as flooding but also from an increased spread of infectious disease and food insecurity. This was made abundantly clear during the COVID-19 pandemic, highlighting the need for expanded internet access, updated medical practices, and infrastructure to support telemedicine in the Arctic. These approaches to community health and resilience can be aided using artificial intelligence. Artificial intelligence can identify gaps in our knowledge of natural processes and aid further research that supports policymakers and community organizers. This forward-thinking approach to community management will hopefully heed lessons learned from the millennia of people who lived in the Arctic and reinvigorate strategies for building social ties and working together in the face of community struggles.