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REVIEW

Climate impacts on migration in the Arctic North America: existing evidence and research recommendations

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Abstract

The Arctic is experiencing a rapid temperature increase, four times faster than lower-latitude regions, disproportionately affecting rural, coastal, and Indigenous communities. These areas confront multiple urgent climate challenges. Adaptation strategies encompass out-migration, community relocation, and enhancing resilience, yet research in this critical area is notably limited, particularly for the most vulnerable communities. This paper presents a comprehensive review of environmental stressors and contextual factors influencing migration decisions in the North American Arctic. While migration is primarily driven by job opportunities, education, healthcare, cultural, and infrastructural factors, factors such as family, culture, safety, subsistence life, and community ties strongly influence residents to stay. The study reveals a lack of clear evidence for climate-driven migration at the individual/household level, but it underscores well-documented community-level relocations. Two major challenges in studying Arctic climate migration are identified: the complexity of migration and the uniqueness of Arctic climate change. Recommendations include considering migration typology, disentangling climate drivers from contextual factors, and addressing data limitations through systematic collection, integration, and creative use of traditional and nontraditional data. The paper underscores the importance of establishing partnerships with local communities to achieve a holistic understanding of factors driving migration or immobility, ensuring research outcomes are connected to addressing community challenges. This review lays the groundwork for empirical research on Arctic migration and community adaptation, aiming to comprehend the challenges faced by these communities and explore potential solutions.

Keywords Climate change · Environmental stressors · Migration · Community relocation · Arctic · Adaptation

Introduction

Climate changes and variations drive migration worldwide, as evidenced by a large and rapidly growing body of literature investigating the impact of environmental change on migratory processes (IPCC 2022). Globally, rising temperature, irregular precipitation, and environmental disasters such as wildfires, tsunamis, and hurricanes have triggered large-scale internal and international migration in recent decades. In 2022 alone, environment-related disasters displaced 32.6 million people, accounting for 53% of global internal displacements (IDMC 2023). Drought- and desertification-related environmental migration is particularly pervasive in African countries, while floods are the primary environmental trigger for migration in some European countries (Piguet et al. 2018). In coastal regions and some island countries, environmental migration is more likely to be triggered by disasters such as hurricanes, tsunamis, and rising sea levels. In South Asia, irregular rainfall and delayed monsoons contribute to out-migration (Thiede and Gray 2016). In tropical regions such as Indonesia and the Philippines, deforestation is an important environmental factor in migration decision-making (Darmawan et al. 2016).

In turn, migration can also impact the environment. For example, migration may exacerbate environmental degradation, especially when remittances from migrants are channeled into intensive grain and livestock farming (Angelsen et al. 2020). As another example, when effectively managed and strategically invested, remittances can serve as a means

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to mitigate environmental risks and enhance the capacity for environmental adaptation (Ali et al. 2023).

Arctic regions are largely absent from this literature and from global debates on climate and migration. This is an important gap because of the severity of Arctic climate change impacts and the regional predominance of Indigenous communities, many of which have already been negatively impacted by centuries of racism, cultural loss, and political disenfranchisement, especially in Alaska (Stewart and Gonzalez 2023). Arctic temperatures are rising four times faster than in lower latitudes (Rantanen et al. 2022; Wadhams 2017), resulting in permafrost thaw, rising sea levels, declining sea ice cover, and extreme storms. When these environmental factors surpass critical tipping points, they will pose a significant threat to community viability, health, and livelihoods, potentially leading to out-migration or the relocation of the entire community. Scientists predict an increase in major Arctic cyclone and other extreme weather events like the 2022 Typhoon Merbok, devastating coastal communities and exacerbating coastal erosion and sea ice loss due to winds and coastal inundation (Parker et al. 2022). Rapidly eroding Arctic coasts threaten subsistence food systems and residents' safety while damaging community infrastructure and cultural heritage (Serreze 2018). These impacts create complex problems, raising critical social, legal, environmental, and engineering science questions.

Some of the hardest-hit areas (Fig. 1) are rural and coastal, which have a predominantly Indigenous population. These areas have strong connections to the local landscape, upon which the local people depend (Borish et al. 2021; Hamilton et al. 2016; Marino 2015; Serreze 2018). One response of residents to increased environmental variability and associated loss of a secure livelihood is to migrate to less impacted areas, which leads to rural to urban migration as residents, especially younger ones, search for jobs and housing (Hamilton et al. 2016; Marino 2015). Community

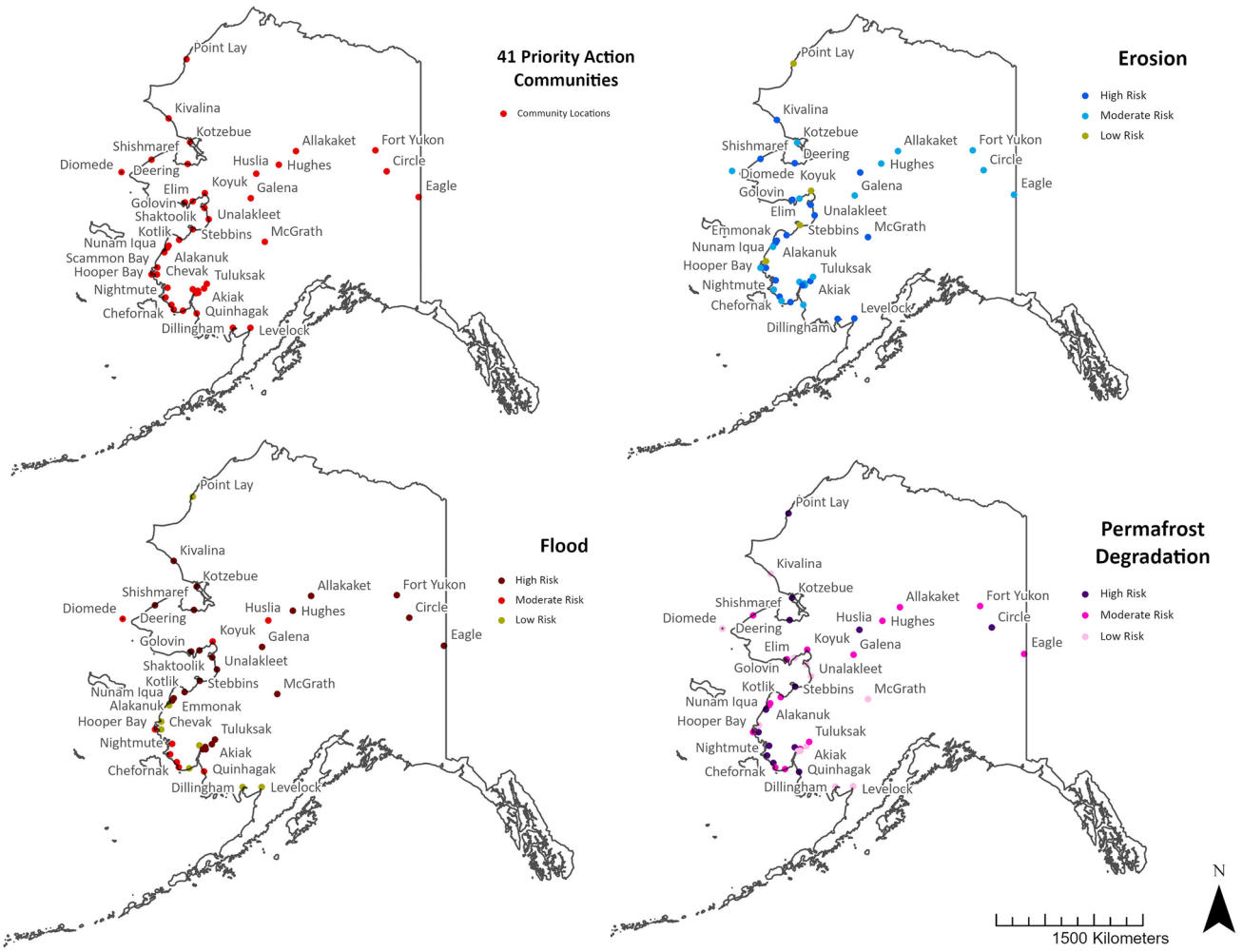

Fig. 1 Communities in Alaska threatened by environmental factors. Source: Department of Commerce, Community, and Economic Development, Division of Community and Regional Affairs, Assistance to Environmentally Threatened Communities https://www.commerce.alaska.gov/web/dcra

relocation might protect the particularly impacted coastal communities, but it is extremely expensive and often impractical (Huntington et al. 2017; Magnan et al. 2022; Marino 2015). To date, there is little and inconsistent evidence of large-scale Arctic rural out-migration, even from the most threatened communities. Thus, it is important to develop a better understanding of migration drivers faced by Arctic communities.

In our review of the Arctic migration literature, we focus on the potential drivers of environmental migration but also include nonclimatic change factors. We address the major gaps that preclude a comprehensive understanding of migration patterns and processes within the context of rapid climate change and social, ecological, and infrastructure disruptions. We also examine the gaps in migration data at individual, household, and community levels. Ultimately, the goals of this paper are to review the evidence, identify research challenges, and recommend how to address them. Specifically, the paper will:

1. Provide a comprehensive review of the roles that environmental stressors—along with demographic, socioeconomic, policy, cultural, and infrastructural factors—play in Arctic migration decision-making; and
2. Identify research gaps, evaluate existing and potential data sources, and recommend strategies for Arctic migration research.

This paper is organized into four sections, starting with a background of Arctic environmental change and migration, followed by a comprehensive review of Arctic migration literature. We then identify research gaps and potential Arctic social science research needs. The paper concludes with major findings and recommendations. The focus is on the North American Arctic, reserving review of the environmental migration literature for the six European countries with Arctic territory—Denmark, Finland, Iceland, Norway, Sweden, and Russia—for future work. Given the geographic, cultural, and demographic similarities across the Arctic, the approach and recommendations from this paper should be relevant to migration research in all Arctic countries and provide a benchmark for future work.

Climate migration in the North American Arctic

Arctic environmental changes and impacts

Rapidly occurring Arctic environmental changes require accelerated responses and adaptation to the magnitude of damages (Ford et al. 2015; Rantanen et al. 2022). Permafrost is thawing, snow and ice cover is decreasing, and wildland fires are becoming more frequent (van Luijk et al. 2022; Schaffner 2020; Thoman and Walsh 2019). For example, in northwest Alaska, all permafrost is predicted to thaw by 2150 (Batir et al. 2017). Rapidly receding summer sea ice is another telling sign of the Arctic's rising temperature. Sea ice recession has been observed since satellites first began taking measurements in 1979; recent estimates suggest the Arctic could be free of *all* summer sea ice by as early as 2026 (Guarino et al. 2020) and predict a 60% overall decrease in sea ice by the end of the twenty-first century (Parker et al. 2022).

These environmental changes will damage some existing infrastructure and can impact human health and quality of life, altering subsistence routines and ways of life (Ford et al. 2021; Harper et al. 2020). For example, increasing rainfall in the summer and fall months challenge fish drying and smoking preservation techniques. In some places, environmental change has resulted in long-term or seasonal loss of important sources of protein and food, such as subsistence salmon closures on the Yukon River in the last several years and the loss of access to caribou but an influx of moose in more northern Alaska communities. Shifting freeze–thaw cycles in rivers and sea ports and increasingly unpredictable weather affect barge shipping of store-bought foods to remote communities, resulting in sparsely stocked shelves and food insecurity (Mead et al. 2010). Dangerous winter travel over unstable and thinning ice and shifting wildlife populations increase risks of hunting excursions (Fleischer et al. 2013).

Loss of sea ice also affects global dynamics as well. Significant changes in the extent of sea ice have already led to new shipping routes that will have important economic and governance implications for the Arctic (Ford et al. 2021; Mudryk et al. 2021; Smith and Stephenson 2013). New shipping routes provide opportunities for new extractive industries in the Arctic. Finally, less sea ice overall may open up new opportunities for offshore oil extraction and mining.

Linking climate change to Arctic migration

The general environmental migration literature presents clear evidence that environmental changes have both direct and indirect impacts on migration in lower-latitude regions. In this section, we provide evidence linking environmental changes and Arctic migration from previous studies.

Generally, the environmental migration literature in the Arctic shows mixed findings, differing on the scale of migration—individual, household, and community. Existing Arctic migration literature finds no evidence that environmental changes directly drive migration for individuals and households. For example, a study of 43 Alaska towns and villages, which covered places most threatened by climate-linked erosion and flooding, found no indication of enhanced

out-migration between 1990 and 2014 compared with places without risk (Hamilton et al. 2016). The reasons residents decided against out-migration included not wanting to leave ancestral homes and lack of appealing alternatives. The literature suggests that it is other factors—e.g., jobs, education, and healthcare—that matter (Mallick and Hunter 2023).

Results are different at the community level when community relocation as a planned and voluntary migration process occurs; such relocation is widely studied in the Arctic context (Albert et al. 2018). Community relocation is defined as the wholesale relocation of a community's housing and public infrastructure to a safer location when it can no longer be protected in place (Bronen 2015). Arctic communities under environmental threats are forced to relocate because flooding, erosion, and storms are destroying their homes and civic infrastructure. Community relocation from climate-related environmental changes is a widely considered option in Alaska (Bronen and Chapin 2013), but it is an expensive process (Magnan et al. 2022). For example, Newtok village, a Yup'ik community on Alaska's West Coast, will have expended more than $200 million to complete its relocation efforts, which has already taken more than 30 years (U.S. Government Accountability Office 2020). Even if financial resources might be available, some communities in the circumpolar North, especially Indigenous communities, have opposed community relocation because of past experiences with displacement or forced and semi-forced population movements (Ford et al. 2015; Stepien et al. 2014). As of 2022, 144 of the 229 Alaska Native Tribes are under environmental threats (Division of Community and Regional Affairs 2021), 15 are exploring relocation, and only one, Newtok, has partially relocated, and it may be several years before the relocation is complete (U.S. Government Accountability Office 2009). Many communities facing environmental threats cannot meet the overly burdensome requirements of federal disaster mitigation programs and are ineligible for disaster funding if funding is available at all (Korkut et al. 2022).

Migration theories

Much of the published Arctic migration literature is based on decennial Census data from Alaska or Canada, with additional sources from household surveys and qualitative and observational studies. Most focus on Indigenous communities and seek to identify who moves and the push and pull factors that drive migration decisions and behavior. Many of these studies are descriptive, while others test standard and classical migration models explicitly or implicitly.

Hierarchical and stepped migration to increasingly urbanized centers are among Ravenstein's "laws of migration" and have been observed and tested in a few studies using data from northwest Alaska (Howe et al. 2014). Migration patterns, however, vary by population and place. Studies find that women leave small Arctic communities for larger urban centers at greater rates than men, while men are more likely to return to small communities (Hamilton et al. 2011; Hamilton and Seyfrit 1994; Howe et al. 2014; Martin 2009). In the Canadian North, White settler youth are more likely to migrate south than members of other Indigenous communities, primarily for economic reasons and opportunities (Hillier et al. 2020).

Economic reasons for out-migration are central to a number of theories. This includes Todaro's model of expected wages in rural to urban migration decisions (Berman 2009; Howe et al. 2014) and Tiebout's hypothesis about the importance of place amenities in moving decisions (Howe and Huskey 2022). Other economic theories follow the new economics of labor migration (NELM) (Stark and Bloom 1985) to posit a household production model across origin and destination areas, where choices between formal employment, subsistence work, and leisure are a household-level negotiation (Howe 2009). Human capital theory is frequently cited as a primary driver of migration, with women migrating from rural to urban areas for higher education (Lowe and Sharp 2021). The super-household theory hypothesizes that 30% of households in a given community are extremely important harvesters, food sharers, and keepers of knowledge; if a super-household leaves, community food security and ways of life are gravely impacted (Wolfe et al. 2010; Lowe 2010; Magdanz et al. 2011).

Social-ecological resilience theory focuses on "stayers" rather than migrants, identifying mechanisms that keep people in place, including cultural and emotional ties and economic resources (McLeman et al. 2014). These include "attachment" that reflects deep identity and affinity with place; "alternatives" that identify small-scale substitutions to livelihood practices to maintain community life, even if at a lower standard of living; and "buffering," which draws on external resources such as subsidies and transfers (Huntington et al. 2018). Examples of each are found across the Arctic (Willox et al. 2012; Voorhees 2010) and should play a role in theorizing climate-related migration. Cultural theories are sometimes invoked; the role of environmental amenities and subsistence in the migration decision have been hypothesized, tested, and found to play a significant role (Berman 2009).

Theories that focus on the environmental consequences of climate change hypothesize that the impacts of disasters, environmental degradation, and loss of ecosystem services increasingly drive rural to urban migration. To date, there is little direct evidence to support these theories in the Arctic (Hamilton et al. 2018). As climate-related disasters increase, it will be important to further test them, especially since there is evidence that environmental amenities and subsistence opportunities are related to migration decisions, and climate change affects those amenities and opportunities.

Nonclimatic change factors of Arctic migration

Migration decision-making at the individual, household, and community levels could be affected by a wide range of factors including demographic, socioeconomic, legal, policy, cultural, and infrastructural. The existing migration literature has often found it is these factors, not environmental stressors, that drive migration in the Arctic (Huntington et al. 2018). Table 1 summarizes these factors and their evidence in the North American Arctic.

Demographic characteristics

Demographic characteristics related to Arctic migration include sex/gender, age/life stage, marriage, family, household status and composition, and race/ethnicity and Tribal affiliation. Research is spotty, especially that which considers multiple demographic variables simultaneously.

Sex/gender and age/life stage are among the most commonly identified demographic variables related to migration patterns. Regardless of population change, there are lopsided sex ratios throughout the Arctic, with more men than women, despite higher male mortality rates. A primary reason is women's out-migration, or "female flight." More women than men leave rural villages, although this varies across the Arctic (Heleniak 2019; Hillier et al. 2020; Howe et al. 2014). Women are more likely to leave for education and employment; if they return, they have more formal employment opportunities, often in education, healthcare, or public service. Additionally, women leave to find an expanded marriage market, to escape dysfunctional family dynamics including domestic violence, or to seek urban amenities and lifestyles (Rasmussen 2009). Alternatively, they may return to home villages to take advantage of family and community support networks, especially childcare. These trends are found in Alaska but not in Canada (Dowsley and Southcott 2017).

Men are more likely to stay or return as adults to rural villages and home communities, despite having fewer formal employment opportunities. Some places offer jobs in natural resource industries. In Canada, in-migration is on the rise in Yukon Territory, where mining and resource development have attracted migrants from the rest of the country (Emelyanova and Rautio 2019). Earmarked jobs for Indigenous men often fail because cultural preferences for traditional lifestyles and subsistence pursuits clash with formal job requirements (Kleinfeld et al. 1983).

Regardless of gender, youth are most likely to migrate, and retirees to return. In Nunavut, higher educational attainment of both parents and children was associated with out-migration, although less for Indigenous youth (Hillier et al. 2020). Retired seniors may move back to their communities of origin for support and cultural reasons, with longevity differences implying more women than men returning at an advanced age.

Job opportunities, income, and education

Economic well-being is often a primary driver of migration, and migration in the Arctic is no exception. Studies have shown that youth and women's migration is largely motivated by job opportunities and higher incomes in destination regions, primarily regional centers or urban areas (Dowsley and Southcott 2017). Contemporary migration in the Arctic is also intimately connected to livelihoods, sustainability, and economic conditions (Dombrowski et al. 2016; Holen 2014). Individuals may migrate to seek better economic or educational opportunities, leaving other family members behind to continue subsistence livelihoods. Recent migration of non-Indigenous people to the Arctic has been driven largely by natural resources, mainly minerals and other resources such as gold, diamonds, oil, and gas (Heleniak 2014).

Education is a critical place-based amenity and a prime motivator for migration to Alaskan urban communities (Holen 2017). As children reach high school age, the family must decide to either send the child to boarding school or relocate to an urban center with larger schools and more diverse educational opportunities. Sometimes children migrate independently to urban areas in Alaska to live with family members and attend an urban school (Lowe 2010).

Social capital

Social capital consists of the resources contained within social relationships (Lin 2002). In rural Arctic communities, local social ties serve as a key resource (Baggio et al. 2016; Lowe 2015). According to Duhaime et al. (2004), social ties within Inuit communities of the Canadian Arctic are established and sustained through a dedication to reciprocity and sharing, as evidenced by the continual exchange of material, emotional, and spiritual support (2004). Extensive social cohesion within rural Arctic communities may therefore discourage out-migration. Relatedly, increasing out-migration from rural areas in the Arctic may weaken social cohesion within origin communities. However, ethnographic research in Alaska suggests that social cohesion in rural communities tends to be resilient to out-migration. Many rural-to-urban migrants in Alaska maintain close ties to their home communities through regular visits and exchanges of traditional foods (Voorhees 2010). Although social capital in places of origin may potentially suppress migration, it is also important to note that for most migration from rural to urban areas, social capital such as a preexisting migration network in destination areas plays an important role in facilitating migration by reducing risks and information costs (Howe et al. 2014).

Table 1 Driving factors of migration in the Arctic

Components	Major factors	Major findings
Environmental stressors	Permafrost erosion, flooding, storms	1. No clear evidence of direct effects from environmental stressors to out-migration at the individual/household level 2. Little and inconsistent evidence of community relocation related to environmental threats
Demographics	Age, gender, race/ethnicity, family	1. Youth and women are more likely to leave rural villages for education, jobs, and marriage 2. Men are more likely to stay or return for subsistence activities 3. Family dynamics are especially influential for women's migration
Socioeconomic statuses	Income, education, and job opportunities	1. Lack of accessible, affordable, and quality education drives rural-to-urban migration and facilitates the continuation and expansion of migration through family connections 2. Higher income and working opportunities in urban areas serve as pull factors that attract in-migration 3. Temporary migration of teachers into small, remote, rural communities creates unique opportunities and challenges
Social capital	Social ties, migrant networks	1. Social ties in rural areas are critical resources sustained by relationships of reciprocity 2. Migrants maintain strong ties to their rural communities through visits, continued engagement in subsistence, and exchanges of traditional foods 3. Ties to family members in cities facilitate the migration of children and youth for educational purposes
Food security	Subsistence, store-bought foods, food sovereignty, super-households	1. Households with characteristics that explain success in subsistence are less likely to migrate out of rural Alaska and Canada
Healthcare	Quality, affordability, accessibility, disparities	1. Inadequate access to affordable and quality healthcare motivates rural-to-urban migration, fostering subsequent waves of migration 2. Arctic communities face physical and mental health disparities
Infrastructure	Roads, bridges, airports; electricity, gas, public water, sewage, telecommunication	1. Permafrost degradation, coastal erosion, and flooding impact physical infrastructure and population growth 2. Infrastructure development drives in-migration for economic opportunities 3. Climate-related infrastructure damage reduces water quality and access, local mobility, and health outcomes 4. Receding sea ice results in new mineral, oil, and gas extraction and new shipping traffic, leading to new development opportunities, in-migration, and employment 5. Government spending includes critical infrastructure support and transfer payments
Legal and policy	Availability of government programs for community relocation	1. Community relocation as a proactive adaptation strategy is widely discussed in the USA but is underfunded 2. Less discussion of community relocation relative to other Arctic countries
Staying factors	Family, culture, feeling safe, jobs, subsistence lifestyle, sense of community, tranquility, natural environment, living costs	1. Reasons to remain in place are consistent across regions: family, culture, and the subsistence way of life 2. Subsistence foods and their places and cultural connections are reasons for vulnerable and food-insecure households to remain in place

Refer to the "Nonclimatic change factors of Arctic migration" section for the key references

Food security

Globally, food insecurity and acute food crises are major determinants of intra- and inter-country migration (Obi et al. 2020). Food-motivated migration is less documented in the USA and Canada and other developed countries. In these regions, food insecurity and regional acute food crises have not reached the extent experienced in countries with lower GDP, less-developed agriculture and economic systems, and chronic food shortages, particularly in rural areas. However, many Indigenous communities in the USA and Canadian Arctic have overall high rates of food insecurity, which is driven by the high cost of market goods, limited employment opportunities, and high rates of income poverty. Consequently, subsistence harvest of traditional resources is a critical factor in enhancing food security in Indigenous communities across the North American Arctic (Green et al. 2021; Berman 2018; Hotez 2010).

As the impact of environmental change on subsistence food systems mounts, Arctic food supplies, peoples, and economies are jeopardized (Green et al. 2021), although the implications for migration remain unclear. Subsistence harvesters identify social, economic, and institutional factors as more salient day-to-day challenges than environmental change (Naylor et al. 2021). Nevertheless, food insecurity can drive migration decisions, with resulting benefits and vulnerabilities (Huntington et al. 2018). The effects of food security on migration (and vice versa) are highly entangled, with no studies—to our knowledge—in Alaska or other Arctic regions that demonstrate whether and how food (in)security motivates migration at the household or community levels. The few studies that compare food security between Indigenous rural and urban residents found that urban households were actually more food insecure than those in rural areas, contrary to the geographic trends of food security for the American population at large (Sowerwine et al. 2019). The reasons are unclear, but they may be influenced by easy access to subsistence foods in rural areas. Furthermore, rural to urban migration often results in accelerated dietary transition and diet-related health issues (Brown et al. 2008; Cidro et al. 2015).

Using Survey of Living Conditions in the Arctic (SLiCA) data, Berman (2021) found that households with characteristics favorable for successful subsistence harvest were less likely to migrate out of rural Alaska and Canada. These characteristics include human capital, high earnings, knowledge of subsistence harvest from childhood, formal education, and use of Indigenous language at home. Contemporary subsistence activities are intimately tied to the cash economy through the use of specialized, modern equipment, leaving rural communities in Alaska vulnerable, especially with declining participation in commercial fishing by rural residents. A decline or crash in the abundance of fisheries, with no viable alternative to support rural livelihoods, can spur a mass out-migration in rural areas. Such out-migration was observed after the collapse of North Atlantic cod fisheries in the Faroe Islands and Greenland (Hamilton et al. 2003; Huntington et al. 2018). Huntington et al. (2018) described "buffering" strategies in Arctic Alaska communities to create "short-term insulation from stressor impacts." These strategies include using food banks or state-run food assistance programs, reducing the size of meals for adults in the household, or eating cheaper, less nutritious foods. The sustainability of these strategies, however, relies on their continuity over time and their ability not to compromise the overall health and well-being of household members.

Healthcare

Like education, lack of high-quality and affordable healthcare in rural communities drives people to urban areas with more robust healthcare systems. Arctic communities experience physical and mental health disparities and have acute needs for healthcare services (Allen et al. 2011; Hotez 2010). Small communities suffer from provider and facility shortages, with limited access to preventive care, specialties, and drug or alcohol recovery centers, resulting in less preventive care and a higher long-term burden of treatment and cost (Driscoll et al. 2010). In the USA, Alaska Native people often migrate to large urban areas for services. In a survey of households who recently moved to the Anchorage school district, 20% of 881 reported needing healthcare upon arrival. Driscoll et al. (2010) noted that families who relocated from rural places for healthcare often bring family members with them, creating a "ripple effect migration." Furthermore, climate change creates additional travel costs and burdens for medical care. Emergency health evacuations in rural areas are increasingly hampered by weather conditions and visibility that strand patients with acute conditions in need of timely critical care not offered in rural regions (Joseph et al. 2013).

Infrastructure

Infrastructure impacts on migration are well documented in the broader migration literature but not for the Arctic. Infrastructure includes transportation (e.g., roads, airports, bridges), civic (e.g., electricity, gas, running water, sewage, schools, hospitals), private (housing), and telecommunications. This infrastructure has been essential to the well-being of contemporary human society and plays a critical role in promoting economic growth and development—and consequently, on population change and migration (Chi 2012; Chi et al. 2006).

Housing conditions in rural Alaska and Canada are often overcrowded, with deficient housing stock and quality. In the Yukon–Kuskokwim Delta of Alaska, the Association of Village Council Presidents Regional Housing Authority, which represents 51 Tribes, identified a demand for 1000 housing units (Agnew:Beck Consulting 2018). The Authority also found 2500 over-crowded units and 655 units with one-star energy ratings, meaning poorly insulated. Population growth will outpace homes that need to be replaced, and action will be required to mitigate overcrowding in Alaska (Alaska Housing Finance Corporation 2018). Similar conditions persist throughout Canada's rural regions (Christensen et al. 2017; Ruiz-Castell et al. 2015).

In some cases, a declaration of intent for community relocation can result in diminished infrastructure development and maintenance (Marino and Lazrus 2015). In 2002, after Shishmaref community members voted to relocate off the island in response to flooding and erosion, nearly all state and federal development money to the village ceased.

The lack of modern sanitation systems in Shishmaref poses major health consequences, encouraging out-migration.

Increases in temperature, flood exposure, and erosion also threaten the traditional infrastructure vital to cultural and community well-being. For example, temperature variability increases the instability of ice cellars that store meat, placing household and community food security at risk. Rising rates of erosion and flood exposure from permafrost degradation place culturally important heritage sites at risk. Erosion has exposed several burial sites throughout the Arctic, with potential loss of cultural knowledge and archeological history, along with an increase in human health concerns (Desjardins and Jordan 2019; Ford et al. 2008).

Changes to transportation infrastructure also have an impact. Investment in bridge construction over waterways in rural Alaskan communities can offset the risk of over-ice travel during fall freeze and spring thaw events, with mixed impact on migration. In some cases, bridge construction can spur out-migration (Schweitzer and Povoroznyuk 2019) while easing the transportation of essential goods and people. A similar trend is true for road development in Arctic regions (Bennett 2018).

Factors keeping people in place

The ability to support subsistence livelihoods and intertwined benefits, both tangible (e.g., food, nutrition, holistic health, economic, language) and intangible (e.g., identity, culture, relationships, spirituality), is a primary reason for continuing to live in rural communities for many households in Canada and Alaska. Participating in subsistence is a way of life embedded in culture; people learn and share ways of being within an extended family, community, and culture through their connection to salmon, large land and sea mammals, and other resources essential for food security and the continuity of cultural practices. Residents of the Gulf of Alaska and Nunavut affirm these reasons for staying in their communities and value connections with home and place that afford a sense of freedom, comfort, and security (Ford et al. 2008; Wu 2021). Summer fish camps in Alaska are annual events that bring extended families together to work for a shared common purpose. Attachment to their communities underlies the desire to remain in place, regardless of higher costs of living or social factors that might influence migration (Huntington et al. 2017; Holen 2017).

Commercial fisheries provide meaningful livelihoods in some rural communities in Alaska, enabling residents to remain in place, often following their parents and creating economic viability (Dombrowski 2007). Lowe (2015) found that youth in coastal Alaskan communities prefer hands-on and outside jobs that allow self-direction and independence. Even with extreme climate threats and hazards, community members strongly desire to maintain their village, homelands, and access to subsistence food systems. Although out-migration occurs, it coexists with circular and seasonal migration critical to maintaining cultural ties and access to land and subsistence foods (Marino and Lazrus 2015).

Adaptation

Migration is not always the only option when climate change threatens human lives, property, and livelihoods; adaptation is an option. With adaptation, the affected areas and populations could take actions to cope with or mitigate the impacts of environmental stressors and adapt to the changing environmental circumstances. For instance, studies have shown that Indigenous people in the Arctic possess mutual respect among people, animals, spirits, and other beings, fostering a sustainable human–environment relationship and a resilient socioecological system (Fondahl and Irlbacher-Fox 2009) that enable them to adapt in place rather than pursue migration.

The climate adaptation literature reveals that, like migration, relocation of an entire community is not the first option chosen in the Arctic. Communities that face direct environmental threats, such as sea level rise, coastal erosion, and flooding, may take actions such as constructing protection (e.g., seawalls and wall revetments) and repairing or replacing damaged community infrastructure to remain in their current location. A recent case study of Utqiagvik in the North Slope Borough of Alaska found that, despite residents observing various hazards and environmental changes, relocation is not a prevalent plan (Garland et al. 2022). Instead, some Utqiagvik residents considered alternative adaptation strategies such as rock walls, home elevation, and sand berms as protection to mitigate the environmental impacts on the community and their properties, livelihoods, and cultural heritage.

Community-driven, collaborative, and participatory research play a crucial role in monitoring environmental change and assessing climate-driven risks, contributing valuable insights to inform effective adaptation strategies. For example, Allard et al. (2023) collaborated with 13 Inupiaq communities in Nunavik, Canadian Arctic, to assess permafrost conditions and geohazard risks. By accounting for diverse soil types and geomorphic conditions within the communities, the authors estimated future rates and locations of climate-induced permafrost thaw. The findings provide valuable insights for communities and policymakers, supporting decisions related to site selection for construction, building renovations, municipal infrastructure adaptation, and potential building relocation as elements of the adaptive strategies. Several additional community-based monitoring projects that can inform a community's

adaptation are showcased on the Exchange for Local Observations and Knowledge of the Arctic (ELOKA) website (Pulsifer et al. 2013).

Finally, more adaptation endeavors could be implemented after migration or relocation. It is important to note that, while migration or relocation may be viewed as adaptation, it is a disruptive process and comes with loss of important values and therefore might require further adaptation (Scudder and Colson 1982). However, as Ford et al. (2015) contend, adaptation becomes challenging in situations involving irreversible loss related to migration or relocation. Overcoming barriers, such as financial concerns, a slow or unprepared response to environmental change, and regulatory issues, is essential to facilitate relocation and adapt to the evolving environmental conditions induced by climate change.

Recommendations for Arctic social science research

Considering the complexity and uniqueness of environmental migration in the Arctic context

In the Arctic, little evidence exists of climate-driven migration at the individual and household levels, but clear evidence is available at the community level. This lack may reflect that migration is a complex and unique system in this context. We suggest four directions for future research.

First, supplement net migration (in-migration – out-migration) or gross migration (in-migration + out-migration) by modeling in-migration and out-migration separately, examining stepwise and circular migration, and considering duration (short-term, long-term, and seasonal). Partitioning migration into different components is particularly important in the Arctic because its demographic composition, socioeconomic status, and culture vary greatly by location. Meanwhile, migration studies should also consider origin and destination characteristics simultaneously, exploring the impacts of demographics, social capital, and social cohesion—and their interactions in both origin and destination in shaping migration decision-making.

Second, investigate how environmental stressors influence migration decisions over time, given the significant differences in environmental stressors that are prominent in lower-latitude regions. Permafrost erosion and diminishing sea ice are chronic or slow-onset environmental stressors, with thresholds problematic to human well-being only recently approached. Long-term consequences of climate change in the Arctic are yet to be fully realized and require study. Collecting longitudinal migration flow data at individual, household, and community levels, along with migrants' socioeconomic and demographic characteristics and their communities' contextual information, enables the exploration of even the impact of slow-acting environmental factors on migration decision-making.

Third, disentangle the drivers of climate and environmental migration from other pressing economic and social issues. Respondents are more inclined to see economic and social factors driving their actions than the impacts of climate change (Huntington et al. 2018). Climate change may indirectly affect economic well-being, social status, and health outcomes motivating migration decisions. Modeling and unraveling relationships among a suite of drivers, including environmental change, is challenging given the complexity, quality, and extent of data, but such research will greatly increase understanding of the drivers and their interactions. Models must include scale and time factors, along with "regional and national socioeconomic and sociopolitical conditions as well as household compositional characteristics" (Hunter et al. 2015: 379).

Fourth, research in the Arctic region often emphasizes the study of migration, focusing on individuals or populations leaving their homelands. However, research on "stayers" should be given weight similar to that of migrants. The narratives of stayers are fundamental in understanding the nuanced dynamics within a community; those who stay play a significant role in shaping the resilience and adaptive capacity of a community. Recognizing the voices of stayers is vital in providing a holistic understanding of the complex landscape of human responses to environmental changes in the Arctic.

Data collection and integration for tackling data challenges

Existing/traditional data Environmental migration studies require data that measure migration as well as environmental factors (see Table 2 for existing environmental migration–related datasets in the Arctic North America). However, the availability and quality of data have been a major issue. Most data, sourced from publicly available statistics like the US Census, the American Community Survey (ACS), Alaska vital statistics, and various State of Alaska sources, are crucial for demographic understanding. However, limitations exist for social and demographic research. For instance, ACS data face reliability issues in small rural areas because of increased sampling error, estimated to be 75% larger than the 2000 decennial Census long-form data's sampling error (Spielman et al. 2014). Alaska's official data, primarily designed for other purposes, may include migration questions in surveys conducted by the Alaska Department of Fish and Game (ADFG) but lack consistency. The Alaska Permanent Fund Dividend (PFD) provides migration analysis incorporating age and gender, as well as other socioeconomic characteristics; however, access to certain information is

Table 2 Existing environmental migration–related datasets for Alaska

Dataset	Time period	Description	Source
Arctic Data Center	Dataset time periods vary across data products	Arctic-related studies including data, software, and documents	https://arcticdata.io
Arctic Biodiversity Data	Dataset time periods vary across data products	Biodiversity data across the Arctic region	https://www.abds.is
Arctic Demography Index	2011–2019	Data on population change and educational, labor, snowbird, and sunshine migration in the five Arctic Council member-states (Russia, Finland, Norway, Sweden, Canada)	https://www.arctic-council.org/projects/arctic-demography-index
Scenarios Network for Alaska and Arctic Planning (SNAP)	Dataset time periods vary across data products	Historical and projected climatic conditions such as temperature, precipitation, and permafrost thickness	https://uaf-snap.org
US Census	1790–2020	Enumerations and estimates of the US population across time	https://www.census.gov
Canadian Community Health Survey	2001–2021	Health-related data at the community level in Canada, including Canadian Arctic	https://www.statcan.gc.ca/en/survey/household/3226
Internal Revenue Service (IRS)	1990–2021	County-to-county migration flows based on address changes reported in tax files	https://www.irs.gov/statistics/soi-tax-stats-migration-data
National Oceanic and Atmospheric Administration	Dataset time periods vary across data products	Data on weather conditions, ecosystems, and natural resources in Alaska	https://www.noaa.gov
Alaska departmental databases	Dataset time periods vary across data products	Vital statistics and historical and projected population in Alaska; can be used to construct migration measures and contextual socioeconomic and demographic factors	https://dhss.alaska.gov/Pages/default.aspx https://labor.alaska.gov
Alaska Satellite Facility	Dataset time periods vary across data products	Remote-sensing data in Alaska such as land cover and Normalized Difference Vegetation Index	https://asf.alaska.edu

restricted due to confidentiality constraints. In the Canadian Arctic, the Canadian Census and the Canadian Community Health Survey face similar issues. Despite various surveys and qualitative case studies, the vastness of territories like Alaska and Canada, coupled with small, scattered communities, limits the scope and timeframe of most studies. The SLiCA survey, conducted between 2001 and 2006 among multiple Indigenous populations in the circumpolar North, provides a comprehensive source of survey data across the Arctic, but it is now outdated (Eliassen et al. 2012).

Utilizing nontraditional data The research community has long advocated for alternative data sources to study human migration (Yin et al. 2022). Nontraditional sources, such as digital trace data, are records of human activities from online information systems, including social media, search engines, websites, and transaction systems. Individuals can be observed during their interactions with the information systems, such as phone calls, social media posts, or credit card transactions. A common use of geo-located digital trace data for migration studies involves tracking the movements of migrants by generating the location history of individuals over time. Three types of geo-located digital trace data are identified in the literature.

1. Mobile device location data: The geo-locations of mobile devices can be identified by mobile positioning technology through cell towers, GPS, and Wi-Fi. Because of the ubiquitous use of mobile devices, these data are useful in studying population distribution, short-term urban mobility, and large-scale human migrations (Hankaew et al. 2019).
2. Geo-located social media data: When people interact on social media, the location information of the interactions is collected by social media platforms. Researchers have used Facebook data to study migration patterns (Spyratos

et al. 2018) and their ties to specific events, such as the impact of Hurricane Maria on out-migration from Puerto Rico (Alexander et al. 2019).

3. Residential history data: Residential history data, also known as consumer reference data, are collected through consumer transactions. Residential history data can provide a much more accurate estimation of an individual's residence (Stewart 2021). The data are particularly useful for examining migration patterns at fine spatial and temporal scales.

Digital trace data show great potential for migration research, contingent upon the widespread adoption of digital technologies. Digital information from smartphones, high-speed Internet, and digital payment systems, are limited in the Arctic (Abramov et al. 2021). Social media use is skewed toward a younger demographic, some populations (particularly low income or homeless) lack cell phone use, and certain populations have poor access to digital transaction systems. Yet, with fast Internet connections from 5G networks and from potential worldwide satellite broadband, it is expected that more people will adopt digital technologies.

Systematic data collection and integration Obstacles to acquiring comprehensive understanding of migration behavior and decisions are rooted in inconsistent units of analysis and study areas and lack of comparable data. Studies often are conducted at different levels of analysis, from individuals to families and households, whole communities, and multiple administrative units. While informative, they lack consistency and comparability. Similarly, noncomparable geography limits comparisons across places. The small populations in widely scattered settlements mean there are small numbers of cases, even in quantitative studies, thereby limiting multivariate data analysis. Difficult data management decisions and tasks arise when data are collected from different sources, such as matching geophysical data on environment and climate with social and demographic data related to migration.

The urgency of managing, mitigating, and adapting to climate change means that more-comprehensive efforts at collecting data across Arctic regions should be a priority. This can be done in three ways. First, existing social data, collected by federal, state, and regional agencies, could be collaboratively integrated into a clean database. Such a database should clearly specify the geography, time, scale, variables, and other information (Pulsifer et al. 2012). The Integrated Public Use Microdata Series (IPUMS) data that were assembled and harmonized by the Minnesota Population Center is a good example. Second, federal, state, and regional agencies, alongside public and private funding bodies, should collaborate to streamline social data collection in the North Slope of Alaska and Canada. Existing efforts, including those by the US Census Bureau, the North Slope Borough, and the National Science Foundation, can be integrated to avoid duplication and reduce the burden of data collection on Arctic communities. However, these data sources are often developed independently, emphasizing the need for a coordinated protocol to enhance comparability, accessibility, and efficiency for research and policy purposes. Third, increased funding for Arctic social science research, particularly longitudinal migration data, is vital. With only 5% of global research funding allocated to social science over the past two decades, our understanding of Arctic social dynamics lags behind that of other regions. Given the urgency of climate change, increased investment is essential for informed adaptation.

Conclusions

Arctic temperatures are rising four times faster than in the lower-latitude regions. Some of the hardest-hit places are rural, coastal, predominantly Indigenous communities. Many communities face multiple urgent climate-related challenges, including thawing permafrost, declining sea ice cover, coastal erosion, and extreme storms. Out-migration, community relocation, and/or staying but enhancing community resilience are common adaptation strategies for addressing these challenges. However, research in this area is limited, even for the most threatened communities.

This paper provides a comprehensive review of the roles that environmental stressors, along with traditionally considered contextual factors, play in Arctic migration decision-making in the North America Arctic. We found that migration is driven mainly by job opportunities, education, healthcare, cultural, and infrastructural factors. But the staying factors—family, culture, feeling safe, subsistence life, and sense of community—have strong effects in retaining residents. We did not find clear evidence of climate-driven migration at the individual/household level, but there is clear evidence of community-level relocation in the existing literature. In addition, some communities adapt to climate threats by enhancing their infrastructure and resilience.

This paper also identified two major challenges in studying climate migration in the Arctic and made recommendations to tackle them. One challenge lies in the complexity of migration and the uniqueness of climate change in the Arctic. We recommend comprehensively considering the migration typology (duration, destination, and status) and disentangling climate drivers from other migration push/pull and staying factors. The other challenge is that existing data in the Arctic are lacking, fragmented both in terms of time and geography. We recommend systematic data collection and integration by leveraging existing social data,

collaborative data collection among the funding agencies and research teams, funding allocation for geographically referenced longitudinal social data, and utilizing nontraditional data creatively. Meanwhile, achieving a holistic understanding of the environmental and nonenvironmental factors driving migration or immobility in the Arctic relies on establishing partnerships and engagements with local communities. This factor helps ensure that the research process and its outcomes are intricately linked to addressing a community's challenges and meeting its specific needs. Overall, this review provides a foundation for empirical migration and community adaptation research to better understand the challenges faced by Arctic communities and the potential solutions to these challenges.

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Data availability This review article does not include any empirical data.

Declarations

Competing interests The authors declare no competing interests.

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