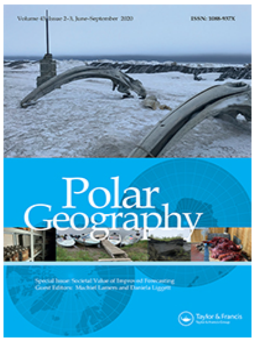

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Usteq: integrating indigenous knowledge and social and physical sciences to coproduce knowledge and support community-based adaptation

Robin Bronen[a,b], Denise Pollock[a], Jacquelyn Overbeck[c], DeAnne Stevens[d], Susan Natali[e] and Chris Maio[f]

[a]Alaska Institute for Justice, Research and Policy Institute, Anchorage, AK, United States; [b]Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, AK, United States; [c]Alaska Division of Geological and Geophysical Surveys Coastal Hazards Program, Fairbanks, AK, United States; [d]Engineering Geology Section, Alaska Division of Geological & Geophysical Surveys, Fairbanks, United States; [e]Arctic Program, Woods Hole Research Center, Falmouth, MA, United States; [f]Department of Geosciences, College of Natural Science and Mathematics, University of Alaska Fairbanks, Fairbanks, AK, United States

ABSTRACT

The Arctic is in the midst of unprecedented and accelerating environmental change and will not return, for the foreseeable future, to a reliably frozen climate of recent past decades. Climate-forced population displacement, including community relocation, will be one of the greatest climate adaptation challenges for Alaska Native communities and the tribal, state and federal governing entities responsible for protecting community residents and providing technical assistance and resources. A new governance framework, based in human rights principles, must be created that can allow institutions to shift their efforts from protecting people in the places where they live to creating a relocation process when environmental and social thresholds are surpassed. Determining which communities are most likely to encounter displacement will require a sophisticated assessment of a community's ecosystem vulnerability to climate change, as well as the vulnerability and adaptive capacity of its social, economic and political structures. In Alaska, understanding the rate of environmental change through the integration of indigenous knowledge with physical and social science is essential. The article describes how this coproduction of knowledge is the foundation for this new governance framework and for transformational climate adaptation in Alaska.

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Introduction

The Arctic region, including Alaska, is warming at an accelerated and unprecedented rate (Huang et al., 2017), resulting in warmer oceans, melting glaciers, decreased seasonal sea ice extent, and thawing permafrost (Jones et al., 2018). The risks and severity of climate impacts are particularly great for coastal communities in Alaska, where loss of land-fast sea ice is increasing storm impacts (Fang, Freeman, Field, & Mach, 2018; Vermaire et al., 2013) at the same time that permafrost thaw is exacerbating coastal erosion rates (Kates,

CONTACT Robin Bronen robin.bronen@akijp.org Alaska Institute for Justice, 431 W. 7th Ave. Suite 208, Anchorage, AK 99501, United States; Institute of Arctic Biology, University of Alaska Fairbanks, Fairbanks, AK, United States

Travis, & Wilbanks, 2012). Since the 1980s, Arctic seas have remained ice-free approximately three weeks longer in autumn compared to the historical record (Jones et al., 2018). Ice loss in late winter and spring is also occurring increasingly earlier in the season; for example, March 2019 sea ice extent in the Bering Sea was the lowest in the 40 years of satellite record for this time period (NSIDC, 2019). The delay in freezing of the Arctic seas prevents the formation of land-fast ice—which creates a natural buffer that attenuates wave energy (Eerkes-Medrano et al., 2017)—thereby exposing many communities to stronger storm impacts in autumn and early winter (Tweedie, Aguire, Vargas, & Brown, 2012). Coastal storms also bring hurricane-strength winds (Shulski & Wendler, 2007), damaging infrastructure vital to Alaska's coastal communities.

In addition to coastal storms, the land itself is affected by increases in air and ocean temperature. Permafrost underlies much of Alaska (Pastick et al., 2015), and this perennially frozen ground helps keep the land intact and habitable along the Alaska coast by providing a stable foundation to build upon and travel across (Jorgenson, Frost, & Dissing, 2018). When ice-rich permafrost thaws, the structural integrity of critical infrastructure, such as airports, health clinics, landfills, and sewage lagoons (City of Quinhagak Mitigation Planning Team, 2012; GAO, 2009), can be at risk from ground collapse, or subsidence. Subsidence also increases flood risk through lowering of the land surface (DHSEM, 2018). Coastal bluffs that were once 'cemented' by permafrost are thawing due to thermo-erosional and mechanical processes, leaving them more vulnerable to erosion from wave attack during coastal storms. In turn, inundation of land by sea water contributes to further destabilization of permafrost (Jorgenson et al., 2018). Working in concert, flooding, erosion, and permafrost thaw exacerbate the vulnerability of land and can lead to *usteq*—catastrophic destruction of permafrost with associated land collapse (DHSEM, 2018).

In Alaska, these climate-induced environmental changes are causing some Alaska Native communities to choose to relocate (Bronen, 2011). Currently, no methodological or governance framework exists in the United States to evaluate climate-change impacts and determine when people can no longer be protected in-place and need to relocate. Recognizing this institutional gap and the complex challenges of climate-induced population displacement, the Congressional Bicameral Task Force on Climate Change recommended in their December 2013 report:

> ... that the Administration devote special attention to the problems of communities that decide they have little choice but to relocate in the face of the impacts of climate change. Because the relocation of entire communities due to climate change is such an unprecedented need, there is no institutional framework within the U.S. to relocate communities, and agencies lack technical, organizational, and financial means to do so. (Waxman et al., 2013)

President Obama's Task Force on Climate Preparedness and Resilience echoed this recommendation in November 2014 and affirmed that the federal government should take a lead role in establishing an institutional relocation framework to respond to the complex challenges of climate-related population displacement (White House, 2014). Despite this recommendation, the federal government has still not established this framework.

In Alaska, former Governors Palin and Walker created working groups to address the impacts of climate change in Alaska, including the urgent planning needs for environmentally threatened communities. These working groups developed recommendations to advance comprehensive integrated planning for these communities (IAWG, 2008; IAWG, 2009). These efforts were suspended after Governor Palin resigned in 2011 and not revived until 2018 when the Climate Action Leadership Team (CALT) made their own recommendations under Governor Walker's administration. The current state government administration disbanded the CALT, leaving the Alaska state government without clear pathways on issues related to climate change including on relocation.

This lack of a definitive governance framework hampers the ability of local, regional, and national government agencies to respond. New governance institutions need to be designed to determine whether people can be protected in-place or require relocation (Bronen, 2011; Bronen & Stuart Chapin III, 2013). Relocation is a long-term planning process requiring the identification of a relocation site where a community's housing, assets, and public infrastructure can be rebuilt (Abhas, 2010). In addition to moving or rebuilding infrastructure, relocation can also include the social processes of rebuilding livelihoods and maintaining kinship ties and social networks. Severe economic, social, and environmental consequences can occur in the relocation process (Bronen, 2011). The potential detrimental effect of relocation on the health and well-being of Alaska Native communities is evidenced by the impacts of past government-mandated forced relocation (e.g. relocation of Alaska Natives on Aleutian Islands during World War II; Mobley, 2012). Yet, in the face of these challenges, community-led relocation can be a transformational adaptation strategy that fosters resilience (Kates et al., 2012; Warner et al., 2019).

This paper will first outline the components of an adaptive governance relocation framework and some of the laws that govern protecting communities in the places where they are located, including the hazard mitigation planning process. The paper next describes how the co-production of knowledge created the foundation upon which we worked with Alaska Native communities to design and implement community-based environmental monitoring, which is an essential component of this framework. The results we present are based on the first phase of our research.

Methodology section

Community engagement and empowerment, well-established relationships, and community-prioritized research are central to meaningful co-production of knowledge. A nonprofit organization with a focus on climate adaptation research (whose name we cannot disclose for confidentiality reasons), has worked to develop these relationships and facilitate community engagement and empowerment in Alaska Native communities since 2015. This paper describes multi-year work with two Alaska Native communities, Nunapitchuk and Quinhagak, located in the Yukon-Kuskokwim Delta to develop the monitoring and assessment tools to facilitate conversations about adaptation strategies, including relocation.

Indigenous self-determination in research is put into action when tribal organizations or Indigenous representational organizations are engaged in the research agenda in their homelands, have equitable opportunities to access funding for Indigenous-led research, and are engaged as partners with researchers in the design, implementation, and dissemination of the research (Inuit Tapiirit Kanatami, 2018). In order to ensure that research activities, goals, and outcomes are led by Indigenous communities, this research was led by Alaska Native researchers who understand the intricacy and extent of Indigenous relationship-building protocols, which require reflection, time, and trust.

The Indigenous-led design of the social-environmental monitoring and assessment tool builds from a foundation of existing relationships developed between the communities participating in this project and the research team. During the past four years, this collaboration has developed through mutual trust and respect, genuine interest in learning from one another, and shared commitment to common goals. Our approach recognizes that communities are likely to be more engaged in, and benefit from, research that empowers them to participate as equal partners in the design and implementation of research to explicitly address their needs (Friere, 1970; Reid & Green, 2009).

Guided by an Alaska Native elder, we engaged in an iterative process of unstructured interviews and biweekly teleconferences with communities to identify four hazards each community wanted to monitor: erosion, storms, thawing permafrost and flooding. Alaska Native peoples' deep connection with their environment, informed by millennia of fishing, hunting, and traveling across the land, helped determine what types of Indigenous knowledge would be applicable to understand local environmental observations and impacts. For example, the criteria for the storm reports, developed with participating Alaska Native communities, outline seven factors that determine the severity of a storm: duration (hours, days, and time of day), high tide of the day, high tide of the month, wind direction, wind velocity (speed), precipitation, and ice thickness/lack of sea ice. The identification of these seven factors was dependent on local Alaska Native Indigenous knowledge holders, whose expertise draws on lifelong experiences of fishing and hunting on nearby waters and lands. These are the parameters by which local individuals assess how high a flood event might be and compare the event to past experienced events to know how to respond.

We also did an extensive literature review, including documentation of Indigenous knowledge and oral histories, a survey of hazard mitigation plans, disaster declarations, and erosion studies. We worked with each community to synthesize the information and understand the large gaps of community-specific information to address identified environmental hazards and understand extreme weather events. For example, local hazard mitigation plans identify hazards and articulate mitigation recommendations. Yet, the plans often include recommendations to monitor local environmental change but provide no financial or technical resources to assist with implementing the recommendation.

> We need to have our own community members monitor climate impacts. We are the ones who have seen the environmental changes occurring since we have lived here over the span of many years or decades. Outsiders will come in and do assessments, but they have no understanding of our cultural knowledge. Our hunters gather food from springtime until freeze-up. They are natural observers and we can train them to assist in climate change monitoring.
>
> -Kwigillingok tribal member.
>
> (Comments submitted by aforementioned nonprofit organization to the Federal Emergency Management Agency updates to tribal hazard mitigation planning process)

In addition, in reviewing state disaster declarations we found that the declarations often covered large areas of land where dozens of villages were located, but only a few of the villages within a declared disaster area had documentation of storm impacts, which is needed to receive state and federal disaster assistance. Based on this review, we synthesized the documentation for each community related to environmental change and storm events. We next validated this information with each community and then asked them to identify the most important environmental factors to monitor.

Following these initial steps of information gathering, we focused on three key levels of collaboration to foster the coproduction of knowledge (1) across multiple governance levels within each community; (2) between Indigenous knowledge holders, scientists, and state and federal government agency representatives; and (3) among participating communities. This co-production of knowledge process occurred through a series of meetings, workshops, and participatory training and data collection in the field, aimed at increasing understanding and exchanging knowledge among researchers and collaborating communities.

At the community level, we worked to ensure the local governing entities and community residents are guiding the research objectives and that these objectives are aligned with community-identified priorities. Through these efforts, we ensured coproduction of knowledge within communities and between Indigenous knowledge holders, scientists, and agency representatives. This collaboration has been facilitated through biweekly teleconferences and annual field visits for the past several years. We found that this frequency is optimal for maintaining regular communications and building trusting relationships.

During annual visits, we have worked with local governing entities to facilitate three community meetings. The first meeting occurred between team members of aforementioned nonprofit organization and the governing entities to provide general updates and information, and to gain feedback and guidance on the work to be done in the community. Working under the direction of these local governing entities, we then organized a second community meeting between local residents and the visiting research team to provide a platform for community residents to guide and inform the research tasks. The third community meeting brought together Indigenous knowledge holders and visiting scientists to develop a relationship that leads to the coproduction of knowledge. These meetings allow for on-site discussions regarding long-term environmental trends in the area and examples of extreme events such as storms or floods.

We have also facilitated integration *among* communities through biweekly teleconferences and, since 2015, at an annual 3-day adaptation workshop. The goal of the inter-community collaboration is to provide a platform where the Alaska Native community participants can openly discuss local research priorities, challenges they have encountered, and successful strategies for coproducing knowledge between the individual communities and the research team. The adaptation workshop provided opportunity for further integration between Alaska Native communities, researchers, and state and federal government agencies. Approximately 40 community members from 15 Alaska Native communities have participated in these workshops each year. The participants work together to develop the agenda of each workshop to ensure workshop outcomes facilitate local adaptation planning. Some sessions are dedicated to the facilitated engagement of community leaders with representatives of state and federal agencies who provide technical assistance and resources to respond to the adaptation needs of each community.

Through these processes of community engagement, the communities of Nunapitchuk and Quinhagak requested the installation of erosion and permafrost monitoring equipment and identified the locations where this equipment needed to be installed.

Alaska examples

In Alaska, the combination of decreased Arctic sea ice extent, thawing permafrost, and repeated extreme weather events is threatening the lives and livelihoods of several Alaska Native communities that are geographically remote, where year-round transportation and importation of goods occurs primarily from airplanes. For most of rural Alaska, there are no built roads to facilitate travel to or from these villages. Most villages are federally-recognised Indigenous tribes, and subsistence hunting and gathering are central to their culture and survival (GAO, 2009). Village life revolves around these activities, with the resources obtained from the natural environment forming the basis for community cohesion, social identity, livelihoods, and cultural events. The villages have small cash economies and only limited work opportunities. Food bought in stores is expensive because of the high cost of its transport to isolated areas, making subsistence activities vital to the communities' food security.

Quinhagak

Quinhagak is bordered by the Bering Sea in Kuskokwim Bay, the Kanektok River, and many shallow lakes in a wetland environment. Much of the community infrastructure is at least 4 meters above mean sea level. The community is home to approximately 700 primarily Yup'ik residents (City of Quinhagak, 2012; POWTEC, 2012). Erosion, river flooding, coastal storm surges, and thawing permafrost threaten residential dwellings, critical community infrastructure, and livelihoods. Flood hazards are high because the developed areas of Quinhagak are adjacent to the floodplain of the Kanektok River. Because of its close proximity to the Bering Sea, Quinhagak is also exposed to storm surges (City of Quinhagak Hazard Mitigation Planning Team, 2012; POWTEC, 2012).

Critical infrastructure affected by these hazards includes the only functional dock in the community, the health care clinic, and the sewage lagoon (City of Quinhagak Hazard Mitigation Planning Team, 2012; POWTEC, 2012). In addition, vessels have great difficulty navigating the channels leading to the dock because of silt and large tidal action (POWTEC, 2012). Fuel barges have been stuck and are often damaged (POWTEC, 2012). The inaccessibility of the dock to the barges sometimes requires that fuel be flown into the community at a huge expense to the community. The communities' sewage lagoon has no barrier between it and advancing coastal erosion (Pleasant, 2013). Because of the importance of this critical infrastructure to the community, an *usteq* monitoring site was installed, through this work, fronting the sewage lagoon (described below). The community also has a housing crisis, with one-third of homes unfit for human habitation due to significant subsidence resulting from permafrost thaw, and subsequent infiltration of mold and rot. Erosion also threatens residences and fish camps (POWTEC, 2012).

The Alaska Legislature established the Alaska Climate Change Mitigation Program (ACCMP) in 2008 with funding to address the immediate planning needs of communities imminently threatened by climate-induced environmental change, such as erosion (Bronen & Stuart Chapin III, 2013). Through this program, Quinhagak was one of six communities that received funding to complete a Hazard Impact Assessment (HIA). No additional funding has been allocated for this program. In addition, the City of Quinhagak completed a Hazard Mitigation Plan in January 2012, a month prior to the completion of the HIA (City of Quinhagak Hazard Mitigation Planning Team, 2012).

The HIA recommends monitoring rates of environmental change, such as sea level rise and erosion, in order to reduce the cost of repairing and replacing infrastructure and to address the critical need for data to better predict rates of climate-induced environmental change (POWTEC, 2012). However, no mechanism was in-place to facilitate this monitoring and no financial or technical resources were provided to assist community residents with this critical process.

Based on the ACCMP legislation, Quinhagak is eligible for additional adaptation funding so it is possible that these funds could be used for monitoring and assessment. However, with limited funding and many critical adaptation needs, it is uncertain whether this funding will be used for monitoring and assessment. In addition, the state of Alaska is currently in a fiscal crisis and no funding has been allocated to continue this work.

Nunapitchuk

Nunapitchuk is built on three riverbanks along the North Fork of the Johnson River, a tributary of the Yukon River, and lies in lowland tundra patterned with thousands of small lakes and rivers. The community is home to over 584 people, who primarily identify as Yup'ik (Alaska Department of Commerce, Community, and Economic Development, 2015). Intense and ongoing erosion, permafrost degradation, and flooding have led residents to relocate infrastructure to locations further away from environmental hazards.

A 2007 U.S. Army Corps of Engineers survey found that homes, fuel tanks, the cemetery, drying racks, smoke houses, food storage facilities, utility poles and lines, power generators, the old Bureau of Indian Affairs school, clinic, church, and the airport runway are all at risk of erosion (USACE, 2007). In 2015, a Nunapitchuk community erosion survey estimated that the erosion rate is 1.2 meters per year (Alaska Department of Environmental Conservation, 2015). *Usteq* is a threat as erosion of the riverbank promotes thawing of permafrost near the river's edge, which results in localized ground failure inland of the riverbank, which contributes to further erosion and flooding.

The Nunapitchuk Hazard Mitigation Planning Committee reported that uneven settling within the community has damaged buildings and boardwalks constructed above permafrost. The City power plant was relocated to Kasigluk, Alaska in 2006; the Moravian Church building collapsed in 2016; the City Laundromat, tank farm foundations, and sanitation structures are failing; and home foundations and boardwalks are failing throughout the community due to impacts from permafrost thaw and ground failure. Recently, sandbags were used to keep water out of lower elevation buildings and homes (Nunapitchuk Hazard Mitigation Plan Local Planning Committee, 2018). In February 2019, a sinking residential home was filled with flood waters after unusual heavy rainfall and mid-winter snow melt (Morris Alexie, personal communication, February 7, 2019).

Erosion and permafrost degradation have also resulted in the collapse of land (*usteq*) that the Nunapitchuk sewage lagoons and dumpsites are located on. As a result, contaminants and leachate from the dumpsites and sewage lagoons may have been transported to groundwater, contaminating drinking water and fish, and resulting in a health and sanitation crisis in Nunapitchuk (Nunapitchuk IRA Council, 2014). The town's sewage lagoons and dumpsites are all located upstream from Nunapitchuk. Education efforts exist in the community regarding the impacts of contact with raw sewage and pathogens that could lead to tuberculosis. There have been numerous cancers within the village, which may be related to contamination of the streams around the village (Nunapitchuk IRA Council, 2014).

The community of Nunapitchuk has implemented erosion mitigation measures; however, all had substantial financial costs, and none have been sustainable in the long-term. In 2007, the community attempted to control erosion with riprap and 2"x12" timbers, at a cost of $900,000 (Nunapitchuk Hazard Mitigation Plan Local Planning Committee, 2018). The measures have not been effective due to subsidence caused by permafrost thaw. Erosion caused damage to the generator building, which was repaired at a cost of $250,000, and one home was relocated by a resident at a cost of $4,000 (Nunapitchuk Hazard Mitigation Plan Local Planning Committee, 2018). Until the community is able to relocate, it has included two erosion mitigation actions in its 2018 Hazard Mitigation Action Plan: (1) submit a written request for a U.S. Army Corps of Engineers Section 14, Emergency Streambank Restoration study; and (2) apply for grants/funding to implement riverbank protection (Nunapitchuk Hazard Mitigation Plan Local Planning Committee, 2018).

While erosion mitigation measures can protect the village short-term, the Native Village of Nunapitchuk recognizes the need to make short-term decisions to prioritize the migration of structures away from erosion and *usteq*. At the same time, the community needs to make long-term decisions related to the relocation of their entire community to higher ground. There is no stable land on which to build additional homes due to land subsidence and erosion (Nunapitchuk Hazard Mitigation Plan Local Planning Committee, 2018). In 2008, the community of Nunapitchuk requested a Relocation Feasibility Study, but the State of Alaska vetoed their $50,000 funding request. The community of Nunapitchuk is still advocating for a Relocation Feasibility Study to help determine whether relocation is warranted and which areas would be well-suited for relocation (Nunapitchuk Hazard Mitigation Plan Local Planning Committee, 2018). In February 2019, Nunapitchuk city and tribal representatives attended a Relocation Meeting hosted by the Alaska Institute for Justice to outline land owned by the Tribe that could potentially serve as a relocation site.

Adaptive governance relocation framework

To address both the severe consequences of government-mandated relocations and the lack of a uniform methodology to assess climate change risk in relation to the ability of people to remain where they currently live, this paper posits the design of an adaptive governance relocation framework that: (1) enables the coproduction of knowledge with Indigenous knowledge holders and physical and social scientists; and (2) supports the design of an environmental monitoring and assessment tool. The design of an environmental monitoring and assessment tool is part of a larger monitoring effort to understand the impact of environmental change on the health and well-being of community residents. An adaptive governance framework would enable governance institutions to dynamically respond to climate-induced environmental changes and shift their efforts from protection in-place to managed retreat and community relocation (Bronen, 2011; Bronen & Stuart Chapin III, 2013).

In Alaska, Indigenous knowledge is foundational to the creation of an adaptive decision-making framework. The governance systems of Arctic Indigenous communities must actively lead the design and implementation of this relocation governance framework because these communities are some of the first to be impacted by severe climate change hazards and faced with the difficult decision to relocate. In Alaska, Alaska Native communities often have three local governing entities: a tribal government, a city government and a village corporation created by the Alaska Native Claims Settlement Act that has governing authority over some land issues within a community. The successful creation and implementation of this framework requires that these governing entities work together to create a multi-level and interdisciplinary governmental decision-making process and that nongovernmental actors understand the importance, relevance, and proper protocol for integrating Indigenous knowledge into governance and adaptation decision making. This will ensure a collaborative process of knowledge production and problem solving.

Protection in-place and hazard mitigation

Responding to environmental hazards in Alaska Native communities presents some unique challenges that require a tailored response based on the environmental, social, and cultural characteristics of each community. The Federal Emergency Management Agency (FEMA) is the national agency responsible for hazard mitigation and disaster relief in the United States (GAO, 2009). These are essential tools for evaluating whether people can be protected in the places where they live and maintain livelihoods. The Robert T. Stafford Disaster Relief and Emergency Assistance Act, enacted in 1988, defines all FEMA post-disaster relief and hazard mitigation activities (Stafford Act, 1988). The Disaster Mitigation Act of 2000 modified the Stafford Act by establishing a national program for pre-disaster mitigation (Disaster Mitigation Act, 2000). Mitigation activities are designed to protect communities from natural hazards that may endanger people or incur permanent property damage (Stafford Act, 1988). Mitigation measures may be implemented prior to, during, or after a disaster and involve 'ongoing actions to reduce exposure to, probability of, or potential loss from hazards' (USDHS, 2004). Hazard mitigation planning is intended to reduce reliance on federal resources in the event of a disaster and to minimize the damage caused by severe weather events (Moss & Shelhamer, 2007).

Federal funding is available through the Hazard Mitigation Grant Program (HMGP) to develop a Local Hazard Mitigation Plan. Only communities that have a Local Hazard Mitigation Plan, adopted by the community and approved by FEMA and the state in which the community is located, can receive FEMA funding to implement hazard mitigation activities (See, 44 CFR §201.6). States are also required to develop a State Hazard Mitigation Plan in order to receive FEMA funding. Mitigation planning requires a comprehensive risk assessment, which consists of three components: hazards identification, vulnerability assessment, and risk analysis (See, 44 CFR §201). The identification and description of hazards is the first step. Vulnerability assessments then identify the critical infrastructure in a community that is susceptible to damage by these hazards. Facilities are designated as critical if they are: (1) vulnerable due to the type of occupant (e.g. children or elderly); (2) critical to the community's ability to function (e.g. health clinics, transportation systems such as airways and roads, power generation facilities, or water treatment facilities); (3) have a historic value to the community (e.g. cemetery); or (4) critical to the community during the post-disaster response and recovery (See, 44 CFR §201).

A risk analysis is the third component of a Hazard Mitigation Plan and is intended to calculate the potential damage to determine which hazard will have the greatest impact on the community (See, 44 CFR §201). This risk assessment requirement is intended to provide information that will help the community identify and prioritize mitigation activities to prevent or reduce losses from the identified hazards. Local mitigation plans must contain a cost benefit analysis that examines the economic assessment of each mitigation action (See, 44 CFR §201.6(c))(3)(iii). There is no requirement to continuously update the hazard mitigation plan as conditions change, although the regulations do recommend that approved mitigation plans be reviewed at least every five years.[1]

The hazard mitigation planning process is a critical tool to evaluate risk, and the primary tool used by communities to assess vulnerability, but as currently configured inadequate to assess whether relocation or protection in place can provide long-term protection from hazards. This assessment is currently made by outside consultants, typically hired by the state government, with limited knowledge of the community. Incorporating community-

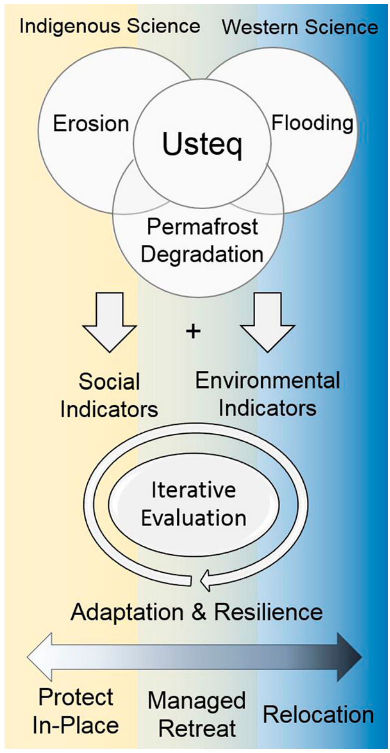

Figure 1. Proposed adaptive governance framework to support sustainable climate change adaptation strategies.

based monitoring into hazard mitigation planning can provide the mechanism to dynamically assess risk and evaluate the best long-term adaptation strategies to protect the lives and livelihoods of community residents (Figure 1).

Community-based monitoring is the foundation of an adaptive governance framework

We have identified four governance questions that must be addressed in order to create an adaptive governance relocation framework that enables a shift from protection in-place and hazard mitigation, and fosters the resilience of relocated populations. The Alaska Native communities with whom we work identified these questions during a 2019 in-person climate adaptation meeting specifically focused on the issue of relocation. The first three questions involve the decision-making process: (1) who has the authority to decide that relocation is warranted; (2) what is the basis for making the decision; (3) and when does the decision need to be made? The fourth question, which must be addressed by a relocation institutional framework, is: what are the mechanisms to foster the long-term resilience of community residents before, during, and after the relocation has occurred? Based on the first phase of our research, our preliminary results show that community-based integrated environmental and social monitoring and assessments can lay the foundation to address all of these adaptive governance issues.

The next phase of our research will focus on developing an Indigenous-led process to answer these questions. The relocation decision-making process is more meaningful and effective when each Alaska Native community outlines their Indigenous knowledge, history, and expertise related to their sense of place and how that will transform in the future. Furthermore, Alaska Native communities must determine which representatives within their communities will draw upon existing Indigenous knowledge and ongoing community-based monitoring to make decisions regarding relocation.

Community-based integrated monitoring and assessments can also foster empowerment, promote human rights protections and encourage transparent decision-making processes—all elements of good governance (Alfredsson, 2013). Monitoring occurs through the qualitative and quantitative documentation of environmental change and assessments are the process of understanding how environmental change is occurring and its impact on community infrastructure, health and well-being. People have the right to make decisions regarding adaptation strategies, including the right to make fundamental decisions about when, how, where, and if relocation occurs in order to protect them from climate-induced environmental threats (Bronen, 2011). To operationalize this right, people need the capacity to assess, document and predict the rate of environmental changes and sociological impacts and vulnerabilities caused by climate change (May & Plummer, 2011). In this way, they can determine whether the risks can be mitigated where they currently reside. However, the ability of this community-based process to foster human rights will depend on the capacity of governance institutions to collaborate, be transparent in decision-making, and be inclusive of all sectors of society.

These assessments can also be the tool to determine whether and when relocation needs to occur. Local-level environmental change assessment is essential in order to determine when relocation needs to occur. Global, regional, and national climate change assessments have generally aggregated information above the level of resolution required for effective community policy (IPCC, 2012). Local landscape conditions and microclimate can outweigh the influence of regional climate trends detected by coarse-scale geospatial analyses and future climate projections estimated by global-scale models (Sallenger, Doran, & Howd, 2012). For example, at local and regional levels, changes to sea level vary and may exceed averaged global projections, depending on a variety of dynamic geologic processes, including ocean circulation, temperature, salinity, and mass redistributions changing the Earth's rotation and shape (Sallenger et al., 2012).

In addition, exposure and vulnerability to climate change are dynamic, varying across temporal and spatial scales, and depend on economic, social, geographic, demographic, cultural, institutional, governance, and environmental factors (IPCC, 2012). Consistent monitoring of environmental change and the impact of these changes on individuals, households, and the larger community offers the opportunity to capture the dynamic nature of a community's vulnerability and resilience to the changes. Decision makers at the local level need to understand how their particular locality is affected by global and regional projections of climate-induced environmental change and have the governance tools to help them effectively identify and evaluate the best policy options to adapt to their local context.

To answer the question about when a relocation process should begin, community-based social and environmental monitoring can identify the social and environmental indicators to assess when protection in-place no longer provides a community with long-term sustainable adaptation to climate hazards and guide the transition from protection in-place to community relocation. These indicators have not yet been identified and are part of the next phase of our research.

Finally, community-based integrated social and environmental monitoring and assessments can facilitate communication between community residents and local, state, regional, and national actors who can bring broader knowledge to local scenarios in order to better understand local dynamics. Government agencies that may not have access to local information to understand local scenarios need this information in order to integrate this information into regional or national models of climate-change scenarios (Lewis, 2012). In this way, both residents and government agencies together can anticipate vulnerability in order to implement a dynamic and locally informed institutional response. They can also bring technical expertise that may not exist at the local level to better assess and implement adaptation strategies. Through the integration of Indigenous knowledge with physical and social science to implement community-based monitoring, the adaptive capacity of communities is strengthened to respond to risks associated with accelerating environmental change and can be one of the mechanisms that fosters the resilience of the populations assessing whether relocation is the best long-term adaptation strategy.

Community-based monitoring requires the coproduction of knowledge

In Alaska, a community-based monitoring and assessment process, designed with Indigenous knowledge holders and physical and social scientists, can provide the foundation for the coproduction of knowledge to build adaptive capacity (May & Plummer, 2011). The coproduction of knowledge provides a critically-needed framework for community-empowered adaptation planning and more effective integration between bottom-up and top-down planning, monitoring, and assessment (Berkes, 2009; Urwin & Jordan, 2008). Collaboration among diverse institutions can provide critical data to determine whether and when relocation needs to occur. Objective assessment of a hazard, the social perception of that hazard, and the ability to anticipate the sociological effects of ongoing environmental changes are critical to the development of adaptive capacity and ability to respond to environmental hazards (Correa, 2011). To integrate the concept of collaboration into conventional hazard risk management, those most directly affected by the hazard must actively participate in the gathering of data during the risk assessment process (May & Plummer, 2011).

Hazard mitigation and adaptation decision making must be based on Indigenous frameworks of knowledge if they are to be relevant to Indigenous communities. The Inuit Circumpolar Council (2013) defines Indigenous knowledge as:

> A systematic way of thinking applied to phenomena across biological, physical, cultural and spiritual systems. It includes insights based on evidence acquired through direct and long-term experiences and extensive and multigenerational observations, lessons and skills. It has developed over millennia and is still developing in a living process, including knowledge acquired today and in the future, and it is passed on from generation to generation.

Indigenous knowledge provides not only a long-term historical perspective but an understanding of the connections between people and the environment, while atmospheric and physical scientific approaches can generate quantified rates and projections of current and future change (Kannen & Forbes, 2011). In Alaska, the wealth of Indigenous knowledge, oral history, and written documentation related to their sense of place must form the foundation upon which community-based monitoring is designed and implemented. In *Erinaput Unguvaniartut: So Our Voices Will Live*, elders from Quinhagak, Alaska describe how the land and waters near Quinhagak have changed and impacted community residents and caused the relocations that have occurred in the past. Elder Arnariaq George Pleasant also shares a long-held prediction about how the people of Quinhagak will relocate five times before they stay in one place. Elder Tartuilnguq Martha Mark recalls that the village has moved and formed three times (Rearden, 2013).

Designing a community-based environmental assessment and monitoring tool

The Hazard Impact Assessment and Hazard Mitigation Planning process in Nunapitchuk and Quinhagak demonstrate the complexity of the issues facing communities threatened by climate-induced environmental change. Difficult decisions need to be made regarding whether protection-in-place is a viable long-term strategy to protect community residents from the threats caused by climate change. The combination of antiquated and damaged infrastructure needing replacement or repair, coupled with the unknown projected risks of permafrost thaw, erosion, flooding and *usteq*, elucidate the need to implement a community-based social-environmental monitoring and assessment tool that can assist in the prioritization of work done to ameliorate risk.

Integrated hazard monitoring assists communities to have a more comprehensive understanding of the environmental changes occurring as a result of warmer air and ocean waters and can provide information about predictive rates of change.

In combination with Indigenous knowledge-based observations of environmental change, the physical changes associated with erosion, permafrost, and flooding are being collected using well-established scientific protocols. In Nunapitchuk and Quinhagak, community members and the local governing entities in each community identified the monitoring sites where physical parameters of erosion, permafrost degradation, and flooding could be established, collocated and quantified. Sites were established in the summer of 2018, so limited monitoring data have been reported to date. Erosion monitoring sites are established by installing time-lapse cameras in combination with vertical stakes near eroding shorelines or river banks. The shoreline and stakes are within the field of view of the time-lapse camera and are identifiable in photos. Photos are collected every hour so that photos can be used to measure the shoreline throughout an erosion event, and the processes by which the erosion is occurring can be interpreted. Upon installation, stakes and the position of the shoreline or river bank are measured using Global Navigation Satellite System (GNSS) Global Positioning System (GPS) mapping, so that geometric corrections are applied to the image-identified shoreline position. Ground-based measurements are periodically collected by community members using a measure tape to validate photo-collected measurements. Flood monitoring sites are established with the installation of a flood staff—a vertically graded staff installed on a piece of infrastructure in a low-lying region of the community. The flood staff is also mapped using GNSS GPS, so that when a flood elevation is read off the staff or a photograph of the staff is collected during a flood event, the elevation of the water level relative to the staff is converted into a consistent vertical datum (North American Vertical Datum of 1988; NAVD88).

Permafrost monitoring sites were established by installing automated temperature sensors in the seasonally thawed active layer and surface permafrost (to 1.5 m ground depth). Along shore-perpendicular profiles, community members collect monthly measurements of ground thaw (during the summer and fall) using a metal probe inserted into the thawed soil layer until the probe hit resistance of frozen ground (e.g. Natali, Schuur, Webb, Hicks Pries, & Crummer, 2014). Although detection of long-term trends will require multiple years of observations, spatial patterns of ground thaw, hot spots of erosion, and maximum elevations of flooding can provide information on vulnerable areas, local environmental drivers, and implications for *usteq*. For example, in Quinhagak there was an abrupt increase in ground thaw with increasing proximity to the coastline (e.g. in late June, ∼50 cm inland to more than 100 cm within meters of the coast), demonstrating the possibility of interacting influences of ground thaw, flooding, and erosion.

In addition to physical monitoring, beginning with the 2017–2018 fall and winter storm season, we documented observations of flooding, erosion, and permafrost degradation from Indigenous knowledge holders. We worked with Alaska Native communities located along the west coast of Alaska and the National Weather Service (NWS) to document Indigenous criteria for understanding the 42 storms and their impact on community infrastructure and the health and well-being of community residents. The storm narratives help the NWS to improve their forecasts specific to rural areas and regions in Alaska where minimal meteorological data are collected, thus ensuring that Alaska Native communities have access to reliable information as they prepare for storms. The storm narratives also provide information about the storm impacts, including damage to infrastructure and harm to the people living within the community. The storm narratives help both scientists and tribal representatives understand the factors that can enhance storms and their impacts on communities. Alaska Native communities can also include documentation of storm impacts and events into hazard mitigation plans and tribal council meetings to better inform climate adaptation decision-making.

Additionally, quantitative and qualitative evidence of disasters or damage from storm surges or flooding can increase tribal access to federal and state funding programs. The coproduction of knowledge provides Alaska Native communities with culturally-relevant, inclusive, and well-informed processes to plan for future scenarios. This synthesis of Indigenous knowledge and physical science enhances tribal self-governance, decision-making, and access to resources to respond to a changing Arctic.

Community-based monitoring of both ongoing accelerating environmental change as well as extreme weather events is critical for decision making and governance processes related to long-term adaptation. We have just started the assessment phase of our research as we gather the data from the community-based monitoring that began in 2017. Government agencies and research institutions are analyzing this information to understand predictive rates of change at a local level so that communities have the information they need to determine whether protection-in-place is possible. Alaska Native communities, in partnership with academic institutions, non-profit agencies, and state and federal government agencies, are developing the tools to better understand the rapidly changing Arctic environment that are needed to make adaptation decisions. Through the design and implementation of community-based environmental monitoring, an interdisciplinary team of Indigenous knowledge holders and physical scientists recognized and formally defined *usteq*, a compound hazard that was recently added to the hazard profiles of the 2018 Alaska State Hazard Mitigation Plan. The creation of the new hazard definition demonstrates an outcome of the coproduction of knowledge and governmental collaboration at the tribal, city, state, and federal levels.

Conclusion

The combination of extreme weather events and ongoing accelerating environmental change will challenge the capacity of people and the governance institutions charged with protecting them. Land will permanently disappear because of sea level rise and the consequent impacts of erosion. Preventive relocations provide an institutional mechanism to proactively protect people before the land on which they live and maintain livelihoods is no longer habitable or ceases to exist. However, no governance framework in the United States currently addresses the essential issues of deciding when a preventive relocation should occur and who should make the decision that relocation is warranted. Government-mandated relocations have impoverished relocated populations and caused the rupturing of kinship ties and social networks. New governance institutions need to be designed and implemented so that the adverse impacts of relocation are minimized or avoided. Being able to monitor gradual and continuous environmental processes and capture unexpected environmental feedbacks that may drastically impact the ability of communities to remain protected in-place will enhance the resilience of relocated populations.

Community-based integrated social-environmental assessments, which create multilevel, multidisciplinary knowledge production with local communities leading the data gathering efforts, can be a critical component of this new governance framework. Future work with Alaska Native communities, research institutions, and state and federal government agencies will focus on the development of a methodology to document how *usteq* occurs and damages, or destroys, community infrastructure, and to identify environmental and social relocation indicators so that adaptation can shift from protection-in-place to community relocation. Future work will also incorporate Indigenous knowledge and social, health, and ecological impacts of climate change into this assessment framework. Alaska residents describe a variety of climate change impacts on health, including morbidity and mortality caused by unpredictable and extreme weather, mental health issues, changes to lifestyle, and damage to water and sanitation infrastructure (Brubaker, Bell, Berner, & Warren, 2011). Similar to the monitoring of environmental change, preventing negative health outcomes requires a local-scale understanding of the type, timing, and rate of change, as well as direct and indirect health effects (Brubaker et al., 2011). Integrated health assessments can systematically identify and quantify the many pathways through which climate change can affect health in different social and ecological contexts. Finally, the integrated assessment will incorporate a component that focuses on the environmental impacts on livelihoods, which would include the availability of subsistence foods. Ecological shifts, including the distribution and productivity of plants and animals that are important subsistence resources, are also critical for assessing the hazards of climate change and developing a sustainable adaptation strategy. Integrating climate change impacts on infrastructure, health and livelihoods has the potential to facilitate community-based adaptation, which dynamically addresses ongoing environmental change.

The work being done by Alaska Native communities to design and implement these community-based assessments can provide a model for other coastal communities faced with increasing risk caused by climate-induced environmental change.

Note

1. 44 CFR §201.6(c)(4)(i).

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