Human Adaptation to Climate Change in Alaska: Overview and Recommendations for Future Research and Assessment

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Abstract

The magnitude of climate warming in Alaska and the Arctic has been more than twice the global average, and related terrestrial and marine impacts are well established. As such, there is a need for climate adaptation as well as a need for research that directly informs adaptation practice. We report results of a pilot assessment of climate change adaptation across a range of natural resource dependent sectors in Alaska and provide recommendations for conducting climate adaptation research and assessment in Alaska. Sectors addressed include forestry/wildfire, coastal vulnerability, Native subsistence food harvest, commercial fishing, the oil and gas industry, shipping and maritime transport, and terrestrial infrastructure. Planning, research, and monitoring occur at a broad range of scales from international to local, however adaptation actions occur largely at a local scale with a few instances of state and regional scale action. Adaptation actions are analyzed according to Pelling’s (2010) classification of purposeful/incidental, planned/spontaneous and proactive/reactive revealing intermediary categories, further analysis of which has the potential to provide useful insights for adaptation research and action. Multi- and cross-sector research and assessment is also important in the region due to cumulative and cascading climate impacts.

Keywords: adaptation; Alaska; Arctic; assessment; climate change; multiple sectors; planning; coping; disaster risk management; boundary organizations
1. Introduction

Over the past 60 years, Alaska and the Arctic have experienced some of the largest climate changes on Earth, as manifested not only in increasing surface air temperatures but also in sea ice loss, glacial retreat, permafrost warming, increased river discharge and changing seasonality (Markon, et al., 2012). Rapid climate change coupled with the multi-decadal residence time of heat trapping gases in the atmosphere make it imperative that Arctic residents and governments prepare for and adapt to the changing climate and associated environmental changes (Larsen, et al., 2014; Warren and Lemmen, 2014).

Human and natural systems are intimately connected and this study focuses on human adaptation. We use the terms climate adaptation and climate change adaptation synonymously to refer to human actions in response to climate change and associated environmental change. Following definitions used by the U.S. Global Change Research Program, which are derived from those used by the U.S. National Academy and the Intergovernmental Panel on Climate Change (IPCC), we consider adaptation to be an “adjustment in … human systems to a new or changing environment that exploits beneficial opportunities or moderates negative effects” (National Academies of Sciences 2010:19).

This paper reports findings from a pilot study in Alaska, USA, designed to better understand the range of climate adaptation occurring in Alaska and to inform more extensive future climate adaptation research and assessment. Scientific assessments evaluate the state of knowledge and synthesize existing peer-reviewed literature on a particular topic at a given point in time (Howden and Jacobs, 2016). Assessment of climate change and related science on international and national scales in the United States and Canada are well established and include a range of topical areas of societal impacts and adaptations (IPCC, 2014; Warren and Lemmen, 2014; Melillo, et al., 2014). These topical areas are known as sectors and include water, energy, transportation, agriculture, ecosystems, human health, land use, forestry, and industrial development. While work is more advanced in Canada (Eyzaguirre and Warren, 2014), some scholars argue that studies analyzing existing adaptations to climate change in developed countries are relatively sparse (Tompkins, et al., 2010; Bierbaum, et al., 2013; Ford, et al., 2014). This lack of climate adaptation research and assessment in Alaska is evident in the Artic Council’s compendium of Artic adaptation (The Arctic Council, 2013b).

Existing climate adaptation research and assessment cover a range of activities. Some focus on the type of activity such as planning and strategic management, creating decision-support tools, developing technological approaches, conducting research, building and engaging networks, enacting legislation, creating financial incentives, raising awareness,
conducting training and education, advocacy, and mainstreaming climate adaptation with other activities (Scientific Expert Group on Climate Change, 2007; Tompkins, et al., 2010; The Arctic Council, 2013b). Other classification schemes center around a societal goal or overall outcome achieved by the action. These include managing risk, reducing vulnerability, enhancing resilience, facilitating transition, and initiating transformation (Eakin, et al., 2009; Pelling, 2010; Kates, et al., 2012). Pelling (2010) summarizes classification of adaptation according to whether a climate driver is a primary or secondary motivation, the degree of forethought or planning, and whether actions are proactive or reactive to changing conditions (Table 1).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Type</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Motivation</td>
<td>Purposeful</td>
<td>Response to climate driver as a primary motivation</td>
<td>Incidental</td>
<td>Response to climate driver as a secondary motivation</td>
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<tr>
<td>Degree of forethought and planning</td>
<td>Planned</td>
<td>High degree of forethought or planning</td>
<td>Spontaneous</td>
<td>Little forethought or planning</td>
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<tr>
<td>Action in preparation or response</td>
<td>Proactive</td>
<td>Anticipating driver, hazard or threat</td>
<td>Reactive</td>
<td>Responding to driver, hazard or threat</td>
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**Table 1. Types of Adaptation.** Based on (Pelling, 2010). Also reproduced in (Trainor, et al., 2017).

Recent literature emphasizes the need for evaluation of adaptation policies and actions in the Arctic, the potential for learning from these evaluations in designing future actions, and the need for cross- and multi-scale adaptation initiatives that foster networking and learning (Loboda, 2014). Effectiveness, efficiency, legitimacy and social equity have been proposed as metrics for evaluating successful adaptation (Adger, et al., 2005a). In their ability to mediate between scientific knowledge and adaptation practice, boundary organizations can serve an essential role in climate adaptation and policy (Guston, 2001; Tribbia and Moser, 2008; Dilling and Lemos, 2011). The capacities and effectiveness of these boundary organizations have been described in agriculture, climate change, and water resource sectors (Agrawala, et al., 2001; Cash, 2001; Feldman and Ingram, 2009). Boundary organizations can be especially helpful in building tribal community empowerment, spanning across-scale, and in facilitating
adaptive management (Cash and Moser, 2000; Chapin, et al., 2016). Examples of boundary organizations in Alaska that support climate adaptation are provided in Table 2.

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<th>Name and Location</th>
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<tr>
<td><strong>Alaska Center for Climate Assessment and Policy (ACCAP), University of Alaska, Fairbanks</strong></td>
<td>Building climate adaptation capacity in coastal communities and research on societal impacts of extreme events.</td>
<td>Funded by the US National Oceanic and Atmospheric Administration (NOAA) since 2006 as one of 10 Regional Integrated Sciences and Assessments (RISA) programs. ACCAP works directly with communities to build community-based adaptation plans and conducts relevant use-inspired climate and social science, and partners directly with tribal, local, state, and federal organizations and agencies to bring science to bear in solving problems.</td>
</tr>
<tr>
<td><strong>Alaska Fire Science Consortium (AFSC), University of Alaska, Fairbanks</strong></td>
<td>Wildfire research and management application</td>
<td>The primary purpose of the Alaska Fire Science Consortium (AFSC) is to strengthen the link between fire science research and on-the-ground application in Alaska by promoting communication between managers and scientists, providing an organized fire science delivery platform, and facilitating collaborative scientist-manager research development. AFSC is funded by the Joint Fire Science Program as part of their regional Knowledge Exchange Network, and has been building relationships and conducting knowledge exchange activities between scientists and managers in Alaska since 2010.</td>
</tr>
<tr>
<td><strong>Community Partnerships for Self-Reliance (CPS), University of Alaska, Fairbanks</strong></td>
<td>Building community self-reliance</td>
<td>CPS has a mission to enhance collaboration between university researchers and Alaska communities to address community-identified research priorities related to self-reliance and sustainability. CPS connects local indigenous knowledge and community information needs with university scientists conducting relevant research, thereby fostering use-inspired science. Leveraged with NSF and NASA funding and focusing on the integrated factors of climate, energy, economics, environmental change, policy, and subsistence practices, this program works closely with rural indigenous communities in Alaska to bridge top-down and bottom-up adaptation planning (Chapin et al. in review).</td>
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**Table 2. Examples of Boundary Organizations that Support Climate Adaptation in Alaska. Modified from similar table in (Trainor, et al., 2017)**
2. Methods

This research was designed as a pilot study to collect preliminary data and identify key issues for consideration in future research and more in-depth assessments of climate adaptation in Alaska. We focus on six sectors, or areas of social/environmental interaction, that were selected based on 2009 U.S. National Climate Assessment (Karl, et al., 2009): forestry/wildfire, coastal vulnerability, Native subsistence food harvest, commercial fishing, oil and gas industry, shipping and maritime transport, and terrestrial infrastructure. As a pilot study, our findings capture only a sample of adaptation actions to inform both on-going and future adaptation assessment, research, and action. This study is limited by the end of data collection in July 2013.

We started with a scoping process including focus groups, informal interviews, and a map exercise. These were aimed at verifying our sector selection and identifying adaptation actions, key informants, and grey literature. Three targeted focus groups were conducted at state-wide meetings of coastal managers, tribal environmental professionals, and resource managers. A short presentation about climate change and its impacts in Alaska was presented followed by focus group questions: What have you done in your community to respond to environmental change? What are your next steps? And what do you need to take these steps effectively? Initial scoping also included an interactive map at the 2011 Alaska Forum on the Environment conference. Conference participants included tribal environmental leaders from rural communities across Alaska as well as representatives of state and federal agencies and non-governmental organizations. Over 60 conference participants responded to the same questions as focus group participants by filling out a pre-printed card and attaching it to a large map.

Semi-structured interviews were conducted with at least two key informants from each sector (n=16). Informants were identified through the scoping process and in consultation with individuals engaged in climate change science, services, and adaptation in Alaska and were selected based on expertise in the field and state-wide experience (Bernard, 1995). Expertise was determined by number of years working in Alaska within the respective sector, direct involvement with communities, industry, or state or federal agencies, and authorship of relevant publications. Interviewees included representatives from state and federal agencies, industry trade organizations and consultants, and university scientists. Interviews were conducted by the three authors between February 2011 and March 2012. Hand-written notes were typed independently, compared, verified with respondents, and coded using NVivo, a qualitative
research software (Gorden, 1992; Bernard, 1995). Relevant reports, memos, brochures and other forms of grey and white literature were identified in the interview process.

Interviews, grey, and white literature were coded for sector, actor, type of action, and level of action (international, national, regional, local). Codes for type of action (planning, research, adaptive action) were identified through the inductive technique of grounded theory whereby concepts, categories, and relationships are based on interview content, rather than pre-determined by existing classifications in the literature (Bhattacherjee, 2012). Search and review of peer-reviewed literature was also conducted with the search terms: Alaska, adaptation, climate change, environmental change, and sector identifiers.

3. Results

3.1 Planning

Community and strategic planning activities are occurring at international, federal, state, regional, tribal and community levels and encompass a range of spatial scales. Some of these activities are part of a national network of climate change planning and strategizing, while others are unique to Alaska. Many of these plans are being implemented (see 3.3.2) and updated, however, there are notable exceptions including the recommendations made by the Alaska State Climate Change Sub-Cabinet.

Internationally, strategic planning is occurring in response to increased Arctic marine access due to diminishing sea ice extent and the resulting potential for a future increase in Arctic marine shipping, fishing, oil and gas exploration, and tourism (The Arctic Council, 2009). For example, the Arctic Council has released an implementation strategy and status report for the Arctic Marine Shipping Assessment (The Arctic Council, 2015). In addition to research and monitoring, international policy has been enacted, guidebooks created, and task forces established.

At the federal level, strategic planning has occurred in the USA at the Executive Office level as well as more targeted planning involving the military and a wide range of agencies. The U.S. Navy’s Task Force on Climate Change released the Arctic Roadmap in 2009, providing a three-phase action plan for response to rapid Arctic change, with goals including promoting strong interagency and international partnerships and actively promoting the safety, stability, and security of the region. The U.S. Environmental Protection Agency (EPA), Region 10 Action Plan from the 2010 Tribal Leaders Summit includes explicit action items related to climate change including education and communication, tribal consultation and interagency collaboration. The National Oceanic and Atmospheric Administration (NOAA) Arctic Vision & Strategy was released in 2011, pointing the way for that NOAA’s strategic research, forecasting,
partnership and vision of regional resilience. The 2009 National Arctic Policy specifically identifies climate change and increasing human activity in the Arctic as significant considerations in U.S. policy and interests related to homeland security, environmental conservation, energy development, transportation, and scientific research. The 2013 National Strategy for the Arctic recognizes the need to respond to changing environmental conditions to safeguard national security, strengthen international cooperation and engage in responsible stewardship. Unique to Alaska is the Alaska Climate Change Executive Roundtable (ACCER), which was collaboratively established in 2007 as a forum for senior level executives of federal agencies to coordinate and share information about climate change research, monitoring and response. ACCER also includes State of Alaska Departments of Environmental Conservation, Fish and Game, and Natural Resources.

At the state level, the Alaska Climate Change Sub-Cabinet was established in 2007 to advise the Office of the Governor on the preparation and implementation of an Alaska climate change strategy. Advisory groups focused on climate change adaptation, mitigation, immediate action and research needs. Technical working groups for the adaptation and mitigation advisory groups included specific analysis of issues such as public infrastructure, health and culture, natural systems, economic activities, greenhouse gas mitigation through conservation, energy supply and demand, agriculture, waste, and cross-cutting issues. Final reports for the advisory and technical working groups were issued in January 2010; as of this writing, however, a comprehensive state implementation plan has not yet been issued. Unlike most other planning efforts that could be described as preparedness planning for future impacts, the Immediate Action Working Group (IAWG) of the Governor’s Subcabinet explicitly addressed actions needed to respond to imminent threats to rural villages, such as from storm surge and coastal erosion, and as such put forward recommendations for reactive adaptation. However, while those imminent threats remain, the IAWG last met in March 2011. Similarly, the Alaska Climate Change Impact Mitigation Program (ACCIMP) provides grants to communities for planning and hazard impact assessment to address the immediate planning needs of communities imminently threatened by climate change-related impacts such as erosion, flooding, storm surge, and thawing permafrost (Bronen and Chapin, 2013). As of this writing, eight communities have received planning grants, and six communities have received funding for hazard impact assessments (S. Russell-Cox, pers. comm.). The community of Newtok is also engaged in village relocation planning (see 3.3.2).

While not explicitly motivated by climate drivers (incidental), the Alaska State Legislature established a Northern Waters Task Force in 2010 to identify how the state of Alaska can best
meet the political and resource opportunities and challenges of rapidly diminishing Arctic sea ice. Findings and recommendations of the Task Force emphasize greater state involvement in Arctic policy and governance, including a top recommendation to ratify the United Nations Convention on the Law of the Sea (UNCLOS).

The Alaska Department of Fish and Game developed a Climate Change Strategy (2010) outlining expected impacts, research needs, management principles, key strategies, and key actions for pursuing the agency’s mission given expected changes. Key actions include research and monitoring; coordination with state, federal and university organizations; developing policy for invasive species; dedicating staff and building program capacity; and public outreach and involvement. The Alaska Division of Forestry Statewide Forest Resources Strategy (2010) explicitly highlights goals for response to climate change, including planning for longer and more intense fire seasons, maintaining forest health through adaptive management, and participating in carbon sequestration measures. Risk assessment, mapping, and planning are conducted by the Alaska Risk Mapping, Assessment, and Planning Program (RiskMAP) and by the Alaska State Division of Geological and Geophysical Surveys.

At the local scale, climate change action plans and vulnerability assessments have been completed by several municipalities including Homer, Juneau, and the Interior Issues Council of the Fairbanks Economic Development Corporation. Local community planning and monitoring has also accompanied climate change health assessments (Brubaker, et al., 2011). These efforts were in explicit response to climate change and as such purposeful. The community planning is largely proactive, however in some cases community health assessments report current health impacts including for example threats to drinking water sources. As such they can be considered reactive responses.

Several of the communities that received funding through the ACCIMP program outlined above have completed hazard impact assessments and community climate change plans; others are still in progress. Twenty wildfire protection plans have been approved, engaging nearly 90 Alaska communities in collaborative efforts between wildfire suppression agencies, federal, state and local governments, community groups, and private land owners.

Most of the strategic planning we found is a purposeful, proactive response to climate change. However, especially in the case of rural, primarily Indigenous communities faced with flooding, erosion and health impacts, reactive planning is also occurring. Similarly, the state shifted focus away from purposeful climate change planning with the Governor’s Subcabinet on Climate change toward incidental planning with the Northern Waters Task Force.
3.2 Research and Monitoring

Research and monitoring are forms of climate adaptation under some classification schemes (Scientific Expert Group on Climate Change, 2007; Tompkins, et al., 2010). Alaska and the Arctic are scientifically data poor, compared to other regions (U.S. Arctic Research Commission, 2013). Ongoing climate change related research and monitoring in Alaska address climate impacts, geographical distribution and rates of climate change, interactions between climate change and other stressors, and the viability of adaptive responses to change. These research and monitoring efforts are being carried out across disciplines and by a wide range of institutions, including federal and state agencies, universities, non-governmental organizations, local communities, and private industry. Due to the nature of research and monitoring, it is by and large planned, purposeful, and proactive. However we found examples of reactive monitoring, such as increased U.S. Coast Guard monitoring and patrols in the Arctic. The following summary provides select examples of research and monitoring activities that may directly or indirectly guide adaptive responses to climate change.

On a federal level, agencies such as the NOAA, the U.S. Geological Survey, the National Park Service, the U.S. Army Corps of Engineers, and the Bureau of Ocean Energy Management conduct a range of research and monitoring to fulfill their agency missions. In particular, in 2009, the NOAA National Center for Environmental Information (NCEI) deployed twenty nine stations in Alaska as part of their U.S. Climate Reference Network. The Department of Interior (DOI) Alaska Climate Science Center and Landscape Conservation Cooperatives (LCCs) also fund research with specific land and resource management application, including climate downscaling and integrated modeling. In 2006, NOAA funded the Alaska Center for Climate Assessment and Policy (ACCAP), one of a network of Regional Integrated Sciences and Assessments (RISA) programs nation-wide that conduct research on climate science, adaptation and vulnerability.

Bathymetric charting of Alaska waters has been spurred by both the increase in marine traffic and the likelihood of offshore oil and gas activity. The U.S. Coast Guard has increased training missions, patrols, and traffic monitoring in the Arctic. These activities are motivated by the increase of commercial ship traffic that is expected to continue following the reduction of sea ice extent and lengthening of the open water season in parts of the Arctic Ocean. The National Science Foundation and North Pacific Research Board co-funded the Bering Sea Ecosystem Research Project (2007-2012) investigating a variety of marine ecosystem, oceanographic and human dimensions questions with climate change components (Sigler, et al., 2010).
On a state level, many of the recommendations in the reports of the Governor’s Sub-Cabinet on Climate Change Immediate Action Working Group and the Research Needs Working Group pertain to monitoring and research activities in support of adaptation. These recommendations, however, have yet to be officially implemented. As of this writing, the Alaska Department of Transportation is in the process of conducting, with federal funds, a climate change vulnerability assessment of state transportation assets.

On the community level, city and tribal governments as well as community residents have become increasingly involved with federal and state agencies to address issues of environmental change (e.g., erosion, river and lake levels, and water availability). Local community observer programs have been established through several organizations, including the National Weather Service (NWS) for weather and river ice observations and the University of Alaska for invasive species (BioMap), and the Alaska Native Tribal Health Consortium for local observations of environmental change (LEO Network), especially related to water availability and the health and availability of subsistence food species. NWS further partners with the University of Alaska, the Arctic Research Consortium of the U.S., and the Eskimo Walrus Commission to sponsor the Sea Ice Outlook for Walrus and both the Yukon-Intertribal Watershed Council and Cook Inletkeeper host community water monitoring programs. Additional examples of community-based monitoring include the can be found through the website of the Alaska Ocean Observing System.

There are, of course, research and monitoring activities conducted at universities, much of which is funded by federal or state agencies. This research spans a wide range of marine, terrestrial, and climatological investigation, including impacts of climate variability and change on hydroelectric production; long-term ecological monitoring of terrestrial ecosystems; research and monitoring of ocean chemistry and ecosystem impacts of ocean acidification; research and monitoring of the range, health, and population dynamics of fish and marine mammals, important for commercial and subsistence harvest; and a monitoring program for invasive species that includes engaging ecotourists in citizen science (Markon, et al., 2012). In addition, the Alaska non-profit organization, Cook Inletkeeper monitors regional stream temperatures for sensitive thresholds in key salmon reproductive phases.

A climate change vulnerability assessment was commissioned in 2009 by one of the major oil and gas producers in the state (Dell and Pasteris, 2010). This study considered the vulnerability of oil and gas operations to ten climate change related variables including coastal erosion, increased wildfire on the tundra, ocean acidification impacts on the speed of sound wave travel, ambient warming impacts on duration of tundra travel season, sea ice coverage
and thickness, snow depth and related snow load on structures, permafrost thaw, sea level rise, and potential disease vectors. Oil and gas companies also routinely monitor caribou and polar bear populations as well as surface water use as required by the state of Alaska (J. Dell, pers. comm.).

Figure 1. Summary of adaptive action and scale of response to changing environmental conditions. This figure summarizes adaptive actions across the range of sectors. “Local” includes individual, household and community; “regional” refers to a sub-region of Alaska (such as the Arctic Ocean, North Slope, Southeast, etc.); and “state” refers to statewide action or a decision made by state level governance or regulatory entity.

3.3 Adaptive Action

In contrast to planning and research, action in response to climate change includes active implementation of plans, changes in policy, protocol or standard operating procedures, as well as direct reaction to hazards and opportunities created by rapidly changing environmental conditions. We describe here identified climate adaptation actions by sector across local,
regional and state-wide scales (Figure 1). Table 3 classifies each action according to the types of adaptation defined in Table 1 (based on Pelling 2010): purposeful, planned, proactive, incidental, spontaneous and reactive. The criteria for characterizing actions as purposeful is explicit mention of climate change in documentation of the action.

3.3.1 Wildfire Suppression and Management

Since the year 2000, severe wildfire years in the boreal forest of the Interior Alaska have become more frequent (Mann, et al., 2012; Partain, et al., 2016), and the recent burning of the boreal forest exceeds the fire regime limits of the past 10,000 years (Kelly, et al., 2013). There have also been unprecedented fire occurrences on the tundra of northern and western Alaska (Chipman, et al., 2015). These increases in fire occurrence correlate with increasing temperatures in the late spring and early summer (Partain, et al., 2016) and have coincided with, and likely been at least partially driven by, increases in lightning frequency and decrease in sea ice extent over the past 15-20 years (Bhatt, et al., 2010). Lightning frequency is projected to increase further in association with climate warming (Romps, et al., 2014).

In the wildfire management and response sector in Alaska, adaptations include establishment of new suppression crew training, evolution of tools used to suppress fire, change in the statutory start date of fire season, and the implementation of community wildfire protection plans. Fire suppression agencies reported logistical challenges in meeting the increasing demand for fire suppression in Alaska as well as increasing expenditures on wildfire suppression annually. The Alaska State Division of Natural Resources initiated several new fire academies throughout the state motivated by the increasing demand for more highly skilled workers as well as the need for income in rural Native villages (incidental) (Chapin, et al., 2008). Experts in wildfire suppression in Alaska also report an evolution in the use of hand tools and aerial resources in fire suppression. Environmental conditions such as reduced soil and vegetative (i.e. fuel) moisture have changed such that former hand tool methods are no longer effective in fire suppression (J. Gould, pers. comm.).

The State of Alaska has moved the statutory start of the fire season forward by one month from May 1 to April 1, enabling seasonal employees and required trainings to begin earlier in the season (Fire Season, 2006). This was a direct and deliberate response to the occurrence of large fires that require more highly trained personnel starting earlier in the season (C. Maisch, pers. comm.). There is no direct mention, however, of climate change in the statute. In communities where Community Wildfire Protection Plans have been implemented, wildfire risk in the immediate vicinity of the community has been reduced through hazard fuel mitigation projects and shaded fuel breaks.
These actions are responses to drier landscape conditions, more flammable fuels, and large wildfires starting earlier in the season, all of which can be attributed to warmer and drier climatic conditions (Kasischke and Turetsky, 2006; Balshi, et al., 2008; Chapin, et al., 2008). These ecological impacts of climate change motivate the emphasis on climate change response in the state-wide Forest Resources Strategy (2010), however climate change is not identified as a driver of adaptive actions. There were both spontaneous (e.g. tool evolution) and planned adaptations (e.g. implementation of community hazard fuel reduction projects). There is proactive adaptation via community hazard fuel reduction projects, however, adaptations in the fire suppression sector are also largely reactions to immediate threats (J. Gould, pers. comm.).

### 3.3.2 Coastal Vulnerability and Community Relocation

Coastal erosion rates are influenced by the frequency and intensity of coastal storms, by the duration of a protective buffer of sea ice and ultimately, by changes in sea level. A decrease in late summer and autumn sea ice extent has led to an increase in severe storms occurring when the shoreline is not protected by shore-fast sea ice (1951-2010), leaving the coast vulnerable to high waves, storm surges, and related coastal erosion (Melillo, et al., 2014; Overeem, et al., 2011). The increase is primarily a function of the longer ice-free season, rather than storm frequency. Overall storm frequencies show little trend south of the Bering Strait. Lack of sea ice has extended the season for off-shore oil and gas development and maritime transportation and shipping as well as increased local hazards for Indigenous subsistence hunters (see 3.3.3.).

In 2009 the US Government Accountability Office identified 31 villages “facing imminent threat” from both coastal and riverine flooding and erosion noting “limited progress” in village relocation since the previous assessment six years earlier (US Government Accountability Office, 2009). In 2006 and 2007, $10 million was invested in the coastal communities of Kivalina, Shishmaref, and Unalakleet to reinforce the shoreline and provide temporary protection to infrastructure, much of which was destroyed by subsequent erosion. Other communities, such as Shaktoolik, are also implementing engineering solutions to guard against severe flooding, yet remain in immediate danger from storm surge and flooding. While efforts continue in these communities to create more sustainable solutions, substantial historical and institutional barriers remain (Marino, 2012; Melillo, et al., 2014).

While several coastal villages are in need of relocation, only one has begun the process of moving to escape severe erosion, Newtok/Mertarvik. The efforts of the collaborative Newtok Planning Group in marshaling community support, multi-agency resources, and ongoing collaboration toward community relocation are an example of both proactive and reactive
adaptive action to community risk related to climate change (Bronen, 2011). The village of Newtok, located on the west-central coast of Alaska, has experienced river bank erosion in combination with permafrost degradation and repeated flooding over the past several decades, with the shoreline projected to erode beyond homes, the school, and the community water source by 2022. Formed in 2006, the Newtok Planning Group has brought together multiple local, regional, state, and federal entities to contribute time, resources and expertise in planning, financing and constructing new village infrastructure in a new location. While ongoing funding and logistical challenges remain, as of this writing a new barge landing, access road, and foundation for an evacuation shelter have been constructed in the new townsite known as Mertarvik. A village relocation report was completed in 2011 and a strategic management and relocation plan was completed in March, 2012. Relocation of the entire community was scheduled for 2016, however, further progress is stalled (Community of Newtok and the Newtok Planning Group, 2011, 2012). While these actions have been described as transformative adaptation (Kates, et al., 2012), the Mertarvik relocation process represents decades of community planning, fund-raising and lobbying, the relocation is only partly accomplished, and institutional barriers still exist for full implementation (Bronen and Chapin, 2013; Melillo, et al., 2014).

3.3.3 Native Subsistence Food Harvest

In rural Alaska, there are over 250 federally recognized tribes and predominantly Indigenous communities that rely on hunting, fishing and gathering of traditional foods. Subsistence food harvest is also an important aspect of traditional ways of life and cultural knowledge. Communities that have relied on intact and predictable ecosystems for food for generations are adjusting the timing, target, location, and storage of their subsistence food harvest activities in response to warming temperatures, and changes in seasonal phenology, hydrologic conditions, and ecosystems (Kofinas, et al., 2010; Cochran, et al., 2013; Wilson, 2014). While Indigenous impacts and opportunities from climate change are not limited to subsistence food harvest (Cameron, 2012), we emphasize them here in part because food security is consistently cited by Indigenous peoples in Alaska as a primary concern related to the environmental impacts of climate change (Markon, et al., 2012, Appendix C).

Similar to adaptations reported elsewhere, most of these activities are occurring on an individual or household scale in order to meet family and community nutritional requirements (Kofinas, et al., 2010; Ford, et al., 2014; Mimura, et al., 2014). These actions are motivated by the need for food harvest rather than response to climate drivers per se and are spontaneous and reactive (Table 3). For example, Inupiat whalers in Barrow and Point Hope have adapted
their whaling practices to changing environmental conditions (Sakakibara, 2010). Similarly, as a result of diminishing sea ice, residents of the St. Lawrence Island Yupik communities of Gambell and Savoonga on St. Lawrence Island in the Bering Sea are now able to boat every month of the year, giving them increased access to marine food sources (Noongwook, et al., 2007). However, inter-annual variability in marine ecosystem and sea ice conditions create hazards as well as opportunities. Warming conditions that degrade both river and sea ice make travel and traditional hunting more dangerous and in 2013 a state of emergency was declared on St. Lawrence Island because the subsistence walrus harvest failed to meet community nutritional requirements (Caldwell, 2013; Cochran, et al., 2013).

These subsistence food harvest adaptations to environmental change are neither purposeful nor planned. They are incidental, spontaneous, reactive, real-time response to changing environmental conditions in order to continue cultural traditions and meet household and community nutritional needs. As Henry Huntington, a long-time research partner with Arctic communities explained, “It is not surprising. If conditions change, people will change their habits in response.” Deputy Commissioner of the Alaska Department of Fish and Game, Craig Fleener, points out that climate change planning and adaptation “is going on because it has to go on. It is a matter of survival and of [people] feeding themselves…” Fleener also notes, however, that “communities are talking a lot about change and what they can do about it,” indicating a trend toward more purposeful planning and collaborative problem solving in the subsistence food harvest sector. There is also evidence of networking and advocacy by means of litigation in response to immediate hazards or threats (Schwartz, 2010; Liebelson, 2013).

### 3.3.4 Commercial Fishing

The commercial fisheries of Alaska, primarily pollock, crab, and salmon, yield 50% (by weight) of the seafood produced in the United States. Commercial fishing is the top employer in Alaska and the third largest economic sector in Alaska (Markon, et al., 2012). To buffer unknowns about future marine conditions and related cascading impacts to the marine food web, the North Pacific Fishery Management Council (NPFMC) proactively implemented risk-averse management measures in recent years. Actions include closing the Arctic Ocean to commercial fishing pending further research on potential ecosystem impacts, limiting bottom-trawl operation, and instituting adaptive management procedures in instances where changing climatic variables can be linked to changing fish and shellfish distributions (North Pacific Fishery Management Council, 2009; Stram and Evans, 2009). This proactive policy follows the precautionary principle and motivations including the impact of climate drivers on the marine ecosystem.
In 2004 toxic vibrio bacteria found in oysters from Prince William Sound made headlines as cruise ship passengers were afflicted after consuming the shellfish (McLaughlin, et al., 2005). Toxic vibrio and paralytic shellfish poisoning (PSP) blooms are both triggered by warming water temperatures. To avoid future shellfish poison outbreaks, Alaska Sea Grant Marine Advisory Program (MAP) agents helped implement a water temperature monitoring and alert system. In a direct response to warming water temperatures, commercial shellfish farmers now monitor water temperatures and raise and lower their nets in the water column to ensure they are placed at an optimal temperature. This spontaneous response involves monitoring linked directly to action in response to changing environmental conditions that are secondary impacts of climate change. It requires some planning, but not a high degree.

Commercial fishermen in other parts of the state are also responding to changing marine conditions by investigating aquaculture and adjusting their timing and location of catch (Loring, et al., 2011). However, climate change is not the only possible cause of changing fish stocks; multiple environmental and human factors play a role (Dew and McConnaughey, 2005).

Terry Johnson, Alaska Sea Grant MAP agent highlighted the reactive and incidental nature of commercial fishers adaptations, “Most adaptation has been on an individual basis. It is simply a response to changes in the fisheries or the marine environment. People wouldn’t necessarily identify themselves as responding to climate change.”

Thus, in the commercial fishing sector we found evidence of purposeful, planned and proactive policy linked to the best available science to mitigate risk. Other adaptive actions in this sector are largely spontaneous, reactive, and motivated primarily by harvest needs rather than climate drivers (incidental).

3.3.5 Oil and Gas Industry

In the oil and gas sector, we find evidence of planning and research in addition to what is noted above. We report this planning and research here because it is directly linked to purposeful, planned, proactive changes related to infrastructure placement and maintenance as well as to exploration and drilling activities. Interviews indicate a change in mind-set in the oil and gas industry and point to specific changes in long-term management, planning, and development of oil and gas operations that explicitly include consideration of projected future conditions under climate change (Dell and Pasteris, 2010). “Companies are not just relying on historic data. They are looking at projections and they are seeing a trend. As they plan new investments and designs, they are planning for change,” remarked Jan Dell, then Oil and Gas Industry Consultant with CH2M-Hill.
Oil companies are responding in the near-term to permafrost thaw, changing species migrations, increased wildfire risk, increased ambient temperatures, and increased river flooding. These environmental changes have impacted long-term management, operations planning and design, and worker safety precautions for terrestrial oil and gas operations on Alaska’s North Slope. For example, companies are changing the design of vertical supports and infrastructure to prepare for projected future permafrost thaw (J. Dell pers. comm.). In response to changing polar bear movements related to declining sea ice, oil companies have built roads around new polar bear dens and halted operations for up to several weeks. Companies are changing the design of infrastructure as well as health and safety measures at both manned and un-manned facilities to reduce risk of wildfire and lightning, now more common on the tundra (Dell and Pasteris, 2010). Companies are also accounting for accelerated coastal erosion in their design and planning. Existing operations have been analyzed for vulnerability to erosion. However, to the best of our knowledge, none have been relocated. The increased threat of ice jams and river bank flooding during spring break-up on the North Slope has led companies to routinely design for two supply routes into and out of near-river sites to ensure that the supply chain is not interrupted by flooding.

As ambient soil temperatures warm, vehicle travel on frozen ice roads is limited to fewer days per operational season. This limits access to resources, forcing required activities to occur in a shorter time window, and increasing competition for existing roads. Combined, these factors pose overland travel and safety concerns. Interviews also told of a change in methodology for ice road construction on the tundra—an adaptation in response to an increasingly shorter ice road construction season. Companies are engaging in purposeful, planned, proactive adaptation. They are relying on scientific assessments and changing infrastructure development, planning, and operations to improve efficiency, output, and worker safety. From the oil and gas perspective, “Adaptation is primarily local.” (Jan Dell, Oil and Gas Industry Consultant, CH2M Hill).

**3.3.6 Shipping and Marine Transport**

Diminishing summer sea ice has provided opportunity for expansion in maritime transport and off-shore oil and gas development in the Chukchi, Beaufort, and Bering Seas. Taking advantage of this opportunity will require investment in infrastructure and emergency management for both human safety and environmental protection (Ho, 2010). Commercial vessel traffic in the Bering Sea has increased, posing risks to human safety, food security, cultural heritage sites, and the ecosystem (Huntington, et al., 2015). The U.S. Coast Guard is the lead federal agency for ensuring maritime safety and security in the Arctic.
most year-round Coast Guard station in Alaska, located in Kodiak, is over 1,000 land miles from Barrow on the Arctic Ocean and over 600 miles from Nome on the Bering Sea. The U.S. Coast Guard implemented the purposeful, planned, proactive Arctic Shield program in 2011 (formerly Operation Arctic Crossroads, 2010) and has been building annually on this effort. The program increases maritime domain awareness while providing operations, outreach, and capability assessment around the Seward Peninsula, Bering Strait and the Northern Alaska Continental Shelf from June through October.

3.3.7 Terrestrial Infrastructure

Climate change has been a factor in decision-making related to coastal road and airport construction and bridge construction for over a decade (McBeath, 2003). Current research investigating vulnerability to climate change notwithstanding (see 3.2), adaptive actions taken by the Alaska State Department of Transportation and Public Facilities (DOT) have been largely immediate responses to hazardous conditions (incidental and reactive). Roads, bridges, airports, and other infrastructure in Alaska are impacted or damaged by floods, landslides, warming permafrost temperatures, and extreme weather events such as winter rain, and icing. The DOT has undertaken erosion control, airport rehabilitation, installation of larger culverts, and new roadway de-icing procedures in addition to research and monitoring. Clint Adler, Chief of Research, Development and Technology Transfer for the DOT explains that,

*The [DOT] activities are often reactive….There are also erosion control projects, flooding studies, airports that are eroding and rehabilitation. You can see that DOT is reacting to damage already occurring. Most can be characterized as emergency response, but we are doing some research to get an idea of what to expect.*

While infrastructure projects require a certain degree of planning, long-term, state-level planning for climate adaptation is in the beginning stages. Climate related permafrost warming is projected to increase maintenance costs for public infrastructure in Alaska by an estimated 10% (Larsen, et al., 2008; Hong, et al., 2014).
<table>
<thead>
<tr>
<th>Human Adaptation to Climate Change in Alaska</th>
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<tbody>
<tr>
<td>Purposeful</td>
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<tr>
<td>Wildfire</td>
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<td>Fire fighting crew training</td>
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<td>Tool evolution</td>
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<td>Change in fire season statutory start date</td>
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<tr>
<td>Implementation of community wildfire protection plans</td>
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<td>Coastal Vulnerability</td>
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<td>Shoreline reinforcement</td>
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<td>Community relocation (Mertarvik)</td>
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<td>Native Subsistence Food Harvest</td>
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<tr>
<td>Commercial Fishing</td>
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<td>NPFMC moratorium</td>
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<tr>
<td>Mariculture oyster net setting</td>
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<tr>
<td>Adjusting timing and location of catch</td>
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<tr>
<td>Oil &amp; Gas Industry Infrastructure and supply route redesign</td>
</tr>
<tr>
<td>Shipping USCG Arctic Shield</td>
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<tr>
<td>Terrestrial Infrastructure</td>
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Table 3. Adaptation actions classified within Pelling’s typology: purposeful, planned, proactive, incidental, spontaneous, reactive. Identified adaptation actions in Alaska included purposeful and incidental, planned and spontaneous as well as proactive and reactive (see Table 1 for definitions). Several adaptation actions fit into both categories of purposeful/incidental and proactive/reactive. Results also suggest a spectrum between planned (high degree of forethought and planning) and spontaneous (little forethought and planning). Primary motivations for incidental adaptations are in parenthesis.

4. Discussion - Recommendations for climate adaptation research and assessment in Alaska

This pilot study suggests the following recommendations for climate adaptation research and assessment in Alaska. Many of these are also applicable Arctic-wide. Given the rapid environmental changes and the associated need for societal response, these recommendations focus on ways to build meaningful links between scientific research and adaptation action at multiple levels, tribal, local, regional, national and international (Cash, et al., 2003; Chapin, et al., 2016; Arctic Observing Summit, 2016), including creating actionable science (The Arctic Council, 2013b). Recommendations include strategies to avoid maladaptation, evaluating the effectiveness of adaptation action, and ways to remain flexible in adjusting adaptation actions accordingly in response to these evaluations (The Arctic Council, 2013a; Eyzaguirre and Warren, 2014).

4.1. Comparisons of Adaptation Types

This overview suggests that future climate adaptation research and assessment in Alaska would benefit from deliberate attention to motivation, degree of forethought and planning, and the extent to which the adaptation is proactive versus reactive (Tables 1 & 2). These distinctions are likely to be important variables in building bridges between science and adaptation action as well as in assessing adaptation success and in adjusting adaptation actions accordingly for continued effectiveness.

4.1.1. Purposeful vs Incidental Adaptation - Building Bridges Between Science and Adaptation Action

Adaptations with climate change as the primary motivation are purposeful. While motivation may be less significant in terms of evaluating the outcomes of adaptation actions, it can be an important variable for climate science communication and application in decision-making. If adaptation actions are incidental, i.e. response to climate change is not the primary
motivation of adaptation action, then scientists who intend their research to have broader impacts to decision-making and the boundary organizations that work to build bridges between science and adaptation will need to:

• *Expand their vision of their audience.* Scientists, science translators, and science communicators may miss important audiences if the relevant decision-makers or stakeholders are not explicitly looking for climate related information (Meadow, et al., 2015).

• *Explicitly investigate and describe links between climate variables and decision-maker concerns.* Conversely, when decisions and actions are primarily motivated by factors other than climate change, scientists and boundary organizations that bridge science and decision-making need to investigate and clearly articulate how climate variables impact the variables of primary concern (see Table 3).

• *Understand the broader context of decision-making.* When the primary motivation for action is a factors other than climate change, making climate related science relevant to decision-making will require having a nuanced understanding of decision-makers’ motivations, priorities, and values (O'Brien and Wolf, 2010).

Better understanding the primary motivation for decisions will allow scientists to more effectively collaborate with decision-makers and design their research to be relevant in specific decision contexts. Investigation of the motivations of adaptation action will also help scientists better analyze potential barriers and catalysts to adaptation. For example, if motivations for action are not climate related, overcoming barriers to action may require cross-disciplinary consideration and a range of innovative approaches. Furthermore, measuring the success of these adaptations will require assessing the extent to which outcomes achieve a range of goals, including non-climate related motivations.

### 4.1.2. Planned vs Spontaneous Adaptation - Building Adaptive Capacity and Assessing Adaptation Action

In Alaska, there is a range of planning happening on international, federal, state, regional, and local levels. This demonstrates that leadership and governance on multiple levels recognize that climate and environmental change is underway, that this change has societal implications, and that there is a need to accurately anticipate, plan, and prepare for continued change. Planning efforts are an important and necessary step toward adaptation. However, time, resources, leadership, political will, and motivation are required for planning and coordination as well as for follow-up, implementation, and subsequent monitoring and evaluation. These assets may be inequitably distributed across sectors (Adger, et al., 2006).
Planning in and of itself does not necessarily lead to effective adaptation, as plans and policy recommendations face an array of challenges and barriers (Moser and Ekstrom, 2010; The Arctic Council, 2013b) and, as with the case of Alaska’s Governor’s Climate Change Sub-Cabinet, may fail to be implemented due to political, economic, or other obstacles.

Spontaneous adaptations do occur, especially in key sectors such as indigenous subsistence food harvest. Analysis and assessment of these adaptations can help identify key factors for building adaptive capacity and adaptation learning networks. Comparing barriers, effectiveness, efficiency, and equity components of planned and spontaneous actions may provide insights for scientists and decision-makers interested in avoiding maladaptation and in working to build adaptive capacity.

4.1.3. Proactive vs Reactive Adaptation—Links Between Climate Adaptation and Disaster/Hazard Response

While we identified actions in response to climate change that are proactive planning to prepare for future conditions, we found several adaptation actions that are reactions to hazards, threats, or imminent emergency conditions (Table 3). Coping with hazards has been addressed in the food security and disaster risk management literature and discussed largely from the standpoint of individual or household level actors (Pelling 2010). Various models in the climate adaptation literature have been proposed to distinguish coping and coping capacity from adaptation and adaptive capacity, most of which similarly view coping as a shorter-term situational response on an individual or household level and distinguish adaptation as change in the contextual legal, cultural, and other institutional conditions within which individuals and households operate (Berkes and Jolly, 2001; Pelling, 2010). While some work has been done to build conceptual linkages between the disaster risk management and climate adaptation fields (Thomalla, et al., 2006; Birkmann and Teichman, 2010; IPCC, 2012), in northern latitudes where rapid warming is linked to extreme hazards as well as to economic impacts and opportunities, there are existing research gaps in both theory building and case study analysis to bridge these fields (Bronen and Chapin, 2013; Cochran, et al., 2013; Ford, et al., 2014; Eicken and Mahoney, 2015; Taylor, et al., 2016).

In Alaska, we found reactive actions occurring across a range of actors, several of which extend beyond the existing theoretical framework for coping with hazards. While individual and household level response to changes in immediate environmental conditions is clearly apparent in subsistence food harvest and also in the case of mariculture, reactive coping responses to short-term emergency and hazard conditions occur on regional and collective levels, such as with terrestrial infrastructure. In addition, the collective efforts of agents across a
range of levels (local, state and federal) to relocate the Native village of Newtok to Mertarvik is another example. This efforts is on-going for over a decade and is a complex situation in which proactive and reactive adaptation occurs simultaneously as the village is coping with short-term immediate threats of erosion while planning for longer-term adaptation and relocation.

Due to the rate and magnitude of climate and related environmental change in the Arctic, we are likely to see an increase in both proactive and reactive adaptation in Alaska and northern latitudes. Additional research could explore how actors can remain nimble to correct maladaptive short-term coping if it is recognized to be detrimental in the longer term (Barnett and O’Neill, 2010) and compare cost and effectiveness between proactive and reactive measures (Easterling, et al., 2004).

4.1.4. Assessing Adaptation Classifications and Cross-Case Learning

Several of the adaptation actions that we identified did not fit squarely into the dichotomous categories of purposeful/incidental, planned/spontaneous, and proactive/reactive (Table 3). Some of the actions, such as community relocation and the US Coast Guard Arctic Shield program, are both purposeful and incidental in that they are motivated equally by response to climate change and other goals and considerations. Similarly, actions in response to coastal vulnerability, both shoreline reinforcement and community relocation, are simultaneously reacting to immediate hazard conditions and proactively planning for future conditions. In the cases of mariculture net setting and adaptations undertaken by the Alaska DOT, adaptation actions required a degree of forethought and planning somewhere between a “high degree” and “little.” Understanding these nuances in adaptation classification and identifying adaptation actions with similar characteristics can facilitate cross-case learning and building adaptive capacity (Loboda, 2014).

4.2. Cross-scale Linkages, Learning, and Networking

Scale is an important factor in assessing adaptation effectiveness (Adger, et al., 2005a). We found that while planning, research, and monitoring occur at a broad range of scales from international to local, adaptation actions occur largely at a local scale with a few instances of state and regional scale action (Figure 1). In some cases, such as Native subsistence food harvest, action occurs in a local area, however, multiple individuals throughout a region may engage in similar activities. Similarly, actions in response to coastal vulnerability occur at the local scale yet may be implemented in multiple locales in a region. Thus, these individual actions are not limited to the local level, but collective actions of multiple individuals can have regional impact.
As local-scale innovation responds to changing conditions, boundary organizations whose mission is to specifically facilitate collaborative information flow between research and policy communities can help bridge the top-down and bottom-up approaches to climate adaptation and also help build communication networks (Cash and Moser, 2000; Cash, et al., 2006; Chapin, et al., 2016). Furthermore, research has shown that especially for rural Indigenous communities, there is a ceiling to localized action, which is constrained by political history, policy, regulatory, and funding barriers (Bronen, 2011; Loring, et al., 2011; Marino, 2012; McNeely, 2012; Wilson, 2014). Solutions for these communities, must thus also involve institutional change, which requires cross-scale connections (Pahl-Wostl, 2009; Cochran, et al., 2013). Bridging the local, regional, state, and national needs, perceptions, and values (O'Brien, 2010) can help ensure that higher level institutional planning sets a trajectory that is complimentary to locally derived needs and resulting adaptations.

As illustrated in the Newtok Planning Group, an informal boundary organization that has overseen relocation of the erosion vulnerable community of Newtok to a new location of Mertarvik, considerable coordination of multiple actors across local, tribal, state, and federal jurisdiction is required (Community of Newtok and the Newtok Planning Group, 2011; Bronen and Chapin, 2013). Overcoming historical patterns of settler-colonial relations between Tribes and state and federal governments, as well as policy and financial obstacles inherent in this type of cross-scale action, will be critical for climate adaptation in Alaska and the Arctic, especially in remote, rural, Indigenous communities that face immediate and complex adaptation challenges (Ostrom, 2010; Cameron, 2012; Marino, 2012; Bronen and Chapin, 2013; Cochran, et al., 2013; The Arctic Council, 2013b). Networks that include actors at multiple levels are effective problem solving mechanisms and foster reflexive learning (Valente, 1996; Agranoff, 2006; Pahl-Wostl, 2009). Cross-scale linkages and the social learning they foster are core elements of adaptive capacity (Adger, 2003; Cash, et al., 2006; Pelling, et al., 2008). Thus, cross-scale networking and social learning are likely to be important elements for climate adaptation in Alaska throughout all sectors.

However, if independent localized adaptations are effectively meeting short-term needs, there may be longer-term unintended consequences to cross-scale integration, the relative benefits of which have yet to be determined. For example, engaging regional or state-level institutions in locally specific adaptation may introduce inhibiting regulation or bureaucratic delays or it may disempower local stakeholders (Adger, et al., 2005b). Balancing the short and long-term practical advantages and disadvantages of cross-scale integration may require case-
by-case evaluation (Barnett and O’Neill, 2010) keeping short, medium and long-term goals in mind. Either way, local empowerment is critical (Cochran, et al., 2013).

4.3. Multi- and Cross-sector Adaptation Research and Assessment

More extensive work is needed on a sector by sector basis in Alaska to identify adaptive actions, investigate motivations and barriers to action, analyze components of successful adaptation, and interrogate the institutional structures that both facilitate and inhibit adaptive action. Existing assessments of climate adaptation research in the Arctic note a research emphasis on Indigenous Peoples at the community, household and individual levels (Ford, et al., 2014; Larsen, et al., 2014). Comprehensive assessment of adaptation in multiple sectors and by government, industry, trade organizations, has been done in Canada (Warren and Lemmen, 2014), however minimal comparable work has occurred in Alaska (see e.g. The Arctic Council, 2013b). The need to more fully incorporate commercial sectors such as manufacturing and services into climate and adaptation assessments has been emphasized with regard to Indigenous communities (Cameron, 2012) and more recently in terms of national level climate assessment (Liverman, 2016). Multi- and cross sector analysis has academic and practical advantages.

First, multi- and cross-sector research and assessment can illuminate areas for cross-sector learning. For example, research to identify the structural and functional aspects of the Newtok Planning Group and the multi-level process of planning and implementation of community relocation in response to coastal vulnerability that this group oversees, may inform parallel adaptation efforts in Indigenous communities related to food security or processes for adapting to increased shipping traffic. Similarly, state level adaptations in the wildfire sector may provide helpful models for adaptation in transportation and infrastructure.

Second, multi-sector research and cross-sector comparisons can help us better understand the cascading and cumulative impacts of climate change, industrial development and societal change, and the complex dynamics of the multi-level linked social and environmental system (Gunn and Noble, 2009; Huntington, et al., 2012; Noble, et al., 2013). Adaptations in one sector may increase or decrease adaptive capacity in other sectors. For example, actions by terrestrial and off-shore resource developers will influence community adaptation and adaptive capacity. This is especially relevant in situations where, for example, industrial development will impact rural indigenous communities and potentially their capacity to adapt to both ecological and industrial changes that effect their subsistence food harvest. Adaptation research and assessment with the singular focus on local indigenous traditional activities, overlooks important community economic opportunity and environmental concerns of
resource development. The policy implications from such research are similarly limited (Cameron, 2012).

5. Conclusion

Rapid climate related environmental change in Alaska and the Arctic require human response and adaptation on multiple levels from local to international. This pilot study identifies existing adaptation planning, research, and action in Alaska across a range of sectors. Planning, research, and monitoring occur at a broad range of scales from international to local, however adaptation actions occur largely at a local scale with a few instances of state and regional scale action. While purposeful, planned, and proactive adaptations are needed, analysis and assessment of incidental, spontaneous, and reactive adaptations can provide both practical and theoretical insights including building bridges between science and adaptation action, building adaptive capacity, assessing adaptation actions, and linking the fields of disaster response and climate adaptation. However, these classifications of adaptation are not dichotomous and considering each as occurring along a spectrum has the potential to provide insight and innovation in climate adaptation. Overcoming adaptation barriers and evaluating adaptation success will benefit from analysis of cross-scale linkages and social learning networks. Due to the complex nature of the regional human/natural system adaptation research and assessment will be most beneficial if it incorporates multi- and cross-sectoral consideration.

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