MAPPING COASTAL EXPOSURE TO CLIMATE RISKS

IN ALASKA'S NORTH SLOPE:

A COLLABORATIVE, COMMUNITY-BASED ASSESSMENT

By

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ABSTRACT OF THE DISSERTATION

Mapping Coastal Exposure to Climate Risks in Alaska's North Slope:

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The rapidly changing Arctic is driving demand for readily usable climate research to address the myriad of challenges and opportunities that are emerging in the region. While the demand is forcing scientist-stakeholder collaborations to enhance usability, scholarship on methods to effectively engage local community stakeholders in the effort is lacking. The need for effective collaboration with local communities has been voiced in the context of efforts to coordinate the pan-Arctic observing network to address stakeholder needs. This dissertation addresses this need by mapping coastal exposure to climate risks in collaboration with Alaska's North Slope Borough and its residents. Using a collaborative web mapping research design, this dissertation investigates three questions: 1) Why is coastal exposure to climate risks a problem for North Slope communities, 2) What is the land use manager usability perspective of the web map, and 3) How does the web map link to the Arctic observing network? The study identifies coastal exposure risks using community mapping workshops organized in three North Slope municipalities in spring 2016. Collectively, through their subsistence land uses, the three communities observe coastal risks across the study area, which covers coastlines of the National Petroleum Reserve – Alaska (NPR-A) and the Arctic National Wildlife

Refuge (ANWR). The coastal exposure web map created for the study was used to assess land use manager usability perspectives in an interactive workshop. Following a live demonstration of the web map, workshop participants discussed its saliency, legitimacy, and credibility. The study then explores web map links to the Arctic observing network by comparing the web map process and product with the structure of the network, which was defined using select reports on its design and activities.

Main findings include coastal exposure risks associated with Alaska Native industrial and subsistence land uses across the study area, well beyond the small stretches of local municipality coastlines that are the usual focus of related efforts. Land use manager usability perspectives suggest that the web map is salient for the borough's land use decision-making process, credible enough to be used as a screening tool, and legitimacy would be enhanced by including local stakeholders who observe coastal risks where hydrocarbon development is currently concentrated between the NPR-A and ANWR. Concerning links to the Arctic observing network, the web map process links via the ecosystem services approach to observing network design, the web map product links to ongoing observing activities such as sea ice monitoring, and both process and product link to societal benefit areas that address community resilience. Study implications include the need to account for coastal exposure risks identified in this study in efforts to monitor coastal risks on the North Slope, potential use of the web map for land use decision support, and the need to focus on community needs in approaches to engage local communities in the Arctic observing network. Collectively, the findings of this study establish the groundwork for coproduction of knowledge to address coastal exposure risks on the North Slope using the Arctic observing network.

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1. Introduction

Climate research is evolving to support decision-making in the rapidly changing Arctic, where temperatures are rising faster than in any other region on Earth (AMAP 2017a). Specifically, the rapid Arctic change is driving demand for readily usable climate science and information to address the myriad of challenges and opportunities that are emerging in the region (Knapp and Trainor 2013; NRC 2014; AMAP 2017b). This demand is forcing scientist-stakeholder collaborations to enhance usability of climate research for decision support (e.g. Pearce et al. 2009; Murray et al. 2012; Lovecraft et al. 2013; NRC 2014; Lee et al. 2015a; Eicken et al. 2016a; AMAP 2017b).

The decision support focus of emerging Arctic climate research has implications for the allocation of research assets including the design and activities of the multinational and international Arctic observing network programs. The Arctic observing network is a pan-Arctic response to understand Arctic changes, monitor impacts, and address stakeholder information needs (SEARCH 2005; NRC 2006; Murray et al. 2012; Payne et al. 2013). International and national observing programs coordinate use of the network of sensors available in the Artic, which range from local community observers to satellite-based instruments (cf. NRC 2006; Druckenmiller et al. 2010; Huntington 2011; Johnson et al. 2015; Lee et al. 2015a). Both science questions and stakeholder information needs drive the network design, and network objectives to address scientific priorities and stakeholder needs vie to influence observing activities (cf. Eicken et al. 2011, 2016a; ADI 2012; Murray et al. 2012; Lee et al. 2015a). The decision support role of the Arctic observing network challenges network coordinators to balance science priorities and stakeholder information needs in network design (cf. ADI 2012; Eicken et al. 2016a).

Currently, science priorities dominate Arctic observing network design (cf. SEARCH 2005; ADI 2012; Lee et al. 2015a), but collaborative research to identify relevant stakeholder needs is emerging as a best practice to translate the network's science and monitoring activities into usable information products for decision support (Pearce et al. 2009; Lovecraft et al. 2013; NRC 2014; Eicken et al. 2016a). Local communities are among the stakeholders that the Arctic observing network is designed to support, but effectively engaging them in the network is challenging (Lee et al. 2015a; Eicken et al. 2016a; Johnson et al. 2013, 2015). As a result, local communities are not making full use of the network and their needs are not fully accounted for in Arctic observing network design. The lack of local community engagement in the network leaves local community stakeholders to face the rapid Arctic changes with less than optimal decision support.

Motivated by this problem, the aim of this dissertation was to initiate a "bottom-up" collaborative research process with local communities in Alaska's North Slope that links to the Arctic observing network. The study was designed to engage the North Slope in the network using a collaborative web mapping process that addresses coastal exposure to climate risks. The web map was based on local knowledge of coastal exposure risks and land use manager usability perspectives. The web map was installed on the borough's land use mapping system to facilitate the usability assessment and establish linkages to the Arctic observing network. The specific objectives of the study were three-fold: 1) identify coastal exposure risks from the local community perspective, 2) assess land use manager usability perspectives of the web map, and 3) explore how the web map links to the Arctic observing network. The three research objectives are closely connected in the sustained web mapping research process described in Section 2.5. Research for objectives 1 and 2 drive web map design, and analysis of the web map process and product is used to identify links to the Arctic observing network.

In this chapter, Sections 1.1 and 1.2 provide background information on coastal exposure to climate risks in the Arctic and the usable science aspect of the Arctic observing network, respectively. Section 1.3 describes the study site and Section 1.4 outlines the structure of this six-chapter dissertation.

1.1 Coastal Exposure to Climate Risks in the Arctic

Since the 1950s, Arctic air temperatures have been rising more than twice the rate of the global average (ACIA 2004; IPCC 2013; USGCRP 2017; AMAP 2017a). Over the next 30 years, autumn and winter temperatures will increase by an average of 4 °C, and the Arctic could be mostly free of summer sea ice as early as the 2030s (AMAP 2017a). The Arctic scientific community is warning that the high rate of change is going to shift the region to a new system state (AMAP 2017a). Among the dramatic changes anticipated for the region is worsening coastal hazards as the increasing exposure of coastlines from sea ice loss and permafrost thaw coincides with strong summer and fall storms (ACIA 2004; AMAP 2017a).

The Arctic has among the highest erosion rates in the world because of its typically ice-rich soil exposed to strong storms during the open water season (cf. Reimnitz et al. 1985; Overeem et al. 2011; Markon et al. 2012; Barnhart et al. 2014a,b, 2016). The average erosion rate for areas covered by the Arctic Coastal Dynamics Database is -0.5 m yr^{-1} (Lantuit et al. 2012), and rates can reach up to -8.4 m yr^{-1} along some permafrost-rich stretches of coastline (Barnhart et al. 2014b). The North Slope has among the highest erosion rates in the Arctic. The average erosion rate for the stretch of North Slope coastline covered by the U.S. Geological Survey's National Assessment of Shoreline Change Project is -1.4 m yr^{-1} and erosion rates range up to -18.6 m yr^{-1} in some places (Gibbs and Richmond 2015).

The changing sea ice cover is a primary driver of coastal erosion in the Arctic region because sea ice buffers the typically ice-rich Arctic coast from coastal storms (Overeem et al. 2011; Barnhart et al. 2014a,b, 2016). The North Slope is particularly exposed to sea ice loss. Summer-time Arctic sea ice extent has declined by an average of 10% per decade since 1979 (Stroeve et al. 2012; Mahoney et al. 2014), with pronounced declines occurring in the Chukchi and Barents Seas adjacent to the North Slope. For example, September sea ice extent in the Chukchi Sea has decreased by 26% per decade (Meier et al. 2007). Arctic coastal erosion rates are rising with climate change as sea ice decline combines with relative sea-level rise and increasing Arctic storms (cf. ACIA 2004; Manson and Solomon 2007; Overeem et al. 2011; Barnhart et al. 2014a,b, 2016). For example, along the Beaufort Sea coast, Jones et al. (2009) estimated an increase in mean coastal erosion rates from -8.7 m yr^{-1} for 1979 – 2002 to -13.6 m yr^{-1} for 2002 – 2007.

The rapid coastal changes have implications for the many Arctic communities that are located near eroding coastlines (Markon et al. 2012; Larsen et al. 2014; Chapin et al. 2014; AMAP 2017a,b). Like many other villages in the state of Alaska, coastal municipalities in the North Slope are exposed to erosion and related risks (cf. GAO 2003). In the North Slope, exposure risks experienced within or near the local municipalities are well documented in government reports and academic studies. However, the exposure risks to current local land uses that extend across the vast North Slope coastline, beyond the local municipalities, have received much less attention in exposure assessments.

The first objective of this dissertation addresses this information gap by mapping local perspectives of coastal exposure risks using hard copy maps that cover vast stretches of the North Slope coastline, beyond the local municipalities. As explained in Section 1.3, land uses in the North Slope extend across the vast coastline, beyond where the local municipalities are located. Addressing coastal exposure risks across the remote stretches of North Slope coastline is important to monitor community impacts from climate change and to support land use decisions for future coastal development (cf. Streever et al. 2011).

1.2. Arctic Observing Networks and Usable Climate Science

As mentioned in Section 1, the Arctic observing network (AON) is a region-wide response to understand Arctic changes, monitor impacts, and address stakeholder information needs. The AON is composed of national and international programs that coordinate Arctic observing activities from all available sources ranging from local community observers to satellite-based sensors. In the United States, the National Science Foundation has an AON program, and there are other national efforts such as the Canadian ArcticNet Program. At the international level, the Sustaining Arctic Observing Networks (SAON) supports the science activities of the Arctic Council including the Arctic Monitoring and Assessment Programme (AMAP).

An important aspect held in common among the AON programs is their focus on addressing both scientific priorities and stakeholder information needs in the Arctic. This dual AON focus was supported by the Fourth International Polar Year 2007-2009 (IPY), which bolstered both the pan-Arctic observing network and usable climate science (cf. SEARCH 2005; NRC 2006; Kruse et al. 2011; ADI 2012; Ford et al. 2013; Lovecraft et al. 2013; SAON 2016). The IPY was the largest international scientific program focused on polar research with 200 research projects conducted by thousands of scientists from over sixty countries (Hovelsrud and Krupnik 2006). The pan-Arctic engagement with usable climate research during the IPY in the context of concurrent efforts to develop the AON contributed to the usability aspect that continues to influence AON programs.

The usable climate science aspect of the AON is a legacy of the IPY that continues to influence the design of Arctic climate science and monitoring programs. In the United States, the Study of Environmental Arctic Change (SEARCH) program defines the research areas used to prioritize Arctic observing activities. In addition to research focused on understanding Arctic systems, the SEARCH has established a core theme called Responding to Change, which is focused on climate science for decision support (cf. ADI 2012). At the international scale, the Arctic Council's AMAP established the Adaptation Actions for a Changing Arctic initiative to promote usable climate science across the pan-Arctic region (cf. AMAP 2017b). The usable science goals provided by the SEARCH and the AMAP, along with their goals for scientific understanding, drive Arctic observing activities.

However, while usable science is a common aspect of the AON, few studies engage local communities in the AON for decision support. To address this problem, this dissertation aimed to integrate the North Slope into the AON with a focus on locally usable coastal exposure risk information for land use decision support. Research objectives 1 and 2 were concerned with engaging the local community residents and the North Slope Borough in the mapping process, respectively. Objective 3 was concerned with identifying how the overall web map research process and product links to the AON.

In addition to addressing goals of the AON to support local Arctic communities (cf. ADI 2012; Eicken et al. 2016a; IDA 2017), the research also addressed the larger challenge to use existing AONs designed for scientific research and monitoring to support decision-making for local communities and other stakeholders using best available information (NRC 2014). The web map research process also addressed the need to develop effective strategies for partnerships with the range of Arctic stakeholders including local agencies to sustain long-standing observing activities (AON 2010).

1.3. Study Site

This section provides background information on the North Slope's geography, unique land use management context (Section 1.3.1), capacity for decision support web map development (Section 1.3.2), and favorable disposition towards collaborative research (Section 1.3.3). A key point made in this section is that the North Slope has unique local capacity for collaborative web mapping research for such a remote Arctic place.

Alaska's North Slope is the United States' most northern municipality located completely above the Arctic Circle (~66.34 N). It is defined as the low-lying land area sloping north from the foot of the Brooks Mountain Range to the Arctic Ocean. About half of its 10,000 residents are Alaska Native Iñupiat and about 2,000 are seasonal workers in the oil and gas industry. Its eight municipalities vary in size from about 250 in Kaktovik to about 5,000 in Utqiaġvik, which is the largest and seat of the North Slope

Borough (NSB) government. The villages are typically small, remote, and primarily accessible by air, and separated by hundreds of kilometers of frozen or wet tundra within its vast 231,000 km^2 of land area. Five villages are located along eroding coastal bluffs, but all eight villages rely heavily on access to coastal resources for subsistence hunting and related cultural activities.

The North Slope has a mixed subsistence and cash economy. Primarily a maritime subsistence culture, the Iñupiat hunt, fish, and gather to thrive in the harsh Arctic climate as they have for millennia. During the winter, the Iñupiat scatter across the North Slope by dogsled or snow machine to camps along the coast and up river to stage for hunting caribou and other fish and game. Communities prepare year-round to hunt the Bowhead Whale during their seasonal migration to and from the Arctic Ocean through the Bering Strait. They travel by snow machine in the spring or by boat in the fall to camps across the coast. The local wage economy is primarily supported by the public administration sector through the North Slope Borough, which is the largest source of municipal income and local employment on the North Slope. The North Slope Borough taxes the extractive industry concentrated on state lands near Prudhoe Bay, the largest oil fields in the United States.

1.3.1. North Slope Land Use Management Context

The Iñupiat-controlled North Slope Borough was established in 1972 to tax oil and gas development after a major oil strike at Prudhoe Bay in 1968 on state lands (Figure 1.1). While the oil and gas development has concentrated on state lands, the majority of the North Slope has been set-aside as national energy reserves by the federal government. Two prominent federal reserves are the National Petroleum Reserve – Alaska (NPR-A) and the Arctic National Wildlife Refuge (ANWR). The NPR-A was originally established in 1923 as an emergency fuel supply for the U.S. Navy, but in the 1970s the federal government began leasing its lands to private oil companies. A section of the ANWR, called the “Section 1002 Area,” holds vast petroleum reserves and development may eventually be permitted there. However, development in the ANWR is controversial and Congress has yet to approve it. Federal waters in the Chukchi and Beaufort Seas may hold the largest undeveloped oil reserves in United States, and exploration there continues. The ongoing and future energy development is a prominent economic activity on the North Slope.

The oil and gas industry presents many challenges and opportunities for North Slope communities to adapt to Arctic change. Relevant opportunities addressed in this study include a well-established municipal land use geographic information system funded by the borough through tax revenues (GIS, Section 1.3.2) and an applied research coordinating body mandated by Congress to support North Slope land use managers – the North Slope Science Initiative (NSSI). Chapter 4 of this dissertation addresses the relevancy of this research for climate change and energy development scenarios research on the North Slope. The NSSI scenarios research is one research activity occurring under the auspices of the federal government to address the complexity of balancing energy development with protection of natural resources and related land use management objectives on the North Slope.

The local autonomy of the Iñupiat-controlled North Slope Borough is another adaptation opportunity supported by energy development. The North Slope Borough has home rule status and is withdrawn from the federal Coastal Zone Management Program.

This provides significant local authority and autonomy to the borough to administer its land use management program across the North Slope. The North Slope Borough Planning Commission reviews hundreds of coastal development land use applications annually. Among its many objectives, the local coastal zone management program protects its subsistence and cultural heritage resources while balancing these traditional land uses with industrial and municipal land use needs. The North Slope Borough's local autonomy is one reason why collaborative web map decision support research performed in this study could be effective in supporting adaptive local responses to change.

In addition to subsistence and related land uses, the Iñupiat also have their own industrial land uses primarily through lands selected under the Alaska Native Claims Settlement Act (ANCSA) of 1971. The ANCSA established regional and village native corporations, which have limited rights to select and develop land in Alaska. The Arctic Slope Regional Corporation (ASRC) and eight native village corporations claim lands on the North Slope. The ASRC is one of 13 regional corporations created by the ANCSA. It can claim surface and subsurface rights, including subsurface rights in the NPR-A if the land is used for commercial land use and meets other conditions. The North Slope has eight native village corporations, which selected lands at existing or reestablished permanent settlements. The ASRC and the eight native village corporations typically specialize in energy services and select lands strategically near hunting grounds and national defense and oil industry sites to benefit from surface and/or subsurface rights within the National Petroleum Reserve – Alaska (NPR-A) and the Arctic National Wildlife Refuge (ANWR). The Iñupiat industrial land uses feature prominently in study results on local perspectives of coastal exposure risks presented in Chapter 3.

In Figure 1.1 below, the native village corporation lands are symbolized in orange and the regional corporation, i.e., the ASRC, is symbolized in brown. Most of the native village corporation lands selected under the ANCSA are located near the eight municipalities, which are symbolized by black dots and annotated with city name. Most of the ASRC lands are located outside of the NPR-A with the exception of a small parcel near Cape Halkett, east of Utqiaġvik. Four of the municipalities are located near one of the 15 Distant Early Warning (DEW) Line sites symbolized by red rings. Most of the North Slope is within the NPR-A or ANWR lands symbolized as light red dotted areas lands that surround Alaska state lands symbolized by blue dotted areas. Kaktovik is the only municipality located within the 1002 Area of the ANWR, the purple dotted area. The Trans-Alaska Pipeline System (TAPS) starts at Prudhoe Pay and passes south through state lands and within the subsistence use area symbolized by diagonal green lines. The subsistence area is the combined area of all eight villages, estimated by Pedersen (1979).

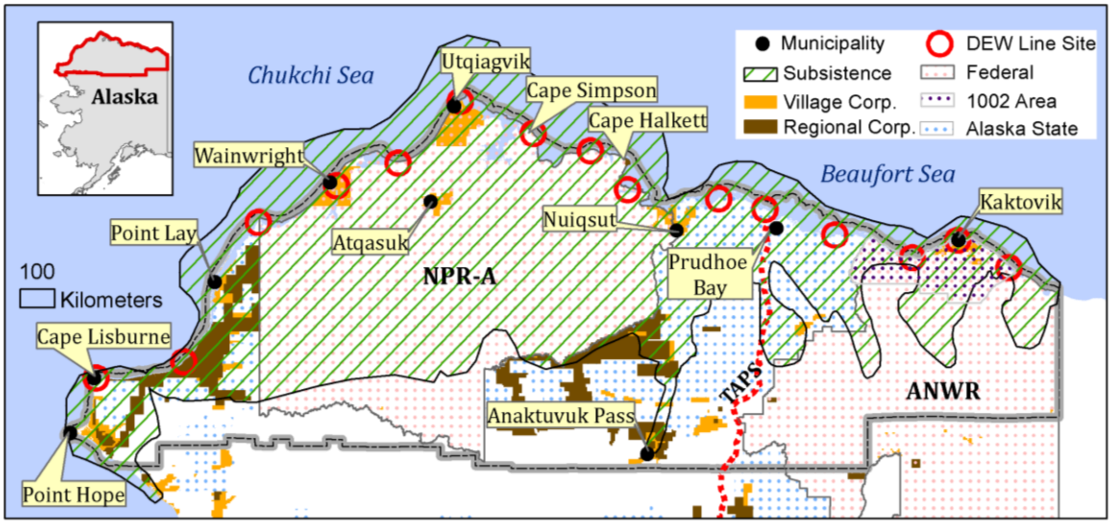

Figure 1.1. Select North Slope Land Use

Figure 1.1 shows the North Slope's eight municipalities, the subsistence area digitized from Pedersen (1979), regional and village native corporation lands, Distant Early Warning (DEW) Line sites, two prominent federal land units: the National Petroleum Reserve – Alaska (NPR-A) and the Arctic National Wildlife Refuge (ANWR) including the Section 1002 Area that may be developed for oil and gas, state lands, the Trans-Alaska Pipeline System (TAPS), and the North Slope Borough boundary (gray line). The DEW Line was a series of radar sites with airstrips located every fifty miles across the North American coast from Alaska to Greenland. The DEW Line was installed for national defense surveillance during the Cold War, but has since been decommissioned. The DEW Line was replaced by the North Warning System, which still operates from three legacy DEW sites. Remediated DEW sites with remaining infrastructure are being transferred to local and state governments.

1.3.2. North Slope Capacity for Web Map Development

The North Slope has a unique capacity for collaborative web mapping for decision support through its Iñupiat-controlled land use mapping system. In support of the local land use management program, the North Slope Borough (NSB) established the Department of Planning and Community Services Department and its GIS Division to administer the borough's land use management program, The GIS Division provides mapping services to support borough programs (cf. Esri 1981). The borough has been developing its geographic information system (GIS) for about four decades. In the early 1980s, with federal Coastal Zone Management funds provided by Alaska State, the NSB contracted Esri President Jack Dangermond to investigate GIS applications in the North Slope. The 536 page conceptual design and implementation plan (Esri 1981) was first demonstrated for the North Slope in 1982 focusing on application in the heavily developed Kuparuk region. The Environmental Information System (EIS module) of the GIS was designed to provide access to accurate environmental data on an independent computer under direct control of NSB personnel (Esri 1981). The EIS module was also designed to share data between data developers and users including various state and federal agencies and universities (Esri 1981). However, despite the recent surge in environmental spatial data now available for the Arctic at spatial scales relevant for NSB land use planning, to-date the intended design of the EIS module to support collaborative environmental data share and use remains unrealized.

Recent NSB efforts to leverage Esri web-based products to facilitate data share and borough management presents an opportunity to revisit the original NSB GIS conceptual design and plan to reassess data share capabilities in the context of Arctic observing networks. The NSB agreed to collaborate in this research in part because it was viewed as a good pilot project to develop the web map and showcase the new web-based map capabilities to local managers.

1.3.3. North Slope Capacity for Collaborative Climate Change Research

Utqiaġvik is known as a hub for climate change research in the Arctic for monitoring and understanding the Arctic and global climate change (Norton 2001). The North Slope also has a long history of collaborative research beginning with the installation of the Naval Arctic Research Laboratory (NARL) in 1947 to support Navy operations where Iñupiat were employed and often partners in collaborative research (Albert et al. 1988; Brewster et al. 2001; Kelley and Brower 2001). The Iñupiat took greater control of Arctic research when NARL was transferred to Ukpeagvik Iñupiat Corporation (UIC) in 1989. By the mid-1970s, many of the local Iñupiat who had worked at NARL took decision-making positions in the North Slope Borough (NSB). And the UIC, through their involvement with NARL, helped create a positive outlook toward collaborating with scientists (Albert 1990). The collaboration legacy from NARL continues and is observed in the research support provided by the NSB's Department of Wildlife Management and UIC's commitment to the Barrow Environmental Observatory (BEO) (Brown 2001).

A formal forum for collaborative climate change research came in 2001 with the establishment of the North Slope Science Initiative (NSSI) tasked by Congress to coordinate applied science needs relevant for North Slope managers.[1] The NSSI coordinates applied science at the federal, state, and local level on the North Slope. The NSB and Arctic Slope Regional Corporation (ASRC) are among the fourteen members of the NSSI. Among its various collaborative research efforts, the NSSI coordinates a sustained scenarios planning effort to include the perspectives of the range of North Slope stakeholders in possible futures research in the context of global change (cf. Streever et al. 2011).

1.4. Research Questions and Dissertation Structure

The dissertation investigated the following three research questions:

1. Why is coastal exposure to climate risks a problem for North Slope communities?

2. What is the land use manager usability perspective of the web map?

3. How does the web map link to the Arctic observing network?

The dissertation has six chapters that address these research questions: the introduction, a literature and methods chapter, three results chapters, and a conclusion chapter. Each of the three results chapters has five main sections: introduction, method,

[1] The NSSI was formally authorized in 2005 under the Energy Policy Act of 2005.

results, discussion, and conclusions. Below are brief outlines for chapters 2 through 6 of the dissertation.

Chapter 2: Literature Review and Research Method provides a review of the literature that the dissertation draws from and contributes to. The literature review is grouped into three themes that correspond with the three results chapters, i.e.: 2.1: Coastal Exposure to Climate Change, 2.2: Evaluating Climate Change Research Usability, and 2.3: Climate Change Decision Support Using the Arctic Observing Network. The literature review is followed by the above research questions restated in Section 2.4 with an explanation of how the chapters contribute to the corresponding literature areas. Section 2.5 explains the overall collaborative web mapping process based on an Instructional Systems Design (ISD).

Chapter 3: Local Views of Coastal Exposure in Alaska's North Slope is the first results chapter. Section 3 introduces the first results chapter putting it in the context of previous coastal risk research on the North Slope, and noting the lack of knowledge of risks outside of the villages where subsistence and industrial land uses are prominent. Section 3.1 describes the study site, collaborative mapping methods used to collect local views of coastline risk, and analysis methods. Results provided in Section 3.2 are organized by the two main risks found: local concern for constrained coastal access for industrial and subsistence land uses. Section 3.3 states that the coastal exposure risks identified in this study are relevant for the North Slope Science Initiative (NSSI), which is Congressionally mandated to coordinate applied science on the North Slope. Section 3.4 concludes the chapter by restating the findings.

Chapter 4: Manager Usability Perspective of the Coastal Exposure Web Map is the second results chapter. Section 4 introduces the second results chapter, putting it in the context of the call in the Arctic for collaborative research to address the need for usable climate science. Section 4.1 describes methods used to collect and analyze local manager usability views of the coastal exposure web map. The results provided in Section 4.2 indicate that the web map could be used as a screening tool to support the North Slope Borough's development permit application review process, local views from the village of Nuiqsut should be included as well ask risks to oil and gas development on state lands, and there is concern about the quality of underlying data. Section 4.3 discusses the unique local management context that provides good conditions for manager uptake of the web map and next steps for enhancing its usability. Section 4.4 concludes the chapter by noting that the prominence of local management and opportunities for uptake that emerged in the usability workshop.

Chapter 5: Linking the Coastal Exposure Web Map to the Arctic Observing Network is the third and final results chapter. Section 5 introduces the chapter, putting the results in the context of the challenge of engaging local communities in the Arctic observing network (AON). Section 5.1 describes the method to analyze web map links to the AON. Results Section 5.2.1 compares the web map research process described in Section 2.5 with AON design approaches. Section 5.2.2 identifies the web map data steward network based on organizations that provided the data used to create the web map and compares results with federal Arctic observing activities. Section 5.2.3 identifies how the web map process and product link to AON societal benefit areas. Section 5.3 discusses the significance of the results in terms of advancing "dual use" observing networks by providing a method to engage local communities in the AON (5.3.1), advancing a North Slope coastal exposure observing network by creating a community of practice (CoP) (5.3.2), and community data management in the context of the Arctic Spatial Data Infrastructure (ASDI) (5.3.3). Section 5.4 concludes the chapter by restating the main findings.

Chapter 6: Conclusions summarizes the main study findings, identifies policy implications, and recommends future research. Section 6 introduces the chapter by restating the aim of the study and contributions to the literature. Section 6.1 summarizes the main findings from results chapters 3, 4, and 5. Section 6.2 identifies policy implications of the main findings, and Section 6.3 suggests future research.

2. Literature Review and Research Method

This chapter reviews three scholarly literature areas addressed by the dissertation: Coastal Exposure to Climate Change (2.1), Evaluating the Usability of Climate Change Research (2.2), and Climate Change Decision Support Using the Arctic Observing Network (2.3). Section 2.4 explains how the three research questions contribute to their respective literature areas, and Section 2.5 provides an overview of the collaborative web map research process used to investigate the three questions.

2.1. Coastal Exposure to Climate Change

In the global change literature, exposure is defined the element of the concept of vulnerability that is concerned with analyzing the nature and degree to which humans experience social or environmental stress (Adger 2006). While the meaning of vulnerability is contested (Cutter 1996; Liverman 1990; Dow 1992; Adger 2006), the meaning of exposure is relatively clear and consistent in the literature. Exposure is often equated with vulnerability in studies that emphasize the role of the environment in causing climate risks (cf. IPCC 2012).

In the global change literature, coastal exposure is a subset of vulnerability research concerned with the populations, economies, land use assets and activities, and other human valuables at risk to sea-level rise and related hazards specific to the coastal zone such as storm surge and coastal erosion. Coastal exposure studies at the global scale coarsely take stock of populations and assets exposed. Regional and local scale coastal exposure assessments emphasize consequences of being exposed such as economic impacts relevant for national or regional economies. In local scale coastal exposure research, collaboration with stakeholders is common to get stakeholder perspectives of risks and impacts, and to develop decision support.

At the global scale, the concept of coastal exposure is typically used to specify the degree to which human settlements occupy flood prone areas and are at risk (Schneider and Chen 1980; Barth and Titus 1984; Nicholls et al. 1999, 2007; Nicholls 2002, 2004; Pelling et al. 2004; Dilley 2005; Anthoff et al. 2006; McGranahan et al. 2006, 2007, 2008; Peduzzi et al. 2009, Peduzzi and Herold 2005; Rowley 2007; Small and Nicholls 2003; Small and Cohen 2004; Ericson et al. 2006; Nadim et al. 2009; Nicholls and Cazenave 2010; Leichenko and Thomas 2012; Jha et al. 2012; Jogman et al. 2012; Newmann et al. 2015). Much of the literature is devoted to the development of global scale human geospatial data (Dobson et al. 2000; Balk et al. 2005; Vafeidis et al. 2008; Gamba 2009) and environment geospatial data (Rabus et al. 2003; Giuliani and Peduzzi 2011) needed to analyze coastal exposure. Coastal exposure is often analyzed in terms of the number of people exposed aggregated by country (McGranahan et al. 2006) or with a focus on particular places or assets of interest to the international community such as highly vulnerable dense settlements (Balk et al. 2009), world heritage cities (Bigio et al. 2014), port cities (Hansen et al. 2011), or national security assets (Hall et al. 2016). In terms of projecting impacts, there are global estimates of exposure to sea-level rise in terms of economic value (Hansen et al. 2011) and ecosystem services (Jarmin and Miranda 2009). Coastal exposure research at the global level also aims to explain what drives coastal change (Ericson 2006) and human settlement patterns (Lall and Deichmann 2010) to explain exposure outcomes.

Global climate change data are applied to regional, national, and subnational geographies to analyze coastal exposure impacts and risks to assets and activities in enough detail to be relevant at those respective scales (e.g. Neumann et al. 2010; Dasgupa et al. 2011; Kulp and Strauss 2017). As with the global scale research, literature is devoted to creating geospatial data to analyze coastal exposure at the larger scales (e.g. Gornitz et al. 1991; Kopp et al. 2014). While many of the global scale coastal exposure assessments provide an analysis by region (e.g. Anthoff et al. 2006) or country (McGranahan et al. 2006), studies that focus on the larger scales generally emphasize impacts from exposure such as projections of costs associated with economic losses and adaptation (Yohe 1996, 1999; Kirshen et al. 2008; Neumann et al. 2010, 2015), populations exposed (Gornitz et al. 2001; Strauss 2012; Martinich et al. 2013; Hauer et al. 2016), municipal risks (Wu et al. 2002; Kulp and Strauss 2017), infrastructure risks (Tate and Frazier 2013; Neumann et al. 2015), and loss of natural resources (Titus 1988). Coastal exposure at these scales often detail risks to specific sectors to inform managers such as energy (Burkett 2011), national defense (Kinner et la. 2006; Marra et al. 2015), and national parks (Murdukhayeva et al. 2013).

Coastal exposure research at the local scale is sometimes done in collaboration with affected stakeholders to get their perspectives of impacts and risk (e.g. Leichenko et al. 2014; Mitchell et al. 2016), develop decision support tools (Lathrop et al. 2012, 2014, 2017), and explore management options (Frazier 2010). Consistent with the broader climate change impacts research field, there is a call in the literature for more collaboration with decision-makers in coastal exposure research to include their perspectives (Vogel et al. 2007; Frazier et al. 2010; Corfee-Morlot et al. 2011; Leichenko et al. 2014; Mitchell et al. 2016; DeLorme et al. 2016). This dissertation builds from these stakeholder-based coastal exposure efforts and applies the approach in the Arctic.

While the Arctic region has received considerable attention from scientists studying the rapidly changing coast (Hume and Schalk 1967; Walker 1991; 1998; 2001; Lantuit 2012; Barnhart et al. 2014a,b, 2016), there is a lack the local perspectives of coastal exposure across the vast remote stretches of the shoreline. As in other Arctic regions, research on coastal exposure along Alaska's northern shore mostly addresses threats to municipal and industrial infrastructure and activity such as roads and airstrips located in proximity to the small stretches of shoreline near Alaska native villages (cf. Brunner and Lynch 2013; Lovecraft and Eicken 2011; Melvin et al. 2016). While these risks are important, less is known about the rest of the vast shoreline where subsistence and industrial activity, the two primary land uses in the region, also occur and are in some places concentrated. Researchers that have investigated coastal exposure outside of the villages have focused on threats to historical and archeological sites (Jones et al. 2008; Jensen et al. 2015), but assessments of risk to current land uses along these stretches of shoreline are lacking. With respect to efforts by the government, resource managers, academia, and industry to understand and monitor the effects of diminishing Arctic sea ice on local communities in the region (ACIA 2004; Streever et al. 2011; Larsen et al. 2014; Chapin et al. 2014; AMAP 2017a,b), the available literature on land use impacts away from the villages provides an incomplete picture with most attention given to land uses that depend directly on sea ice conditions. For example, available studies detail land use risks associated with sea ice used as platforms to support subsistence hunting (George et al. 2004; Hinzman et al. 2005; Eicken et al. 2009; Druckenmiller et al. 2010) and oil and gas industry operations (Eicken et al. 2009). Less is known about the land use impacts from shoreline change as a physical system response to sea ice loss.

Chapter 3 of this dissertation contributes to coastal exposure research by collaborating with local community stakeholders to identify coastal exposure risks across remote stretches of the North Slope coastline.

2.2. Evaluating Climate Change Research Usability

In the Arctic context where climate change is pronounced and impacts are widespread, there is growing consensus in the scientific community that the predominant “top-down” Arctic systems science needs to adapt to make the science more useful for resource managers (Streever et al. 2011; Knapp and Trainor 2013; NRC 2014). The call for Arctic science to adapt to address manager needs is driven by pressures to improve knowledge integration with governance in the region to better respond to climate impacts and manage risks. In Alaska where average annual temperature has increased 1.7°C (Stafford et al. 2000), permafrost is thawing and sea-ice is diminishing (Barnhart et al. 2014a,b, 2016), climate change effects are obvious including widespread and worsening coastal flooding and erosion impacts (GAO 2003). Usable climate information is limited in the region in comparison with less remote places in the United States due to the lack of long-term data and analysis expertise (Knapp and Trainor 2013). Inadequate information combined with an understanding that access to information also requires a desire and capacity to act (NRC 2014) demands collaborative research with information users that address these and other usability aspects in the process.

In the global change literature, usability refers to the degree to which scientific climate information derived by combing and interpreting multiple sources of data is readily usable to support decision-making in policy and practice (Pielke 1995; Dilling and Lemos 2011; Wall et al. 2017). Usable climate science in global change research is a goal of coproduction of knowledge methods where researchers collaborate with stakeholders in all phases of research to produce new scientific knowledge or refine existing science with the goal to support decision-making (Wall et al. 2017). As the presumed mechanism for decision-maker uptake (Cash et al. 2003, Weichselgartner and Kasperson 2010; Lemos and Morehouse 2005; Mitchell et al. 2006; Dilling and Lemos 2011; Cutts et al. 2011; Lemos et al. 2012; Kirchhoff et al. 2013; Ford et al. 2013; Moss 2014; Meadow et al. 2015; Wall et al. 2017; Beier et al. 2017), achieving climate science usability is the focus of emerging research on evaluating the success of coproduction of knowledge (Fazey et al. 2014; Wall et al. 2017). Usability is a complex phenomena determined by a range of factors including achieving stakeholder perspectives of saliency, credibility, and legitimacy (Cash et al. 2003), mutual trust and learning, and understanding the management context for information uptake (Wall et al. 2017). This new area of research addresses the broad demand for publically-funded research to support decision-making (Flyvbjerg and Sampson 2001; Cash et al. 2003; Ford and Smit 2004; Lemos and Morehouse 2005; Sarewitz and Pielke 2007; Pearce et al. 2009; Dilling and Lemos 2011; Lemos et al. 2012, cited in Ford et al. 2013) and the problem that, despite billions of dollars spent on research for decision support, there is little evidence of improved decision-making (Cash et al. 2003; Ebi et al. 2009; Ford et al. 2013; Dilling and Lemos 2011; Ford et al. 2011; Lemos et al. 2012; Wall et al. 2017).

The lack of evidence that coproduction achieves what it claims to exposes it to the critique that the approach may be unpractical and, due to its extremely high cost, should not be a standard method (Sutherland et al. 2017). The gravity of this critique comes into focus when evaluating coproduction for use in sustained assessments such as the

International Panel on Climate Change (IPCC), which currently excludes non-peer reviewed stakeholder knowledge. Excluding local community or other stakeholder knowledge blocks what Cash and Moser (2000) referred to as scale-specific comparative advantage - the value from diverse scale-specific knowledge needed for decision support. Blocking scale-specific comparative advantage is problematic for usability because stakeholder knowledge for science aimed to support decisions at particular locals may be more valuable than scientific knowledge (Reid et al. 2006). For example, while state and national institutions provide their interests and management resources such as scientific databases, local knowledge defines locally salient impacts such as on subsistence (Berkes et al. 2009). A failed experiment with coproduction in the Millennium Ecosystem Assessment (MA) suggests the claimed benefits of coproduction are not achievable systematically due to epistemological diversity preventing application of uniform standards for credibility demanded by sustained assessments (Reid et al. 2006). However, while balancing dimensions of information usability has proven difficult, the MA process has yielded some evidence that both legitimacy and credibility can be established, but only for observations of basic environmental processes where epistemological differences to explain the processes are not invoked (Reid et al. 2006). This suggests that coproduction should focus on answering questions that do not require agreement in explanation such as local knowledge of values and salient impacts (Reid et al. 2014), i.e.: “co-assessment” (Sutherland et al. 2017).

Acknowledging that knowledge about cost-effective methods for collaborative decision support research is incomplete (DeLorme et al. 2016), much of the literature on coastal exposure usability documents actual project experiences to provide a window into the research process to evaluate effectiveness of usability methods under (collaborative) development (Lathrop et al. 2012, 2014, 2017; Stephens et al. 2015; DeLorme et al. 2016; DeLorme et al. 2017). Analyzing the research process in terms of collaboration for decision support is the state-of-the-art with respect to evaluating usability of climate change research (cf. Ford et al. 2013; Wall et al. 2017).

Chapter 4 of this dissertation contributes to climate research usability literature by assessing local land use manager usability perspectives of the coastal exposure web map developed for the study.

2.3. Climate Change Decision Support Using the Arctic Observing Network

The approach of using the Arctic observing network (AON) to support decision-making has emerged in the Arctic global change literature to address the high demand for usable climate science in the region. The Arctic observing network aims to serve the dual function of supporting decision-making and scientific research (NRC 2006; Eicken et al. 2009; Lovecraft et al. 2013; Lee et al. 2015a,b; Starkweather et al. 2016; Eicken et al. 2016a; Sommer and Fleener 2016). Arctic observing networks that include local community input support a range of Arctic management objectives including national security by supporting Maritime Domain Awareness (MDA) (Eicken et al. 2016a,b) and “early warning systems” for severe social and environmental threats that emerge in the Arctic (Alessa et al. 2013, 2016). Arctic observing networks with local community input are also designed to support the wide-range of stakeholders operating in the region such as the maritime and oil industries as well as the local communities themselves (Russel et al. 2013; Eicken et al. 2016a).

Arctic observing network capacity continues to grow since the bolstering the network received during the 2007-2008 International Polar Year (IPY) (see Chapter 1). A growing number of web maps were established to make Arctic observations available to address the range of stakeholder information and science needs such as U.S. Arctic Observing Viewer (Manley et al. 2015). The Alaska Ocean Observing System (AOOS), another Web-based data steward system, makes Arctic observations available and engages stakeholders to make them accessible for use in decision-making (cf. Alessa et al. 2016). The recently established United States Arctic Observing Network (U.S. AON) office coordinates Arctic observing networks for the U.S. across geographic scales from the local community level to the international scale by linking with the Sustaining Arctic Observing Networks (SAON) program initiated by the Arctic Council (Starkweather et al. 2016). Through SAON, the US AON links with sustained Arctic climate assessments including the Arctic Council's Arctic Monitoring and Assessment Programme (AMAP) and International Arctic Science Committee (IASC).

Arctic observing network programs typically make efforts to engage stakeholders and scientists to transform raw observations and data into usable information products (Lovecraft et al. 2013, 2016; Timm et al. 2016; Armstrong et al. 2016). However, a major challenge for Arctic observing networks is effectively engaging local community stakeholders to address their information needs (Lee et al. 2015a; Eicken et al. 2016a; Johnson et al. 2013, 2015). Though the Arctic observing network role of addressing local community needs has been established (cf. Eicken et al. 2016a), there is no standard approach to engage local communities for input in network (cf. Lee et al. 2015a; IARPC 2015, cited in Eicken et al. 2016a). To address this challenge, the Arctic observing network research community is working to better align priorities of environmental change monitoring efforts for science with priorities of local and regional stakeholder information needs, but admit integrating local community stakeholder input and local knowledge into the network is challenging (Lee et al. 2015a; Eicken et al. 2016a). Local input in Arctic observing networks is also a major challenge for "bottom-up" approaches such as community-based monitoring (CBM). In an assessment of CBM research contribution to the Arctic observing network, Johnson et al. (2015) found significant challenges with connecting CBM research with wider research and governance networks such as resource decision-makers.

Chapter 5 of this dissertation contributes to Arctic observing network literature by advancing methods to engage local community stakeholders in the network.

2.4. Research Questions

The review of the literature on coastal exposure to climate change, evaluating the usability of climate change research, and climate change decision support using the Arctic observing network has identified areas needing more research. This dissertation addressed these literature gaps by researching the three questions described in the following paragraphs.

Research Questions 1*: Why is coastal exposure to climate risks a problem for North Slope communities?*

This research question addresses the need for more collaborative coastal exposure risk research from the perspective of impacted stakeholders. Getting the local perspective of exposures along the remote stretches of the North Slope coastline addresses a locally salient information gap for resource managers that have to balance competing subsistence and industrial land uses that occur across the vast coastline. As a front-end evaluation in the overall collaborative web map research process (Figure 2.1, Step 1), the research addressed calls to advance usable climate science by engaging with stakeholders early in the research process, enhancing salience of coastal exposure information through a front-end evolution effort, and building relationships and trust with local informants.

***Research Question** 2: What is the land use manager usability perspective of the web map?*

Answering this question contributes to collaborative research to evaluate climate science by applying the widely used conceptual model to assess climate science information usability: credibility, and legitimacy based on Cash et al. (2003). The usability analysis contributes to literature specific to collaborative mapping in the Arctic context. It also contributes to emerging collaborative web map research for coastal exposure by providing a window into the collaborative research process, which is useful for evaluating the research design in terms of likelihood of science being usable. In the overall collaborative web map research design (Figure 2.1, Step 3), the research addresses climate science by engaging stakeholders in a formative usability evaluation to identify improvements and continue the ongoing interaction necessary to build decision support.

***Research Question 3**: How does the web map link to the Arctic observing network?*

Investigating this question through initiating a collaborative web map contributes to innovative ways to interact with local communities to develop decision support. In terms of the overall collaborative web map research design, this question addresses the call for more research to advance usable climate science through sustained interaction with local communities to develop land use decision support. The collaborative research design used in this study is based on an Instructional Systems Design (ISD). The ISD provides a practical method to engage local communities in the Arctic observing network and communicate information needs.

Research questions 1, 2, and 3 are answered in chapters 3, 4, and 5, respectively. Section 2.5 below provides an overview of the research methods used to answer the research questions. Detailed methods are provided in each of the three results chapters.

2.5. Research Method

The three questions in Section 2.4 were investigated by initiating a coastal exposure web map in collaboration with the North Slope Borough and its residents using an Instructional Systems Design (instructional design) (Figure 2.1). Instructional design is a well established and widely used collaborative research process based on systems theory (Von Bertalanffy 1956) for developing education and training programs in a consistent, reliable, creative, iterative, and flexible fashion (Saettler 1968; Gagné and Briggs 1974; Gagné and Glaser 1987; Steel et al. 2017; Branch 2017). A central tenant of instructional design is evaluation throughout the process of designing the system. Instructional design is common in collaborative web map development in the context of the classroom (Baker 2015) or stakeholder usability workshop setting (Lathrop et al. 2012, 2014, 2017). With respect to web-based decision support tools, the instructional design is consistent with user-centric models for decision tool system design specified by international standard (ISO 2010).

Evaluation through instructional design or similar interactive design is increasingly common in collaborative coastal exposure web map development specifically (Lathrop et al. 2012, 2014, 2017; Stephens et al. 2015; DeLorme et al. 2016;

DeLorme et al. 2017) including in the context of the Arctic observing network (Eschenbach 2017; Baschek et al. 2017). With respect to connections with the global change literature, the instructional design responds to the call for innovative approaches for scientist-stakeholder interaction (Dilling and Lemos 2011; AMAP 2017b), iterativity (Lemos and Morehouse 2005), and evaluation of the various phases of coproduction (Dilling and Lemos 2011; Wall et al. 2017) to advance usable climate science.

Instructional design draws from evaluation research to enhance the ability for instructional materials to meet defined goals. Research questions 1 and 2 in Section 2.4 correspond with the two evaluation efforts typical of an instructional design process, i.e.: front-end and formative evaluations (cf. Gagné 1987; Dick et al. 2005). A front-end evaluation is an effort to assess needs while a formative evaluation is done to improve instructional materials during the development process. In the web map research process shown in Figure 2.1, Collaborative Research Step 1 is the front-end evaluation, and Collaborative Research Step 3 is the formative evaluation.

In Figure 2.1 below, the three collaborative research steps in bold are distinguished from research tasks done by the researcher without interacting with the local community. Collaborative research steps 1 through 3 are in an infinite loop, and the North Slope Borough controls the model output through information dissemination via the web map after the formative evaluation in Collaborative Step 3. The solid black arrows in Figure 2.1 indicate the direction of the progression of research, and dotted arrows indicate the direction of feedback during research phases. The front-end evaluation in ***Collaborative Step 1*** corresponds to the first research question addressed in chapter 3: *Why is coastal exposure to climate risks a problem for North Slope* *communities?* In the instructional design, this step consists of verifying local risks using participatory mapping methods to collect local perspectives of coastal exposure risk. Results from Collaborative Step 1 were used to identify the assets to represent in the web map and understand why their exposure is a problem. While the focus of the local risk verification was to identify at-risk assets, participants often volunteered information on environmental drivers of shoreline change. This feedback in Collaborative Step 1 is illustrated in Figure 2.1 as the dotted line from Step 1 to the Researcher Develop Shoreline Change Susceptibility Data Model task. The formative evaluation in ***Collaborative Step 3*** corresponds with the second research question addressed in Chapter 4: *What is the land use manager usability perspective of the web map?* Prior to Collaborative Step 3, the researcher collaborates with the North Slope Borough to develop the coastal exposure web map in Collaborative Step 2. As described in more detail in Section 4.1.2, at-risk asset data representing risk found in Step 1 were integrated with a shoreline change susceptibility model to create coastal exposure datasets. In ***Collaborative Step 2***, the researcher works with the North Slope Borough to create the coastal exposure web maps using the exposure data. In Collaborative Step 3, the dotted arrows indicate that land use managers provide feedback for all research steps and tasks to adapt the web map process to address manager needs.

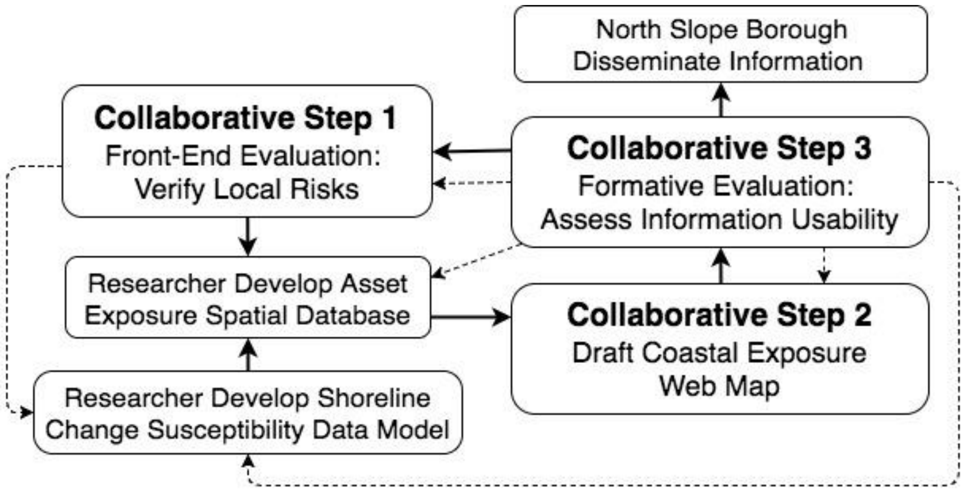

Figure 2.1. Collaborative Coastal Exposure Web Map Research Process
The collaborative research is based on an instructional systems design (ISD) consisting of three collaborative research steps, two non-collaborative research tasks before Step 2, and one North Slope Borough non-collaborative information dissemination task after Step 3.The solid arrows indicate the direction of successive research steps, and dotted arrows indicate direction of feedback from study participants during evaluation steps 1 and 3.

Research question 3 addressed in Chapter 5: *How does the web map link to the Arctic observing network*, corresponds with the overall research process illustrated in Figure 2.1. To identify web map links to the Arctic observing network (AON), the web map process and product were compared with the structure of the network. To facilitate link identification, the structure of the AON was defined using three key reports that address important organizational aspects of the network. The three reports address AON design approaches (ADI 2012), federal Arctic observing activities (Jeffries et al. 2007), and societal benefit areas (IDA 2017). The method to answer research question 3 is described in more detail in Section 5.1.

Dissertation results chapters 3, 4, and 5 each provide detailed methods that correspond with the three research objectives. Chapter 3 describes the community mapping workshop materials used to collect data and method to analyze the local coastal exposure risk perspectives provided on hard copy maps. Chapter 4 describes the web map materials and the method to collect and analyze land use manager usability perspectives using the Cash et al. (2003) usable science conceptual framework. Chapter 5 describes the method to identify web map links to the Arctic observing network, which was summarized in the paragraph above.

The metadata for the web map datasets created for this study were submitted to the National Science Foundation Arctic Data Center (https://arcticdata.io/). Excerpts of the metadata are provided in Appendices A to D.

3. Local Views of Coastal Exposure in Alaska's North Slope

The Arctic shoreline is changing rapidly along some stretches of the Arctic Ocean coast and changes are likely accelerating due in part to diminishing sea ice (Overeem et al. 2011; Barnhart et al. 2014a,b, 2016). The average erosion rate for areas covered by the Arctic Coastal Dynamics Database is 0.5 m yr^{-1} (Lantuit et al. 2012), and rates can reach up to 8.4 m yr^{-1} along some permafrost-rich stretches of coastline (Barnhart et al. 2014b). One study found a doubling of erosion rates of a segment of the coast on the North Slope over the last 50 years (Mars and Houseknecht 2007).

While significant research attention is being given to the environmental changes, there is less research on how the changes are impacting coastal communities. Coastal exposure research along Alaska's North Slope mostly addresses threats to municipal and industrial infrastructure such as roads and airstrips located within proximity to the small stretches of shoreline near Alaska native villages (e.g. Brunner and Lynch 2013; Lovecraft and Eicken 2011). While these risks are important, there has been less research attention on the rest of the vast shoreline where subsistence and industrial activity, the two primary land uses in the region, also occurs and is in some places concentrated. Researchers that have investigated coastal exposure outside of the villages have focused on threats to sites associated with historical land uses such as cultural heritage and archeological sites (Jones et al. 2008; Jensen et al. 2015), but assessments of risk to current land uses along these stretches of shoreline are lacking.

With respect to efforts by the government, resource managers, academia, and industry to understand and monitor the effects of diminishing Arctic sea ice on local communities in the region (ACIA 2004; Streever et al. 2011; Larsen et al. 2014; Chapin et al. 2014), the available literature on land use impacts away from the villages provides an incomplete picture with most attention given to land uses that depend directly on sea ice conditions. For example, available studies detail land use risks associated with sea ice used as platforms to support subsistence hunting (George et al. 2004; Hinzman et al. 2005; Eicken et al. 2009; Druckenmiller et al. 2010) and oil and gas industry operations (Eicken et al. 2009). Less research attention is given to the land use impacts from coastal exposure as a physical system response to sea ice loss.

The aim of this chapter is to address the above research gap by documenting local views of coastal exposure to climate risk across Alaska's North Slope coast using a collaborative mapping research method. While this chapter focuses on the coastal exposure research gap, it is also part of the overall study design for innovative collaborative research explained in Chapter 2. This chapter does a "front-end" evaluation for the coastal exposure web map created for this study. The objective of the evaluation effort was to identify local risks from the perceptive of North Slope residents. This research was done to identify coastal exposure risks to include in the coastal exposure web map described in Chapter 4.

3.1. Method

The research question that guided the front-end web map evaluation is: *Why is coastal exposure to climate risks a problem for North Slope communities*? The semi-directive collaborative mapping method detailed in Section 3.1.1 was designed to collect local views of the problem at a regional scale to avoid a focus on well-documented risks in or near the local municipalities. Results were analyzed by identifying emergent themes from digitized coded stickers used to spatially document participant views (Section 3.2). Of the three land uses identified from toponym analysis, i.e.: industrial, subsistence, and municipal, the first two sectors were the focus of further analysis to identify coastal exposure risks across the vast North Slope coast outside of the local municipalities.

3.1.1. Data Collection

The primary method to collect local views of coastal exposure risks was through community-mapping workshops in Wainwright, Utqiaġvik, and Kaktovik (Figure 3.1) using a semi-directive interaction design and snowball sampling. The semi-directive interview is an accepted method for collecting local information and knowledge in an open-ended format (Briggs 1986; Pretty et al. 1995), and is common in collaborative Arctic research (Huntington 1998). In semi-directive interviews, the researcher focuses participant attention on the research topic, but associations made by the participant ultimately direct the responses (Huntington 1998). This open-ended format has been used in the Arctic as well as elsewhere in other regions of the world for community-based investigations of climate vulnerability to leverage its strength in allowing unanticipated and novel concepts to emerge (cf. Ford et al. 2006). The community map instrument described in 3.1.2 served as the "boundary object" (cf. Star and Griesemer 1989; Lynch et al. 2008; Cutts 2011) to enhance access to local knowledge by stimulating conversation (Huntington 1998, 2011) and keeping participants focused on the research topic and study area (Vullings et al. 2004).

The research focused on the perspectives of Arctic residents in three North Slope municipalities: Wainwright, Utqiaġvik, and Kaktovik. Collectively, the subsistence land use areas of the three municipalities cover the Arctic Ocean coast adjacent to the National Petroleum Reserve – Alaska (NPR-A) and the Arctic National Wildlife Refuge (ANWR).

The NPR-A and ANWR coastlines are relevant for decision support research because they are the focus of important land use decisions for large-scale onshore and offshore hydrocarbon development. Both Wainwright and Utqiaġvik are located within the NPR-A. Wainwright is a medium size city with about 550 residents, and Utqiaġvik is the seat of borough government and largest city with a population of about 5,000. Kaktovik, located in the ANWR, is the smallest city among the three with a population of about 250.

Prior to fieldwork, I sent requests to do research to the three main local authorities in each place: the village corporations, the native village governments, and city governments (Appendix E). The Cities of Wainwright and Kaktovik provided meeting space for the mapping workshops in their community centers, and the Iñupiat Heritage Center provided space in Utqiaġvik. In some cases, to include key informant elders, I was invited to bring the maps to participant homes. To encourage participation, study participants received a $75 credit to their local grocery store.

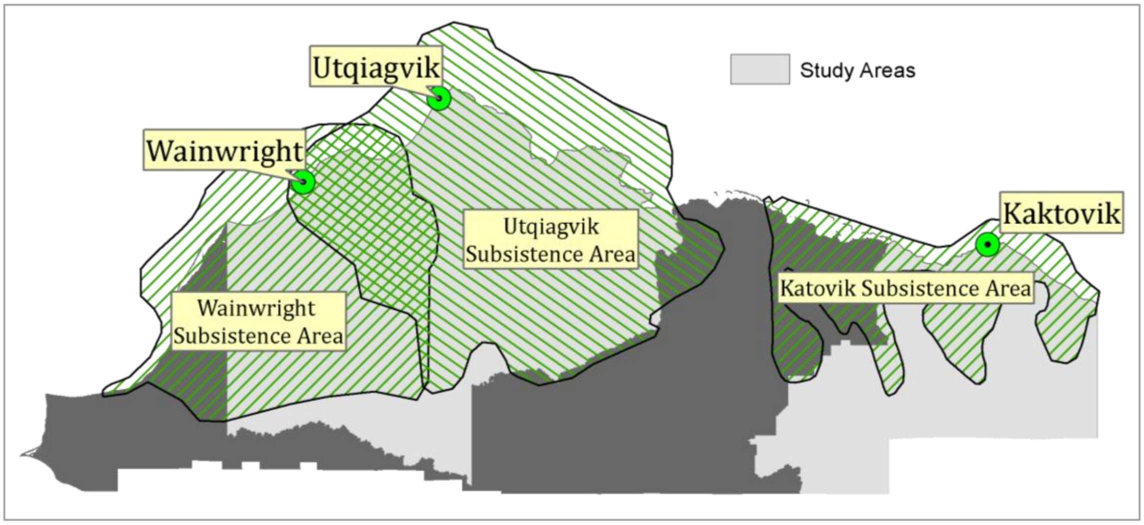

Figure 3.1. Data Collection Area
The data collection focus was on the two stretches of coastlines along the National Petroleum Reserve – Alaska (NPR-A) and the Arctic National Wildlife Refuge (ANWR) in Alaska's North Slope indicated in the map as light gray land areas. The locations of the three municipalities that participated in the community mapping workshops are shown in the map as green circles annotated with the municipality name. The green line-filled areas correspond to the estimated areal subsistence land use extent of the municipalities annotated respectively. The subsistence extents were digitized from Pedersen (1979). The Wainwright and Utqiaġvik subsistence areas together cover the NPR-A, and Kaktovik's subsistence area covers the ANWR. While the data collection focused in these three municipalities, the subsistence areas of other North Slope municipalities (not shown) extend into the collection area, and all eight municipalities depend on access to these coastlines for subsistence. Also, residents of communities may travel beyond these areas including into subsistence areas of other municipalities.

With respect to the sampling strategy, the majority of the 2016 participants in Utqiaġvik attended one large community-mapping workshop that was not audio-recorded, but it opened the door to all community members wishing to share their perspectives by marking directly on the maps. I conducted follow-up audio-recorded interviews with select workshop participants in Utqiaġvik. I used purposive snowball sampling in the two smaller villages, Wainwright and Kaktovik, to target subsistence hunters who have knowledge about remote stretches of the shoreline.

Findings from previous fieldwork in summers 2013 and 2014 motivated the design of the workshops to collect local views of coastal exposure risks with a geographic focus outside of the local municipalities. Informal interviews in summer 2013 with community leaders[2] in Wainwright, Utqiaġvik, Nuiqsut[3], and Kaktovik identified that, in addition to risks within the villages, coastal exposure concerns extend across the vast shoreline from exposed industrial and subsistence-related land uses. Semi-structured interviews in 2014 with community leaders in Utqiaġvik and Katovik[4] identified rich local knowledge and a strong willingness within the communities to share the knowledge about specific places along the shoreline (the 2014 interview instrument is provided in Appendix F). By identifying the local concerns across the vast shoreline and rich local knowledge and willingness to share it, the 2013 and 2014 findings shaped and justified the 2016 mapping workshop design to systematically collect local views of coastal exposure risks across the coast. While the 2016 workshops were the primary data sources in the study, transcribed interviews from the 2013 and 2014 fieldwork were used to supplement analysis of the 2016 data by providing additional statements or perspectives about particular exposure risks. Also, while not the data collection focus, the 2016 web map usability workshop described in Chapter 4 was another source of coastal exposure information.

3.1.2. Materials and Procedure

The research materials used in the 2016 community mapping workshops to document participant views of coastal exposure risks included hard copy maps of the study area, an instructions packet including biographical questions, coded stickers, wax pens, and an audio-recording device (see Appendix G). The map-set consisted of three large-scale maps at around 1:6000 (~1 cm to 60m) with imagery covering village locations, and three medium-scale maps around 1:100,000 (~1 cm to 1km) with U.S. Geological Survey

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[3] Nuiqsut was excluded from data collection in 2014 and 2016 fieldwork due to limited research resources.
[4] Wainwright was excluded from data collection in 2014 due to canceled flights from bad weather.

(USGS) topographic base maps of the coastal region surrounding each village. Recent coastal exposure rate data provided by the USGS (Gibbs and Richmond 2015) were overlain onto all six maps, and select asset data such as DEW Line site and camp locations were included on the medium scale maps for additional reference.

Each participant received an instructions packet and ten numerically coded one, quarter-inch arrow-shaped stickers to identify shoreline "problem places." The participants annotated the problem places by marking directly on the map near a sticker using a wax pen or by audio-recorded oral response. Of the total 50 participants, 23 were audio-recorded. Only 5 of the 32 participants in Utqiaġvik were audio recorded, all 8 participants in Wainwright and all 10 in Kaktovik were audio-recorded.[5] The metadata for the resulting community map dataset is provided in Appendix A.

3.1.3. Analysis

Sticker locations and written responses were digitized and oral responses were transcribed and associated with digitized sticker points. Participant statements corresponding to particular places were linked to the digitized point locations by sticker codes using Esri ArcGIS software. Participant biographical information collected on the instruction form was also attached to the points using the sticker codes. The biographical information allowed point locations to be grouped such as by participant name to focus analysis of digitized markings and geo-referenced audio-recorded transcriptions on individual participants.

[5] Only 5 were audio-recorded in Utqiaġvik because the door was open to all residents at the Heritage Center for a total of four hours between two days, and most participants completed the mapping activity on the first day. It was not possible to record each participant. The 5 that did get audio-recorded were arranged separately from the Heritage Center community mapping event. In Wainright and Kaktovik, on the other hand, I had unlimited access to the community center for several days, which allowed me to accommodate each participant individually.

Participant statements were organized using three main land uses found using a basic toponym analysis technique - industrial, municipal, and subsistence/ environment.[6] The toponym analysis consisted of creating a 1-kilometer buffer around all digitized sticker locations and linking them with existing land use data provided by the U.S. Geological Survey (USGS) Board of Geographic Names.[7] The Geographic Names dataset provides place name and land use type for each location in the database. The transcribed statements linked to digitized sticker point locations were coded with one of the three land use types for most locations where sufficient information was available. Subsequent qualitative analysis consisted of further grouping the statements to identify prominent themes, and viewing associated point locations overlain with relevant spatial layers to provide geographic context to better understand the statements. For example, if a participant indicated that a particular subsistence hunting camp was at risk, relevant layers were added to the map such as camp locations, native allotment parcels, cultural heritage data, geo-referenced photographs of the coast, and recent high spatial resolution satellite imagery.

3.2. Results

The 50 participants collectively identified 297 coastal exposure risks (Figure 3.2). The geographic extent of the contributions along the coast correspond to the estimated subsistence land use extents shown in Figure 3.1. The sticker points do not extend west of the NPR-A because that is the western limit of the hard copy maps used to collect the data. The general finding suggested by this map is that coastal exposure to climate risks

[6] These results are based on a total of 118 USGS place names that were each found to be within 1km of participant-identified places. The remaining 179 of the total 297 problem places were not within 1km of a USGS place name.

[7] https://geonames.usgs.gov/

from the local community perspective extend well beyond the extent of the municipalities, which is the usual research focus due to the high level risk.

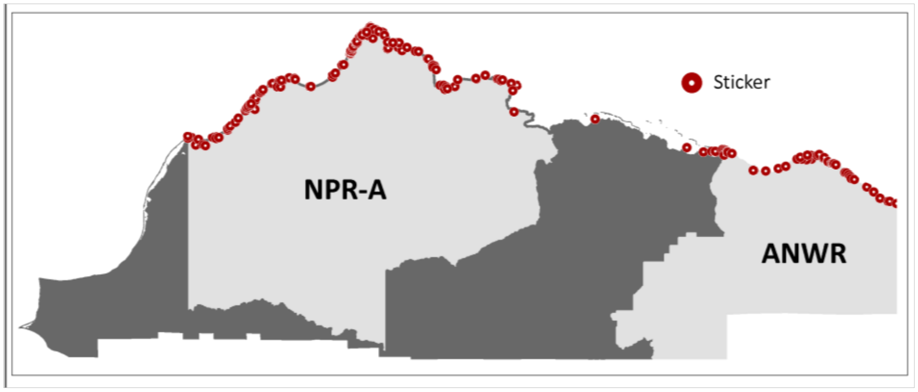

Figure 3.2. Coastal Exposure Risks Indicated by Digitized Sticker Locations
This map shows the locations of all 297 digitized sticker locations placed where participants identified coastal exposure risks. The map shows that the fifty participants in the three local communities collectively have local knowledge of coastal exposure extending across the coastlines of the National Petroleum Reserve – Alaska (NPR-A) and the Arctic National Wildlife Refuge (ANWR).

The analysis of the local perspectives of coastal exposure risks collected in the community mapping workshops identified risks associated with changing access for industrial and subsistence land uses. The analysis identified four main exposure categories: North Slope Borough assets (3.2.1), Alaska native corporation lands (3.2.2), subsistence camps (3.2.3), and subsistence boating (3.2.4). The following sections summarize the coastal exposure risks identified by North Slope residents.

3.2.1. Distant Early Warning Line Coastal Exposure Risks

Many of the Distant Early Warning (DEW) Line sites mentioned in the study site description in Chapter 1 are severely threatened by erosion. Erosion has contributed to closing some of the sites retrofitted for the North Warning System (NWS), and erosion impacts at the remaining 3 NWS sites are prompting millions of dollars in adaptations (Hughes 2016). Several study participants echoed the well-known concern that the sites are still contaminated, and erosion may be releasing hazardous materials into the marine environment. But one North Slope land use manager identified a potentially very significant erosion risk that has implications for current North Slope land use planning for industrial development.

The risk that the land use manager identified may be best summarized as opportunity costs associated with the current and future land use roles of the DEW Line i.e.: supporting industrial development and mitigating harmful impacts on subsistence. If the DEW Line continues to erode into the ocean, it will take the very valuable airstrips, building pads, and other facilities with it. Just west of the NPR-A (and west of the data collection area in Figure 3.2) is an eroding DEW site called Point Lonely. While Point Lonely has yet to support production in the reserve, the land use manager sees it as a valuable asset because of its potential use by the industry, as indicated by his comment below:

> Point Lonely has got a 5,000-foot runway there - enough to land the biggest airplane there is on earth. [It's] [c]apable of still being used; we need to do everything we can to preserve their use, so that continuing oil and gas development has an opportunity to reuse them. (NSB Land Use Manager)

From the borough's perspective, the value of keeping the assets viable is two-fold: they are potential taxable assets if industry uses them and reusing the sites would mean less construction elsewhere on valued subsistence lands. The land use manager addressed both of these points when he said:

> If you use them (DEW sites) and increase their value, the borough can tax it and provide for additional revenue … If we were to protect these resources, you could save a billion dollars in constructing new ones for the oil and gas industry to stage out of. … And these locations happen to be where you can theoretically put a production facility, a CPF [Central Processing Facility, which would be economically beneficial to the borough] without having to build another one with billions of dollars worth of gravel resources on virgin land. At the same time minimizing these impacts [referring to subsistence impacts mentioned previously in the interview] for the community needs of these local resources so that you

> won't put the caribou a hundred miles off the way somewhere else when they need them to hunt and shoot close by to provide food on the table. (NSB Land Use Manager)

While the Point Lonely risks refer to future potential land use opportunity costs, the borough currently leverages land use benefits from the eroding Cape Simpson DEW site located in the NPR-A about 50 miles east of Utqiaġvik (Figures 1.1 and 3.3). The borough owns a parcel of land at the site, called the Cape Simpson Industrial Port (CSIP). The borough uses remaining infrastructure including an airstrip and building pads to encourage oil and gas industry to stage from the site when exploring in the northeast portion of the NPR-A. From the borough's perspective, using the site to support oil and gas exploration reduces the industry's "footprint" on substance lands by avoiding the need to stage somewhere not yet developed. The runway is losing upwards of ~9 meters (~30 feet) per year, so it may become inaccessible to the industry in the foreseeable future. From the North Slope Borough land use manager's perspective, loss of oil and gas industry access to the site would mean an increase in harmful impacts to subsistence resources. Therefore, the borough may need to invest in adapting the site, as suggested by the participant statement below:

> Cape Simpson. That one actually was a DEW Line site that was transferred to the North Slope Borough by the federal government. There was a runway there, a pad there - all eroding away by the way. And we use it to minimize subsistence impacts to have oil and gas explorations occur from there. So that they're not crisscrossing where primary subsistence use areas where they were able to get to their leased plots from there. It helped facilitate a co-existence. But it is eroding and we need to do other things to maintain that. ... (NSB Land Use Manager)

Figure 3.3. Cape Simpson Industrial Port
This is a picture of the Cape Simpson Industrial Port (CSIP) taken by the US Geological Survey. The CSIP is located in the NPR-A, about 50 miles east of Utqiaġvik. The site is owned by the North Slope Borough and used by oil and gas industry to explore in the NPR-A. The site is threatened by erosion. The North Slope Borough is concerned that erosion of the airstrip will make the port inaccessible to the oil and gas industry. The site mitigates oil and gas impacts on subsistence because it provides a place for the industry to use and not have to build elsewhere on subsistence lands (US DOI 2012).

The DEW Line was constructed before there were environmental laws protecting communities from harmful environmental and social impacts. The accounts of the harm caused during their construction are harrowing, including bulldozed sod homes (traditional housing prior to Quonset Huts were introduced by the military) and forced community relocation in Kaktovik (Mikow 2010). The land use manager alluded to the harm caused from DEW Line construction when he extended the development mitigation benefits now realized from reuse of the CSIP to the other DEW sites in the NPR-A when he said:

> A lot of these DEW Line sites are in the NPR-A … for the federal government, and to reuse these sites to provide environmental justice, to not repeat these things because they're so environmentally damaging when you do it on pristine lands…"
> (NSB Land Use Manager).

When the land use manager discussed coastal exposure risks associated with the DEW Line, he made several references to climate change and an increasingly accessible Arctic. For example, referring to the need for the Coast Guard to have access to the North Slope coast to regulate increasing maritime activity in the region as the Arctic becomes more accessible with climate change, he said: "A lot of these things need to be revisited as the Arctic opens up and the need for presence of enforcement folks like the Coast Guard" (NSB Land Use Manager).

3.2.2. Native Corporation Land Coastal Exposure Risks

Study participants identified coastal exposure risks on Alaska native corporation lands that may not already be well documented.[8] Two industrial risks identified are: constrained maritime access for industrial development on Olgoonik (Wainwright's village corporation) lands and rapid coastal erosion at an Arctic Slope Regional Corporation (ASRC) parcel selected for industrial development in the NPR-A.

Wainwright's native village corporation, Olgoonik, has surface rights to a parcel located along an eroding spit of land where the village is located (see Figure 1.1). The parcel extends inland to the decommissioned Wainwright DEW Line site. The DEW Line site is the planned staging area for large-scale offshore oil and gas support facilities. Industry has proposed to reuse and expand on existing DEW Line facilities including an airstrip and building pads in anticipation of offshore development in the Chukchi Sea. In this development scenario, the DEW Line site would be used to support transfer of product barged through the Wainwright Inlet to transfer facilities, and transported through a proposed pipeline connecting from the DEW Line site, across the NPR-A to the

[8] As stated earlier, this dissertation focuses on coastal exposures associated with subsistence and industrial land uses, and not the well-documented municipal risks.

Trans-Alaska Pipeline System (TAPS), and ultimately to Valdez to be shipped to market (cf. Bartholomew et al. 2014; Vargas-Moreno et al. 2016).

A critical exposure identified by one local informant is the high risk to the chain of offshore product transportation to market in this scenario from the potential loss of access to the Wainwright Inlet from a "blown" spit or shoaling. The participant said:

> … [I]n regard to coastal erosion hazard … the key importance and sensitivity of the geologic feature depicted here [Entrance to the Wainwright Inlet] that is the narrow mouth of the river at the ocean entrance. If the narrow deep-water constriction was to be lost by a general blow-out of the long sandbar bordering it to the south, the river mouth would become a large-plain delta, impassable to all but flat bottom skiffs. In such case, the inland Air Force base would become unreachable by boat, an important requirement for it being an industrial base. (NSB Land Use Manager)

Similarly, one participant identified the risk of constrained access to oil spill response assets staged in the Wainwright Inlet. The informant explained that during a recent oil spill response drill, boats staged near the Wainwright DEW Line site could not pass through the mouth of the inlet because it became too shallow. For example, the participant said:

> [They're] [h]aving a lot of problems with shoaling there [at the mouth of the Wainwright Inlet]. Originally it was dredged because that's one of the things the borough dredge originally did. … I have just heard recently that when they tried to run a drill for oil spill response they couldn't get the boats out. They actually had to put them on motors and carry them over to the ocean side, which obviously wasn't part of their original plan. But it's the only place you can put stuff [inside the inlet]. The ocean shoreline is eroding to the point I wouldn't put a dingy on the beach, let alone a twenty something foot two-hundred-thousand-dollar boat. That's why everyone keeps their boats in the lagoon, that's just where you put your boats. (UIC Stakeholder)

The Arctic Slope Regional Corporation (ASRC) selected an important parcel of land in the National Petroleum Reserve – Alaska (NPR-A) by the Cape Halkett area, about 100 miles east of Utqiaġvik (US MMS 1984) (see Figure 1.1). Most of ASRC's lands are located outside of the NPR-A, just south of the reserve where there is little potential for hydrocarbon development. This parcel is unique because it’s the only native corporation land within the NPR-A with subsurface rights. Under the ANCSA, the federal government has subsurface rights within the NPR-A and Arctic National Wildlife Refuge (ANWR). However, the Alaska National Interest Lands Conservation Act of 1980 (ANILCA) permitted the ASRC to obtain subsurface rights to village corporation lands within the NPR-A and ANWR, but such claims have to be developed for commercial use. Development of the ASRC parcel has been denied due to historically very high erosion rates in the Cape Halkett area, a trend that ASRC contests. For example, a study participant said:

> We're looking to do something with that property and the federal agencies were saying 'oh no that's all eroding away, look at this USGS report' and we're saying 'no, that's wrong, yes there's erosion, there's a lot of erosion in different areas but this area is growing rapidly; wetlands are being protected by these offshore barrier islands and the giant spit that was formed.’ (ASRC Stakeholder)

The ASRC has also pursued lands with subsurface rights in the Section 1002 Area of the ANWR in anticipation of it opening to leasing for energy development (see Figure 1.1). The ANILCA doubled the size of the ANWR to 19 million-acres, and designated 1.5 million-acres of the coastal plain as the Section 1002 Area, which was opened to natural resources evaluation. However, Congress has not acted on Department of Interior recommendations to open the Section 1002 Area to oil and gas leasing (Gallaway 2001; US FWS 2015).

3.2.3. Subsistence Hunting Camp Coastal Exposure Risks

Participants also identified coastal exposure risks associated with camping for subsistence hunting. Risks include loss of camps due to erosion and constrained boating access due to coastal exposure along the ocean coast and up rivers. Camp impacts can be distinguished by the number of families that depend on a site and range from single-family to sites that entire villages depend on. However, entire communities can also depend on a single-family camp as one whaling captain noted:

> The erosion and it impacts on camps along these rivers that are community assets. When I'm fishing I fish for the community as a whaling captain. During the dead of winter, I'm going to travel to my camp about 75 miles east of here, and haul my resources that I've caught back to Barrow. It's thousands and thousands of dollars to replace some of these [camps]. Because the impact to the community is less food, you're more dependent on store-bought things for your diet. (Utqiaġvik Whaling Captain)

Many participants identified camps and related infrastructure such as ice cellars used to store meat being lost to erosion. There were also numerous accounts of the extensive chain of barrier islands that line the North Slope coast losing land and narrowing. Erosion impacts on camps, combined with barrier island narrowing and loss of coastal protection from diminishing sea ice, are rendering subsistence camps used for generations unusable. Griffin Point, east of Kaktovik, is perhaps the most illustrative case of an important camp depended on by multiple families for generations being lost to erosion and becoming increasingly dangerous to use. For example, one participant said:

> If I would point out one [an important camp being lost to erosion], the main one we go out on is Griffin Point. Because you cut across, but the whole thing really, is this spit, because it connects to Barter Island. We depend on this whole thing for traveling. This is our hunting grounds - we look for the caribou. .... That's where my grandma had her smoke house and everything. … We used to live in a sod house when I was a little boy. Same here. We used to love to go there. And it's all gone, it all got washed away. (Kaktovik Subsistence Hunters)

> ... [W]e don't hardly have Griffin Point anymore, our barrier island is what they call it. We used to be able to land planes on there. And used to be at least a whole football field wide, and it's only like a hundred feet wide now.
> (Kaktovik Subsistence Hunter)

A camp used by multiple families east of Utqiaġvik is increasingly difficult to access. One local informant said he worries that the site may become inaccessible due to the changing shoreline. For example, the participant said:

> There's this place called Smith Bay, that's where about a dozen of us families go. ... So the mouth of the Ikpikpuk River, there's only one entrance. ... The mouth of this river, this is the only way to get into this huge river system. ... There used to be an entrance over this way. When you know 20 years ago, now it's here. The question is will it persist here or not? And then this mouth itself changes gradually over time, so every year we have to nose into here into shallow water we have to redefine the mouth. (Utqiaġvik Whaling Captain)

While Nuiqsut was not included in the community mapping, North Slope residents mentioned that Nuiqsut is especially vulnerable due to coastal exposure impacting access to hunting camps depended on by the entire community. One critical threat is the diminishing Cross Island, a barrier island north of the village beyond the Colville River Delta.

> Cooper Island (corrected to: Cross Island) outside of Nuiqsut. They're a fall whaling community only. They go out here [Cross Island] to whale in the fall time. And they depend on it when they stage out here, far from town they have to take everything way out there with them to reside on Cooper [corrected to: Cross Island] Island. That island is of critical importance. Without it, Nuiqsut wouldn't be able to successfully sustain a fall whaling exercise. It's diminishing. It's eroding. It's losing its height, it's losing its breadth and width and length. It's getting smaller. I can't think of any other island that is so important as that one. (NSB Land Use Manager)

3.2.4. Subsistence Boating Coastal Exposure Risks

Study participants also identified coastal exposure risks associated with subsistence boating during summer months along the North Slope coast. Subsistence boaters rely on the long chain of barrier islands that run across much of the North Slope for shelter from the ocean as they transit. They also rely on cuts in the barrier islands to access hunting grounds or escape waves during stormy weather. For example, one subsistence boater said:

> Sanigaruak Pass is another deep cut between barrier islands. If all hell breaks through in the ocean, that's a place we can rely on to get in and out for safety behind the barrier islands. We've dragged whales through here.
> (Utqiaġvik Whaling Captain)

Two main themes of boating impacts identified by participants are: 1) changing access due to coastal exposure such as shoaling cutting off boating routes, and 2) loss of protection from barrier islands compounded by loss of sea ice protection making boating increasingly risky. Perhaps the most conspicuous case of the shoaling problem is the Bernard Spit just north of Kaktovik. Bernard Spit is migrating towards the Barter Island mainland, which threatens to cut-off the main boating route used by hunters to haul whales into the community for processing. For example, one participant said:

> [Bernard] Spit [is] getting shallower. So, I don't know if they're going to meet, eventually hit the land and close it off, I don't know. We wouldn't be able to tow our Bowhead Whale here to butcher it at the butchering site. Some folks are already talking about it now being unusable in the future. Might have to go over here to butcher it. Different spot, you know. Drag the whale. There's a road there we could utilize. Right now, we tow the whale here, pull it onto the beach, and butcher it there where we have a butchering shack where they cook for the community there in the summer. (Kaktovik Native Village Stakeholder)

Participants shared numerous locations where the coastline has changed significantly. Several boaters said that the changes have been so significant over the years that their navigation systems, equipped with global positioning systems (GPS), indicate that they’re transited over islands or well inland. For example, one participant said:

> They're (barrier islands) moving all over the place - you don't use maps anymore. We use a GPS to navigate in the summer months, and we're driving over mapped islands, according to this map there should be an island there and when we see it you know tens of yards or hundreds of yards away, so islands move around and that's just what they do. Our job is to just keep track of it.
> (Utqiaġvik Whaling Captain)

Participants also shared numerous locations where the rapidly changing barrier island is cutting off access to hunting grounds, removing cuts used to escape storms, and making boating routes between barrier islands and the mainland inaccessible. Perhaps the best example where a diminishing barrier island is impacting boat travel is the narrowing of Icy Reef, a barrier system that runs close to the mainland from Kaktovik to Canada. The Icy Reef barrier island provides safe travel by boat from Egaksrak Lagoon, east of Kaktovik, to Demarcation Bay and Canada. Hunters travel to Demarcation Bay when few caribou are taken closer to Barter Island, or on the way to visit relatives in Canada (Jacobson et al. 1982). For example, one participant said:

> This area is really shallower, we used to go inside all the way and come out over here to go to Demarcation - hard to do now. We have to go through the ocean. And it's dangerous too, especially you got these reefs that go out people are traveling and it's foggy. You get too close to the waves breaking. That's how we lost a family about 10-15 years ago maybe. … You don't have the ice you normally have to travel so it's calm even though it's windy."
> (Kaktovik Subsistence Hunter)

3.3. Discussion

The coastal exposure risks identified in this study are relevant for efforts by the North Slope Science Initiative (NSSI) to coordinate applied research in support of North Slope resources management. Established by federal, state, and local governments in 2001 and formalized in Section 348 under the Energy Policy Act of 2005, the NSSI coordinates applied science relevant for North Slope resource managers and reports to Congress annually (Streever et al. 2011). The NSSI has an external advisory group called the Science Technical Advisory Panel (STAP), which is composed of 15-members including Iñupiat elders, university and industry scientists, and non-profit organizations. The STAP identified coastal erosion risk monitoring that includes local knowledge as an emerging research need (NSSI 2014). This dissertation addressed the local knowledge aspect of this research need.

The coastal exposure risks identified in this study suggest the need for the NSSI to re-articulate the coastal erosion problem to address current land use exposure risks. In addition to exposed historic infrastructure and cultural sites (cf. Jones et al. 2008), this study identified local community exposure risks associated with current industrial and subsistence land uses along the coastline. The identified exposure risks were summarized in this chapter as constrained industrial and subsistence land uses due to shoreline change. The identified coastal exposure risks based on local knowledge should be considered by the NSSI's efforts to coordinate erosion risk monitoring research on the North Slope.

The coastal exposure risks to current industrial land uses identified in this study are also relevant for the NSSI's energy development and climate change scenarios research. Since the Prudhoe Bay oil discovery, the government, industry, academia, and nongovernmental organizations have made extensive efforts to understand and monitor oil and gas development impacts on the North Slope. Understanding that the development impacts are occurring in the context of climate change, the NSSI has taken a scenarios research approach to assess impacts into the future (Streever et al. 2011). One reason that the coastal exposure risks to current industrial land uses are relevant for the scenarios research is because it provides a reason to project shoreline-dependent access at industrial locations that become active under various energy development scenarios. For example, under projected coastal exposure scenarios, will shoreline change at the Wainwright Inlet allow barge traffic under a high energy development scenario (cf. Vargas-Mereno et al.

2016). Under the high development scenario, offshore oil in the Chukchi Sea is transported to market through a pipeline from Wainwright through Nuiqsut to the Trans Alaska Pipeline System (TAPS). Which DEW line sites along the NPR-A shoreline would still be accessible under high coastal exposure scenarios? Which DEW Line sites would need to be adapted to support offshore and onshore exploration and development that would come with increased project feasibility in the Chukchi Sea and NPR-A from the new pipeline?

The identified exposure risks associated with constrained subsistence land uses contribute to public awareness of the multiple stressors that the local communities face from development and climate change. It is well known that energy development can have harmful impacts on subsistence and that climate change may exacerbate the problem by impacting species habitat and other subsistence-related ecosystem services. This study contributes to better understanding of the effects that coastal exposure under climate scenarios may have on access for subsistence boating and camping near important hunting grounds. These coastal exposure impacts on subsistence should be considered in development scenarios that would also impact subsistence and related consequences such as community health effects.

3.4. Conclusions

This chapter analyzed local views of coastal exposure to climate risks in Alaska's North Slope. The analysis identified risks to industrial and subsistence land uses due to constrained access from shoreline change. This section summarizes the identified risks, and reiterates why they are significant for future scenarios research organized by the North Slope Science Initiative (NSSI).

Study participants identified locations used for industrial land uses that are exposed to coastal risks. For example, erosion of the landing strip at the Cape Simpson Industrial Port (CSIP) will eventually make the site inaccessible to oil and gas companies. The North Slope Borough maintains the CSIP to avoid additional impacts on subsistence grounds from oil companies operating elsewhere. Shoaling at the entrance to the Wainwright Inlet makes it difficult for boats to access the Wainwright DEW Line site, which may be used as a support base for future offshore oil and gas development. The native village corporation, Olgoonik, owns the land, so loss of industry access from shoaling puts the benefits Olgoonik would receive from development at risk. Lastly, historically high erosion in the Cape Halkett area is preventing the Arctic Slope Regional Corporation (ASRC) from developing a parcel of land in the NPR-A that they selected for oil and gas development.

The participants also identified numerous locations where shoreline change is causing problems for subsistence boating during summer months. For example, changes to the chain of barrier islands that stretch across much of the North Slope coast are creating boating hazards. One example is shoaling along the Icy Reef barrier island, which provides protection for boaters transiting between Kaktovik and Canada. Shoaling between the barrier island and the mainland is forcing boaters to travel outside of the barrier island where they are exposed to the open ocean no longer buffered by sea ice. Participants also identified many locations used to camp for subsistence hunting that are being lost to erosion. One example is Griffin Point, a multi-family camp on a barrier island near Kaktovik. The site has been used by multiple generations but is now being washed into the ocean.

The industrial and subsistence land use risks identified in this study are relevant for scenarios research organized by the North Slope Science Initiative (NSSI). In the NSSI scenarios research, land use impacts are evaluated under future energy development and climate change scenarios (Streever et al. 2011). The industrial coastal exposure risks identified in this study are relevant for the NSSI research because access and demand of the at-risk industrial sites will depend on climate change and energy development scenarios. The coastal exposure risks associated with subsistence land uses are relevant for the NSSI scenarios research inasmuch as they capture multiple stressors faced by the local communities that warrant consideration when analyzing scenario impacts and outcomes.

4. Manager Usability Perspectives of the Coastal Exposure Web Map

As social-environmental transformations occur in the Arctic with rapid environmental changes underway, there is a need to enhance Arctic climate science usability to support decision-making (Streever et al. 2011; Knapp and Trainor 2013; NRC 2014; Vörösmarty et al. 2015). Since the 1950s, Arctic air temperatures have been rising more than twice the rate of the global average (ACIA 2004; IPCC 2013; USGCRP 2017; AMAP 2017a). In Alaska, the average annual temperature has increased 1.7 °C from 1949 to 1998 (Stafford et al. 2000). The warming is causing permafrost to thaw and sea-ice to melt, which has subsequent impacts such as increasing Arctic coastline susceptibility to coastal erosion (GAO 2003; Overeem et al. 2011; Barnhart et al. 2014a,b; 2016). Summer-time Arctic sea ice extent has declined by an average of 10% per decade since 1979 (Stroeve et al. 2012; Mahoney et al. 2014), with pronounced declines occurring in the Chukchi and Barents Seas, which are adjacent to the North Slope coast. For example, September sea ice extent in the Chukchi Sea has decreased by 26% per decade (Meier et al. 2007). Arctic coastal erosion rates are rising with climate change as sea ice decline combines with relative sea-level rise and increasing Arctic storms (cf. ACIA 2004; Manson and Solomon 2007; Overeem et al. 2011; Barnhart et al. 2014a,b, 2016). For example, along the Beaufort Sea coast, Jones et al. (2009) estimated an increase in mean coastal erosion rates from 8.7 m yr^{-1} for 1979 – 2002 to 13.6 m yr^{-1} for 2002 – 2007.

Despite the dramatic changes, actionable climate information is limited in the region in comparison with less remote places in the United States due in part to the lack of long-term data and analysis expertise (Knapp and Trainor 2013). The rapid Arctic change combined with lack of actionable information is driving efforts to create usable climate science for resource managers in the region.

Motivated by the call for usable climate science in the Arctic, this dissertation mapped coastal exposure risks in collaboration with the North Slope Borough and its residents. As stated in Chapter 1, the three objectives of the dissertation were to: 1) identify coastal exposure risks from the local community perspective, 2) assess land use manager usability perspectives of the web map, and 3) engage the North Slope in a collaborative web map research process to link them to the Arctic observing network for decision support. Chapter 3 addressed the first objective. This chapter addresses the second objective by conducting a collaborative web mapping effort to assess coastal exposure risk information usability while also promoting local manager engagement in the research. The strategy to engage the local managers was to focus the research on their perspectives of usability. In addition to addressing usability, the research process initiated a researcher-manager network and identified opportunities for local manager uptake of the web map. Because the managers can address coastal exposure risks using the web map and drive coastal observations and additional collaborative research, their engagement is critical to link the web map research process to the Arctic observing network. With local engagement established, the web map product is the physical object that links the coastal risk mapping process in Chapter 3 and the usability research process in this chapter to the Arctic observing network. Chapter 5 addresses the third research objective by identifying how the web map process and product link to the Arctic observing network. This chapter is primarily concerned with local usability and establishing local manager engagement in the web mapping process.

In the overall study design shown in Figure 2.1, the collaborative effort addressed in this chapter is a formative evaluation of the web map based on North Slope manager feedback. The formative evaluation, as defined in Chapter 2, is the third collaborative research step in the web map process. The formative evaluation occurs after the verification of coastal risks with local residents and creation of the asset exposure web map in Collaborative Step 2

4.1. Method

The research question that drives this formative evaluation effort is: *What is the land use manager usability perspective of the web map?*

The dimensions of usability investigated in this dissertation are perspectives of saliency, legitimacy, and credibility. These three usability dimensions are based on the Cash et al. (2003) science and technology usability framework. The usability framework is widely used to evaluate and advance climate science usability (e.g. Girod et al. 2009; White et al. 2010; Kirchhoff et al. 2013; Dilling et al. 2015). Adapted for this study, saliency is defined as relevancy of exposure information for North Slope land use manager needs, credibility refers to information trustworthiness, and legitimacy refers to the degree two which the exposure information is consistent with and addresses the diverse stakeholder views in the region.

4.1.1. Data Collection

The North Slope land use manager usability perspectives were collected in a web map usability workshop in April 2016 with sixteen prospective users. [9] The coastal exposure web map was developed collaboratively with the North Slope Borough Planning and

[9] The workshop did not include an interface usability evaluation with the land use managers. Rather, the evaluation focused on information usability based participant responses to a live demonstration of the web map, which was completed in a ~one-hour presentation.

Community Services Department in Collaborative Research Step 2 shown in Figure 2.1. The web map product was the focus of the workshop, which was a 3-hours event organized into three main parts. The first part was a presentation of web map development methods, including research process and exposure data development (the presentation research instrument is in Appendix H). The development presentation was followed by a live demonstration of the web map. The third part of the workshop was focused on collecting usability perspectives after users were exposed to the web map methods and product. The participants were briefed on the purpose of the workshop to assess usability perspectives as part of the larger collaborative web map research process. The participants were briefed on the Rutgers University Institutional Review Board (IRB) human subjects protection protocol and signed consent forms. It was made clear that the approximately 1-hour long usability discussion that followed would be audio-recorded and transcribed for use in the study.

After signing consent forms, workshop participants responded verbally to three questions that were based on the Cash et al. (2003) usable science framework. The questions were stated before and after the live demonstration to enhance focus on the usability dimensions of interest. The questions stated for discussion are as follows:

1. How are the maps relevant to your responsibilities as a manager?
    - What specifically could you use them for?
    - What modifications would be needed to make them more useful to you?
2. What is missing?
    - Thinking about your responsibilities, what other erosion risks should be mapped?

- Thinking about others not in the room, what erosion risks would they want to see included?

3. Do you trust the data and maps?

- Would U.S. Geological Survey erosion data suffice for some applications?
- What other erosion and asset data should be incorporated into the Web-maps?

The audio recording from the workshop was transcribed and stored in an Excel file. The metadata for the usability perspectives dataset are in Appendix D

This web map usability data collection protocol described above is consistent with human-centered design in system usability research where user perspectives are included in system development and design to enhance usability (cf. ISO 1999; ISO 2009). Human-centered design is widely used in development of decision support systems including in the climate change context (cf. NRC 2009; Moss et al. 2014).

4.1.2. Materials

This section describes the coastal exposure web map evaluated in this chapter. The metadata for all data sets described are in Appendices A through D. The data sets described include a shoreline change susceptibility spatial data model, a coastal asset data model, and coastal exposure risk data models created by integrating the shoreline susceptibility and asset data. The coastal exposure risk data models consist of shoreline change susceptibility information detailed in Table 4.1 summarized at asset locations identified using asset spatial data described in Tables 4.2 - 4.4. Specifically, the exposure data provides shoreline susceptibility information in the asset spatial data attribute tables. The exposure data were used to create the coastal exposure web map described below. Detailed metadata for the exposure data are in Appendix C.

Shoreline Susceptibility Data

The shoreline change susceptibility data model is based on the U.S. Geological Survey's Coastal Vulnerability Index (CVI) adapted to the Arctic context. The model is composed of shoreline change rates, coastline type, and wind-fetch distance based on coastal geometry and the September 2012 sea ice extent. The model consists of coastline type data and wind-fetch distance estimations added to coastline transects created for the U.S. Geological Survey's National Assessment of Shoreline Change Project, Alaska (Gibbs and Richmond 2015). Table 4.1 below describes the shoreline data. The metadata for the shoreline change susceptibility model are in Appendix B. The methods used to create the shoreline model are in Appendix I.

Table 4.1. Shoreline Change Susceptibility Data Description

Data Name	**Description**	**Source**
Historic Shoreline Change Rates	Much of the Arctic Slope coastline is included in the U.S. Geological Survey's (USGS) National Assessment of Shoreline Change Project. Motivated by erosion concerns, the project aims to provide accurate shoreline change information on a periodic basis using consistent methods for the U.S. region.	USGS
Landform Types	Incorporating best available data, the ShoreZone mapping system includes landform type information for segments of the Arctic Slope shoreline mapped for the National Oceanic and Atmospheric Administration's Office of Response and Restoration Environmental Sensitivity Index (ESI) Maps.	ShoreZone
Coastlines and Sea Ice	The shoreline susceptibility spatial data model includes wind-fetch data consisting of distances calculated between the sea ice extent edge to the shoreline for all wind directions at every 10 degrees. Distances were calculated for the September 2012 record low extent. The National Oceanic and Atmospheric Administration (NOAA) National Center for Environmental Information maintains a high-resolution global database of shorelines and the National Snow and Ice Data Center (NSIDC) maintains the sea ice data used in this study.	NOAA; NSIDC

Asset Data

The asset data set used to represent at-risk coastal assets was based on semi-structured interviews with local managers during preliminary fieldwork in 2013 and 2014 in Wainwright, Utqiaġvik, Kaktovik, and Nuiqsut. The assets identified were aggregated into three categories: subsistence, industrial, and municipal. Risk perspectives related to municipal land use such as threats to water utilities emerged during interviews. However, municipal assets were not included in this relatively coarse, regional-scale coastal exposure risk assessment. Instead, city boundaries were used to represent municipal risk in the coastal exposure web map. What follows are descriptions of the asset data used to create the coastal exposure risk web map. The asset data used in this study are listed in the metadata for the exposure model in Appendix C.

Subsistence assets were defined in the dissertation as any asset that supports subsistence hunting or related cultural activity. Traditional assets represented in the model include built features such as camps and places with cultural ecosystem values that do not necessarily have built features, such as important hunting grounds. Table 4.2 lists and briefly describes the traditional land use spatial data used in the web map.

Table 4.2. Subsistence Asset Data Description

Data Name	**Description**	**Data Source**
Subsistence Hunting Camps	The North Slope Borough (NSB) maintains a spatial database of around 500 camp locations and descriptive attributes such as owner, place name location, and recent photograph. The camps are generally located away from village centers and are used for shelter during subsistence hunting. Many camps are located near the coast and are threatened or were lost from erosion.	NSB
Alaska Native Allotments	The Bureau of Land Management (BLM) manages a spatial database of Alaska native allotments transferred under the Alaska Native Allotment Act of 1906. Many Alaska natives selected allotments near places important to them such as near favorable hunting sites or places that have cultural heritage value.	BLM
Cultural Heritage Sites	The Alaska Department of Natural Resources (DNR), Office of History and Archeology maintains the Alaska Heritage Resources Survey (AHRS), a spatial data base with over 45,000 cultural resources in Alaska from prehistoric to modern time. Permission to access this database was provided for this study. Aside from the highly restricted Traditional Land Use Inventory (TLUI) maintained by the North Slope Borough, the AHRS is the best available cultural heritage spatial data.	Alaska DNR

Industrial land use assets were defined as physical assets that support industrial activities. Industrial assets represented in the model are those that relate to threats voiced by study participants. Oil and gas assets were not included in the web map because study participants did not emphasize coastal exposure of the oil and gas industry. Table 4.3 lists and describes the industrial asset data that were used in the web map.

Table 4.3. Industrial Asset Data Description

Data Name	Description	Data Source
Native Village Corporation Parcels	The BLM manages a spatial database of Alaska native land selections under the Alaska Native Claims Settlement Act of 1971(ANCSA). These selections include Alaska native corporation lands.	BLM
DEW Line Sites	Spatial data for the remaining assets at Distant Early Warning (DEW) line sites such as airstrips and solid waste sites are maintained by separate agencies. The Alaska Department of Transportation (DOT) maintains a database for public airstrips and the Alaska Department of Natural Resources (DNR) maintains a database for other airstrips such as those accessed by industry and government. The Alaska Department of Conservations (DOC) maintains a database for solid waste sites at DEW Line and other locations on the North Slope.	Alaska DOT; Alaska DNR; Alaska DOC
Military Parcels	The BLM manages a spatial database of lands withdrawn by the Department of Defense. These parcels are usually located near a legacy Distant Early Warning (DEW) Line site or active North Warning System (NWS) site.	BLM

As explained above, city boundaries were used to represent municipal exposure in this relatively course coastal exposure risk web map (Table 4.4).

Table 4.4. Municipal Asset Data Description

Data Name	Description	Data Source
Village Boundaries	The Alaska Department of Natural Resources (DNR) maintains a database of incorporated cities having certificates with the State of Alaska Department of Community and Economic Development.	Alaska DNR

Coastal Exposure Web Map

During April 2016 fieldwork, the coastal exposure data model described in Section 4.1.2 was installed onto the North Slope Borough's Web-based ArcGIS Portal. The model was used to create an Esri Story Map Journal (Story Maps), which is a built-in feature of the portal. Esri Story Maps is a widely used web application designed to easily create interactive maps with rich narrative text. In addition to being visually appealing, Story Maps is very accessible for developers and users. Built-in GIS capabilities allow easy display of spatial data using common display options such as "heat maps," and a simple way to share supporting information such as permit review application comments, images, and supporting documents. Anyone with an Internet connection can view a public story map or create a map without an Esri license. Story Maps developers range from regular citizens to federal agencies that use the application for official programs. Developers have the option to host the data and maps on the web or on a local network as the North Slope Borough has done to get around current limited Internet access in the remote location. Story Maps is a communication tool designed with flexibility to be tailored to a general audience or specific group. If a data share protocol is in place, the data storage method allows setting-up parallel systems between the Intranet version for local managers and Internet versions for the public and/or specific stakeholder access. Additionally, a mobile app supports easy integration of data collected in the field and crowd sourcing capabilities.

In the screenshot of the North Slope Borough's ArcGIS Portal shown in Figure 4.1, the coastal exposure risk web map module created for this study is shown third from the right, called "Coastal Erosion."

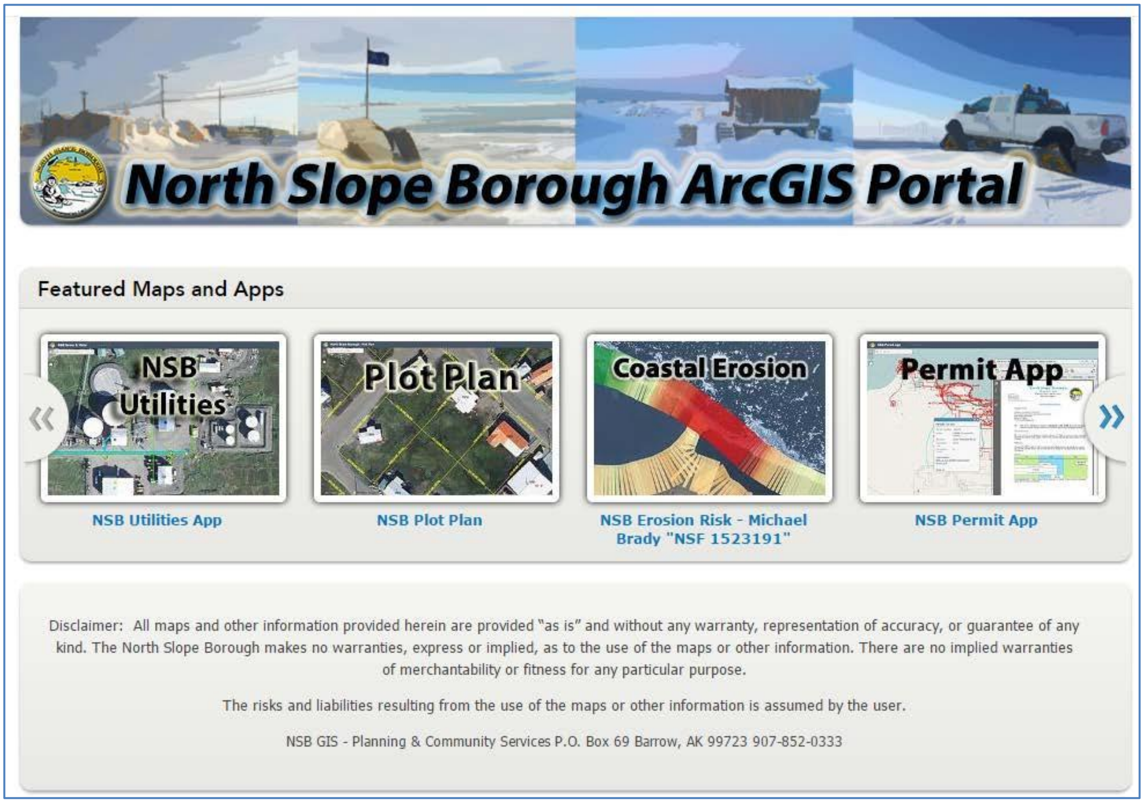

Figure 4.1. North Slope Borough ArcGIS Portal
Figure 4.1 is a screenshot of the North Slope Borough's web map portal hosted on a local Intranet (not publically accessible on the Internet). The four featured web maps and apps are Esri ArcGIS web maps created by the borough to support land use management. The third module from the left called "Coastal Erosion" shows the coastal exposure web map developed for this study. When selected, the Coastal Erosion module opens a set of web maps organized thematically by exposed asset types such as Distant Early Warning Line exposure.

Story Map Organization and Capabilities

The coastal exposure web map is organized by asset type such as Distant Early Warning (DEW) Line exposures. The first web maps in each set of coastal exposure maps organized by asset type are regional overview maps, which provide regional-scale exposure information and risk summaries for each asset type (Figure 4.2). The user can zoom and pan the screen and query more detailed information on a specific site by selecting an asset represented by a mapped feature (Figure 4.3) or a nearby transect (Figure 4.4).

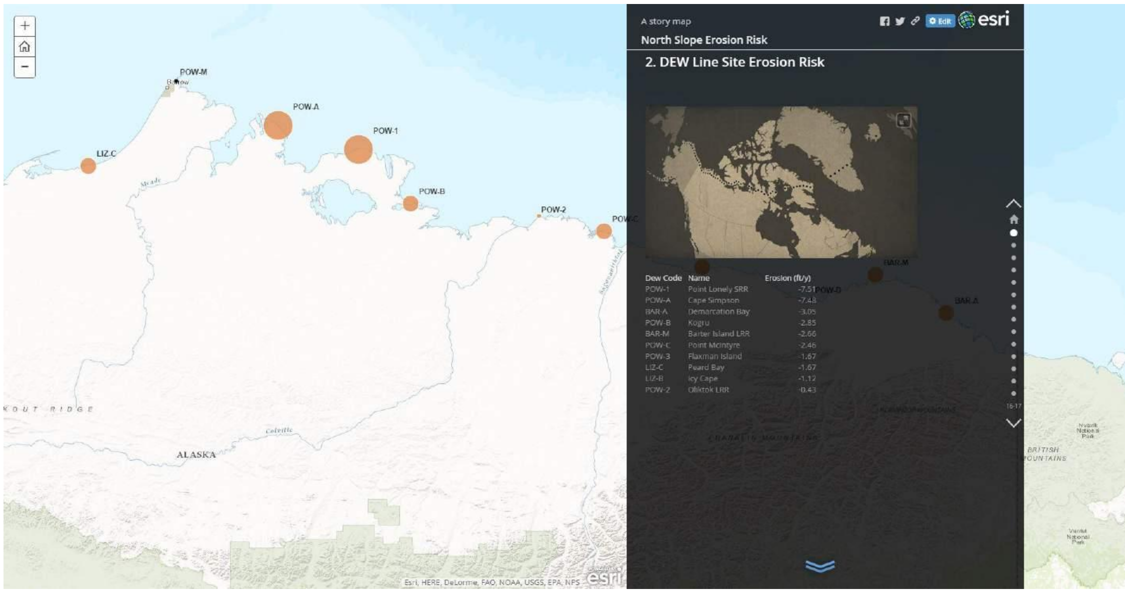

Figure 4.2. DEW Line Exposure Regional Overview Map
Figure 4.2 is a screenshot of an overview map of Distant Early Warning (DEW) Line coastal exposure. The interactive map is included in the North Slope Borough ArcGIS Coastal Erosion model described in Figure 4.1. In this map, the user can pan, zoom, and click on a DEW Line site of interest. When a DEW Line site is selected, exposure information including erosion rates will appear in a “pop-pop” window. In the left pane on this map, the size of the circles representing the DEW Line sites correspond to rates of erosion with high erosion represented by a large circle. The right pane lists all DEW Line sites with erosion rates, sorted from high erosion listed at the top to low erosion at the bottom.

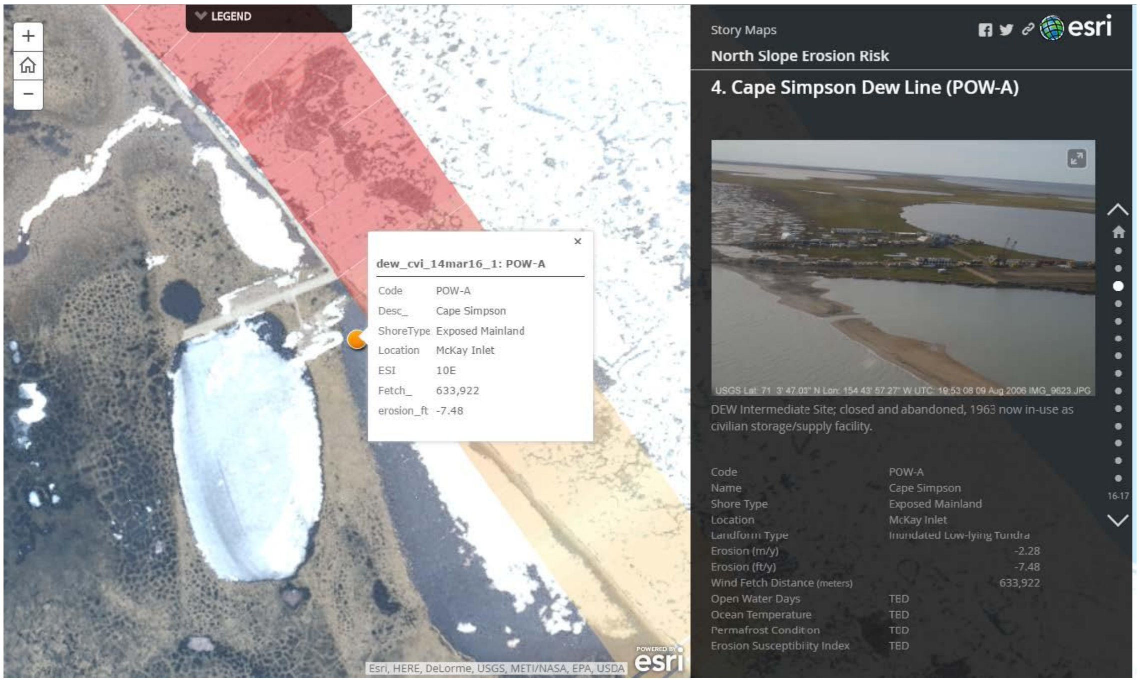

Figure 4.3. Zoomed-in DEW Line Site Map Showing Information Query by Asset
Figure 4.3 is a screenshot of a close-up of the Cape Simpson DEW Line site coastal exposure map. The interactive map is included in the North Slope Borough ArcGIS Coastal Erosion model described in Figure 4.1. In the left pane of the map, the orange circle has been selected to show exposure information derived from the nearest 50 meter coastal transect. The 50 meter transects are symbolized by erosion rates with red being high erosion and green being accretion. The right pane on the map shows a picture of the Cape Simpson DEW Line site taken by the U.S. Geological Survey. Below the picture is coastal exposure information associated with the site derived from the nearest 50 meter transect.

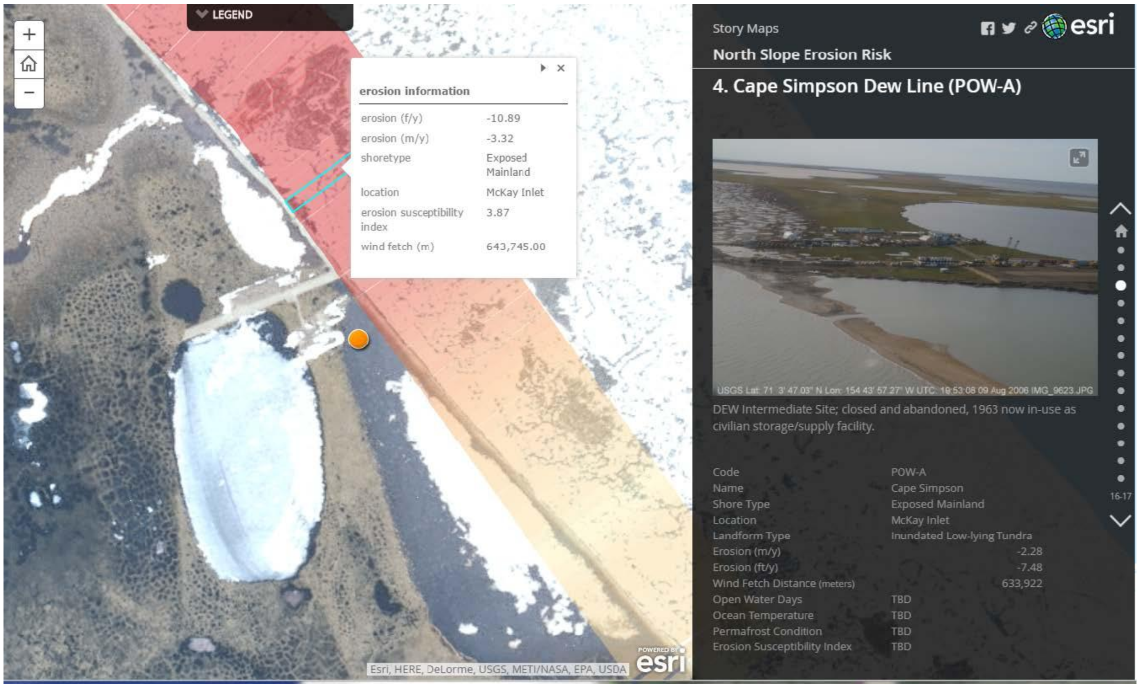

Figure 4.4. Zoomed-in DEW Line Site Map Showing Information Query by Transect
Figure 4.4 is a screenshot of a close-up of the Cape Simpson DEW Line site coastal exposure map. The interactive map is included in the North Slope Borough ArcGIS Coastal Erosion model described in Figure 4.1. In the left pane of the map, a 50 meter transect has been selected to show exposure information near the Cape Simpson DEW Line site. The 50 meter transects are symbolized by erosion rates with red being high erosion and green being accretion. The right pane on the map shows a picture of the Cape Simpson DEW Line site taken by the U.S. Geological Survey. Below the picture is coastal exposure information associated with the site derived from the nearest 50 meter transect.

Closest transects were used to attribute shoreline information for point features (Figure 4.3) and average intersecting transect values were used to summarize exposure for polygons (Figure 4.5).

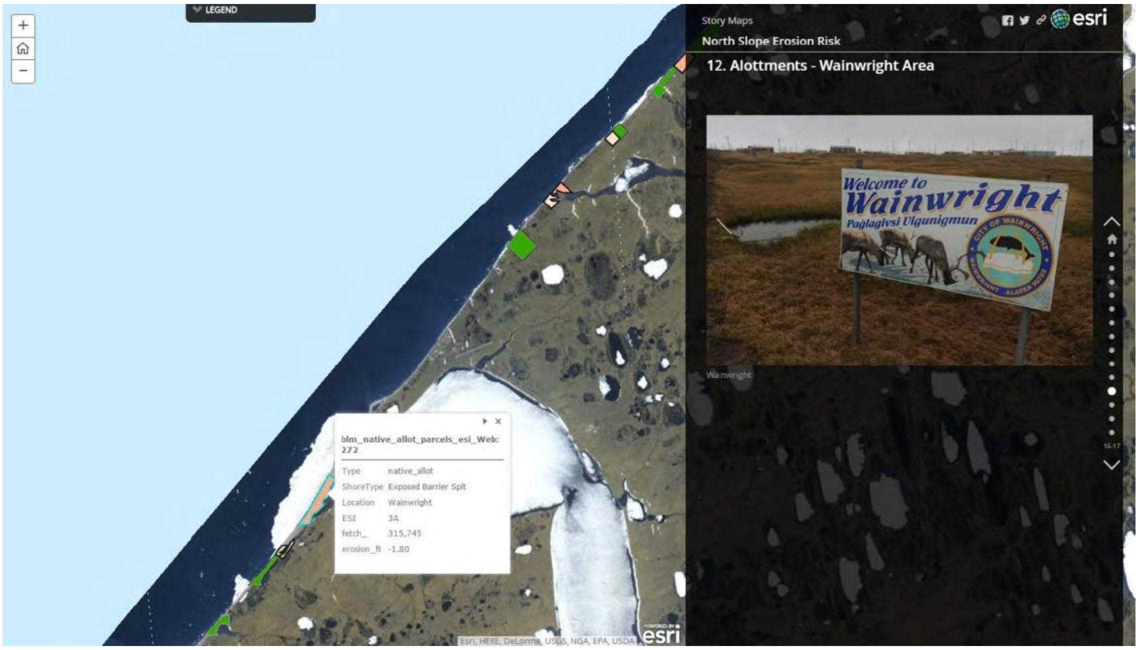

Figure 4.5. Zoomed-in Native Allotment Map Showing Information Query by Polygon
Figure 4.5 is a screenshot of a close-up of an Alaska native allotment coastal exposure map. The interactive map is included in the North Slope Borough ArcGIS Coastal Erosion model described in Figure 4.1. In the left pane of the map, an allotment parcel has been selected to show exposure information derived from the average values of the 50-meter coastal transects that intersect the parcel. The right pane on the map is a placeholder for an illustration of exposure at the site and a summary of exposure information.

In the coastal exposure risk web map, the larger scale maps follow asset exposure overview maps and focus on specific assets (e.g., Figure 4.6).

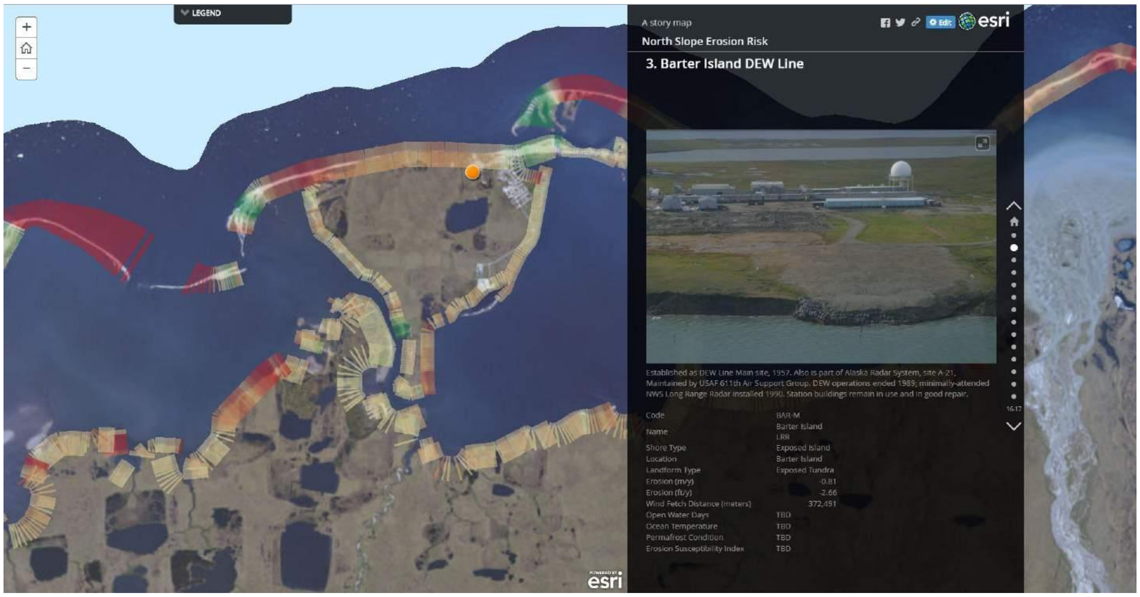

Figure 4.6. Barter Island DEW Line Exposure Large Scale Area of Interest Map
Figure 4.6 is a screenshot of a large scale DEW Line coastal exposure map. The interactive map is included in the North Slope Borough ArcGIS Coastal Erosion model described in Figure 4.1. In the left pane of the map, the Barter Island DEW Line site is represented as an orange circle. In this large-scale map, the 50 meter transects are symbolized by erosion rates with red being high erosion and green being accretion. The map shows coastal exposure patterns in the area surrounding the site. The right pane on the map shows a picture of the Barter Island DEW Line site taken by the U.S. Geological Survey. Below the picture is coastal exposure information associated with the site derived from the nearest 50 meter transect.

4.1.3. Analysis

The usability workshop transcript was organized using the three usability categories that correspond to the workshop questions. As explained in Section 4.1.1, the workshop questions were based on the Cash et al. (2003) usable science conceptual framework. This section restates the workshop questions and describes the usable science categories used to organize the transcript and write results.

How are the maps relevant to your responsibilities as a manager? This question addressed salience, which was defined for this study as relevance of the assessment for the needs of North Slope land use managers. The saliency discussion was prompted by two questions:

- What specifically could you use them for?

- What modifications would be needed to make them more useful to you?

All statements that answered questions relating to web map relevancy for North Slope management were coded as “salience.” The salience discussion dominated, and remerged throughout the workshop. As is explained in Section 4.2, many workshop participant statements referred to management context. The management context statements were also coded as “salience.”

What is missing? This question addressed legitimacy perspectives, i.e.: that the production of the information and technology has been respectful of stakeholders' divergent values and beliefs, unbiased in its conduct, and fair in its treatment of views and interests. As a formative evaluation effort, asking the land use managers this question was an effort to increase legitimacy. The discussion on legitimacy was promoted by two questions:

- Thinking about your responsibilities, what other erosion risks should be mapped?
- Thinking about others not in the room, what erosion risks would they want to see included?

All statements that answered the questions relating to perspectives on what was missing in the web maps were coded as “legitimacy.”

Do you trust the data and maps? This question addressed credibility: the scientific adequacy of the technical evidence and arguments. The saliency discussion was prompted by two questions:

- Would U.S. Geological Survey erosion data suffice for some applications?
- What other erosion and asset data should be incorporated into the Web-maps?

All statements that answered the questions relating to trust perspectives were coded as “credibility.”

As was the case for the saliency, the group discussion on legitimacy and credibility reemerged several times during the workshop. Also, while most participants contributed to the discussion, some community leaders in attendance were most vocal.

There were other themes that emerged in the group discussion including at-risk assets, environmental variables of interest, planned web portal updates, and recommended updates to the exposure maps. A summary of potential Version 2 web map updates based, in part, on fieldwork is provided in Appendix J.

4.2. Results

While there was some mention of specific shoreline information needs in response to the web map demonstration, the usability discussion with managers went beyond needed environment information and focused on where decision support is needed, why, and how specific coastal exposure information could be used to support land use decisions in the North Slope management context. In particular, there was in-depth discussion on how the web map could be used to support decisions through the borough's land use permit application review program.

Discussion on legitimacy focused on the need to include energy sector risks. In this context, participants also voiced the need to include perspectives of the village of Nuiqsut because their traditional land use extends across the state lands where coastal energy projects are currently concentrated around the Prudhoe Bay oil fields (Figure 4.7).

The credibility discussion focused on fitness-for-use of the web map, where participants commented on its potential as a screening tool to better account for coastal exposure to climate risks. The web map was perceived as salient, but participants stated that they need more information to assess reliability for uses beyond initial assessment. However, participants stated that initial coastal exposure assessments using the web map could provide the justification for more thorough assessments. In addition to perspectives on overall reliability, credibility was questioned at specific locations where historical erosion rates conflict with more recent stakeholder observations. Inaccuracies in underlying asset spatial data and the challenge of maintaining the web map such as applying regular updates also caused credibility concerns. The metadata for the web map usability perspectives dataset is provided in Appendix D.

The following sections expand on the summary of usability perspectives provided above.

4.2.1. Web Map Saliency Perspectives

Workshop participant responses to the saliency questions indicate that the web map could be used to support land use decisions for developments near the coast. Specifically, the web map could support the borough’s development permit application review process. The borough currently lacks shoreline change information for the region, which forces land use managers to rely on information provided by developers in permit applications for relevant coastal development proposals. One land use manager was particularly vocal on this topic; he made the following statements at various times during the workshop:

> I could see this as an everyday tool for the many project reviewers that we have that have to review some 600 permits annually. It can be a desktop tool also for our inspectors or enforcement arm and monitoring.
> (NSB Land Use Manager)

> ... I think it's a quick reference for us when we're talking about project development, talking about expansion or abandoning infrastructure. This gives me a tool where I can quickly go and look to see what your thoughts would be to gathering information produced on that area... (NSB Land Use Manager)

> I think this is going to be useful … for future development … like ports, and the other thing that would be useful is to make recommendations on large project reviews for oil and gas development, where they're often looking to develop right along the shoreline. (NSB Land Use Manager)

> A lot times we often are at the mercy of the industry to provide information. We do have the policies in place that say we need to account for erosion. … But if we had it at our fingertips we would be able to create the dialogue more in detail about what our policies are intended to protect. (NSB Land Use Manager)

> We rely on the applicant [developer]. Our policies say we should look out for it [erosion], but we don't have the tools right now, and perhaps this might be the tool to help us factor that in much better.
> (NSB Land Use Manager)

Coastal exposure risk information is relevant for the North Slope Borough's land use permitting process. Participant statements on this topic echoed the North Slope Borough Municipal Code stipulation that the burden of proof to account for erosion risk is on the developer. This applies to projects that have to comply with requirements to mitigate shoreline change impact. Participant statements indicate that providing the borough with access to coastal exposure information would support borough efforts to require developers to account for coastal exposure risks. According to the participants, the enhanced engagement with developers about coastal exposure risks would advance conversations about how to manage threatened assets. Again, one land use manager was vocal on this point:

> I think it does further the conversation of: Do we get a borough asset to disappear, or is it at a critical point where maybe we put money into it to make it a continuing viable asset for the borough? People often hear some of this kind of information ... They need to express their concern to advance something and the gravity of what's going on with some assets. (NSB Land Use Manager)

> Our system is not geared to deny something but geared to review something. If there is no unmitigable adverse impacts, and that the mitigation using the tool was warranted and the applicant met up to it, and it can go forward maybe through the Planning Commission's approval through our conditional use. But we do have some limitations with what the administrator can do. (The administrator being the

> Department of Planning and Community Services Director.) It may mean that a permit either the administrator is comfortable to review it at her level and if the tool suggested more drastic erosion rates or a development that would be critical, it might mean that that permit got elevated to a Planning Commission level for review, and conditionally approved. (NSB Land Use Manager)

Participants indicated relevancy of the tool for two Alaska native-controlled assets where there is a current need for coastal exposure information to support coastal development decisions. One is the Cape Simpson Industrial Port (CSIP), a borough asset at a decommissioned Cape Simpson Distant Early Warning (DEW) Line site. As explained in Chapter 3, the North Slope Borough uses the CSIP to mitigate development impacts on subsistence in the National Petroleum Reserve -Alaska (NPR-A). The same land use manager that mentioned the CSIP in the local risk verification in Chapter 3 mentioned the risk during the usability workshop. In the web map workshop, the land use manager focused on information needs that the web map could support. For example, the manager said:

> There's a point on by Cape Simpson over there, and there's a North Slope Borough asset over there that is being inundated by erosion, there's an entire runway. It's millions of dollars worth of an asset and the need for the borough to do something about this is going to come to a head sometime - either to reclaim it or to enhance it because it's a great asset. It's leased out to be able to mitigate for subsistence impact and try to centralize oil and gas exploration where it doesn't impact the community too much. It's a good example if the interaction is working right, we can look at the vectors [i.e, web map exposure information], and try to anticipate what's the anticipated useful life of that runway. We know it's getting shorter every year. That's a 30-foot zone, and hitting about 30' of runway (lost) every year. How long is it going to be a useful landing strip? (NSB Land Use Manager)

Another asset identified in the workshop as needing coastal exposure information is the Arctic Slope Regional Corporation (ASRC) land parcel located by Cape Halkett (see Figure 1.1). According to the participant, the high erosion rates for the Cape Halkett area shown in the web map do not reflect recent rates. He said that the erosion rates in the area have decreased and, in some locations, the shoreline is growing (accreting). For example, the participant said:

> ASRC, within your study area, has about 8.5 miles of shoreline ... So, you're dealing with this giant area and of course we just have this 8.5 miles of coastline, but just so happens that that's a big area of accretion and we're just, you know someone saying 'oh no this land has little value because it's all going to be gone' and we're saying 'no, it's stabilized, in the past it's suffered erosion, but in the past 10 or 15 years it's been growing.' It would be helpful for me and us to have a study or something where it says 'no look right here is different, because on those USGS maps, it all just kind of looks red and bad. (ASRC Stakeholder)

4.2.2. Web Map Legitimacy Perspectives

Concerning legitimacy, participants commented that a major omission of tool is the oil and gas facilities and perspectives from the residents of Nuiqsut. Though much of the oil and gas data needed to include the sector in the tool is difficult to access due to security concerns, land use manager participants have extensive knowledge about the at-risk assets as many of them are involved with regulating the industry's development. Some of these participants acknowledged the problem of regulating the industry without access to coastal exposure information. One participant mentioned that the borough land use permit application reviewers evaluate proposed projects without having erosion information. For example, the participant said:

> Every single coastal oil field facility … from the mouth of the Colville River to the Sag River. Every single one of those is being developed annually, and our permitters are being asked to evaluate those applications. We're doing it without erosion information. (NSB Land Use Manager)

About 60 miles west of Prudhoe Bay, Nuiqsut is located inside the NPR-A, just west of state lands leased for oil and gas development. The village's subsistence use area extends across the coastal area where petroleum development is concentrated, making their perspective relevant for collaboratively assessing risk at oil and gas lands and facilities (Figure 4.7). One participant said that he has heard Nuiqsut residents complain that the changing coastline is impacting subsistence boating:

> Nuiqsut, even though they're inland a bit, the subsistence use along that coastline is great, those people have a lot of input, maybe add those to your query list next time. We've heard them complaining about boating traffic to Cross Island and the water's getting so shallow it's becoming more and more difficult. [...] [W]e're seeing some building going on at Cross Island. (NSB Land Use Manager)

The ASRC manager who contested the coastal exposure information in the web map (see Section 4.2.1) said that residents of Nuiqsut could attest to a decrease in erosion rates in the Cape Halkett area. The participant’s statement suggests that the residents of Nuiqsut are valuable sources to verify local coastal exposure risks in the region. For example, the participant said:

> And also, just off the shore there, so the wells are back about a half mile, and off the shore, hundreds of yards of barrier islands are forming so anyway, we're kind of battling the opposite thing. It's not so much that it's a problem, there's actually a spit over 2 miles long that wasn't there in say 2000, and there's all kind of drift wood. Some locals from Nuiqsut have also seen what I'm talking about and mentioned it in another meeting. (ASRC Stakeholder)

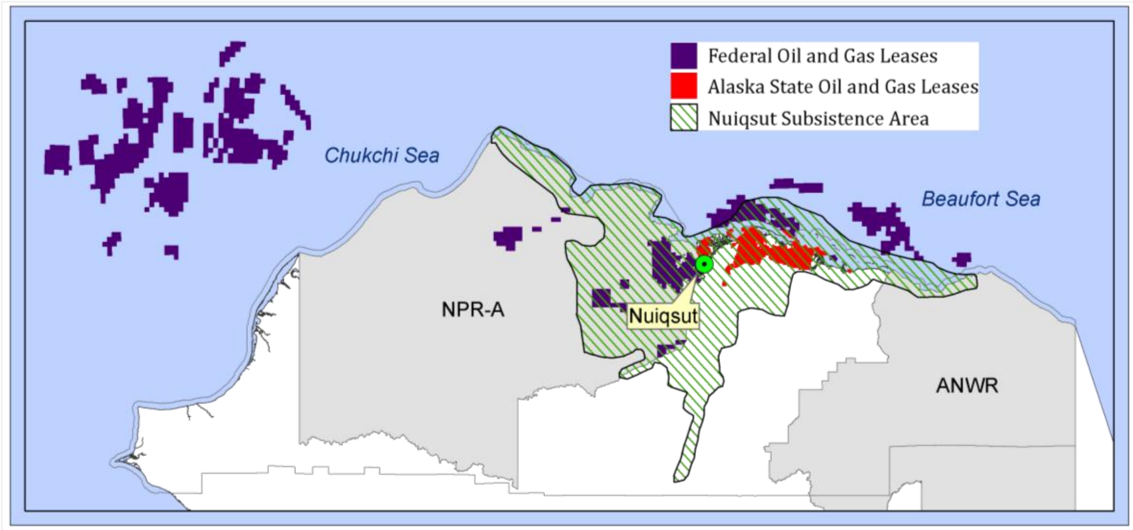

Figure 4.7. Nuiqsut Subsistence Area and Oil and Gas Leases
The purpose of this map is to illustrate that oil and gas activity is concentrated near Nuiqsut and within its subsistence area. The Nuiqsut subsistence area was estimated by Pedersen (1979).

4.2.3. Web Map Credibility Perspectives

Three themes emerged when participants were asked if they trust the tool based on what they saw in the live web map demonstration. The first theme that emerged was fitness-for-use, or that the tool could be used as a screening tool despite unknown reliability. As a screening tool, the web map could provide an initial assessment of coastal exposure in an area of interest. The web map would be one source of information to decide whether or not to pursue more detailed exposure analyses. For example, one land use manager said:

> ... [We could] take a look at that information and then make a decision whether it requires further analysis or … if we feel comfortable with the information that you have presented is complete enough to help us with the final decision. And I don't anticipate that to be, I mean it's going to give us a good indicator on whether we need to dig a little deeper or not. (NSB Land Use Manager)

One land use manager said that having access to a web map for coastal exposure screening would promote consideration of adaptations in land use decisions. As stated above, screening with the web map could support decisions for a more detailed exposure assessment. In turn, a more detailed assessment would support existing borough policy on erosion risk. The participant said that it would be hard for developers to “push back” against a land use decision to prevent developing in harms way if definitive exposure information were available. The reason is, with definitive exposure information, the borough could enforce existing policy and promote adaptation. For example, the land use manager said:

> Well once you start to get definitive information on the rate of erosion, I don't think they can push back when your policies say you must take into account … putting projects in harm's way unless you're going to intentionally fortify the area. That might be a tool to help and say 'hey this should be fortified to a 200 year event factor,' or something like that. (NSB Land Use Manager)

Another dimension of credibility that emerged in the usability workshop was the loss of web map credibility when information in the tool is inconsistent with stakeholder observations. As was mentioned in Section 4.2.1, the Arctic Slope Regional Corporation (ASRC) recently proposed to develop a parcel of land they own in the Cape Halkett area. As a condition for obtaining surface and subsurface rights, the ASRC is required to use the parcel for commercial development. However, the ASRC’s attempts to develop the parcel were denied due to the well-known and documented historical high erosion rates in the area. Similar to what the same ASRC stakeholder said in Section 4.2.1, the USGS data used in the coastal exposure web map are inconsistent with ASRC observations of coastline changes in the Cape Halkett area. For example, the participant said:

> We're looking to do something with that property and the federal agencies were saying 'oh no that's all eroding away that's all eroding away, look at this USGS report' and we're saying 'no, that's wrong, yes there's erosion, there's a lot of erosion in different areas but this area is growing rapidly, wetlands are being protected by these offshore barrier islands and the giant spit that was formed.’ (ASRC Stakeholder)

Unknown accuracy of the asset data was another web map credibility concern that emerged in the workshop discussion. Specifically, the ASRC participant noted that several gas test well locations were inaccurate.

> … [W]ith the red dot on map number 5, that well is about a half mile from the coast, so I'm confused by that in particular, if that dot is referring to the WT4 test wells, because it's showing something that I don't believe is particularly accurate.
> (ASRC Stakeholder)

The asset inaccuracies result from lack of data maintenance. The credibility concern related to web map maintenance emerged several times during the workshop. For example, one participant said:

> And I don't know what you're looking at in terms of if this is going to be updated and what the frequency of updates is going to be, so we're not using something that's severely outdated at times.
> (NSB Land Use Manager)

4.3. Discussion

The participant responses guide next steps for collaborative research on coastal exposure risks in the North Slope. The responses provide adequate specificity to offer new avenues for stakeholder-driven collaborative research of coastal exposures in the region including linking the web map with the borough's permit application review process.

Perhaps the most significant finding with respect to web map relevancy is that the participants saw the potential of the web map for supporting development decisions through the borough's permit application review process for proposed developments in the region. Integration of the web map with the permit program could be a pathway for mainstreaming coastal exposure risk information with decisions and plans on the North Slope. The unique North Slope management context makes this potentially very significant for science-based land use decision support in the region for several reasons.

First, as with the rest of Alaska, as of 2011 the North Slope Borough does not participate in the federal Coastal Zone Management (CZM) program. Withdrawal from the CZM provides local autonomy for decision-making and high capacity to pursue local management objectives. Second, the North Slope Borough is an Alaska native-controlled territorial government with Home Rule Charter, which allows legal governmental power over the vast region that has immense value ranging from heritage of local and national significance to vital national defense and energy security infrastructure. Through North Slope Borough Municipal Code (NSBMC) Title 19, the NSB created the Department of Planning and Community Services Department (Planning Department). The Planning Department's responsibilities include administering the borough’s planning and zoning ordinances and the Coastal Zone Management Plan within the approximately 51,800-sqkm coastal management zone (cf. Mitchell 1987) adjacent to the Arctic Slope's vast 3,000-km (2,000-mile) shoreline (cf. Walker 2001). The Planning Department is also required to gather information and develop the borough's Capital Improvement Program (CIP), which improves municipal services through infrastructure development using borough tax revenues that primarily come from energy development on state lands. Last, the NSBMC mandates that the Planning Department use the permitting system and provide a geographical data base covering the entire borough along with mapping services to support its program (NSBMC Title 19). The mapping service supports the complicated decision process of protecting subsistence and heritage within a region heavily developed for oil and gas production. This municipal code gives the North Slope a uniquely high capacity to use maps to support decisions and plans through a locally-controlled formal land use planning process for the region.

The web map workshop also identified coastal exposure information needs to manage specific assets, which present opportunities for additional collaborative research. As mentioned in Section 4.2.1, participants voiced two Alaska native-controlled industrial assets where they need coastal exposure information to support their land use decisions, i.e.: the eroding Cape Simpson Industrial Port (CSIP) controlled by the borough and a land parcel in the NPR-A controlled by the Arctic Slope Regional Corporation (ASRC). As one participant noted, the borough needs additional exposure information to decide planning actions for the CSIP. Another participant said that the ASRC wants to develop their parcel in the NPR-A by Cape Halkett, but they cannot get approved because of the high erosion rates in the area. The identification of specific coastal exposure risks where decision support is needed is significant because it could drive future collaborative research and manager engagement in the web map research.

An important finding with respect to legitimacy is that the coverage of the coastal exposure web map should expand into the state lands where oil and gas development is currently concentrated. When asked whose perspectives of coastal exposure risks were missing in the web map, the participants identified the residents of Nuiqsut. Nuiqsut's subsistence land use extends across the oil and gas developments on state lands (Figure 4.7). The identification of the need to include Nuiqsut in the mapping process suggests that North Slope managers do not want to be left in the dark about coastal risks where oil development is concentrated. Also, the borough's mapping system plays an important role in supporting land use decision where oil and gas development is concentrated. Because of the relevance and import role of the mapping system there, including Nuiqsut's perspectives near the petroleum developments would likely encourage North

Slope manager engagement in the coastal exposure web mapping process.

4.4. Conclusions

This chapter provided the results of land use manager usability perspectives of the coastal exposure web map collected in the usability workshop. An important finding with respect to saliency perspectives is that participants indicated that the web map could support the borough's land use permit application review program. The borough has policies in place to account for coastal exposure risk in development decisions, but it currently does not have access to coastal exposure information. Workshop participants also identified two Alaska native industrial land use sites where they need coastal exposure information to support development decisions. With respect to web map legitimacy, workshop participants indicated that the residents of Nuiqsut should be included in Collaborative Research Step 1 to get their perspectives of coastal exposure risks (see Figure 2.1). Nuiqsut's subsistence land use area extends across the area of the coastline where oil and gas development is concentrated, and where there are known coastal exposure risks such as barrier islands used for whaling. With respect to web map credibility, in addition to voicing reliability concerns such as unknown data quality, the participants discussed web map fitness-for-use as a screening tool for initial coastal exposure risk assessments.

In summary, the land use manager perspectives suggest that the web map is relevant for the borough's land use decision-making process, credible enough to be used as a screening tool, and a next step to enhance legitimacy is to include Nuiqsut's perspective of coastal exposure risks. Collectively, these findings inform future research to continue the research process illustrated in Figure 2.1 and encourage local North Slope manager engagement in the web mapping process.

5. Linking the Coastal Exposure Web Map to the Arctic Observing Network

A major challenge for the Arctic observing network (AON) is effectively engaging local communities in AON activities to address their information needs (cf. Lee et al. 2015a; Eicken et al. 2016a; Johnson et al. 2013, 2015). While local communities are among the stakeholders that AON programs aim to support (Eicken et al. 2016a), no systematic framework exists for local community engagement (cf. Lee et al. 2015a; IARPC 2015, cited in Eicken et al. 2016a). Therefore, there is a need for innovative collaborative research approaches to integrate local communities into the AON. In pursuit of this methodological need, this chapter addresses the third research objective of the dissertation to link local North Slope communities to the AON via the coastal exposure web map developed for this study (see Chapter 4).

Chapter 4 addressed the second objective of the dissertation to assess land use manager usability perspectives of the web map. As noted in Chapter 4, in addition to assessing usability, performing the second objective also establishes local manager engagement in the web map research, which is critical to link the North Slope to the AON. This chapter explores answers to the question: *How does the web map link to the Arctic observing network?* Answering this question is important because web map links to the observing network would also link the North Slope Borough as the web map owner. Answering this question therefore addresses the challenge of engaging local communities in the AON.

5.1. Method

Web map links to the AON were identified by comparing the description of the coastal exposure web map research process in Section 2.5 and an analysis of the web map product in Section 5.2.2 with the structure of the AON defined in Section 5.1.1. Section 5.1.1 below further explains the analysis methods used to identify web map links to the AON.

5.1.1. Analysis

This chapter presents results for three analysis steps used to identify web map links to the AON. The first step in Section 5.2.1 analyzes web map research process links to AON design approaches defined by the Arctic Observing Network Design and Implementation Task Force (ADI 2012). The second step in Section 5.2.2 identifies the web map spatial data steward network (Table 5.1 and Figure 5.1) and identifies how the data steward network links to federal Arctic observing activities defined by the Study of Environmental Arctic Change (SEARCH) summarized by Jeffries et al. (2007). The network analysis was inspired by the approach of Pulsifer et al. (2014b) to identify an emerging Arctic data management network. Finally, the third step in Section 5.2.3 analyzes web map process and product links to AON societal benefit areas defined by the Science and Technology Policy Institute (STPI) and the Sustaining Arctic Observing Networks (SAON) program (IDA 2017).

Below are brief descriptions of the three reports used to define the AON structure for the purpose of exploration how the web map links to the AON.

- ***Designing, Optimizing, and Implementing an Arctic Observing Network*** (ADI 2012) was the source used to identify web map process links to AON design approaches. The Arctic Observing Network Design and Implementation Task Force (ADI) was established in 2009 to guide the National Science Foundation (NSF), the scientific community, and other agencies engaged in the AON on how to design effective U.S. Arctic observing efforts. The ADI (2012) report focuses on the continued development of the AON by assessing its current state, synthesizing lessons learned, and identifying approaches for system design.

- **Arctic Observing Network: Toward a US Contribution to Pan-Arctic Observing** (Jeffries et al. 2007) was the source used to identify web map product links to federal Arctic observing activities. This report by the Interagency Arctic Research and Policy Committee (IARPC) summarizes ongoing and future federal Arctic observing activities. The IARPC consists of 16 federal agencies established by the Arctic Research and Policy Act of 1984 (ARPA) to enhance research and monitoring of environmental issues in the Arctic.
- **International Arctic Observations Assessment Framework** (IDA 2017) was the source used to identify web map links to AON societal benefit areas (SBA). This is a report from the IDA Science and Technology Policy Institute (STPI) and the Sustaining Arctic Observing Networks (SAON). The STPI provides analysis support to the White House Office of Science and Technology Policy (OSTP), the National Science Foundation, the National Science Board, and other offices within the executive branch of the U.S. government. The SAON was initiated by the Arctic Council to support multinational engagement to coordinate pan-Arctic observing and data sharing systems. The IDA (2017) report is the product of a workshop co-hosted by the STPI and the SAON to develop an international framework for assessing societal benefits from the AON.

5.2. Results

This chapter is focused on identifying how the web map process and product link to the Arctic observing network (AON). Section 5.2.1 identifies how the web map process links to AON design approaches. Section 5.2.2 identifies how the web map data steward network links to federal Arctic observing activities. Finally, Section 5.2.3 identifies how the web map process and product link to AON societal benefit areas.

5.2.1. Web Map Process Links to Arctic Observing Network Design Approaches

This section summarizes the web map research process and identifies how it links to AON design approaches defined by the Arctic Observing Network Design and Implementation (ADI) Task Force (ADI 2012).

As explained in Section 2.5, the web mapping process used in this dissertation is based on an instructional system design with two evaluation phases to verify local risks (Figure 2.1: Collaborative Step 1) and assess land use manager usability perspectives of the coastal exposure web map (Collaborative Step 3). Collaborative Steps 1 and 3 are focused on getting local community feedback to drive web map development. Chapter 3 provided the results of the local risk verification and Chapter 4 provided results for the web map usability assessment. Step 1 drives the asset data used to create the exposure web map, and Step 3 drives the design of the exposure information in the web map.

According to the AON design approaches defined by the ADI Task Force (ADI 2012), the ecosystem services component best links the coastal exposure web map process to the AON. The Task Force defined a hierarchy of 6 approaches to design and optimize the AON. The ecosystem services approach is one of three qualitative approaches. The other two approaches identify observation gaps learned from previous observing projects. The ecosystem services approach to AON design is to "… identify observation parameters based on ecosystem services that are important to stakeholders at local and regional scales" (ADI 2012: 2).

The ecosystem services approach addresses a core element of the AON structure. Referencing the Study of Environmental Arctic Changes (SEARCH) Understanding Change Panel (Elliot et al. 2010), the Task Force defined the current state of the AON in terms of science questions that currently drive the network. However, the Task Force also identified the "dual role" of the AON to address both science priorities and stakeholder information needs. The Task Force cited the core SEARCH theme Responding to Change as the charge of the AON dual role. With regard to the ecosystem services approach to designing the AON and the stakeholder information support role, the Task Force found the following:

> Ecosystem services are the benefits that society derives from ecosystems. They are a potentially useful construct for observing system design because they link the biophysical environment to the needs of society. Thus, they can help in prioritizing variables to measure, provide a context for communication with stakeholders, and help integrate community-based observations. The latter in turn can inform the placement of sensors and other aspects of system design (ADI 2012: 19).

All of the environmental information in the web map (Table 4.1) can be defined in terms of ecosystem services that affect the North Slope and can be put in terms of physical components to monitor quantitatively using AON resources. For example, one of the many ecosystem services provided by sea ice extent in the Arctic is the protection is provides to the coastline from forces that erode the coast and put people and valued assets at risk. The sea ice can be monitored quantitatively to inform stakeholders that rely on its ecosystem services.

5.2.2. Web Map Product Links to Federal Arctic Observing Activities

This section identifies the web map data steward network based on the organizations that archive and maintain spatial data (i.e. data stewards) used to create the web map (see Table 5.1). The description of the web map data steward network is then used to identify how the web map product links to federal Arctic observing activities.

Stewards of the data used to create the shoreline change susceptibility model (Table 4.1) are: the U.S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), the National Snow and Ice Data Center (NSIDC), and ShoreZone. The Polar Geospatial Center (PGC) was included as a proposed contributor of elevation data. Stewards of the data used in the asset data model (Tables 4.2 - 4.4) are: The North Slope Borough (NSB), the Bureau of Land Management (BLM), the Alaska Department of Natural Resources (DNR), Department of Transportation and Public Facilities (DOTPF), and the Department of Conservation (DOC). The Exchange for Local Observations and Knowledge of the Arctic (ELOKA) was included as a proposed steward of the local community views of coastal exposure risks identified in Chapter 3. The NSF Arctic Data Center is the steward of data products used in the NSB Web Portal to provide access to researchers.

Table 5.1. North Slope Borough Coastal Exposure Web Map Data Steward Network

Scale	Data Steward	Website
Local	NSB (North Slope Borough)	http://www.north-slope.org/
State/ Regional	DNR (Alaska Department of Natural Resources).	http://www.asgdc.state.ak.us/
	DOTPF (Alaska Department of Transportation and Public Facilities).	http://www.dot.state.ak.us/
	DOC (Alaska Department of Conservation).	http://dec.alaska.gov/
	ShoreZone.	http://www.shorezone.org/
	*ELOKA (Exchange for Local Observations and Knowledge of the Arctic).	https://eloka-arctic.org/
	*PGC (Polar Geospatial Center).	http://pgc.umn.edu/
National	BLM (Bureau of Land Management).	https://www.blm.gov/ak/st/en.html
	NSF (National Science Foundation) Arctic	https://arcticdata.io/

	Data Center.	
	USGS (U.S. Geological Survey) National Assessment of Shoreline Change Project.	https://coastal.er.usgs.gov/shoreline-change/
	NOAA (National Oceanic and Atmospheric Administration) National Center for Environmental Information.	https://www.ncei.noaa.gov/
	NSIDC (National Snow and Ice Data Center).	https://nsidc.org/

* Asterisks denote proposed linkages in web map version 2 described in Appendix J.

Figure 5.1. North Slope Borough Coastal Exposure Web Map Data Steward Network
Figure 5.1 illustrates the network of organizations that provide the data used to create the coastal exposure web map. Solid black lines indicate already established organizational links to the NSB Portal. Dotted black lines indicate proposed networks where data were manually entered into the NSB Web Portal to create the web map (Chapter 4). Dotted red lines indicate a proposed link in version 2 of the web map.

The links illustrated by dotted lines in Figure 5.1 are proposed based on the coastal exposure web map created in this dissertation research. Dotted black lines indicate an organization that was the source of spatial data used to create the web map. Red dotted lines indicate data stewards that would provide data in version 2 of the web map. The solid line indicates that the NSB data steward link to the web map is already established. The NSB is currently the only organization with an established link to the coastal exposure web map.

According to the Arctic observing activities defined by the IARPC (Jeffries et al. 2007), the categories: Ocean and Sea Ice, Terrestrial Ecosystems, Human Dimensions, and Data and Information Management best link the web map product to AON observing activities. The IARPC organized observing activities into seven categories defined by the SEARCH Environmental Arctic Change Implementation Plan (SEARCH 2005). This section follows the IARPC format by identifying and describing the observing activities relevant for the web map based on the data steward network defined above.

Ocean and Sea Ice

- The National Snow and Ice Data Center (NSIDC) archives a time series of sea ice extent using National Aeronautical and Space Administration (NASA) passive microwave satellites that begins in 1978. The sea ice data were used in the web map to provide wind-fetch distances from the sea ice to places along the North Slope shore. Also, days of open water calculated from the NSIDC sea ice data will be added to version 2 of the web map (see Appendix J).

Terrestrial Ecosystems

- Much of the Arctic Slope coastline is included in the U.S. Geological Survey's (USGS) National Assessment of Shoreline Change Project (Gibbs and Richmond 2015). Motivated by coastal exposure risk concerns, the Shoreline Change Project aims to provide accurate shoreline change information on a periodic basis using consistent methods for the United States region.

- The National Oceanic and Atmospheric Administration (NOAA) National Center for Environmental Information (NCEI) maintains a high spatial resolution global database of shorelines. The NCEI shorelines database was used to calculate wind-fetch distances in the shoreline change susceptibility data model (see Appendix I).
- The ShoreZone mapping system provides landform type information for segments of the North Slope shoreline created for the National Oceanic and Atmospheric Administration (NOAA) Office of Response and Restoration Environmental Sensitivity Index (ESI) maps. The ESI was used to represent coastal resistance to shoreline change in the web map.
- The Polar Geospatial Center (PGC) provides high spatial resolution elevation data for the pan-Arctic region. While the dataset is currently beta, its strength is its ability for efficient repeat coverage. Elevation information would be added to version 2 of the web map (see Appendix J).

Human Dimensions

- The Exchange for Local Observations and Knowledge of the Arctic (ELOKA) is an ongoing effort to archive and provide access to community observations and knowledge data collected in the Arctic. The ELOKA archives local observations and provides restricted access to sensitive community-based observation data sets. In the web map network shown in Figure 5.1, ELOKA is proposed as the data steward to manage participant observations for the coastal exposure web map developed in this study.

Data and Information Management

- The organizations in the web map data steward network shown in Figure 5.1 manage data and information in their own archives or support for other organizations. For example, the NSIDC manages storage and access to NASA remote sensing data sets such as the sea ice extent time series mentioned above. ShoreZone stores the Environmental Sensitivity Index (ESI) created by the NOAA. In addition to storing data, the stewards add value by creating data and information products from data provided by other organizations. For example, the commercial satellite company DigitalGlobe is the source of imagery used by the Polar Geospatial Center (PGC) to create, store, and provide access to elevation data products.

5.2.3. Web Map Links to Arctic Observing Network Societal Benefit Areas

This section identifies how the web map research process and product link to AON societal benefit areas (SBAs) defined by IDA (2017).

According to the SBAs defined in the IDA (2017) report, the Resilient Communities SBA best links the coastal exposure web map process and product to AON SBAs. In a 2017 workshop co-hosted by the IDA and the SAON to evaluate the AON, the participants defined 12 high level SBAs using a hierarchical value tree framework. Resilient Communities, or " … sustaining and preserving the vitality and security of Arctic communities in a changing region" (IDA 2017: 39) is composed of three sub-areas: Adaptation and Response of Communities, Baseline Conditions of Communities, and Future Projections of Community Change.

The coastal exposure web map directly addresses the first two. The web map supports Adaptation and Responses by the North Slope Borough by addressing sub-components including developing capacity to adapt, improving community education on Arctic changes and impacts, and mitigating the impacts on Arctic system changes by providing land use decision support. The web map also supports identifying Baseline Conditions by addressing the SBA's subcomponent of assessing community understanding of the threats and impacts of Arctic changes.

5.3. Discussion

The results in Section 5.2 identify ways that the North Slope Borough coastal exposure web map research process and product link to the Arctic observing network (AON). In this discussion, Section 5.3.1 proposes the application of the instructional systems design web mapping research process (ISD Process) used in this study to implement the scientist-stakeholder interaction conceptual model developed by Eicken et al. (2016a). Section 5.3.2 proposes a North Slope coastal exposure community of practice (CoP) as a way to influence and use Arctic observing activities. Finally, Section 5.3.3 discusses the role of responsible data management of local community observations in collaborative research using the AON.

5.3.1. Dual Use Arctic Observing Networks

The Arctic observing network (AONs) is intended to address both science priorities and stakeholder information needs (Lee et al. 2015a; Eicken et al 2016a). As stated in the introduction to this chapter, it is a challenge to engage local communities in the AON. The instructional systems design process (ISD Process) implemented in this dissertation offers a practical way to engage the North Slope in AON activities. In this section, the ISD Process is presented as a method to apply the scientist-stakeholder interaction conceptual model for advancing “dual use” observing systems put forward by Eicken et al. (2016a).

Eicken et al. (2016a) proposed a conceptual framework for stakeholder-scientist interaction called “data co-management.” The framework is based on a two-way conversation between scientists and stakeholders to produce data and information that is relevant for both science and stakeholder information needs (Figure 5.2a). The data co-management framework combines co-management approaches (Berkes 2009) with observation and data management frameworks established to support existing Arctic observing networks. Co-management brings managers and users across scales together in an iterative mutual learning process to better understand and manage natural resources. The observation and data management framework is based on data management best practices such as coproduction of data.

The notion of Arctic system services in the data co-management framework is a key concept in the model; it translates between Arctic system variables observed for science and Arctic system services of value to stakeholders. Arctic system services, as described by Eicken et al. (2009), are essentially Millennium Ecosystem Assessment ecosystem services (cf. MA 2005) specific to the Arctic. For example, coastal protection is an Artic system service that sea ice provides (cf. Eicken et al. 2009). The role of Arctic system services in the data co-management framework is to help identify components of Arctic systems that are monitored and studied for science that are also relevant for stakeholders.

In the data co-management framework, scientists and stakeholders engage in a two-way conversation focused on identifying Arctic system variables that are of mutual interest to monitor. The co-management framework establishes the two-way conversation, which, in theory, drives scientific observations, synthesis, and information products (Figure 5.2a). In the co-management model, the two-way conversation focuses on collaboratively defining the Arctic system problem to research or system variable to monitor. By communicating using the concept of Arctic system services, scientists can identify information products to deliver to stakeholders, and stakeholders, in turn, can provide feedback to improve information product usability (Figure 5.2a).

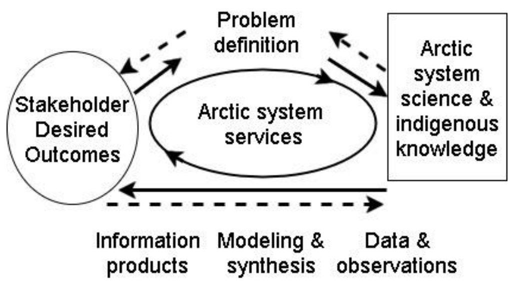

Figure 5.2a. Co-production and Co-Management Cycle
From Eicken et al. (2016a). Solid lines indicate data and information product direction, and dashed lines indicate feedback direction.

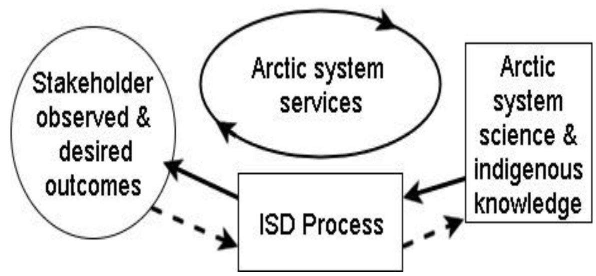

Figure 5.2b. Adapted Co-production and Co-Management Cycle
Adapted from Eicken et al. (2016a). Solid lines indicate data and information product direction, and dashed lines indicate feedback direction. In this adapted model, problem definition is included in the ISD process in front-end information product evaluation efforts, and observed stakeholder outcomes is added to desired outcomes component. Note that Arctic system science data, modeling, and information product activities and stakeholder feedback are mediated by the ISD process.

However, while the data co-management framework offers a helpful theoretical framework, it does not specify how scientist-stakeholder interactions will occur in practice. This problem is apparent when we imagine that the stakeholders are local resource users. Many local resource users in the Arctic, such as subsistence hunters, do not have access to a network to voice observed or desired Arctic system service outcomes. Co-management institutions would enhance such access, but, for the data co-management model to work, the institutions would have to be linked with scientists such as through an observing network. Lastly, even if local resource users had full access to voice Arctic system information needs to scientists willing to provide it, generating relevant information is not enough for stakeholder information to be usable for decision-support. Scientist-stakeholder engagement needs to be designed to advance and balance dimensions of scientific information usability including saliency, legitimacy, and credibility (cf. Cash et al. 2003). A model that includes a proactive engagement with stakeholders focused on information usability is needed to establish effective communication between scientists and stakeholders to negotiate Arctic observing priorities and generate usable information products.

The instructional design in this dissertation described in Section 2.5 provides a mechanism to engage the North Slope in a two-way conversation with scientists in practice. In Figure 5.2b, the instructional design (i.e. ISD Process) offers a social process through which stakeholders may communicate with scientists to negotiate observing priorities and advance coastal exposure risk information usability. For example, in Chapter 3 of this dissertation, local residents identified coastal exposure risks in ISD Process Collaborative Step 1 to verify local risks to include in the coastal exposure web map. The local risk verification identified coastal exposure risks associated with Alaska Native industrial and subsistence land uses that warrant a re-articulation of the erosion problem for North Slope research coordinators such as the North Slope Science Initiative (NSSI) (cf. Section 3.3). In ISD Process Collaborative Step 3 in Chapter 4, land use managers provided usability perspectives on the coastal exposure web map. The usability workshop identified relevancy of the web map to support North Slope Borough land use decisions through the borough's land use permit application review process. The workshop also identified specific locations where coastal exposure information is needed to support land use decisions. In addition, the usability workshop goes beyond mere relevancy and provides a forum to advance credibility and legitimacy dimensions of usability through a sustained collaborative research process. For example, the usability workshop identified that legitimacy of the web map would be enhanced by including the residents of Nuiqsut in the web mapping process.

5.3.2. Toward a North Slope Coastal Exposure Observing Network

The instructional systems design web map research process (ISD Process) described in Section 2.5 provides a practical method for scientists and stakeholders to interact to identify coastal exposure information needs and promote web map usability. However, the method does not ensure that identified exposure information needs will be prioritized in the Arctic observing network (AON) over other observing needs. Another social process is needed for North Slope information needs voiced through the ISD Process to influence and use AON activities. In this section, a North Slope coastal exposure community of practice (CoP) is proposed as a method to influence and use AON activities.

The observing activity prioritization framework described in Lee et al. (2015a) offers guidance on how to influence Arctic observing activities to address North Slope coastal exposure information needs identified in the ISD Process. The Lee et al. (2015a) framework inserts the concept of Arctic system services mentioned in Section 5.3.1 (cf. Eicken et al. 2009, 2016a) into the primary phase of AON coordination. The primary phase described below drives the AON activities mentioned in Section 5.2.2. The framework described in Lee et al. (2015a) is based on a hierarchy approach (ADI Hierarchy) proposed by the Arctic Design and Implementation Task Force (ADI 2012) mentioned in Sections 5.1.1 and 5.2.1. In the ADI Hierarchy, an Arctic change research problem identified at the top of the hierarchy by AON coordinators such as the Study of Environmental Arctic Change (SEARCH) in the U.S. drives observing activities. For example, the SEARCH 5-Year Science Goals developed by the SEARCH Science Steering Committee (SSC) with input from the broader science community and agency representatives identified four focus areas that drive the coordination and prioritization of public and private observing assets. The 5-Year Plan focused on understanding and predicting the Arctic environment and analyzing the societal implications. As mentioned in Section 5.3.1, the Arctic system services framework (cf. Eicken et al. 2009, 2016a) is focused on identifying stakeholder-desired outcomes to drive AON observing activities (cf. Figure 5.2a). The Lee et al. (2015a) framework works to address stakeholder information needs by inserting the Arctic systems services concept with its focus on outcomes desired by stakeholders into the SEARCH problem definition at the top of the ADI Hierarchy that drives Arctic observing activities. Therefore, one way to influence Arctic observing activities is to insert North Slope Borough coastal exposure information needs identified in the ISD Process into the Arctic problem definition by SEARCH at the top of the ADI Hierarchy.

However, in addition to influencing the top of the ADI Hierarchy, the Lee et al. (2015a) framework offers another pathway for stakeholders to influence and use AON activities. The other pathway is through exploiting flexibility in observing activities lower in the hierarchy. A key goal of the ADI Hierarchy process is to build connections between emerging and desperate networks to optimize observing (Lee et al. 2015a). A multi-network framework described by Lee et al. (2015a) could help to balance observing resources and integrate long-term observing that requires robust monitoring with more flexible networks the emerge in short-term projects that can respond rapidly to stakeholder information needs. In the ADI Hierarchy, these linkages would occur between Problem Definition at the top and Network Implementation (i.e., observations) at the bottom. At the Strategy Level in the hierarchy, just below the Problem Definition, specific observation goals and information products are planned. At the Strategy Level, the Arctic Council's SAON, the Interagency Arctic Policy Committee (IARPC), and SEARCH Science Steering Committee (SSC) are among the key members that determine the strategy including funding and support strategies. The strategy is implemented at the Tactical Level where observing protocol and data management standards are developed and implemented. At the Tactical Level is where network integration occurs across disciplines and projects such as sharing resources. In the ADI Hierarchy described in Lee et al. (2015a), network integration occurs through "nodes," or communities of practice (CoP) that emerge from mutual interest in observing Arctic system variables such as sea ice extent. Lee et al. (2015a) notes that SEARCH Action Teams and IARPC Collaboration Teams may lead to nodes that result in observing network integration at the Tactical Level.

The web map research process (ISD Process) created for this dissertation creates a social process for a CoP, or "node" in the ADI Hierarchy framework, to form at the local community scale. A CoP consists of three main characteristics: shared domain of interest, information share and learning through interaction of a community defined by the shared interest, and shared practice (Wegner 2011). The iterativity built into the ISD Process (see Section 2.5) provides a mechanism at the local community scale to create a coastal exposure CoP that includes the data steward network identified in Section 5.2.2. The ISD Process is based on learning through interaction, and web map updates through regular interaction would tailor information products to address manager information needs. The regular interaction to develop the web map provides the “boundary object” that holds the CoP together. The relevancy of coastal exposure information for a wide range of stakeholders in the North Slope suggests a diverse shared domain of interest would likely grow with iterations of the ISD Process.

5.3.3. Coastal Exposure Web Map Community Data Management

This chapter identified a network of data stewards based on the identification of the organizations that manage the data used to create the North Slope coastal exposure web map (Figure 5.1). This section discusses the need for the coordination of community data management to share local observations and promote trust between researchers and Arctic residents in future coastal exposure web mapping.

It is widely recognized that effective coordination of information and data management plays an important role in realizing societal benefits from Arctic observing networks (Jeffries et al. 2007; Johnson et al. 2011; Parsons et al. 2011; Huntington 2011; Pulsifer et al. 2012, 2014a,b; Payne et al. 2013; Johnson et al. 2013, 2015; Lee et al 2015a; Eicken et al. 2016a). The Arctic Spatial Data Infrastructure (Arctic SDI) is an effort to coordinate data management in the Arctic by leveraging technology, policy, standards, and people to support Arctic geospatial data sharing in the Arctic (Arctic SDI

2015). Among the goals of the SDI is the application of policy and standards that make data accessible by promoting open data and interoperability between systems to promote access for the range of Arctic users. The National Science Foundation has taken a leading role in the Arctic SDI by enhancing access to Arctic scientific data including establishing data portals to centralize data storage and access (Jeffries et al. 2007). However, more work is needed to develop interoperability of the Arctic SDI to engage local Arctic communities in decision support observing networks.

In addition to developing technical aspects of interoperability, the coastal exposure observing network illustrated in Figure 5.1 depends on willingness to share information. Willingness to share is a fourth dimension of interoperability that has received less attention in interoperability research (Pulsifer and Taylor 2005). In the coastal exposure network in Figure 5.1, most entities are either state or federal government and therefore are required to share their non-sensitive public data and information. The Exchange for Local Observations of the Arctic (ELOKA), on the other hand, is constrained by ethical considerations when sharing data and information provided by Arctic residents (cf. Pulsifer et al. 2012). The ELOKA is a proposed actor in the coastal exposure observing network, indicated by a red arrow connecting to the North Slope Borough web map in Figure 5.1. The ELOKA would manage and share local observations collected in this study with the North Slope Borough. Data management using ELOKA would encourage local communities to share their observations in future coastal exposure web mapping by establishing trust that the data will be handled responsibly.

5.4. Conclusions

This chapter explored how the coastal exposure web map created for this study links to the Arctic observing network (AON). To identify links, the web map process described in Section 2.5 and a network analysis of web map data stewards in Section 5.2.2 were compared with the structure of the AON. The structure of the AON was defined using key reports on three important aspects of AON organization including design approaches (ADI 2012), federal Arctic observing activities (Jeffries et al. 2007), and societal benefit areas (SBA) (IDA 2017). The results in Section 5.2 indicate that the web map links to the ecosystem services approach to AON design, several federal observing activities, and the Resilient Communities SBA. Section 5.3 discusses the results with respect to advancing "dual use" observing networks to address both science and stakeholder information needs, establishing a coastal exposure observing network community of practice, and the role of responsible local community data management.

6. Conclusions

This dissertation investigated coastal exposure to climate risks in the North Slope from the local community perspective. It also advanced a collaborative mapping effort to integrate the North Slope in a web mapping process that links to the Arctic observing network. The study contributes to collaborative coastal exposure to climate change research that includes the perspective of impacted stakeholders (Chapter 3). It also contributes to evaluating usability of climate change research by analyzing North Slope land use manager usability perspectives of the exposure web map created for the study (Chapter 4). Lastly, the study contributes to advancing methods to engage local communities in the Arctic observing network by creating a web map and map process that links to the network (Chapter 5).

This concluding chapter summarizes the main findings of the dissertation research (Section 6.1), identifies policy implications (Section 6.2), and suggests future research directions (Section 6.3).

6.1. Research Findings and Implications

This section summarizes the research findings in Chapter 3 (Section 6.1.1), Chapter 4 (Section 6.1.2), and Chapter 5 (Section 6.1.3).

6.1.1. Chapter 3 Research Findings

Chapter 3 identified coastal exposure to climate risks based on the perspectives of local communities in Alaska’s North Slope using participatory mapping methods. Analysis of the results identified exposure risks associated with constrained coastal access for industrial and subsistence land uses during the open water season. Many of the risks identified are not within proximity to the municipalities, which is the usual geographic focus of coastal exposure assessments on the North Slope. The dissertation grouped the identified exposure risks into four themes based on asset type. The identified risks are summarized by theme below:

- ***Distant Early Warning (DEW) Line (Section 3.2.1)*** – Exposure of the decommissioned DEW Line sites on the North Slope present risks associated with current local uses of the sites. The North Slope Borough uses the remaining infrastructure at the Cape Simpson DEW Line site including airstrips and building pads to support oil and gas exploration in the National Petroleum Reserve – Alaska (NPR-A). Use of the DEW site mitigates impacts on subsistence that would result from industry building elsewhere, not yet developed, to support their operations. Reuse of the DEW Line for industrial development also presents potential taxable income from the assets from future development. Therefore, from the local perspective, loss of the DEW Line from coastal exposure is a risk to current land use-based strategies to mitigate subsistence impact and support taxable developments.
- ***Alaska Native Corporation Lands (Section 3.2.2)*** – Exposure of native corporation lands to climate risks constrains access for oil and gas and related industrial development that would benefit the corporations. Two such risks identified include shoaling occurring at the Wainwright Inlet near Olgoonik Corporation lands and historical high erosion rates on Arctic Slope Regional Corporation (ASRC) lands near Cape Halkett. Shoaling of the Wainwright Inlet would make it difficult for barges and boats to pass, which may discourage the decision to develop an offshore oil and gas support base at the Wainwright DEW Line site on Olgoonik Corporation lands. The

high erosion near Cape Halkett is preventing the ASRC from developing a parcel of land in the NPR-A.

- ***Subsistence Hunting Camps (Section 3.2.3)*** – Participants identified numerous camps used for subsistence hunting along the North Slope coasts that are eroding into the ocean or are becoming inaccessible by boat due to coastline changes. The camps impacted range from single family camps to sites that support entire communities. For example, Griffin Point, east of Kaktovik, is a multi-family camp that has been used for millennia but is now being washed into the ocean. Multiple families depend on the single entrance to the Ikpikpuk River in Smith Bay to access their hunting camps. Coastal exposure changes the entrance and may one day make it inaccessible, which would impact the multiple families that depend on it. The entire community of Nuiqsut depends on Cross Island for whale hunting. The island is eroding away and may not support the whale hunt, which is a critical risk to the community.
- ***Subsistence Boating (Section 3.2.4)*** – In addition to affecting camp access, coastal exposure is negatively impacting summer subsistence boating more generally. Local boaters depend on the chain of barrier islands that stretch across much of the North Slope coast. Participants identified numerous locations where barrier island changes are creating problems for boating such as cutting off subsistence boating routes and increasing risk by closing barrier island cuts used to escape stormy seas. For example, Bernard Spit, north of Kaktovik, is moving toward the mainland, which is constraining a boating route used to haul whales into the community. Bernard Spit movement threatens to cut-off the route altogether. Many participants noted that navigation devices equipped with global positioning systems (GPS) are unreliable due

to the rapid changes, which makes maps of the coastline inaccurate. With respect to increasing boating risk, erosion of an important barrier island that provides protection to boaters traveling between Kaktovik and Canada is forcing boaters to travel along the open ocean coast exposed to seas no longer dampened by sea ice.

6.1.2. Chapter 4 Research Findings

Chapter 4 analyzed North Slope land use manager usability perspectives of the coastal exposure web map in a usability workshop. The results were organized into the three aspects of usability defined by Cash et al. (2003): saliency, legitimacy, and credibility. The identified usability perspectives are summarized below:

- ***Saliency (4.2.1)*** –The land use managers viewed the web map as relevant to support the North Slope Borough's land use permit application review program by providing access to coastal exposure information during the review process for proposed coastal developments. In addition to the general discussion about relevancy for the permit program, participants also identified two places were coastal exposure information is currently needed: the borough's Cape Simpson Industrial Port and an Arctic Slope Regional Corporation (ASRC) parcel within the National-Petroleum Reserve – Alaska (NPR-A).
- ***Legitimacy (4.2.2)*** – According to workshop participants, including the perspectives of Nuiqsut residents would enhance the web map's legitimacy. Nuiqsut's subsistence area covers stretches of the North Slope coastline where most oil and gas developing is occurring. Nuiqsut's local knowledge about coastal exposure risks would expand the study area coverage onto state lands between the NPR-A and the Arctic National Wildlife Refuge (ANWR). However, local knowledge of risks may also be located

on barrier islands where federal oil and gas activity is taking place. One barrier island exposure risk identified in Chapter 3 is the eroding Cross Island, which the entire community of Nuiqsut relies on for subsistence whaling.

- ***Credibility (4.2.3)*** – A prominent discussion in the workshop related to credibility was fitness-for-use of the web map. That is, even with credibility concerns, North Slope land use managers said that the web map might be useful as a screening tool to identify places that may need more in-depth exposure analyses. Participants also expressed concern about accuracy of the web map data and whether or not the web map would be maintained.

6.1.3. Chapter 5 Research Findings

Chapter 5 identified ways the coastal exposure web map links to the Arctic observing network (AON). The web map was analyzed to identify the organizations that are the stewards of the data used to create the web map. The web map process described in Section 2.5 and the analysis of the web map product in Section 5.2.2 were used to identify how the web map links to the AON. To identify the links, Sections 5.1.1 defined the AON structure using three key reports on AON organization (i.e., ADI 2012; Jeffries et al. 2007; IDA 2017). A summary of how the coastal exposure web map links to the AON is provided below:

- ***Web Map Process Links to the Arctic Observing Network Design Approaches (5.2.1)*** - The web map process links to the AON via the ecosystem services approach to designing the network described in ADI (2012). In the ecosystem services approach to AON design, the prioritization of environmental variables to observe using the network is based on ecosystem services that are important to stakeholders. For example, coastline protection is a sea ice ecosystem service that warrants monitoring using the AON.

- ***Web Map Product Links to Federal Arctic Observing Activities (5.2.2)*** **–** The coastal exposure web map links to several federal Arctic observing activities including the National Aeronautics and Space Administration (NASA) sea ice extent time series, which the National Snow and Ice Data Center (NSIDC) archives. Most web map links to current observing activities described in Jeffries et al. (2007) are associated with the data used to create the shoreline change susceptibility spatial data model described in Section 4.1.2 and Appendix I.
- ***Web Map Links to Arctic Observing Network Societal Benefit Areas (5.2.3)*** **–** The web map links to the Resilient Communities societal benefit area (SBA) described in IDA (2017). The web map is linked to the Resilient Communities SBA because it supports Arctic community adaptive responses and assessment of community threats and impacts from Arctic changes.

6.2. Implications of the Research Findings

This section identifies policy implications of the research findings listed above. Section 6.2.1 identifies the implications of the coastal exposure risks found in Chapter 3 for North Slope Science Initiative (NSSI) research coordination efforts. Section 6.2.2 identifies the implications of web map usability perspectives found in Chapter 4 for the North Slope land use decision-making process. Finally, section 6.2.3 identifies the implications of the web map links to the Arctic observing network (AON) found in Chapter 5 for AON programs that are tasked with engaging local communities for decision support.

6.2.1. Rearticulating the North Slope Erosion Problem

The coastal exposure risks identified in this study have implications for the North Slope Science Initiative (NSSI), which is mandated by Congress to coordinate applied science to support North Slope resource managers. Specifically, the risks identified suggest that the NSSI should rearticulate the erosion problem to include the risks to industrial and subsistence land uses identified in this study. Rearticulating the erosion problem would influence how coastal exposure to climate risks are represented in NSSI stakeholder-driven scenarios planning activities and other research. The NSSI currently focuses on risks to village infrastructure and historical land uses such as industrial and cultural heritage sites (cf. Streever et al. 2011; Vargas-Moreno et al. 2016), and does not adequately account for current land use risks identified in this study. The current NSSI focus with respect to coastal exposure risks is based on available literature (i.e. Jones et al. 2008), which the NSSI relied on to identify its research priorities (cf. NSSI 2014). The current articulation of the erosion problem based on available literature limits the NSSI erosion research priority and associated research activities to addressing the need for accurate erosion models, asset data, and instrumentation to monitor the impacts on municipal infrastructure and historical land uses (cf. Vargas-Moreno et al. 2016). A focus from the NSSI on risks to current industrial and subsistence land uses from the local community perspective would enhance relevancy for North Slope land use managers that are actively implementing a plan for a sustainable future (cf. NSB 2015).

6.2.2. Coastal Exposure Information for North Slope Land Use Management

The finding that the coastal exposure web map could support the North Slope Borough's (NSB) land use permit application review program has implications for the NSB land use decision-making process. As mentioned in Section 1.3.2 and Section 4.3, the NSB established a geographic information system (GIS) to support NSB Planning Department land use decisions. The GIS includes a module dedicated to environmental information, and the conceptual design called for collaboration across local, state, and federal agencies and universities to make relevant environmental information accessible to North Slope land use managers. However, the conceptual design has not been effectively implemented in practice and the environmental information module is not being used to its full potential. The web mapping technologies that the borough has recently adopted provides capabilities needed to realize the original collaborative design of the environmental module of the boroughs mapping system. The process of engaging local managers with coastal exposure information via the NSB GIS has implications for implementing borough policies that aim to consider coastal exposure risks in land use management decisions, including the borough's land use regulations, Capital Improvement Program, and Coastal Zone Management Plan. Continued collaborative coastal exposure web map development could address the coastal exposure information gap in North Slope land use planning.

6.2.3. Designing Local Community Engagement in the Arctic Observing Network

The coastal exposure web map links to the Arctic observing network (AON) identified in this study have implications for the design of local community engagement in AON activities. The links identified in Section 5.2 (summarized in Section 6.1.3) suggest that local communities could be integrated with AON activities to address stakeholder information needs with some additional effort. The community-based approach in this study is a "bottom-up" effort that facilitates the AON in addressing local community stakeholder information needs. The bottom-up effort to link the local communities to the AON also compliments efforts of long-term scientific monitoring programs to have direct beneficial societal impacts on communities located near monitoring sites. For example, the National Science Foundation's Long-Term Ecological Research (LTER) Program broader impacts area: Translating Science for Society (https://www.nsf.gov/pubs/2005/nsf0533/nsf0533.pdf) engages local community stakeholders to identify local science needs that can be addressed as part of existing LTER programs. The recently established Beaufort Sea Lagoons LTER on the North Slope addresses coastal erosion and related environmental changes to understand ecosystem impacts (NSF #1656026). The LTER research is designed to include collaboration with local community stakeholders in Utqiaġvik and Kaktovik. With some additional effort, the Beaufort Sea Lagoons LTER could address local North Slope science needs related to coastal exposure risks as part of the larger environmental monitoring program.

The web mapping research process created in this study could be expanded to initiate coproduction of knowledge to address coastal exposure risks. Coproduction is emerging as a best practice in climate change research to address stakeholder climate science needs (cf. Lemos and Morehouse 2005; Weichselgartner and Kasperson 2012; Rosenzweig et al. 2011; Kirchhoff 2013; Leichenko et al. 2014, 2015) including in the Arctic context (Petrov et al. 2016). Stakeholder collaboration in all phases of research for decision support distinguishes coproduction from other participatory methods. This dissertation included collaboration in data collection (Figure 2.1 Collaborative Step 1), analysis (Step 3), and dissemination of results (Figure 2.1). However, this dissertation fell short of coproduction because the research questions were not defined in collaboration with the local community stakeholders. The collaborative web map research created for this study could be adapted to advance coproduction of knowledge to address coastal exposure risks by integrating it with existing AON programs like the Beaufort Sea Lagoons LTER. Application of the adapted Eicken et al. (2016a) co-production and co-management cycle proposed in this study (Figure 5.2b) could be used to facilitate the collaboration between LTER scientists and local community stakeholders to co-develop coastal exposure research questions and methods to address local information needs.

Efforts to address local community climate research needs using the Arctic observing network would be met with many benefits associated with enhanced local community engagement in scientific research and monitoring. For example, well-designed local community engagement would support science and monitoring goals by providing better access to reliable and low cost in situ observations in remote and difficult to access locations observed by local community members. Giving back to the community in research to enhance interaction to achieve broader science goals is a well-established strategy in collaborative mapping at the local community scale (e.g. Bryan and Wood 2015; NOAA 2015) and in participatory research methods more generally (cf. Cornwall and Jewkes 1995; Chambers 2006; Mercer et al. 2008; Johnson et al. 2013). The bottom-up research process created in this dissertation presents an opportunity to apply the well-established collaborative mapping strategy to enhance local community interaction to support AON science goals.

6.3. Limitations of the Study and Directions for Future Research

This section addresses some study limitations that should be addressed in future research.

A limitation of this study is that there were geographic gaps in the coastal exposure assessment. In particular, the assessment did not include the local community stakeholders of Nuiqsut. Including Nuiqsut in the coastal exposure assessment would be significant for identifying important local community risks on the North Slope while also advancing land use manager engagement in the coastal exposure web map. Community mapping workshop participants identified some potentially serious coastal exposure risks for Nuiqsut including the eroding Cross Island, which is an important barrier island that the community uses for whaling (Section 3.2.3). Usability workshop participants also voiced the need to include Nuiqsut because of their local knowledge of coastal exposure risks where oil and gas development is currently concentrated (Section 4.2.2). As was noted in Section 4.3, including Nuiqsut's coastal exposure risks would help establish local manager engagement in the coastal exposure web map research process because of the important role of the borough's mapping system in supporting land use decision where oil and gas development is concentrated.

A limitation of the coastal exposure web map usability evaluation in this study is that it was not designed to account for tradeoffs between usability factors. Tradeoffs between saliency, legitimacy, and credibility arise when stakeholder inclusion in the production of science to address saliency and legitimacy negatively impacts perspectives of scientific credibility, or when "sound science" isolated from stakeholder involvement comes at the cost of low saliency and legitimacy (Mitchell 2006; Girod et al. 2009; White et al. 2010). For science products to be perceived as usable by multiple stakeholders, "boundary work" at the science-policy-practice interface is necessary to balance perspectives of saliency, legitimacy, and credibility (Cash et al. 2003). The web map created in this study provides a “boundary object” to facilitate communication to identify and negotiate conflicts to mitigate usability tradeoffs (cf. Lynch et al. 2008; Cutts et al. 2011; Preston et al. 2011). Future research should deliberately engage the range of stakeholders represented on the web map to collaborate in coastal exposure risk information development. For example, the Arctic Slope Regional Corporation (ASRC) should be included in the development of the coastal exposure information for their assets including the ASRC parcel of land in the National Petroleum Reserve – Alaska (NPR-A) (see Section 3.2.2). In addition to advancing usability of the web map, additional research on usability tradeoffs with diverse stakeholders could also be designed to address the National Science Foundation’s interest in researching effective Arctic climate science communication for decision support (cf. Vörösmarty et al. 2015).

As noted in Section 6.2.3, another limitation of the dissertation is that it did not establish coproduction because the study did not include local community stakeholders in all research stages for decision support. That is, the web mapping research process did involve local community stakeholders in data collection (Chapter 3), data analysis (Chapter 4), and dissemination of study results (Figure 2.1). However, the researcher defined the research questions without consultation with the local communities. The research questions were based on pre-dissertation fieldwork observations of coastal exposure risks and the academic literature on science usability evaluation and Arctic observing networks. Future research should expand the web mapping process developed in this dissertation by including the local community stakeholders in defining research questions. For example, what exposure risks do the local communities want to investigate, and what methods would they use to evaluate coastal exposure information usability? The advancements made in this study including the articulation of coastal exposure risks that are relevant for North Slope resource managers and web map development provide the groundwork for future coproduction of knowledge to address coastal exposure risks. The next step is to deliberately engage local communities and Arctic observing network coordinators in coproduction of knowledge by collaboratively defining coastal exposure research questions and further developing the web map for decision support.

Appendix A

Metadata: Local Community Verification of Shoreline Change Risks Along the Alaskan Arctic Ocean Coast (North Slope)

Data Set Citation

When using this data, please cite the data package

Brady M. 2017.
Local community verification of shoreline change risks along the Alaskan Arctic Ocean coast (North Slope).
doi:10.18739/A2TH5P (https://arcticdata.io/metacat/metacat/doi:10.18739/A2TH5P/default)

General Information

Title:	**Local community verification of shoreline change risks along the Alaskan Arctic Ocean coast (North Slope).**
Identifier:	autogen.2017022717381824290.1
Abstract:	In April 2016, local perspectives of shoreline change risks in the Arctic Slope covering the National Petroleum Reserve - Alaska (NPR-A) and the Arctic National Wildlife Refuge (ANWR) were collected using a collaborative mapping process. About 300 shoreline change "problem places" contributed by 50 participants in Wainwright (8), Utqiagvik (32), and Kaktovik (10) were mapped, described, and digitized. The resulting geodatabase consists of problem feature locations linked to transcribed verbal or hand-written description and basic participant background information. Transcripts from audio recorded interactive mappings stored in MS Excel files also include statements that are not associated with a specific location. The purpose of the data set is to verify local shoreline change risks as a front-end evaluation effort to develop a shoreline change risk WebGIS for Alaska's Arctic Slope using a collaborative mapping and Instructional Systems Design (ISD) process.
Keywords:	None: ◦ Arctic Social Spatial Data
Publication Date:	2017-02-24

Data Set Characteristics

Geographic Region:

Geographic Description:	Mapping workshops were held in Alaskan Villages Wainwright, Utqiagvik, and Kaktovik. Map contributions extend approximately from the western extent of the National Petroleum Reserve - Alaska (NPR-A) through the Arctic National Wildlife Refuge (ANWR) to the United States - Canada Border.
Bounding Coordinates:	West: -161.9158 degrees East: -141.0344 degrees North: 71.5131 degrees South: 69.6719 degrees

Time Period:

Begin:	2016-04-01
End:	2016-05-01

Sampling, Processing and Quality Control Methods

Step by Step Procedures

Step 1:

Description:	**Verify shoreline change risks with local communities using semi-directive mapping workshops with hard-copy maps and coded stickers.** Summary: In April 2016, a total of 50 community mapping workshop participants in Alaska communities Wainwright, Utqiagvik, and Kaktovik placed coded stickers on printed maps of the shoreline where they perceive problems with shoreline change and described them verbally and/or directly on the maps and/or instruction sheets using a marker. Collectively, the 50 participants identified just under 300 such places within the study area extent. The "problem places" and descriptions were digitized and linked with participant biographical surveys and audio recordings for qualitative geographical analysis using the sticker codes. Not all interviews were audio recorded; 23 of the 50 participated in audio recorded, one-on-one or small group interactive mappings (8 in Wainwright (100%), 5 in Utqiagvik (~16%), and 10 in Kaktovik (100%)), and the

Figure A.1. Metadata: Local Community Verification of Shoreline Change Risks

	other 27 in Utqiagvik participated by placing stickers and marking the maps without audio or significant researcher interaction. The audio recording transcriptions were stored in MS Excel files. Each transcript includes the unique participant sticker code to link with biographical information collected when participants registered at the workshop. Sticker locations and markings were digitized by geo-rectifying high resolution photographs of resulting maps and manually entering spatial contributions (e.g., sticker point locations) and sticker numbers in corresponding feature attribute tables using Esri ArcGIS tools. Participants were assigned 10 stickers with the same code, so after digitization a random number was attached to each sticker to make all stickers uniquely coded. The extended unique codes allowed individual participant verbal and marker contributions that correspond with a specific location to be associated with a specific sticker point feature in the geodatabase. Semi-directive Collaborative Mapping Methods: The community mapping workshops were semi-directed, guided by an instruction form (Form 2, described below) and the researcher in one-one-one and small group mappings to focus attention on shoreline change risks. Participants were provided basic information about the study and were encouraged to talk about shoreline change problems in terms of social impact rather than in environmental terms alone. In addition, the maps directed participants to focus spatially on the coastline within the study area of interest. Otherwise participants were free to make associations and direct their contributions. Collaborative Map Instrument Design: The map set used in the community mapping workshop consisted of 3 medium-scale maps at approximate representative fraction (RF) 1:100,000 (~1 cm to 1km) of the coastal region in the study area, and 3 large scale maps at around RF 1:6000 (~1 cm to 60m) covering village locations in relatively high spatial detail. The base data for the medium scale maps was U.S. Geological Survey (USGS) 1:250,000 scale topographic maps (1 cm to 2.5 km), and the base data for the large scale maps was recent high resolution DigitalGlobe imagery. Recent USGS 50 meter shoreline change rate data were overlain onto all 6 maps, and select asset data such as Department of Defense Distant Early Warning (DEW) Line site and camp locations were included on the medium scale maps for additional reference. The decision to include the medium scale maps showing coastal regions beyond village boundaries is supported by pre-dissertation research in 2013 where it was discovered that, in addition to concerns of risks within villages that have historically been the focus of vulnerability assessments, communities are also concerned about lands and assets that extend across the vast Arctic Slope coastline, well beyond formal municipal limits. Village locations were not prominent features on the medium scale maps, which encouraged participants to focus on risks to lands that extend across the vast coastline within the study area of interest. The large scale maps allowed participants to focus on specific risks within villages as prominent features at this scale included built infrastructure footprints. As noted elsewhere, participants placed uniquely coded stickers at shoreline change "problem places." The stickers were 1/4 inch and pointed on one side allowing for an expected spatial accuracy greater than 500 meters. While high spatial accuracy of qualitative data collection was not a priority in this research, approximate locations of stickers uniquely coded for each participant supported the qualitative geographical analysis. Collaborative Map Process: Each of the 50 community mapping workshop participants received 10 arrow-shaped colored stickers all marked with the same code unique to them, a wax-based marker with the same color as their stickers, and a packet containing three forms to complete. One of the 10 stickers was colored black to complete a map orientation exercise explained below (Form 2). Form 1 was the Rutgers University Institutional Review Board (IRB) Consent Form. Form 2 was the map activity guide sheet. In addition to documenting participant ID (i.e., sticker number) and color, for the purpose of providing map orientation for participants, Form 2 prompted placement of the black sticker at a location familiar to the participant and to note the level of historical erosion from low to high based on their observations. Participants were then asked to indicate whether or not the USGS erosion rate data on the map was accurate to get them familiar with the map legend. Form 2 then provided instructions to place the remaining 9 colored stickers at places where erosion is occurring and then describe the problem or issue (i.e., impact of shoreline change) verbally or by marker directly on the map or pen in the comment section provided on the form. Form 3 collected participant information such as name, contact information, and demographic details.
Sampling Area And Frequency:	The spatial extent of the study corresponds with the segment of shoreline included in the U.S. Geological Survey's National Assessment of Shoreline Change Project, Alaska for the Alaskan Arctic Ocean coast. The area covers much of the shoreline extending across two major federal land units: the National Petroleum Reserve - Alaska (NPR-A) and the Arctic National Wildlife Refuge (ANWR), and state-controlled lands in between.
Sampling Description:	The overall sampling strategy was to collect local knowledge at shoreline segments adjacent to the NPR-A and ANWR. Workshops were held in Wainwright, Utqiagvik, and Kaktovik because the traditional land use extent of these three villages collectively cover the coastline in the study area. While not located on the coastline, traditional land use extents of other North Slope villages including Atqasuk, Point Lay, and Nuiqsut also cover the coastline area of interest, but due to budgetary constraints were omitted from data sampling. In Wainwright with 8 participants and Kaktovik with 10 participants, the "snowball" approach purposive sampling strategy targeted hunters who travel extensively along the coast with eyes on remote and hard to reach stretches of the Arctic Slope shoreline. In Barrow with 32 participants, the door was open at the Inupiat Heritage Center for all community members wishing to participate. In Utqiagvik, I conducted follow-up audio-recorded interviews with select workshop participants with knowledge about specific areas of interest, and brought the hard-copy maps to homes and offices to allow elders and key informant managers that did not attend the workshop to participate.

Figure A.2. Metadata: Local Community Verification of Shoreline Change Risks (cont.)

Appendix B

Metadata: Arctic Slope Shoreline Change Susceptibility Spatial Data Model

Data Set Citation

When using this data, please cite the data package

Brady M. 2017.
Arctic Slope Shoreline Change Susceptibility Spatial Data Model, 2015-16
urn:uuid:38450a8f-dc1a-41a4-ae65-f1da9342ee44 (
https://arcticdata.io/metacat/metacat/urn:uuid:38450a8f-dc1a-41a4-ae65-f1da9342ee44/default)

General Information

Title:	**Arctic Slope Shoreline Change Susceptibility Spatial Data Model, 2015-16**
Identifier:	autogen.2017051715374245224.1
Abstract:	Shoreline change susceptibility information added to 50-meter transects created by the U.S. Geological Survey (USGS) as part of their National Assessment of Shoreline Change Project, Alaska (Gibbs and Richmond 2015). Shoreline change susceptibility information added to the USGS transects are based on the USGS Coastal Vulnerability Index (CVI) adapted to the Arctic context by including wind-fetch distances based on historical sea ice extents. Transects also include landform information from ShoreZone (ShoreZone.org), and historical shoreline change calculated by the USGS (Gibbs and Richmond 2015). The purpose of the data is to identify shoreline change susceptibility at areas of interest to stakeholders selected during an Instructional Systems Design (ISD) process to develop a shoreline change risk WebGIS in collaboration with the North Slope Borough. Gibbs, A.E., and Richmond, B.M., 2015, National assessment of shoreline change: Historical shoreline change along the north coast of Alaska, U.S.-Canadian border to Icy Cape: U.S. Geological Survey Open-File Report 2015-1048, 96 p., https://dx.doi.org/10.3133/ofr20151048. Data are forthcoming and inquiries concerning the data should be directed to Michael Brady.
Keywords:	GCMD: ◦ Natural Hazards
Publication Date:	2017-03-24

Data Set Characteristics

Geographic Region:

Geographic Description:	The geographic scope of the data extent is approximately from the western extent of the National Petroleum Reserve - Alaska (NPR-A) through the Arctic National Wildlife Refuge (ANWR) to the United States - Canada Border.
Bounding Coordinates:	West: -161.9161 degrees East: -141.0347 degrees North: 71.5131 degrees South: 71.5131 degrees

Time Period:

Begin:	2015-10-01
End:	2016-09-30

Sampling, Processing and Quality Control Methods

Step by Step Procedures

Step 1:

Description: **Geoprocessing shoreline change susceptibility**

Historical wind-fetch distances for every 10-degree direction were calculated for the entire Arctic coastline using monthly September sea ice extents averaged over two time periods: 1979-1999 and 2000-2015. Fetch calculations were based on two 500-meter land-ice scenario grids created for the study using an ArcGIS model created by the U.S. Geological Survey (USGS) (Rohweder et al. 2012). The two land-ice grids were created using average monthly Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data, Version 1 (Cavalieri et al. 1996). Ice extents were

Figure B.1. Metadata: Arctic Slope Shoreline Change Susceptibility Data Model averaged for the two time periods using a 15% sea ice concentration threshold. To create the two land-ice grids, the two resulting ice grids were added separately to the same land grid created using coastline data from the GSHHG - A Global Self-consistent, Hierarchical, High-resolution Geography Database (Wessel and Smith 1996, Version 2.3.4 Jan 1, 2015). USGS coastlines for the Arctic Slope coast were imposed on the resulting land grid to ensure spatial consistency with the USGS 50-meter transects created by Gibbs and Richmond (2015). To resolve the problem of 500-meter fetch grids not intersecting with 50-meter transects in some cases from inconsistent spatial resolutions between the fetch grids and transects and varying coastline geometry, the fetch grids were spatially extended using Inverse Distance Weighting (IDW). Appropriate IDW settings such as search radius were found interactively for grid sets from the two time periods and exposed versus sheltered shorelines, and results were visually checked for quality by comparing resulting IDW fetch grids against original fetch grids. Each fetch grid was then intersected with the 50 meter transects separately. Since multiple grid cells from a single fetch grid often intersected with a single transect due to varying coastal geometry, highest intersecting fetch grid values were attributed to exposed transects and the lowest intersecting grid values were assigned to sheltered shoreline segments were multiple grid cells intersected with a single transect.

Landform type data from ShoreZone (ShoreZone.org) was attributed to the USGS 50-meter transects created by Gibbs and Richmond (2015) by intersecting ShoreZone shoreline line segments with the 50-meter transects. The mode was used to attribute ShoreZone (categorical) data were multiple ShoreZone shoreline line segments intersected with a single transect due to varying coastal geometry.

Cavalieri, D., C. Parkinson, P. Gloersen, and H. J. Zwally. 1996, updated yearly. Sea Ice Concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data, Version 1. [NSIDC- 0051]. Boulder, Colorado USA: NASA DAAC at the National Snow and Ice Data Center. http://dx.doi.org/10.5067/8GQ8LZQVL0VL. [Accessed in 2015].

Rohweder, J., Rogala, J. T., Johnson, B. L., Anderson, D., Clark, S., Chamberlin, F., ... & Runyon, K. (2012). Application of wind fetch and wave models for habitat rehabilitation and enhancement projects 2012 update. Contract report prepared for US Army Corps of Engineers: Upper Mississippi River Restoration Environmental Management Program.

Wessel, P., and W. H. F. Smith, A Global Self-consistent, Hierarchical, High-resolution Shoreline Database, J. Geophys. Res., 101, #B4, pp. 8741-8743, 1996.

Figure B.2. Metadata: Arctic Slope Shoreline Change Susceptibility Data Model (cont.)

Appendix C

Metadata: Arctic Slope Shoreline Change Risk Spatial Data Model

Data Set Citation

When using this data, please cite the data package

Brady M. 2017.
Arctic Slope Shoreline Change Risk Spatial Data Model, 2015-16
urn:uuid:d25941ab-26d1-4c7f-bd3f-41ee39a4096d (
https://arcticdata.io/metacat/metacat/urn:uuid:d25941ab-26d1-4c7f-bd3f-41ee39a4096d/default)

General Information

Title:	**Arctic Slope Shoreline Change Risk Spatial Data Model, 2015-16**
Identifier:	autogen.2017051715181103921.1
Abstract:	The Arctic Slope Shoreline Change Risk Spatial Data Model consists of shoreline change susceptibility information from the Arctic Slope Shoreline Change Susceptibility Spatial Data Model (Brady 2017) summarized at asset locations defined by a local community-verified Arctic Slope at-risk asset spatial data model. Specifically, this data product is shoreline change susceptibility information added to attribute tables of a variety of asset spatial data for at-risk coastal Arctic Slope assets. The purpose of the data is to identify shoreline change risk to assets of interest to stakeholders selected during an Instructional Systems Design (ISD) process to develop a shoreline change risk WebGIS in collaboration with the North Slope Borough. Data are forthcoming and inquiries concerning the data should be directed to Michael Brady.
Keywords:	GCMD: ◦ Natural Hazards
Publication Date:	2017-03-24

Data Set Characteristics

Geographic Region:

Geographic Description:	The WebGIS usability workshop was held in the North Slope Borough Assembly Room in Utqiagvik, Alaska. The geographic scope of the WebGIS covers the study area extent approximately from the western extent of the National Petroleum Reserve - Alaska (NPR-A) through the Arctic National Wildlife Refuge (ANWR) to the United States - Canada Border.
Bounding Coordinates:	West: -161.9161 degrees East: -141.0347 degrees North: 71.5131 degrees South: 69.6722 degrees

Time Period:

Begin:	2015-10-01
End:	2016-09-30

Figure C.1. Metadata: Arctic Slope Shoreline Change Risk Spatial Data Model

Sampling, Processing and Quality Control Methods

Step by Step Procedures

Step 1:

Description:

Geoprocessing shoreline change risk

Shoreline change susceptibility information from Brady (2017) was attributed to asset spatial data by intersecting shoreline change transects with asset spatial data. Nearest transect was used for point data, and spatial intersect was used for line and polygon asset features were multiple transects intersect. Minimum, mean, and max values (or mode for categorical data) were used for line and polygon assets with multiple intersecting transects.

Asset data (and sources) include: subsistence hunting camps (North Slope Borough); Alaska Native Allotments (Bureau of Land Management); cultural heritage sites (Alaska Department of Natural Resources); Native Regional and Village Corporation parcels (Bureau of Land Management); airstrips including at Distant Early Warning (DEW) line sites (Alaska Department of Transportation and Alaska Department of Natural Resources); solid waste sites at DEW line sites (Alaska Department of Conservation); military parcels (Bureau of Land Management); village municipal boundaries (Alaska Department of Natural Resources).

Brady, M. (2017). Arctic Slope Shoreline Change Susceptibility Spatial Data Model. NSF Arctic Data Center. arctic-data.10114.1.

Figure C.2. Metadata: Arctic Slope Shoreline Change Risk Spatial Data Model (cont.)

Appendix D

Metadata: Shoreline Change Risk WebGIS Usability Workshop

Data Set Citation

When using this data, please cite the data package

Brady M. 2017.
North Slope Borough shoreline change risk WebGIS usability workshop.
doi:10.18739/A2PT0N (https://arcticdata.io/metacat/metacat/doi:10.18739/A2PT0N/default)

General Information

Title:	**North Slope Borough shoreline change risk WebGIS usability workshop.**
Identifier:	autogen.2017022718135283492.1
Abstract:	In April 2016, local and regional North Slope manager perspectives were collected on usability of a beta version shoreline change risk WebGIS developed for the Arctic Slope covering the National Petroleum Reserve - Alaska (NPR-A) and the Arctic National Wildlife Refuge (ANWR). The WebGIS is a collaborative effort with the North Slope Borough (NSB). Transcripts from the audio recorded workshop were stored in a MS Excel file. The purpose of the data set is to assess usability of the WebGIS as a formative evaluation effort to develop a shoreline change risk WebGIS for Alaska's Arctic Slope using a collaborative mapping and Instructional Systems Design (ISD) process.
Keywords:	None: ◦ WebGIS Usability Perceptions ◦ Arctic Social Spatial Data
Publication Date:	2017-02-24

Data Set Characteristics

Geographic Region:

Geographic Description:	The WebGIS usability workshop was held in the North Slope Borough Assembly Room in Utqiagvik, Alaska. The geographic scope of the WebGIS covers the study area extent approximately from the western extent of the National Petroleum Reserve - Alaska (NPR-A) through the Arctic National Wildlife Refuge (ANWR) to the United States - Canada Border.
Bounding Coordinates:	West: -161.9161 degrees East: -141.0347 degrees North: 71.5131 degrees South: 69.6722 degrees

Time Period:

Begin:	2016-04-01
End:	2016-05-01

Sampling, Processing and Quality Control Methods

Step by Step Procedures

Step 1:

Description:	**WebGIS usability assessment using a live WebGIS demonstration and an information usability framework to guide participant discussion.** In April 2016, a total of 16 usability workshop participants consisting mostly of local North Slope managers and GIS programmers in Utqiagvik, Alaska provided feedback on a live demonstration of a beta shoreline change susceptibility WebGIS. The shoreline change risk WebGIS is an interactive Esri Web-based Story Map hosted on the North Slope Borough's official Web Portal that allows user interaction with a shoreline change susceptibility spatial data model (i.e., wind fetch, shoreline type, historical change). The system allows users to query shoreline information by select asset locations such as hunting camps or by 50 meter transects. After a live demonstration of the WebGIS, participants were asked a series of questions to get responses to important aspects of information usability, i.e.: saliency, credibility, and legitimacy. The audio record from the workshop was transcribed and stored in an MS Excel file.

Figure D.1. Metadata: WebGIS Usability Workshop

Sampling Area And Frequency:	The spatial extent of the study corresponds with the segment of shoreline included in the U.S. Geological Survey's National Assessment of Shoreline Change Project, Alaska for the Alaskan Arctic Ocean coast. The area covers much of the shoreline extending across two major federal land units: the National Petroleum Reserve - Alaska (NPR-A) and the Arctic National Wildlife Refuge (ANWR), and state-controlled lands in between.
Sampling Description:	As part of a collaborative arrangement with the North Slope Borough Planning and Community Services Department, the NSB sent emails to borough employees and personally invited specific key informant participants.

Figure D.2. Metadata: WebGIS Usability Workshop (cont.)

Appendix E[10]

Wainwright and Kaktovik Research Request Letter

March 18, 2016

Native Village of Kaktovik
P.O. Box 73
Kaktovik, AK 99747

To Whom It May Concern:

I am a doctoral student in the Geography Department at Rutgers University. My dissertation research focus is on mapping coastal erosion risk in collaboration with local communities in Alaska's North Slope.

I am writing to respectfully request permission to visit Kaktovik from April 17 to April 21, 2016 to conduct my research. I request to show maps of erosion patterns along the North Slope shoreline and threatened assets such as Native Allotments and buildings within the village to local community members and ask them to share their views of erosion risk by marking on the maps and completing a short survey. I would offer $75 credit to the local grocery store to the first ten participants.

Attached to this letter are several documents about the project including a brief description of the study by the National Science Foundation, letters of support from North Slope Borough Planning & Community Services Department and Applied Research in Environmental Sciences Nonprofit, letter of approval from the Rutgers University Office of Research and Regulatory Affairs, draft study consent form, a flyer I would post prior to arrival, and a project data management plan.

Thank you for your consideration and I look forward to hearing from you soon.

Sincerely,

Michael Brady
Department of Geography
Rutgers University
54 Joyce Kilmer Avenue
Piscataway, NJ 08854
(401) 578-0480
michael.brady@rutgers.edu

Figure E.1. Research Request Letter Send to Wainwright and Kaktovik

[10] This is one of six letters sent in 2016 to request permission to do research in Kaktovik and Wainwright. Each letter was slightly modified for each recipient. Letter recipients include: Native Village of Kaktovik, Kaktovik Iñupiat Corporation, City of Kaktovik, Native Village of Wainwright, Olgoonik Corporation, and City of Wainwright.

National Science Foundation
WHERE DISCOVERIES BEGIN

SEARCH

FUNDING AWARDS DISCOVERIES NEWS PUBLICATIONS STATISTICS ABOUT NSF FASTLANE

Award Abstract #1523191

Doctoral Dissertation Research: Mapping Community Exposure to Coastal Climate Hazards in the Arctic: A Case Study in Alaska's North Slope

NSF Org:	PLR Division Of Polar Programs
Initial Amendment Date:	September 25, 2015
Latest Amendment Date:	September 25, 2015
Award Number:	1523191
Award Instrument:	Standard Grant
Program Manager:	Anna Kerttula de Echave PLR Division Of Polar Programs GEO Directorate For Geosciences
Start Date:	October 1, 2015
End Date:	September 30, 2016 (Estimated)
Awarded Amount to Date:	$13,590.00
Investigator(s):	Robin Leichenko rleichen@rci.rutgers.edu (Principal Investigator) Michael Brady (Co-Principal Investigator)
Sponsor:	Rutgers University New Brunswick 3 RUTGERS PLAZA NEW BRUNSWICK, NJ 08901-8559 (848)932-0150
NSF Program(s):	GEOGRAPHY AND SPATIAL SCIENCES, ARCTIC SOCIAL SCIENCES
Program Reference Code(s):	1079, 1352, 5221, 9179
Program Element Code(s):	1352, 5221

ABSTRACT

This research investigates community exposure to coastal climate hazards in Alaska?s North Slope and incorporates community assessment of the potential effects on loss of land, infrastructure, and other assets. This analysis will inform response strategies and planning by developing new methods of hazard assessment that can support community resilience in the North Slope and potentially serve as a model for advancing assessment and planning in other rural and urban communities. This research will expand traditional assessments of financial exposure to also include non-material factors such as values and priorities of diverse social groups within a community including a diverse set of stakeholders, ranging from multinational oil companies to individual subsistence hunters. This study surveys community views of asset importance and integrates results with a geophysical hazard data model for a coproduced community exposure map of the North Slope coast. This research will contribute to understanding the human and social dimensions of climate change impacts, including how social, economic, political, and cultural factors shape vulnerabilities and condition response strategies. Methods and findings could enhance nation-wide efforts in the United States to map community exposure to

Figure E.2. Research Request Letter Send to Wainwright and Kaktovik (cont.)

coastal climate hazards by demonstrating methods for, and the importance of systematically incorporating non-market values in exposure analysis.

The objectives of the proposed research include adapting the U.S. Geological Survey's (USGS) coastal vulnerability index (CVI) to the Arctic context, and integrating results with formal asset databases and a spatial community landscape value model while working with affected communities during the process to coproduce exposure maps. Specifically, working with North Slope Alaskan communities the study will incorporate wind fetch (i.e., the open water distance over which wind can generate near shore waves, determined by sea ice extent) into the CVI and get community feedback on the results. In addition to community input on the CVI maps, coproducing the exposure maps includes the community assigning values to traditional land use places using existing spatial datasets and mapping and investigating specific sites threatened by coastal hazards with the aim to learn why exposed assets threaten the community.

Please report errors in award information by writing to: awardsearch@nsf.gov.

Figure E.3. Research Request Letter Send to Wainwright and Kaktovik (cont.)

NORTH SLOPE BOROUGH
PLANNING & COMMUNITY SERVICES DEPARTMENT
Community Planning Division
P.O. Box 69
Barrow, AK 99723
Phone: (907) 852-0333
Fax: (907) 852-5118

Rhoda Ahmaogak, Director

September 16, 2014

Michael Brady
Doctoral Student
Geography Department
Rutgers University

michael.brady@rutgers.edu
Phone: 401.578.0480
Fax: 732.445.0006

Dear Mr. Brady,
This letter is in regard to our impression supporting the value for your current research on north slope Alaska coastal hazards, specifically in context to the concern regarding the observations of community infrastructure risks, declining animal habitat, and near shore material transport changing the coastal landscape. Our department often is tasked to quantify subjective concerns in justifying the pursuit of activities that mitigate the easily observed problem, but in these attempts we often find ourselves thwarted by lack of research and documentation. Your efforts identify the observed changes and assessing their risk potential will better allow us as managers of our resident environment to justify our interdiction or reaction to the posed problems. In some cases, your effort may be able to identify problems we are not aware of, which is the greatest value of all.

Please continue with your efforts, allow our division to support you in any manner that may be useful, and use this letter as a personal referral for your study effort.

Sincerely,

Robert Shears, acting Community Planner

Figure E.4. Research Request Letter Send to Wainwright and Kaktovik (cont.)

Applied Research in Environmental Sciences Nonprofit, Inc.
Mailing Address: 1042 Maple Avenue, Suite 106, Lisle, IL 60532
Principal Office: Attn: Dr. Anne Garland, 20206 Olde Towne Court, Smithfield, VA 23430

Francisco San Juan, Ph.D., President (252)335-3451
Kathleen M. Fischer, Ph.D., Treasurer (630)324-6402
Anne W. Garland, Ph.D., Secretary (757)334-9568

September 26, 2014

Michael B. Brady
Department of Geography
Rutgers University
Piscataway, NJ

Re.: Letter of Support for Doctoral Dissertation Research in the North Slope of Alaska

Dear Mr. Brady:

It is my pleasure to write a letter in support of your doctoral research investigating community vulnerability to coastal climate hazards in Alaska's North Slope. We are very supportive of this research as it has direct relevance to our work on the North Slope of Alaska with indigenous coastal communities that face risks related to coastal erosion.

Applied Research in Environmental Sciences NonProfit, Inc. (ARIES) is a 501(c) (3) organization with a mission of environmental research, public education, and community outreach (www.ariesnonprofit.com). Over the past six years, ARIES has worked with tribal communities in the area of risk management.

During summer 2014, the ARIES program “Historical Ecology and Risk Management: Youth Sustainability” (HERMYS) conducted preliminary studies of the impact of coastal erosion on the North Slope communities of Barrow and Browerville, particularly with respect to critical infrastructure. Additionally, we reviewed various options for engaging the local community in the management of risk stemming from this hazard. In conjunction with our effort, we were very fortunate to have had you collaborate with us this summer while you were performing your dissertation research. Your research goal of investigating the importance and value of a broader range of community assets than encompassed by ARIES' research goals both complemented and enhanced our effort.

Your dissertation research will provide essential information on two key factors in community decision-making: traditional values and knowledge, and a desire to preserve social identity and important cultural resources. As the North Slope and other coastal communities face environmental changes, your dissertation research will provide information on factors that are determinative of successful planning of adaptation to these changes.

A guiding principle of ARIES is to collaborate with other organizations, academic institutions, and corporations to benefit the projects we undertake. Because of our mutual interests in this work and the complementary nature of our research, ARIES will contribute support to your dissertation research by sharing data and information, assisting you in establishing local governmental and nongovernmental connections, and, where feasible, providing transportation, lodging, field equipment, and other logistical support. Additional monetary support is a possibility as well depending on our available funds in 2015.

ARIES enthusiastically supports this research. Please feel free to contact me by phone or email.

Francisco San Juan

Francisco San Juan, Jr., Ph.D.
President
Phone: (252) 335-3451
Email: fcsanjuan@ecsu.edu; fransj77@gmail.com

Email: ariesnonprofit@yahoo.com
Website: www.ariesnonprofit.com
Phone: (757)334-9568
An Illinois Nonprofit Corporation

Figure E.5. Research Request Letter Send to Wainwright and Kaktovik (cont.)

RUTGERS

Office of Research and Regulatory Affairs
Arts and Sciences IRB
Rutgers, The State University of New Jersey
335 George Street / Liberty Plaza / Suite 3200
New Brunswick, NJ 08901

orra.rutgers.edu/artsci

732-235-9806

February 3, 2015

P.I. Name: Leichenko
Protocol #: E14-756

Robin Leichenko
Department of Geography
Lucy Stone Hall
54 Joyce Kilmer Avenue
Piscataway NJ 08854

Dear Robin Leichenko:

This project identified below has been approved for exemption under one of the six categories noted in 45 CFR 46, and as noted below:

Protocol Title: "Doctoral Dissertation Research: Mapping Community Exposure to Coastal Climate Hazards in the Arctic: A Case Study in Alaska's North Slope"

Amendment Exemption Date: 1/27/2015 **Exempt Category:** 2

This exemption is based on the following assumptions:

- **This Approval** - The research will be conducted according to the most recent version of the protocol that was submitted.
- **Reporting** – ORSP must be immediately informed of any injuries to subjects that occur and/or problems that arise, in the course of your research;
- **Modifications** – Any proposed changes MUST be submitted to the IRB as an amendment for review and approval prior to implementation;
- **Consent Form (s)** – Each person who signs a consent document will be given a copy of that document, if you are using such documents in your research. The Principal Investigator must retain all signed documents for at least three years after the conclusion of the research;

Additional Notes:	• **Amendment to Exemption Granted on 1/27/15 for Change in Title , Doctoral Dissertation Research: Mapping Community Exposure to Coastal Climate Hazards in the Artic: A Case Study in Alaska's North Slope" to be consistent with NSF Proposal; Revised Protocol to Update Study Design.**

Failure to comply with these conditions will result in withdrawal of this approval.
Please note that the IRB has the authority to observe, or have a third party observe, the consent process or the research itself. The Federal-wide Assurance (FWA) number for the Rutgers University IRB is FWA00003913; this number may be requested on funding applications or by collaborators.

Sincerely yours,

Michelle Watkins

Acting For--
Beverly Tepper, Ph.D.
Professor, Department of Food Science
IRB Chair, Arts and Sciences Institutional Review Board
Rutgers, The State University of New Jersey

cc: Michael Brady

(MW)

Figure E.6. Research Request Letter Send to Wainwright and Kaktovik (cont.)

Interview Consent Form
with Audio Recording

You are invited to participate in a research study that is being conducted by Michael Brady under the advisement of Dr. Robin Leichenko, Professor of Geography at Rutgers University. Michael Brady is a doctoral student in the Geography Department at Rutgers University. The purpose of this research is to collaboratively map community risks from exposure to coastal erosion along Alaska's North Slope.

During the month of April, 2016 Michael Brady will conduct approximately 40 interviews with local North Slope managers and community members in Wainwright, Barrow, and Kaktovik and will facilitate a group workshop with approximately 10 - 15 individuals in Barrow at the end of April. Interview participants will be asked to respond to a short survey and comment on laminated erosion risk maps to collect their feedback on the maps. Duration of interviews will be approximately 1 hour and the workshop will last up to approximately 2 hours.

This research is confidential. Confidential means that the research records will include some information about you and this information will be stored in such a manner that some linkage between your identity and the response in the research exists. Some of the information collected about you includes your affiliation and your title. Please note that we will keep this information confidential by limiting individual's access to the research data and keeping it in a secure location such as password protected computers.

The research team and the Institutional Review Board at Rutgers University are the only parties that will be allowed to see the data, except as may be required by law. If a report of this study is published, or the results are presented at a professional conference, only group results will be stated. All study data will be retained indefinitely, as stated in study protocol. Per Federal Regulations it must be at least three years.

There are no foreseeable risks to participation in this study.

The benefits of taking part in this study include contributing to a community-based assessment of coastal erosion risks. Additionally, the first 10 interview participants in Wainwright and Kaktovik and the first 20 participants in Barrow will directly benefit by receiving $75 of credit to a local grocery store.

Participation in this study is voluntary. You may choose not to participate, and you may withdraw at any time during the study procedures without any penalty to you. In addition, you may choose not to answer any questions with which you are not comfortable.

The audio from this interview or group meeting will be recorded. The recordings will be transcribed into text document form to allow the research team to analyze participant responses.

The recordings will include identifier information, including your name and position title. You can ask that certain text be removed from the audio recordings and transcriptions.

The recordings will be stored as digital computer files on a password protected external hard drive kept in a locked office. The recordings will be retained indefinitely unless requested by a participant to be destroyed.

If you have any questions about the study or study procedures, you may contact Michael Brady at michael.brady@rutgers.edu and 401-578-0480 or Dr. Robin Leichenko at robin.leichenko@rutgers.edu.

For IRB Use Only. This Section Must be Included on the Consent Form and Cannot Be Altered Except For Updates to the Version Date.

IRB Stamp Box	IRB Stamp Box

Version Date: v1.0
Page 1

Figure E.7. Research Request Letter Send to Wainwright and Kaktovik (cont.)

If you have any questions about your rights as a research participant, you can contact the Institutional Review Board at Rutgers at:

Institutional Review Board
Rutgers University, the State University of New Jersey
Liberty Plaza / Suite 3200
335 George Street, 3rd Floor
New Brunswick, NJ 08901
Phone: 732-235-9806
Email: humansubjects@orsp.rutgers.edu

Once you, the subject, have read and understand the information above and agree to participate in the study, please print your name, sign, and add the date signed below.

Your signature on this form grants the investigators named above permission to record you during the interview or group meeting. The investigators will not use the recording(s) for any other reason than those stated in the consent form without your written permission.

Subject (Print) ______________________________

Subject Signature________________________ Date ________________

Principal Investigator Signature________________ Date _____________

For IRB Use Only. This Section Must be Included on the Consent Form and Cannot Be Altered Except For Updates to the Version Date.

IRB Stamp Box

IRB Stamp Box

Version Date: v1.0
Page 2

Figure E.8. Research Request Letter Send to Wainwright and Kaktovik (cont.)

NORTH SLOPE COMMUNITY-BASED EROSION MAPPING STUDY

LOOKING FOR LOCAL COMMUNITY MEMBERS IN KAKTOVIK TO PROVIDE FEEDBACK ON EROSION MAPS. THE ACTIVITY WILL TAKE APPROXIMATELY 1.5 HOURS.

FIRST 10 PARTICIPANTS WILL RECEIVE A $75 GIFT CARD TO THEIR LOCAL GROCERY STORE

MUST BE 18 YEARS OR OLDER.

WHEN: APRIL 19 AT 2P.M.
& APRIL 20 AT 6P.M.
WHERE: CITY HALL

FOR QUESTIONS CONTACT:
MICHAEL BRADY
PHONE: 401-578-0480
EMAIL: MICHAEL.BRADY@RUTGERS.EDU

Figure E.9. Research Request Letter Send to Wainwright and Kaktovik (cont.)

DATA MANAGEMENT PLAN

Doctoral Dissertation Research: Mapping Community Exposure to Coastal Climate Hazards in the Arctic: A Case Study in Alaska's North Slope

1. The following data will be collected for this project:

    a) Interviews with federal, state, and local government officials, local industry experts, NGO and Non-profit representatives, and regular citizens in Alaska's North Slope.
    b) Cultural resources spatial and tabular data provided by the Alaska Department of Natural Resources Office of History and Archeology and the North Slope Borough.
    c) Various geospatial municipal asset datasets provided by the North Slope Borough.
    d) Publically available geophysical coastal hazard data.

2. Data collection and management standards employed:

The graduate student conducting this dissertation research, Michael Brady, will be responsible for collecting and managing all project data. Any discrepancies will be inspected and corrected by Michael and reviewed by the PI, Dr. Robin Leichenko. The plan to access, use, and store restricted data (a-c) is outlined in Rutgers University Institutional Review Board (IRB) Protocol #E14-756.

All interviews will be conducted following the NSF's Principles for the Conduct of Research in the Arctic. Interview data (a), including field notes, and interview recordings and transcripts, will be maintained in paper format on original datasheets, digitally scanned and saved as PDFs, and, transcribed into electronic format (MS Excel files). Cultural resources and municipal asset data (b and c) will be managed following protocol established by the Alaska Department of Natural Resources Office of History and Archeology and the Iñupiat Heritage Center. Public data (d) will be used according to standards set by respective managing organizations.

A copy of the electronic data will be stored on the Graduate Student's computers, backed up to an external hard drive which will be stored away from the other computers, and also stored on a password-protected, cloud-based backup system such as Drop Box.

3. Data and metadata formats, media and dissemination methods:

Central to the design of the proposed research is collaborative interaction with North Slope communities. As the project unfolds, I intent to establish data share agreements with interested parties following protocol set by data sources and Rutgers IRB. In addition to information dissemination methods outlined in the Project Statement, final data, information, maps, and metadata records will be made available to all interested parties upon request if approved by organizations that manage the data.

I am actively consulting managers of relevant national, regional, and local data platforms (e.g., Advanced Cooperative Arctic Data & Information - ACADIS - Gateway) to explore suitability of hosting data products created for this project within 3-5 years of development.

Page 1

Figure E.10. Research Request Letter Send to Wainwright and Kaktovik (cont.)

Additionally, I am currently developing a personal Website and content management system accessible publically to communicate project research and of fer downloadable data, maps, and other products. If approval is granted by managing organizations, asset exposure data products (derived from a-d) will be aggregated and coded in a 500 meter raster file format including full metadata. All geospatial datasets created for this project will follow Federal Geographic Data Committee (FGDC) standards and guidelines. Interview data (a) will be only provided in aggregated form to protect privacy. All data will be kept for at least 10 years after project completion.

Page 2

Figure E.11. Research Request Letter Send to Wainwright and Kaktovik (cont.)

Appendix F

2014 Fieldwork Interview Instrument

RUTGERS
UNIVERSITY

Interview Date and Time ______________
Interview ID # ______________

August 1, 2014
Michael Brady, Ph.D Student, Department of Geography, Rutgers University
michael.brady@rutgers.edu
Adviser: Dr. Robin Leichenko

Project Title: Coastal hazard exposure of communities in Alaska's North Slope

Introduction

I am a doctoral student in the Geography Department at Rutgers University. In this study, I am speaking with experts, officials, and regular citizens in Barrow, Wainwright, and Kaktovik to investigate North Slope economic and socio-cultural assets/activities (e.g., taxable and heritage assets and community-building social activities) exposed to coastal threats. I am asking study participants to indicate on a map where coastal hazards have impacted important assets in the past in addition to where hazards are currently impacting or threaten to impact assets, including at locations beyond city limits. The objectives of the project are twofold. The first objective is to identify assets exposed to coastal threats and the second objective is to understand why the exposed assets are important for community survival and well-being, and if views of importance are changing. The overarching goal of this research is to identify North Slope sites that should be prioritized for monitoring coastal hazard and climate change impacts.

Interview Questions

The questions below focus on identifying important assets/ critical sites historically and currently exposed to coastal threats and estimating their importance (see Tables 3a, 3b, and 3c). The remaining questions (Tables 4 - 6) aim to facilitate a discussion on perceptions of the severity of coastal hazards, and if severity is changing or may change in the future. Questions in Tables 7a and 7b ask about other information sources. Maps showing select North Slope places in the Wainwright-Barrow coastal region and the mid-Beaufort Sea region are provided to assist with identifying vulnerable sites. Additionally, maps showing the Public Land Use System (PLUS) grid are provided to facilitate documenting vulnerable asset locations.

1. The following is a set of screening questions	
1.1. Do you currently live in the North Slope?	Yes____ ; No____
1.1.1. If yes, which North Slope village do you consider home?	
1.2. Were you born in the North Slope?	Yes____ ; No____
1.3. Have you lived most of your life in the North Slope?	Yes____ ; No____
1.4. Are you Iñupiaq?	Yes____ ; No____
1.5. Many questions below refer to your community. What is the name of your community?	
1.6. Do you consider yourself very knowledgeable in any of the following industries/sectors: municipal infrastructure management, emergency mgmt, natural or wildlife resources mgmt, cultural resources mgmt, military asset mgmt, or oil and gas development?	Yes____ ; No____
1.6.1. If yes, what industry/sector and how many years experience do you have?	
1.6.2. If yes, have you ever been formally employed in that industry/sector?	
1.7. Can you describe any professional background you may have in any of the following industries/sectors: municipal infrastructure management, emergency mgmt, natural or wildlife resources mgmt, cultural resources mgmt, military asset mgmt, or oil and gas development?	Yes____ ; No____
1.7.1. If yes, what industry/sector and how many years experience do you have?	
1.8. Do you consider yourself a professional with expert knowledge in some aspect of managing hazards (technological or natural)?	Yes____ ; No____
1.8.1. If yes, how many years experience do you have?	
1.9. Have you ever served as a public official in the North Slope?	Yes____ ; No____
1.9.1. If yes, what was your title and in what years did you hold this title?	

Figure F.1. 2014 Fieldwork Interview Instrument

2. General questions about North Slope community vulnerability	
2.1. Do you think your community is significantly threatened by natural hazards such as coastal erosion and flooding?	Yes____ ; No____
2.1.1. Why or why not?	
2.1.2. If yes, what specific hazards do you think threaten the community?	
2.2. Do you think your community is significantly threatened by oil and gas development?	Yes____ ; No____
2.2.1. Why or why not?	
2.2.2. If yes, what specific hazards do you think threaten the community?	

3a. Past losses of important assets to hazards in the coastal zone	
4.1. Do you have knowledge about important community assets or critical sites (including prehistoric, historic, and current assets) that have already been significantly impacted or lost to natural coastal hazards (e.g., erosion)?	Yes____ ; No____
4.1.1. If yes, can you indicate on a map the location(s) of the lost community asset(s)? When did the loss occur and how?	
4.1.2. If yes, how do you think the losses impacted your community?	
4.2. Do spatial data for these assets exist? If yes, are they accessible?	Yes____ ; No____

3b. Current hazard threats to important assets in the coastal zone
4.1. Which assets / critical sites are currently (or could be in the future) most threatened by coastal hazards?
4.1.1. Why? What are the impacts or concerns?
4.2. Which assets / critical sites are currently (or could be in the future) most threatened by O&G development?
4.2.1. Why? What are the impacts or concerns?
4.3. Do spatial data for these assets exist? If yes, are they accessible?

3c. Exposed prehistoric, historic, and current assets [1]			Community Importance				
	Asset /site name	PLUS ID(s)[2]	Don't Know	Not Important	Somewhat Important	Very Important	Critically Important
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							

[1] Note: a map listing the community sites is provided to facilitate identifying site locations and identifying other locations not shown on the map.
[2] See map in the appendix

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Figure F.2. 2014 Fieldwork Interview Instrument (cont.)

4. Asset importance
4.1. Which currently exposed assets / critical sites from Table 3c are most important to you?
4.1.1. Why are these assets / critical sites important to you?
4.1.2. What would be the impact to you if the assets / critical sites were significantly damaged or lost?
4.2. Which assets / critical sites do you think are the most important for the community?
4.2.1. Why do you think they are significant for the community?
4.2.2. What do you think the impact to the community would be if these assets/ critical sites were significantly damaged or lost?
4.2.3. How do these assets / critical sites contribute to survival of the community?
4.2.4. How do these assets / critical sites contribute to well-being of the community?

5. Changing views of coastal threats	
5.1. Do you think impacts from coastal hazards are getting worse?	Yes____ ; No____
5.1.1. Why or why not? What specific impacts have you observed?	
5.2. Do you think impacts from oil and gas development are getting worse?	Yes____ ; No____
5.2.1. Why or why not? What specific impacts have you observed?	

6. Changing views of asset importance	Site Importance Change
6.1. Has your perspective on importance of asset/critical site that you identified in Table 3c changed during the past 50 years?	Yes____ ; No____
6.1.1. If yes, how has your perspective changed?	
6.1.2. Why do you think your perspective has changed?	
6.2. Do you think community perspectives on asset/critical site importance that you identified in Table 3c have changed during the past 50 years?	Yes____ ; No____
6.2.1. If yes, how have community views of importance for these assets changed?	
6.2.2. Why do you think importance changed for these assets / critical sites?	
6.3. Compared to current time, how do you think community views of importance of these assets / critical sites will change by the year 2050?	Increase ____ ; Decrease ____ ; Stay the Same____
6.3.1. What specific assets / critical sites may significantly changed in importance?	
6.3.2. Why do you think importance will change for these assets / critical sites?	

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Figure F.3. 2014 Fieldwork Interview Instrument (cont.)

7a. Questions about other information and data sources
7.1. Who else should I speak with about coastal vulnerability in the North Slope?
7.2. What other resources should I consult to learn more about North Slope coastal zone vulnerability?
7.3. Can you recommend data sources for both coastal hazard and community site locations and importance?

7b. Questions about other information and data sources		
7.4. Barrow	• North Slope Borough (NSB):	
	o Planning	
	o Public Works	
	o Risk Management	
	o Administration and Finance	
	• Arctic Slope Regional Corporation (ASRC):	
	• Iñupiaq Community of the Arctic Slope (ICAS):	
	• The City of Barrow:	
	o City Mayor Office	
	• The Native Village of Barrow Iñupiat Traditional Government (NVB):	
	• Ukpeaġvik Iñupiat Corporation (UIC)	
	• Barrow Utilities and Electric Coop.	
	• Regular residents (cultural resources – past exposed activities and sites).	
	• Regular residents (cultural resources – current exposed activities and sites).	
7.5. Kaktovik	• City of Kaktovik	
	o City Mayor Office	
	• Native Village of Kaktovik	
	• Kaktovik Inupiat Corporation	
	• Regular residents (cultural resources – past exposed activities and sites).	
	• Regular residents (cultural resources – current exposed activities and sites).	
7.6. Wainwright	• City of Wainwright	
	o City Mayor Office	
	• Native Village of Wainwright	
	• Olgoonik Corporation	
	• Regular residents (cultural resources – past exposed activities and sites).	
	• Regular residents (cultural resources – current exposed activities and sites).	

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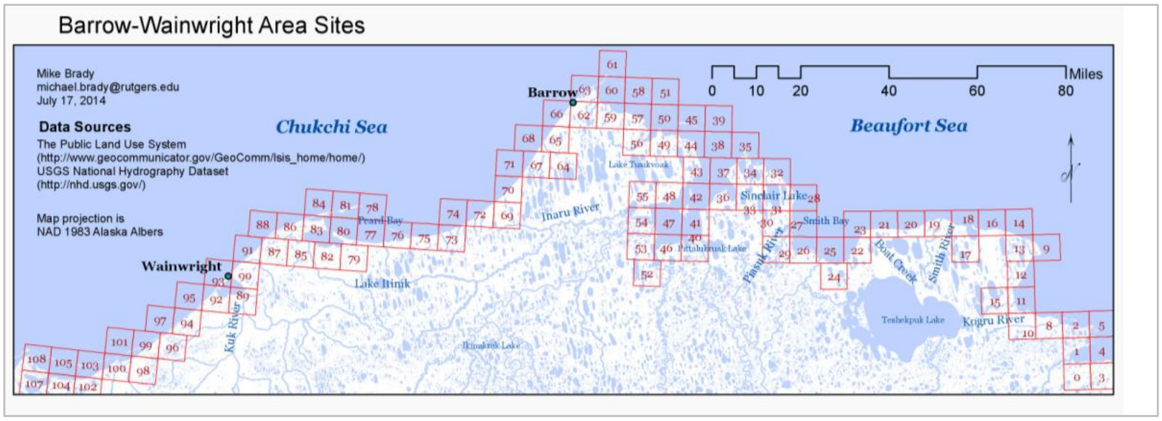
Figure F.4. 2014 Fieldwork Interview Instrument (cont.)



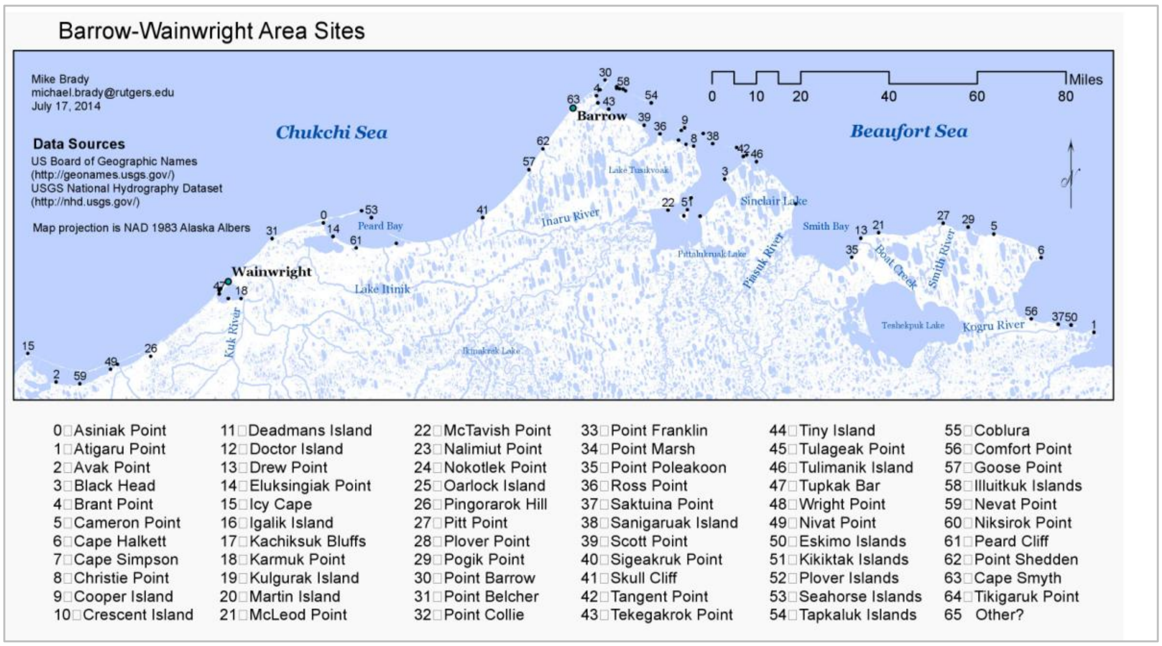
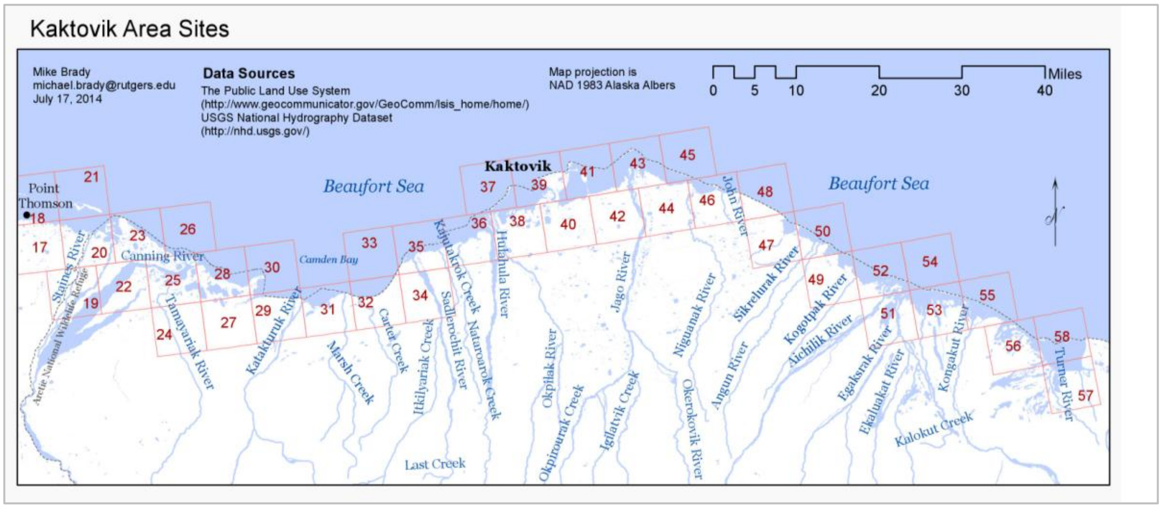


Figure F.5. 2014 Fieldwork Interview Instrument (cont.)



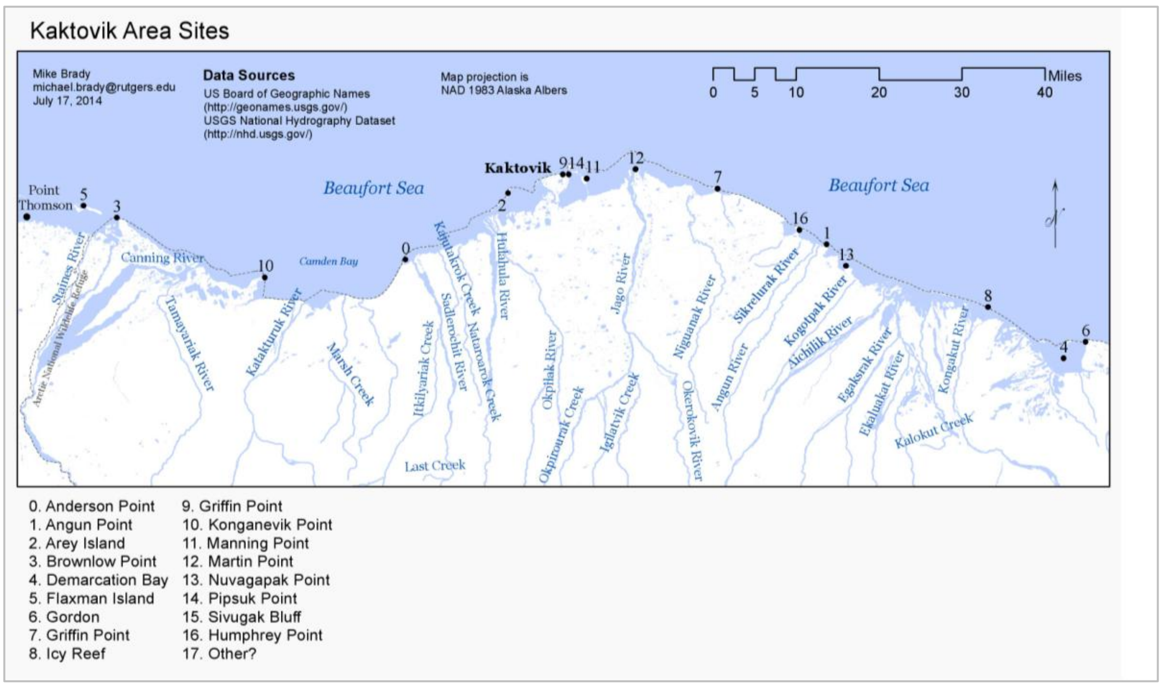


Figure F.6. 2014 Fieldwork Interview Instrument (cont.)

Appendix G

2016 Fieldwork Community Mapping Instrument

<u>Interview Consent Form</u>
<u>with Audio Recording</u>

You are invited to participate in a research study that is being conducted by Michael Brady under the advisement of Dr. Robin Leichenko, Professor of Geography at Rutgers University. Michael Brady is a doctoral student in the Geography Department at Rutgers University. The purpose of this research is to collaboratively map community risks from exposure to coastal erosion in Alaska's North Slope.

During the month of April, 2016 Michael Brady will conduct an interactive mapping activity with approximately 40 local North Slope community members in Wainwright, Barrow, and Kaktovik and will facilitate a group workshop with approximately 10 local managers in Barrow at the end of April. During the map activity, participants will be asked to respond to a short survey and comment on laminated erosion risk maps to collect their feedback on the maps. Duration of the map activity will be approximately 1.5 hours and the workshop will last up to approximately 2 hours.

This research is confidential. Confidential means that the research records will include some information about you and this information will be stored in such a manner that some linkage between your identity and the response in the research exists. Some of the information collected about you includes your affiliation and your title. Please note that we will keep this information confidential by limiting individual's access to the research data and keeping it in a secure location such as password protected computers.

The research team and the Institutional Review Board at Rutgers University are the only parties that will be allowed to see the data, except as may be required by law. If a report of this study is published, or the results are presented at a professional conference, only group results will be stated. All study data will be retained indefinitely, as stated in study protocol. Per Federal Regulations it must be at least three years.

There are no foreseeable risks to participation in this study.

The benefits of taking part in this study include the opportunity to contribute to an assessment of coastal erosion risks. Additionally, the first 10 map participants in Wainwright and Kaktovik and the first 20 participants in Barrow will directly benefit by receiving $75 of credit to a local grocery store.

Participation in this study is voluntary. You may choose not to participate, and you may withdraw at any time during the study procedures without any penalty to you. In addition, you may choose not to answer any questions with which you are not comfortable.

The workshop with local managers will be audio recorded. The audio recording will be transcribed into text document form to allow the research team to analyze participant contributions.

The recordings will include identifier information, including your name and position title. You can ask that certain text be removed from the audio recordings and transcriptions.

The recordings will be stored as digital computer files on a password protected external hard drive kept in a locked office. The recordings will be retained indefinitely unless requested by a participant to be destroyed.

For IRB Use Only. This Section Must be Included on the Consent Form and Cannot Be Altered Except For Updates to the Version Date.

IRB Stamp Box	IRB Stamp Box	Version Date: v1.0 Page 1

Figure G.1. 2016 Fieldwork Community Mapping Instrument

If you have any questions about the study or study procedures, you may contact Michael Brady at michael.brady@rutgers.edu and 401-578-0480 or Dr. Robin Leichenko at robin.leichenko@rutgers.edu.
If you have any questions about your rights as a research participant, you can contact the Institutional Review Board at Rutgers at:

Institutional Review Board
Rutgers University, the State University of New Jersey
Liberty Plaza / Suite 3200
335 George Street, 3rd Floor
New Brunswick, NJ 08901
Phone: 732-235-9806
Email: humansubjects@orsp.rutgers.edu

Once you, the subject, have read and understand the information above and agree to participate in the study, please print your name, sign, and add the date signed below.

Your signature on this form grants the investigators named above permission to record you during the interview or group meeting. The investigators will not use the recording(s) for any other reason than those stated in the consent form without your written permission.

Subject (Print) ____

Subject Signature ________________________________ Date ______________________

Principal Investigator Signature _____________________ Date __________________

For IRB Use Only. This Section Must be Included on the Consent Form and Cannot Be Altered Except For Updates to the Version Date.

IRB Stamp Box	IRB Stamp Box

Version Date: v1.0
Page 2

Figure G.2. 2016 Fieldwork Community Mapping Instrument (cont.)

FORM 2: MAP COMMENTS

Complete Steps 1 and 2 below once using your one black sticker. Complete steps 3 and 4 using the rest of your colored stickers and colored pencil.

Participant ID #: __________

Color of Pencil: __________

1. Place the black sticker at a location where you know there is a lot of erosion occurring. What level of erosion does the map say is occurring? Circle one below.

No Erosion	Very Low Erosion	Low Erosion
Medium Erosion	High Erosion	Very High Erosion

2. Based on your own knowledge, does the erosion shown on the map look accurate at this location? Y or N

3. Place your other stickers at locations where you know there is high erosion occurring. (Note you do not need to use all of your stickers.)

4. At each sticker location, use your colored pencil to mark an X if there is something threatened by the erosion such as a camp, important place, a house, a grave, or infrastructure.

Comments:

Figure G.3. 2016 Fieldwork Community Mapping Instrument (cont.)

FORM 3: Participant Information

1. Date and Time:	
2. Your Identification Number:	
3. What color pencil were you assigned?	
5. Full Name:	
7. May I contact you again about this study for additional information?	Yes No
Phone Number and Email:	

8. Do you currently live in the North Slope?	Yes No
If no, where do you live?	
9. Were you born in the North Slope?	Yes No
If no, where were you born?	
10. How many years have you lived in the North Slope?	
11. Are you Iñupiaq?	Yes No
12. Gender:	Female Male
13. Which North Slope village do you consider home?	
14. What is your age?	

15. Check boxes for all employment/employers you've had in the North Slope.	☐ Subsistence Hunter	☐ Regional Corporation	☐ Borough
	☐ Native Village	☐ Village Corporation	☐ City

Figure G.4. 2016 Fieldwork Community Mapping Instrument (cont.)

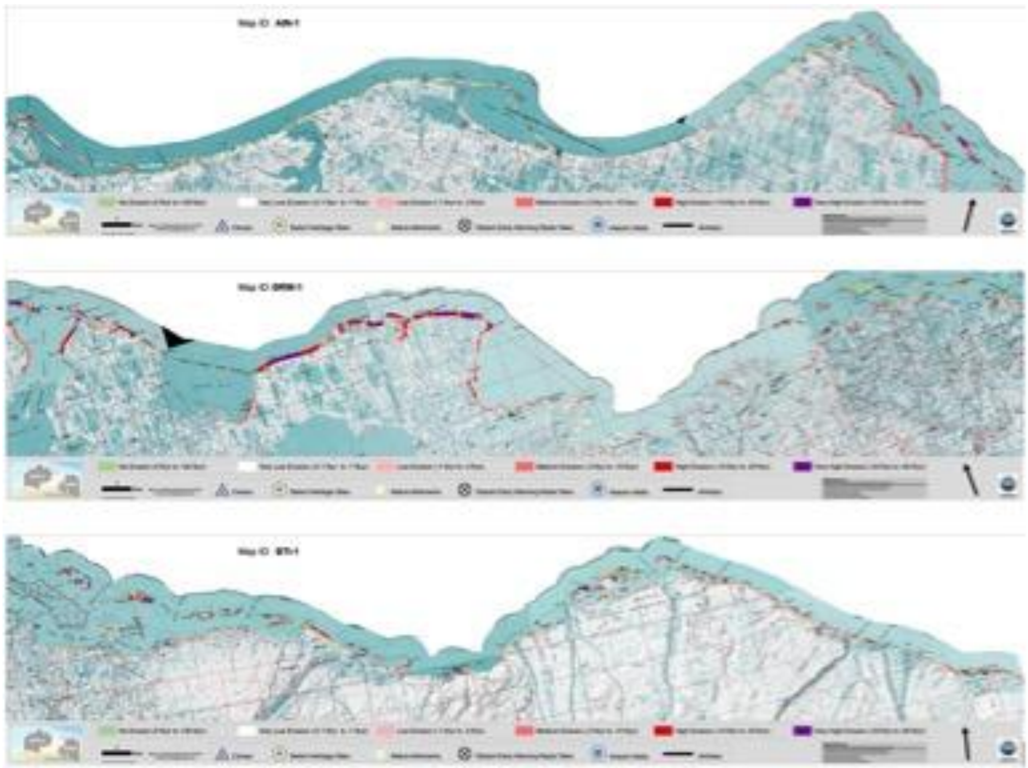


Figure G.5. 2016 Fieldwork Community Mapping Instrument (cont.)

Figure G.6. 2016 Fieldwork Community Mapping Instrument (cont.)

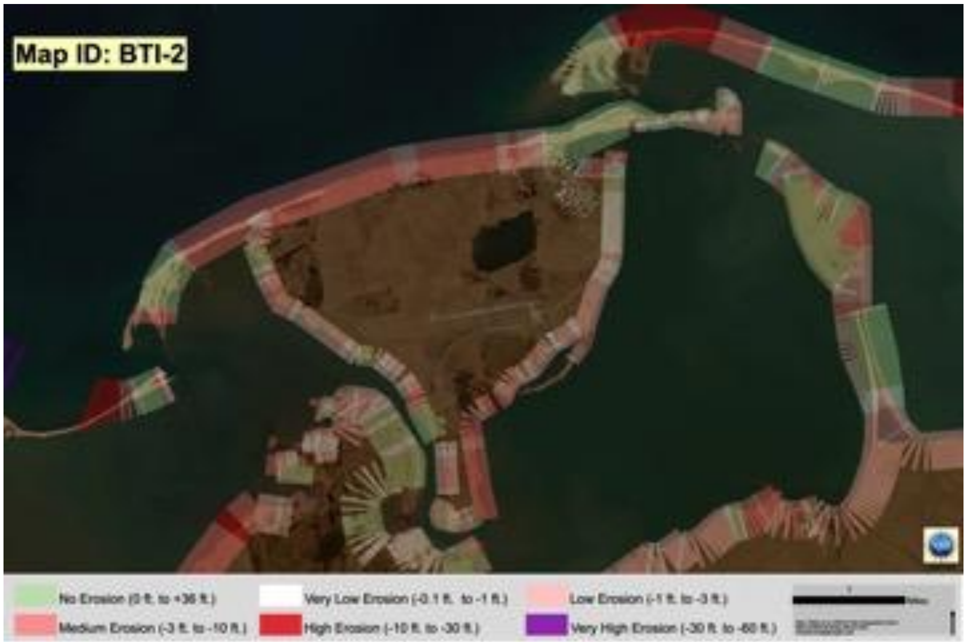


Figure G.7. 2016 Fieldwork Community Mapping Instrument (cont.)

Appendix H

2016 Usability Workshop Presentation Slides

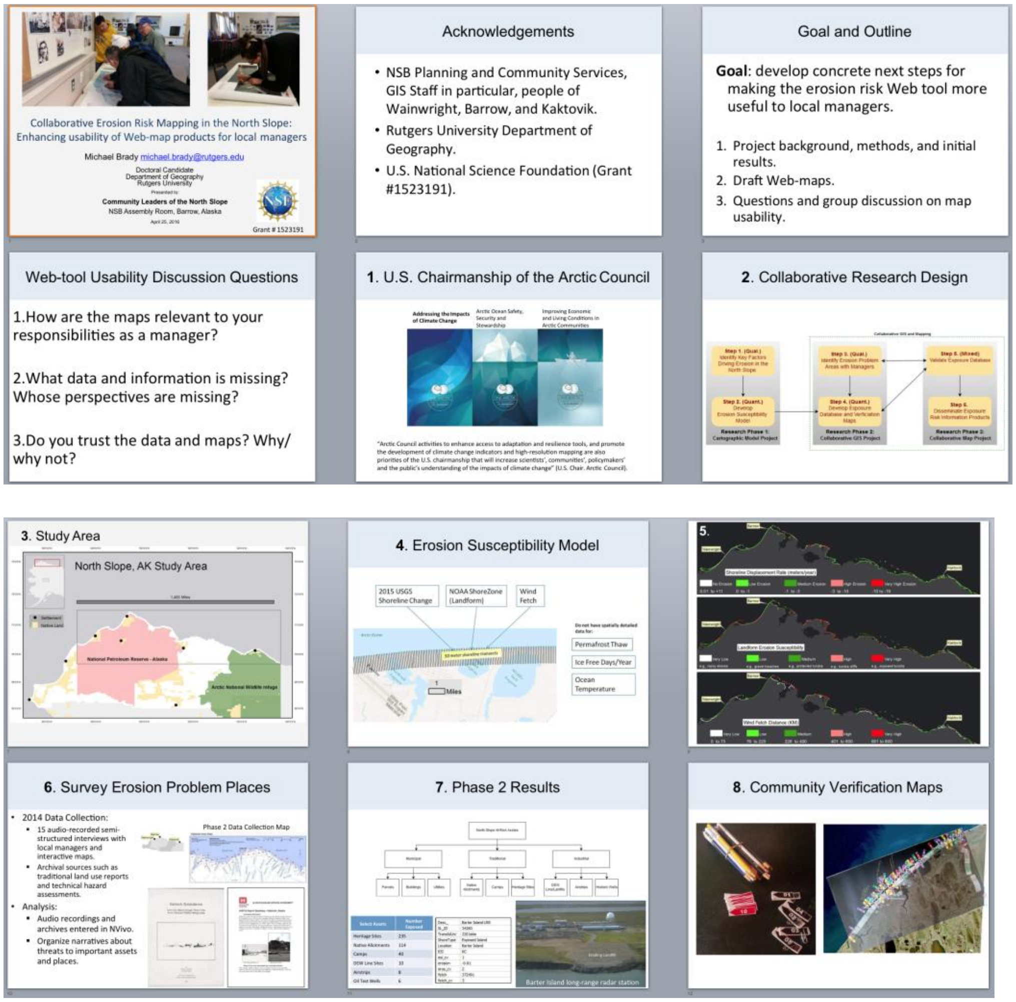


Figure H.1. 2016 Usability Workshop Presentation Slides

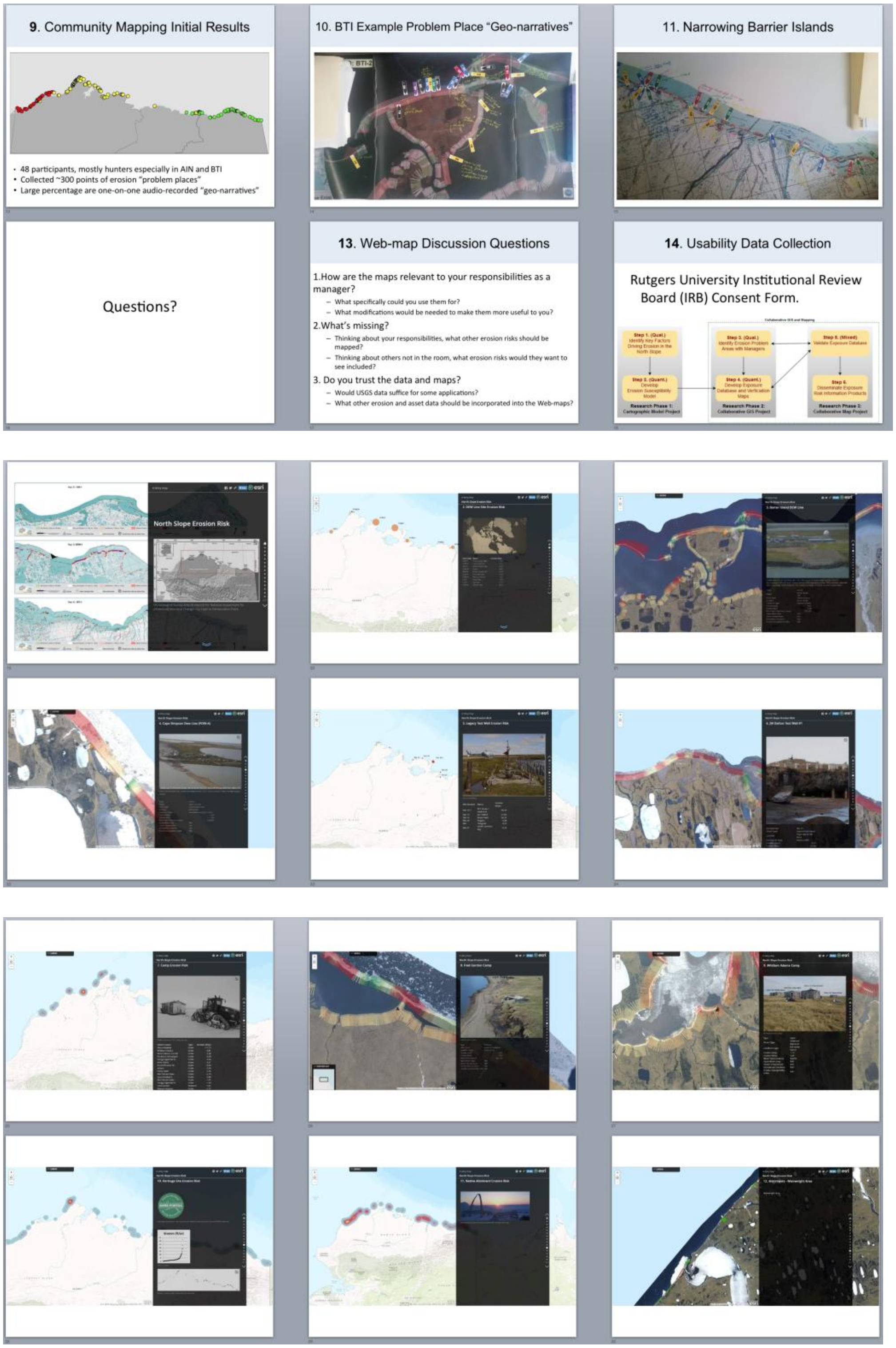


Figure H.2. 2016 Usability Workshop Presentation Slides (cont.)

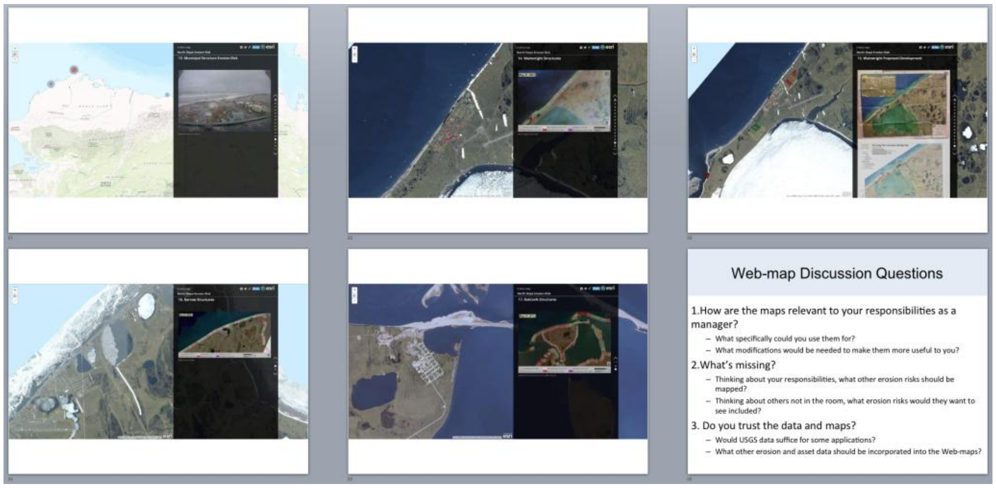


Figure H.3. 2016 Usability Workshop Presentation Slides (cont.)

Appendix I

Methods to Create the Shoreline Change Susceptibility Data Model

As explained in Chapter 4, the exposure data used in the coastal exposure web map provides shoreline susceptibility information in the asset spatial data attribute tables. This section explains how the shoreline change susceptibility data were created.

The Shoreline Change Susceptibility Spatial Data Model (Shoreline Model) is based on the U.S. Geological Survey's Coastal Vulnerability Index (CVI) (Thieler and Hammar-Klose 1999). The CVI shows relative physical vulnerability of coastlines to sea-level rise. It ranks coastal physical vulnerability from low to high using environmental variables that contribute to coastline change. The variables used in the CVI for the U.S. Atlantic Coast are: geomorphology, shoreline erosion and accretion, coastal slope, relative sea-level rise rate, tidal range, and mean wave height. The CVI variables in Version 1 of the Shoreline Model are: shoreline erosion and accretion and geomorphology. Wind-fetch distance is an additional variable used in the Shoreline Model because it is an important coastline physical vulnerability factor in the Arctic (cf. Barnhart et al. 2014a). Table I1 below summarizes the data used in the Shoreline Model.

Table I.1. Shoreline Change Susceptibility Spatial Data Model Environmental Variables

Variable	Time Period	Measurement	Source
Shoreline change	1940s-2010s	Meters/year	USGS (Gibbs and Richmond 2015).
Geomorphology	N/A	Ordinal value	ShoreZone (ShoreZone.org).
Wind-fetch	1979-2015	Kilometers	Wind direction (USW00027502), sea ice extent (NSIDC: cf. Cavalieri et al. 1996), and coastlines (NOAA: cf. Wessel and Smith 1996).

The USGS National Assessment of Shoreline Change provided data for shoreline change rates in the study area using 50-meter coastline transects (Gibbs and Richmond

2015). Version 1 of the Shoreline Model was created by attributing the USGS 50-meter shoreline change transects with the two other variables in Table I1, i.e., geomorphology and wind-fetch. Methods to attribute geomorphology and wind-fetch exploited the distinction between exposed and protected coastlines in the USGS shoreline transects. The following paragraphs explain the methods.

Geomorphology Variable

The geomorphology variable accounts for differences in coastline erodibility. In the Shoreline Model, landform type such as sand or gravel was used as an indicator of geomorphology. ShoreZone provided the landform data, which they acquired from NOAA's Environmental Sensitivity Index (ESI) (Harper et al. 2011). The ESI is widely used in the United States to support oil spill response (cf. Jensen et al. 1998; Peterson 2002). The ESI data are linear features that represent the coastline, segmented by landform type information collected at a scale of 1:250,000 (cf. Peterson 2002). For this study, Ann Gibbs with the USGS ranked the landform types from 1 to 5 to specify low to high erodibility, respectively (Table I2). The ESI linear features ranked by erodibility were linked to the USGS transects using Spatial Join in ArcGIS ModelBuilder.

Table I.2. North Slope Land Form Type Ranked by Erodibility

Landform Type	Protected Shore	Exposed Shore
Exposed Rocky Shores	-	1
Exposed Solid Man made Structures	-	1
Fine to Medium grained Sand Beaches	3	3
Tundra Cliffs	4	4
Coarse grained Sand Beaches	3	3
Mixed Sand and Gravel Beaches	2	2
Gravel Beaches	2	2
Riprap	1	1
Exposed Tidal Flats	-	5
Sheltered Rocky Shores and Sheltered Scarps in Mud or Clay	3	3
Peat Shorelines	3	5
Sheltered Tidal Flats	3	-
Sheltered Vegetated Low Banks	3	-
Salt and Brackish water marshes	3	-
Inundated Low lying Tundra	3	5

Landform rank from low to high (1-5) erodibility.
Source: Pers. comm. Ann Gibbs, USGS (October 27, 2015).

Wind Fetch Variable

In the Shoreline Model, the wind-fetch variable accounts for differences in coastline distances to land and the September sea ice extents averaged over the satellite record. Wind-fetch distance is relevant for assessing the level of coastal protection provided by sea ice (cf. Barnhart et al. 2014b). Version 1 of the wind-fetch variable, which was installed on the coastal exposure web map described in Chapter 4, is wind-fetch distances calculated for every 10-degree wind direction using the record low September 2012 sea ice extent. The variable was created using an ArcGIS wind-fetch model created by Rohweder et al. (2012). The wind-fetch model calculates distances over water between land areas for wind direction intervals specified by the user. Each land cell in a resulting wind-fetch grid dataset is the distance between that location and the nearest cell also coded as land in kilometers, measured from a specified wind direction. The model also creates an average wind-fetch grid for all wind direction intervals weighted using wind direction frequency. Version 1 of the wind-fetch model that was installed on the North Slope web map (see Chapter 4) is based on the September 2012 sea ice extent for each 10-degree direction, weighted by wind-direction frequency measured at Barrow Post Rogers weather station (USW00027502) from 1926 - 2015.

The wind-fetch model was adapted to the Arctic by treating sea ice as land, and calculating distances between the coastline, land features, and the sea ice extent. The sea ice extent was derived from 25-kilometer sea ice concentrations from Nimbus-7 SMMR and DMSP SSM/I-SSMIS Passive Microwave Data, Version 1 (Cavalieri et al. 1996). The sea ice extent data were resampled from 25-kilometers to 500-meters. The 500-meter cells with an average value of 15% or greater were coded as land and cells less than 15% were coded as water. A 500-meter coastline grid was created for the Arctic using NOAA’s Global Self-consistent, Hierarchical, High-resolution Geography Database (GSHHG) (Wessel and Smith 1996, Version 2.3.4 Jan 1, 2015) by converting the vector shoreline data to grid. The two “land” grids based on sea ice extent and coastlines were integrated to create the land-water dataset needed to run the wind-fetch model. Version 1 of the wind-fetch model based on the September 2012 sea ice extent includes 36 fetch distance grids (one for each wind direction) and one averaged grid weighted by Barrow wind direction frequency for September from 1926 - 2015.

In Version 1 of the wind-fetch variable described above, the distance values provided by the weighted wind-fetch grid were used to attribute the USGS transects. To overlap spatially with all transects, the 500-meter wind-fetch grid was expanded landward. Inverse Distance Weighting (IDW) was used to expand the grid landward to intersect USGS transects. Appropriate IDW settings such as search radius were found interactively for both exposed and sheltered shorelines, and results were visually checked for quality by comparing the resulting IDW fetch grid with the original. The resulting expanded fetch grid was intersected with the 50-meter transects. Since multiple grid cells from a single fetch grid often intersected with a single transect due to varying coastal geometry, highest intersecting fetch grid values were attributed to exposed transects and the lowest intersecting grid values were assigned to sheltered shoreline segments were multiple grid cells intersected with a single transect.

Version 2 of the wind-fetch variable mentioned in Appendix J is based on average sea ice extends for two time periods (1979-1999 and 2000-2015). In addition, in Version 2, fetch values associated with all wind-directions are attributed to the USGS transects. Version 2 of the wind-fetch variable would be included in Version 2 of the coastal exposure web map described in Appendix J.

Appendix J

North Slope Borough Coastal Exposure Web Map Version 2 Updates

This section describes coastal exposure updates based on local community feedback from 2016 fieldwork.

Version 2 Shoreline Change Susceptibility Data Model Updates

While this study focused on coastal exposure risk, many of the study participants volunteered information on environmental drivers of coastal change during both the community mapping in Chapter 3 and web map usability workshop in Chapter 4. The environmental variable feedback informed potential Version 2 updates to the shoreline change susceptibility model. The paragraphs that follow detail the updates that would be installed on Version 2 of the coastal exposure web map.

Wind-fetch – Version 1 of the fetch layer was calculated from the average sea ice extent for September 2012. Version 2 of the fetch layer includes distance values averaged for September extents for two time periods: 1979-1999 and 2000-2015 to show the impact of recent recurring record breaking minimum sea ice extents since the turn of the century. Figures I.1a and I.1b below show the change in September sea ice extents averaged for the two time periods 1979-1999 and 2000-2015 relative to the Arctic coastline. Some study participants noted the recent sea ice decline and increasing wind-fetch. For example, one community mapping workshop participant said: "The larger the ice sheet the less wave action we get. ... [B]ut over the last decade, as the ice has gone further and further out, we've got pretty substantial fetch" (NSB Risk Manager).

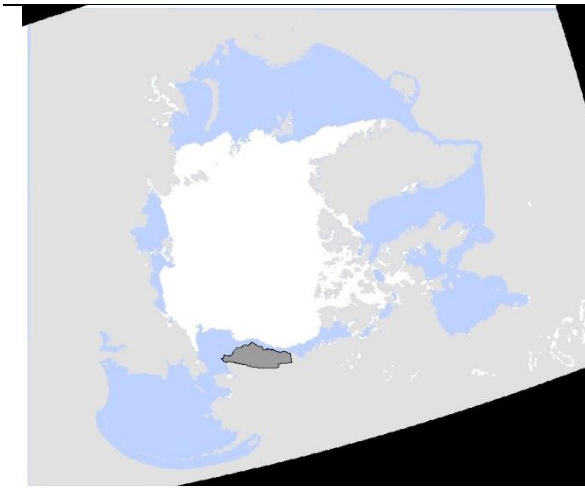


Figure J.1.a. Average September Sea Ice Extents (1979-1999)

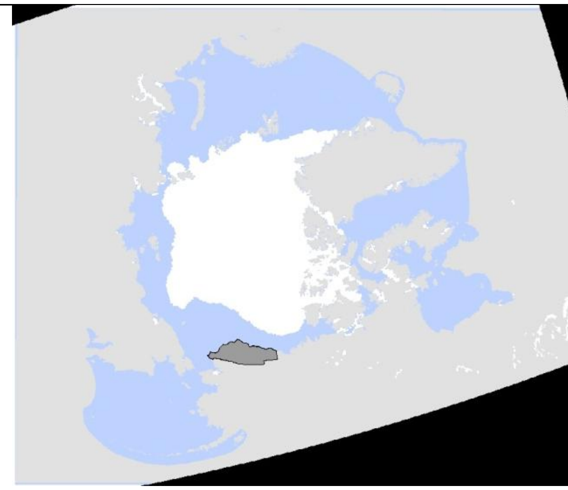


Figure J.1.b. Average September Sea Ice Extents (2000-2015)

Ice-free Days – Version 1 of the coastal exposure web map did not include spatial data on the number of days without sea ice. The literature shows that length of the ice-free season is an important driver of shoreline change in the Arctic (Barnhart et al. 2016). Local managers mentioned the problem of longer ice-free seasons on coastal erosion. For example, one community workshop participant said: "[W]e have less beach, we have longer ice free seasons. It's a pretty bad recipe" (NSB Risk Manager). Version 2 of the coastal exposure web map would include average number of days with open water for 1979-1999 and 2000-2015 based on a 25-kilometer resolution data set created by researchers at the NSDIC (Barnhart et al. 2016).

Elevation - Elevation was not included in Version 1 of the shoreline change susceptibility model because the North Slope has little relief.[11] While regional coastal slope is not an important indicator of shoreline change along the Arctic Slope coast as it is in other regions of the world, topography is still important according to one local key informant. For example, the local informant said:

[11] Regional slope is a factor in the USGS CVI.

> … [W]e're vulnerable to east winds and waves and ice wedge patterns that line themselves up just right where massive roll offs of acres of land - it's strange the high topography is the most vulnerable to erosion if the ice wedge pattern is lined up just so, they just start sprawling off because they're broken down the back center line of the ice wedges. If there's a line that's semi parallel to the bluff, gravity wants to take it this way. That's a natural process, and the lowest lying topography you think would be more vulnerable to erosion it's more immune to it because it doesn't have the ice wedge sprawl off occurring. (Utqiaġvik Whaling Captain)

Version 2 of the coastal exposure web map would include satellite-based elevation data product from the Polar Geospatial Center's (PGC) ArcticDEM product (http://pgc.umn.edu/arcticdem). While the ArcticDEM is currently beta, the recurring collection makes it suitable for the coastal exposure web map because regular updates for areas of interest in the vast Arctic Slope region would otherwise not be feasible.

Version 2 At-risk Asset Data Model Updates

This section describes potential Version 2 updates to the at-risk asset spatial data model product based on 2016 fieldwork (see Chapter 3 and metadata in Appendix A).

As explained in Chapter 3, 50 study participants in three North Slope communities collectively provided 297 shoreline change "problem places" as point locations using coded stickers, and described the problems verbally and/or by marking directly on maps. In many cases, specific problem places identified in the 2016 community mapping workshops corresponded with coastal exposure risks already included in Version 1 of the web map using existing asset spatial data (see Tables 4.2 – 4.4). The transcripts from the audio-recorded verbal responses and map sketch comments were combined with existing sources in Version 2 of the at-risk asset model. In addition to providing local verification of risks at asset locations, many of the problem places shared in the 2016 mapping workshop corresponded with changes in ecosystem services, which present a variety of risks not always spatially adjacent to assets such as loss of hunting camps or diminished access to them from coastal change. Version 2 of the at-risk asset model would capture these asset network exposures.

Version 2 At-risk Asset Spatial Data Model

Version 2 of the at-risk asset data model would include important environmental dependencies of asset access, and not just asset locations. For example, in the Version 2 at-risk asset model, an ecosystem service problem place such as a constrained river entrance used to access camps near important hunting grounds would be included in the model along with relationships to the relevant spatially "distant" asset locations (e.g., camps). Many participants in the 2016 community mapping workshops identified numerous coastline changes that are affecting boating access to camps and/or important hunting grounds. In most cases, individual hunters were impacted, but in some cases several families or entire communities are being impacted such as the entrance to Ikpikpuk River in Smith Bay noted in Section 3.2.3. Version 2 of the at-risk asset model and derivative coastal exposure risk data sets would be included in Version 2 of the coastal exposure web map.

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