

North Slope

Rapid Ecoregional Assessment



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*It is the mission of the Bureau of Land Management
to sustain the health, diversity, and productivity of
the public lands for the use and enjoyment of
present and future generations.*

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Acronyms Used in This Document:

ACEC	Area of Critical Environmental Concern
ACS	American Community Survey
ADEC	Alaska Department of Environmental Conservation
ADFG	Alaska Department of Fish and Game
ADNR	Alaska Department of Natural Resources
AFS	Alaska Fire Service
ASGDC	Alaska State Geo-spatial Data Clearinghouse
AKDOLWD	Alaska Department of Labor and Workforce Development
AEA	Alaska Energy Authority
AKGAP	Alaska Gap Analysis Program
AKNHP	Alaska Natural Heritage Program
ALFRESCO	Alaska Frame-based EcoSystem Code
AMT	Assessment Management Team
ANILCA	Alaska National Interest Lands Conservation Act
ANCSA	Alaska Native Claims Settlement Act
ARDF	Alaska Resource Data File
ASI	Arctic Social Indicators
ATV	All-Terrain Vehicle
AVEC	Alaska Village Electric Cooperative
AVCP	Alaska Village Council Presidents
AWC	Anadromous Waters Catalog
BLM	Bureau of Land Management
BpS	Biophysical Setting
CA	Change Agent
CE	Conservation Element
CPI	Consumer Price Index
CSIS	Community Subsistence Information System
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
EIS	Environmental Impact Statement
ESRI	Environmental Services Research Institute
FAA	Federal Aviation Administration
GAP	Gap Analysis Project
GCM	Global Circulation Model
GIPL	Geophysical Institute Permafrost Lab
GIS	Geographic Information System
GMU	Game Management Unit
HUC	Hydrologic Unit Code
IK/AK	Indigenous Knowledge/Aboriginal Knowledge
ISER	Institute of Social and Economic Research

LCM	Landscape Condition Model
LEK	Local Ecological Knowledge
LK	Local Knowledge
MAGT	Mean Annual Ground Temperature
MQ	Management Question
NANA	Northwest Arctic Native Association
NED	National Elevation Dataset
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPR-A	National Petroleum Reserve-Alaska
NPS	National Park Service
NWR	National Wildlife Refuge
PCE	Power Cost Equalization
PRISM	Parameter-elevation Regressions on Independent Slope Models
REA	Rapid Ecoregional Assessment
REF	Renewable Energy Fund
SNAP	Scenarios Network for Alaska and Arctic Planning
STATSGO	State Soil Geographic Database
Tech Team	Technical Team
TEK	Traditional Ecological Knowledge
TK	Traditional Knowledge
TTL	Tribal Traditional Lifeways
TNC	The Nature Conservancy
USFS	United States Forest Service
USGS	United States Geological Survey
UA	University of Alaska
USFWS	United States Fish and Wildlife Service

Note on Structure of the Final Report

The final report for the North Slope (NOS) Rapid Ecoregional Assessment (REA) is partitioned into eleven distinct documents organized by topic listed below. Each section is assigned a letter heading:

Section A. Cover Sheet (this document)

Section B. Introduction

Section C. Abiotic Change Agents

Section D. Biotic Change Agents

Section E. Anthropogenic Change Agents

Section F. Landscape and Ecological Integrity

Section G. Terrestrial Coarse-Filter Conservation Elements

Section H. Terrestrial Fine-Filter Conservation Elements

Section I. Aquatic Coarse-Filter Conservation Elements

Section J. Aquatic Fine-Filter Conservation Elements

Section K. Data Gaps and Omissions

Tables of contents, management questions, figures, and tables with associated page numbers are listed at the beginning of each section.

The report is organized into stand-alone sections to help readers quickly navigate to sections of interest without having to read the entire assessment comprehensively.

B. Introduction to the Final Report

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Summary

Section B. *Introduction to the Final Report* provides an overview of the REA process, general methodological approaches, study area, Conservation Elements, Change Agents, Management Questions, and limitations.

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1. What is a Rapid Ecoregional Assessment?

The Bureau of Land Management (BLM) recently developed a landscape approach to enhance management of public lands (BLM 2014). As part of this landscape approach, the BLM and collaborators are conducting Rapid Ecoregional Assessments (REAs) in the western United States, including Alaska. To address current problems and future projections at the landscape level, the REAs are designed to transcend management boundaries and synthesize existing data at the ecoregion level. A synthesis and analysis of available data benefits the BLM, other federal and state agencies, and public stakeholders in the development of shared resources (Bryce et al. 2012).

REAs evaluate questions of regional importance identified by land managers, and assess the status of regionally significant ecological resources, as well as Change Agents that are perceived to affect the condition of those ecological resources. The resulting synthesis of regional information is intended to assist management and environmental planning efforts at multiple scales. REAs have two primary purposes:

- To provide landscape-level information needed in developing habitat conservation strategies for regionally significant native plants, wildlife, and fish and other aquatic species.
- To inform subsequent land use planning, trade-off evaluation, environmental analysis, and decision-making for other public land uses and values, including development, recreation, and conservation.

Once completed, this information is intended to provide land managers with an understanding of current resource status and the potential for future change in resource status in near-term future (year 2025) and long-term future (year 2060).

A number of REAs are underway or have recently been completed in Alaska. These include the Seward Peninsula (Harkness et al. 2012), Yukon Lowlands – Kuskokwim Mountains – Lime Hills (Trammell et al. 2014), and the Central Yukon (in-progress).

2. Approach and Process

To address the regionally important questions, significant ecological resources, and Change Agents, REAs focus on three primary elements:

- **Change Agents (CAs)** are features or phenomena that have the potential to affect the size, condition, and landscape context of ecological systems and components.
- **Conservation Elements (CEs)** are biotic constituents or abiotic factors of regional importance in major ecosystems and habitats that can serve as surrogates for ecological condition across the ecoregion.
- **Management Questions (MQs)** are regionally specific questions developed by land managers that identify important management issues.

MQs focus the REAs on pertinent management and planning concerns for the region. MQs are used to select CEs and CAs by identifying critical resources and management concerns for the study area. CEs are also identified by an Ecoregional Conceptual Model (see Section A.3.5. Ecoregional Conceptual Model). Although a basic list of CAs is provided by the BLM, MQs can also identify regionally-specific CAs to be considered in the analysis. An important strength of this approach is the integration of current management concerns and current scientific understanding into a comprehensive and forward-looking regional assessment.

The core REA analysis refers to the status and distribution of CEs and CAs and the intersection of the two. The core REA analysis addresses the following five questions:

1. Where are Conservation Elements currently?
2. Where are Conservation Elements predicted to be in the future?
3. Where are Change Agents currently?
4. How might Change Agents be distributed in the future?
5. What is the overlap between Conservation Elements and Change Agents now and in the future?

2.1. Change Agents (CAs)

CAs are those features or phenomena that have the potential to affect the size, condition, and landscape context of CEs. CAs include broad factors that have region-wide impacts such as wildfire, invasive species, and climate change, as well as localized impacts such as development, infrastructure, and extractive energy development. CAs can affect CEs at the point of occurrence as well as through indirect effects. CAs are also expected to interact with other CAs to have multiplicative or secondary effects. Although they are listed separately, most anthropogenic CAs generally occur in concert with one another. Mining and energy development, for example, require other CAs like transportation and transmission infrastructure.

2.2. Conservation Elements (CEs)

Conservation Elements (CEs) are defined as biotic constituents (e.g., vegetation classes and wildlife species, or species assemblages), abiotic factors (e.g., soils) of regional importance in major ecosystems and habitats across the ecoregion, or high biodiversity priority sites (e.g., designated Important Bird Areas). CEs are meant to represent key resources that can serve as surrogates for ecological condition across the ecoregion.

The selected CEs are limited to a suite of specific ecosystem constituents that, if conserved, represent key ecological resources and thus serve as a proxy for ecological condition. CEs are defined through the “Coarse-Filter / Fine-Filter” approach, suggested by BLM guidelines; an approach used extensively for regional and local landscape assessments (Jenkins 1976, North Slopes 1987). This approach focuses on ecosystem representation as “Coarse-Filters” with a limited subset of focal species and species assemblages as “Fine-Filters”. The Coarse-Filter / Fine-Filter approach is closely integrated with ecoregional and CE-specific modeling exercises (Bryce et al. 2012).

Coarse-Filter Conservation Elements

Terrestrial and Aquatic Coarse-Filter CEs include regionally significant terrestrial vegetation classes and aquatic ecosystems within the study area. They are intended to represent the habitat requirements of most characteristic native species, ecological functions, and ecosystem services.

Fine-Filter Conservation Elements

Fine-Filter CEs represent species that are critical to the assessment of the ecological condition of the North Slope study area for which habitat is not adequately represented by the Coarse-Filter CEs. Fine-Filter CEs selected for the REA are regionally significant mammal, bird, and fish species. A list of CAs and Coarse-Filter and Fine-Filter CEs is given in Table B-1.

Table B-1. Change Agents and Conservation Elements selected for the North Slope REA.

Change Agents (CAs)	Conservation Elements (CEs)	
	Coarse-Filter CEs	Fine-Filter CEs
Climate	Terrestrial Coarse-Filter	Terrestrial Fine-Filter
precipitation	coastal plain moist tundra	Nearctic brown lemming
temperature	coastal plain wetland	Arctic fox
thaw date	sand sheet wetland	caribou
freeze date	sand sheet moist tundra	Lapland longspur
climate envelopes	foothills tussock tundra	willow ptarmigan
Fire	alpine dwarf shrub	greater white-fronted goose
return interval	tidal marsh	raptor concentration areas
vegetation response	marine beach, barrier islands, and spits	Aquatic Fine-Filter
Permafrost	Aquatic Coarse-Filter	broad whitefish
mean annual ground temperature	deep connected lakes	Dolly Varden
active layer thickness	shallow connected lakes	Arctic grayling
Invasive Species	large streams	burbot
Anthropogenic Uses	small streams	chum salmon
subsistence		
natural resource extraction		
transportation and communication infrastructure		
recreation		
energy development		

2.3. Management Questions

Management Questions (MQs) provide regional managers the opportunity to highlight specific concerns relevant to the larger ecoregions, and provide a tangible way in which these REA efforts can be translated into management plans and actions. Unlike previous REA efforts, no preliminary list of MQs was provided at the onset of this REA. Instead, the UA Team reviewed various documents that identify management and research objectives for the North Slope to create an initial list of MQs. These documents include the *Emerging Issues Summaries* (NSSI 2009), the research gaps identified by *Wildlife Response to Environmental Arctic Change* (Martin et al., 2009), and the future needs identified by the *Arctic Landscape Conservation Cooperative Future Needs Assessment* (Arctic LCC 2013). Additionally, the BLM Arctic Field Office identified MQs for the National Petroleum Reserve-Alaska (NPR-A) in 2011 and also provided additional questions specifically for this effort. This produced a list of approximately 275 potential MQs.

Because the REA is intended to be a rapid assessment, the BLM has mandated that only 20-40 MQs be addressed through an REA. Our initial list was therefore too numerous and covered topics well outside the scope of an REA. To reduce the list to a workable number, the UA Team refined the list by:

1. Removing questions (111 total) that were considered “out of scope” for this REA because:
 - a. They were at an inappropriate scale (i.e., asked site specific questions) – 14 questions
 - b. They asked specific policy questions – 21 questions
 - c. They were methodological questions – 33 questions
 - d. They were outside the REA boundaries (e.g., marine) – 37 questions
 - e. They required new data to be collected – 2 questions
 - f. They were too theoretical (i.e., ecological theory) – 2 questions
 - g. They were not appropriate for the timeframe of REA – 2 questions
2. Ranking questions (High, Medium, Low) based on:
 - a. Whether the question fit into an REA-type analysis
 - b. Whether products developed would be useful to managers
 - c. Effort required to address the question

This produced a list of 54 high-ranked (recommended) MQs, 38 medium-ranked MQs, and 71 low-ranked MQs. This list of high-, medium-, and low-ranked questions, as well as those 111 questions considered out of scope were then given to state and field BLM offices for further review and prioritization. We received feedback from four BLM staff (one field office, three state office specialists) that resulted in 72 high-ranked (recommended) MQs, 35 medium-ranked MQs, and 68 low-ranked MQs. We then presented the 72 MQs that ranked highest priority to the AMT in June 2013, during the AMT 1 Workshop. The UA team proposed that a Delphi survey method (Hess and King 2002, Scolozzi et al. 2012, O'Neill et al. 2008) be used to prioritize and focus our MQ list.

Following the AMT workshop, we submitted the 72 MQs to the AMT and Technical Team for prioritization. Each member was to rank 20 questions that were their top priority questions, and 20 additional questions that were of a lower tier of priority. After receiving 13 responses (representing most of the AMT), we tallied the ranks for each question, reordered them based on those tallies, and sent the ranked questions for another round of ranking. The second round yielded 16 responses that we again tallied and sorted accordingly. The questions were sent out for a final ranking and we received 13 responses. By the final ranking, there were a clear set of 20 MQs that were considered the highest priority by the AMT and Technical Team (Table B-2). These questions were consistently ranked the highest priority by over half of the AMT and therefore are widely representative of the top issues for the region by land managers.

Table B-2. MQs selected by the AMT for analysis as part of the North Slope REA.

Abiotic Change Agents (Section C)	
AB-1	<i>Is the fire regime changing on the North Slope and what is the likely future fire regime (or range of regimes) based on climate projections and current knowledge of the relationships between climate and fire?</i>
AB-2	<i>How will permafrost change spatially and temporally over the next two decades?</i>
TC-3	<i>How will changes in precipitation, evapotranspiration, and active layer depth alter summer surface water availability in shallow-water and mesic/wet tundra habitats and how reliable are these projections?</i>
TC-5	<i>How is climate change affecting the timing of snow melt and snow onset, spring breakup and green-up, and growing season length?</i>
Anthropogenic Factors (Section E)	
AP-1	<i>What physical and perceptual limitations to access to subsistence resources by local residents are caused by oil/gas activities?</i>
AP-2	<i>How are oil, gas, and mineral development on the North Slope impacting near- and far-field air quality, with particular emphasis on communities and “sensitive class 2” areas such as ANWR, Gates, Noatak?</i>
AT-1	<i>What parameters can help measure impacts from anthropogenic activities independently of natural cycles and vice versa?</i>
AT-2	<i>What potential impacts will oil/gas exploration and development have on CE habitat?</i>
AT-3	<i>What additional contaminants baseline data are needed for fish, birds, marine and terrestrial species, particularly those that affect the health and safety of subsistence foods?</i>
AF-2	<i>What are the measurable and perceived impacts of development on subsistence harvest of fish?</i>
TF-3	<i>What are the measurable and perceived impacts of development on subsistence harvest of caribou?</i>
Aquatic Coarse Filter CEs (Section I)	
AC-1	<i>How does water withdrawal from lakes for oil and gas activities (year-round industrial and domestic use and winter operations) affect lake water quantity and water quality, outflow/stream connectivity, and down-basin stream habitat?</i>
Aquatic Fine Filter CEs (Section J)	
AF-1	<i>What are baseline characteristics and trends in fish habitat (lakes and streams), fish distribution, and fish movements?</i>
AC-2	<i>How does oil and gas infrastructure (e.g., roads, pads, pipeline), both permanent and temporary, affect fish habitat, fish distribution, and fish movements?</i>

Terrestrial Coarse-Filter CEs (Section G)	
TC-1	<i>What are the impacts of oil/gas development (i.e. gravel pad and road construction; pipeline construction) on vegetation and hydrology? (Known impacts include burial, dust, saline runoff and altered soil moisture.)</i>
TC-2	<i>What are the changes in habitat and vegetation related to changing permafrost conditions, and what will these changes mean to wildlife and habitats?</i>
TC-4	<i>What are the expected changes to habitat as a result of coastal erosion and coastal salinization?</i>
Terrestrial Fine-Filter CEs (Section H)	
TF-1	<i>What are the baseline data for the species composition, numbers of individuals, vegetation type used, and change in numbers/species composition of land birds and their habitat over time?</i>
TF-2	<i>What are caribou preferences for vegetation communities? Where do these vegetation communities exist?</i>
TF-4	<i>What are caribou seasonal distribution and movement patterns and how are they related to season and weather?</i>

2.4. Project Team

The Alaska Natural Heritage Program (AKNHP) served as the lead for this REA, with close collaboration from the Scenarios Network for Alaska and Arctic Planning (SNAP), Institute of Social and Economic Research (ISER), and Meg King and Associates. Throughout this document this team is collectively referred to as the University of Alaska (UA) Team. The UA Team as a whole was responsible for assessing the current and potential future status of CEs at the ecoregional scale and their relationships to CAs, as well as addressing the Management Questions (MQs), identifying data gaps, and delivering data to the BLM. Project leads are identified for the various sections reflecting the multi-disciplinal expertise and knowledge used in assessing this region.

2.5. Land Owners and Stakeholders

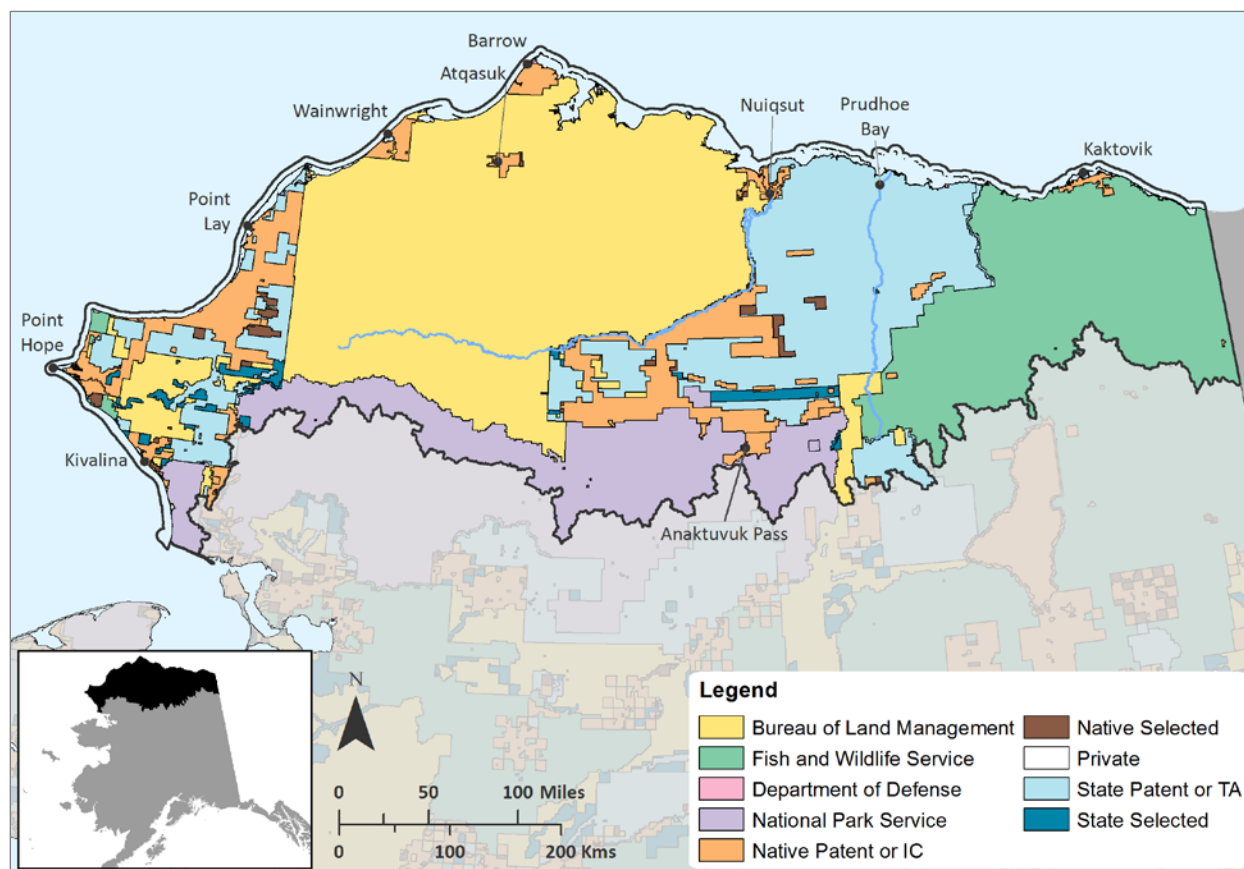


Figure B-1. Land management status in the North Slope study area in 2014.

Community meetings were an important part of this REA to ensure broader regional stakeholders were included and informed about the effort. The UA team and BLM State and Field offices coordinated informational meetings with the North Slope Borough Planning Commission as part of a series of three community meetings: the 1st meeting was held 26 September 2013, the 2nd meeting was held 30 October 2014, and the 3rd meeting will be held after completion of the project, tentatively scheduled for September 2015. The Planning Commission was chosen for our community meetings, as representatives from each of the North Slope villages regularly attend those meetings. During these meetings the UA team informed the planning commission about the REA process, its expected outcomes, and gathered input on CEs, CAs, and MQs.

A larger stakeholder group was also informed on the status of the assessment through a series of four newsletters (spring 2014, summer 2014, spring 2015, and anticipated delivery fall 2015). Each newsletter was delivered by hard copy via the postal service and through e-mail, reaching a group of almost 200 interested parties ranging from local business owners to state government officials. Correspondence and questions on expected products were exchanged via e-mail in a few instances between the UA team and regional stakeholders.

Additional stakeholder engagement came from the representatives of various state and federal agencies that manage land parcels within the North Slope study area (Figure B-1) that served on the Assessment Management Team (AMT) and Technical Team (Tech Team). The AMT and Tech Team provided guidance and direction to the objectives of the assessment through regular project communication and meetings (interim project memos and presentations can be accessed here: <http://aknhp.uaa.alaska.edu/landscape-ecology/north-slope-rea/products/>). The Bureau of Land Management, State of Alaska, US Fish and Wildlife Service, and National Park Service are the primary land management agencies by area in the North Slope study area (Table B-3). A full list of AMT and Technical Team members is included after the cover page.

Table B-3. Total area and percent of study area by land management status.

Land Ownership	Area (km²)	Percent of Total Study Area
Bureau of Land Management	97,364	39%
State Patent or TA	49,493	20%
Fish and Wildlife Service	45,834	18%
National Park Service	29,165	12%
Native Patent or IC	23,134	9%
State Selected	3,009	1.2%
Native Selected	1,674	0.7%
Department of Defense	81	0.03%
Private	0.05	0.00%

3. Description of Rapid Ecoregional Study Area

The assessment area, referred to in this REA as the North Slope study area, consists of three ecoregions as defined by Nowacki et al. (2001): the Beaufort Coastal Plain, Brooks Foothills, and Brooks Range north of the crest of the range (Figure B-2). These ecoregions are described below. The ecoregions represent a unified mapping approach that blends traditional approaches (Bailey et al. 1994, Omernik 1987) with regionally-specific knowledge and ecological goals. The assessment boundary, following BLM guidelines, constitutes the three component ecoregions and any 5th level hydrologic units that intersect the ecoregion boundaries. The inclusion of intersecting hydrologic units results in a significant portion of the Assessment Area extending south of the crest of the Brooks Range.

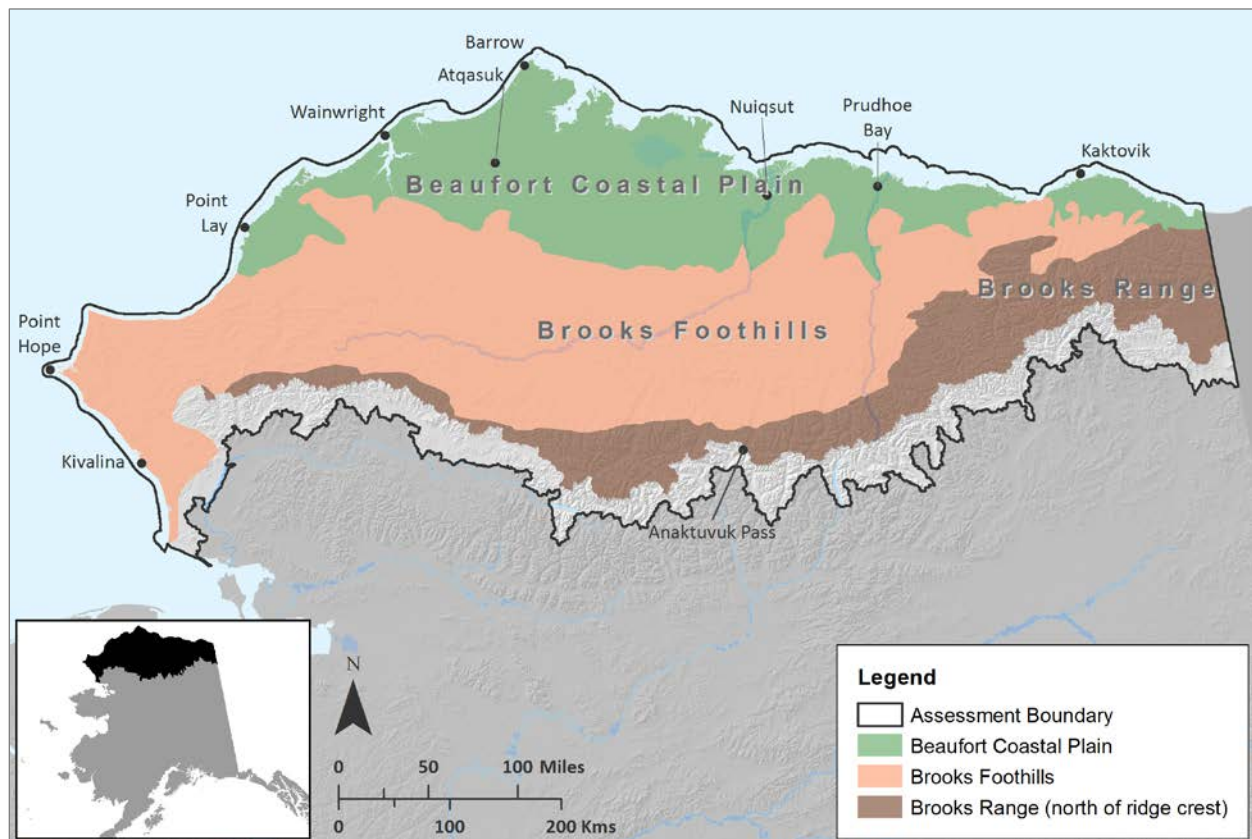


Figure B-2. Ecoregions included in the North Slope study area.

The North Slope study area is almost entirely treeless arctic tundra, hosting numerous ecological resources and phenomena that are not found elsewhere in the state or country. The extremely cold climate, long dark winters, and short nightless summers generate a major influence over the landscape and resident organisms. The action of ice and soil dynamics generate unique landform patterns such as patterned ground, polygons, pingos, and thermokarst depressions. While species diversity is low relative to other regions, a number of species are endemic to the North Slope study area (e.g., *Poa hartzii* ssp. *alaskana* and Alaska marmot [*Marmota broweri*]); and the area is home to other iconic arctic species with broader distributions such as polar bears, arctic foxes, and ivory gulls. Additionally, the North Slope

supports an abundance of nesting shorebirds and waterfowl. Herds of thousands of caribou continue mass migrations to calving and summer ranges in the study area.

Ecosystems in the Arctic are often considered to be pristine, as large-scale habitat conversion and landscape fragmentation has remained limited; however, oil and gas and mining industries are expanding, high levels of contaminants are present, and the region is also facing some of the most rapid and dramatic changes in climate globally (Hinzman et al. 2005). Arctic ecosystems are expected to face an array of impacts from a warming climate, stemming from both direct and indirect effects (e.g., increasing tundra fire frequency, increasing active layer depth, and establishment of invasive species; [Chapin et al. 2005, Lassuy and Lewis 2013]). Additionally, arctic systems are inherently fragile, and once altered are very slow to return to previous states (see Woodin and Marquizz 1997). Arctic systems are defined by extreme conditions and have seen significant climatic and environmental change in the past 10,000 years.

3.1. Coastal Plain

The Coastal Plain gradually ascends from the Arctic Ocean south to the foothills of the Brooks Range. Terrain is flat to undulating and underlain by unconsolidated deposits of marine, fluvial, glaciofluvial, and aeolian origin. Climate is dry polar with short, cool summers and long, cold winters. Summers are frequently foggy due to the close proximity to the Arctic Ocean. Annual precipitation is low and mostly falls as snow during the winter. Permafrost is continuous throughout the Coastal Plain except for under large rivers and thaw lakes. Permafrost and frost processes contribute to a large variety of surface features, such as pingos, ice-wedge polygons, and oriented thaw lakes (Figure B-3A). Soils are typically saturated mineral substrates and some have thick organic layers because permafrost prevents surface drainage. Thaw lakes cover up to 50% of the coastal plain and the entire region supports wetland communities. Vegetation is treeless and is dominated by wet sedge tundra, tussock tundra, and sedge-dwarf shrub tundra. Low willows are abundant along well-drained riverbanks. Anadromous Arctic cisco, broad whitefish, least cisco, and Dolly Varden char overwinter in the numerous large, braided rivers that originate in the Brooks Range. Smaller streams freeze completely in winter. During summer, fish migrate to nearshore waters. The coastal plain supports and serves as calving grounds for large caribou herds. Other herbivores include musk ox, lemmings, and arctic ground squirrels. Predators include such species as gray wolves, arctic foxes, and brown bears. Polar bears den on the Coastal Plain. The region supports a high abundance and diversity of breeding shorebirds, ducks, geese, swans, and passerines.

The majority of the human population in the North Slope study area is concentrated on the Beaufort Coastal Plain. Primary communities include Point Lay, Wainwright, Atkasuk, Barrow, Nuiqsut, and Kaktovik. Most communities have resident populations of less than 600 individuals. Barrow is the largest community, with over 4,000 individuals, and is the regional hub of goods and services. Prudhoe Bay and the surrounding oil fields are industrial complexes with associated support services, maintaining a population of over 2,000 largely transient workers; it is the only population center connected to the state road system in the region. The majority of oil and gas development has been focused on the Coastal Plain.

3.2. Brooks Foothills

The Brooks Foothills consist of gently rolling hills and broad exposed ridges that extend along the northern flank of the Brooks Range. Narrow valleys and glacial moraines and outwash are interspersed among long, straight ridges and buttes composed of tightly-folded sedimentary rock (Figure B-3B). The surface is overlain with colluvial and aeolian deposits. A dry, polar climate dominates the region, although it is slightly warmer and wetter than the Coastal Plain. Permafrost is thick and continuous. Slope related periglacial features such as solifluction lobes and stone stripes are common. Soils range from well drained mineral substrates to saturated organic horizons. The soil in the lower foothills is frequently basic while the soil in the upper foothills is often acidic. Dominant vegetation classes include expanses of shrub-sedge tussock tundra, willow thickets along rivers, and *Dryas* tundra on ridges. Calcareous areas support sedge-*Dryas* tundra. Braided streams and rivers are numerous and support large populations of Arctic char and Arctic grayling. Lakes are infrequent. Herbivores include caribou, musk ox, and arctic ground squirrels. Predators include gray wolves, brown bears, and peregrine falcons.

The coastal communities of Point Hope and Kivalina are two of the primary population centers in the Foothills ecoregion. Red Dog Mine is located in this region and is connected to Kivalina by an access road.

3.3. Brooks Range

This east-west range is the northern extension of the Rocky Mountains. Accreted terranes originating from the Arctic Ocean underlie most of the range. The central portion of the range consists of steep, angular summits of sedimentary and metamorphic rock flanked by rubble and scree (Figure B-3C). Rivers and streams cut narrow ravines into the terrain. During the Pleistocene, the higher portions of the range were glaciated and remnant glaciers still remain in some cirques. Permafrost is continuous north of the crest of the range. The eastern and western portions of the range are less rugged. A dry, polar climate dominates the land. Winters are long and cold, and summers are short and cool. Temperature decreases rapidly with increasing elevation. Valleys and lower slopes north of the crest of the range are dominated by mixed shrub-sedge tussock tundra with willow thickets along rivers and streams. Higher elevation slopes and ridges are dominated by alpine tundra or are largely barren. Arctic grayling occur in groundwater-fed springs and streams. Herbivores include Dall sheep, marmots, and caribou. Primary large predators include gray wolves and brown bears.

Anaktuvuk Pass is the only community in the Brooks Range ecoregion. Although close to the Dalton Highway, access is still very limited to the village. Anaktuvuk Pass is the only interior native village in the North Slope study area.

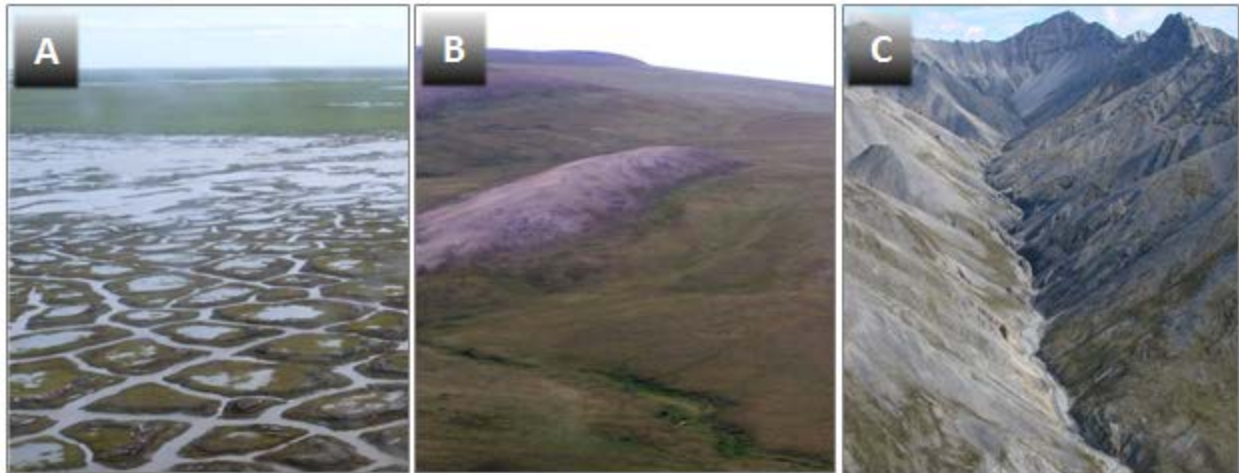


Figure B-3. Ecoregions included in the North Slope study area: Beaufort Coastal Plain (A), Brooks Foothills (B), and Brooks Range (C).

3.4. Assessment Boundary and Scale

As per BLM guidance, reporting units for the North Slope REA are at the landscape level in scale and intent. For most analyses, the BLM has specified that data be reported at the 5th level, 10-digit, hydrologic unit code (HUC) with raw data being provided at 30 m grid cells for raster data or other native resolution as appropriate. Climate data will be provided at a resolution of 800 m grid cells and therefore any climate related questions will be answered at this scale as well. Many of the primary landscape level datasets for Alaska are also coarser than the 30 m pixel resolution recommended by the BLM (for example, the best available resolution for Digital Elevation Model is at 60 m pixels). Thus the ultimate reporting unit of each analysis was limited by the coarsest resolution of the data. In general, however, raw data was provided at 60 m grid cell resolution, and results are reported at the 5th level HUCs.

3.5. Ecoregional Conceptual Model

The Ecoregional Conceptual Model portrays an understanding of critical ecosystem components, processes, and interactions (Figure B-4). By summarizing known and accessible existing information and hypotheses on the structure and function of ecosystems, the Ecoregional Conceptual Model provides the framework to assess ecological conditions and trends. The model also offers justification for the selection of CAs and informs the selection of CEs.

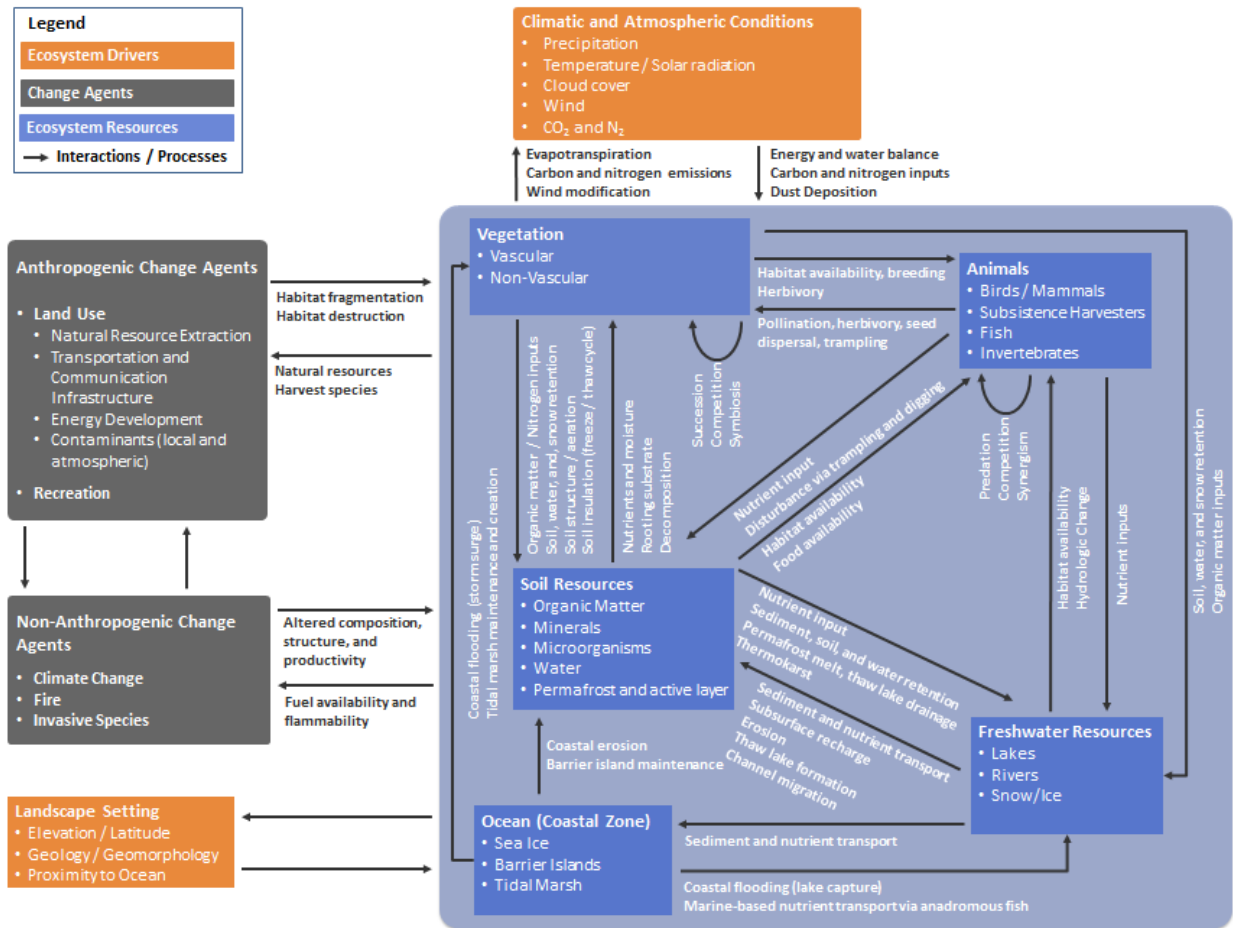


Figure B-4. Ecoregional Conceptual Model for the North Slope study area.

The Ecoregional Conceptual Model for the North Slope study area is divided into the following components:

- **Principal ecosystem resources**, including vegetation, animals, soil resources, freshwater resources, and ocean (coastal zone).
- **Ecosystem drivers**, including climate and atmospheric conditions (i.e., precipitation, temperature, cloud cover etc.) and landscape setting (i.e., geology, elevation, and proximity to ocean)
- **Anthropogenic** (land use, commercial / sport harvests, recreation) and **non-anthropogenic CAs** (climate change, fire, and invasive species).
- **Relationships between ecosystem resources** with interactions between them identifying key ecosystem processes and functions (for example, soils resources provide nutrient and sedimentation inputs into freshwater systems).
- **Relationships of ecosystem drivers and CAs** as external forces for ecosystem resources (for example, climate change is expected to alter composition, structure, and productivity of the ecosystem, which in turn is likely to affect soil resources and nutrient cycling).

4. Assessing Current and Future Conditions

In addition to performing the core analysis between CEs and CAs, we examined the general landscape to describe overall conditions. Key to this assessment was an evaluation of landscape integrity. Landscape integrity is derived from modeling landscape condition and intactness. Landscape condition examines the level of human modification on the landscape, while intactness provides a measure of fragmentation across the region. When taken in combination with CE distributions (Figure B-5), our assessment can be used to infer overall ecological integrity of the region.

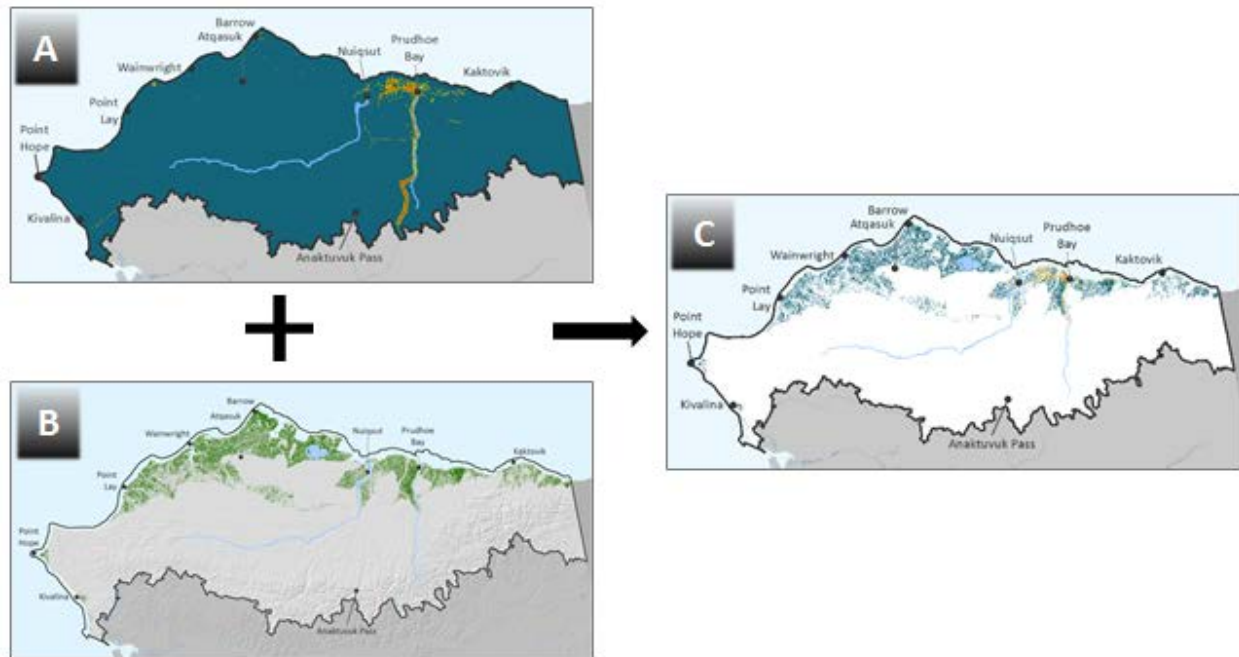


Figure B-5. Example process of assessing status of a Conservation Element (CE). Landscape condition (A) is extracted to the distribution of a CE (B) to generate the CE status (C). Warmer colors in the CE status represent areas of lower expected ecological condition.

Finally, we explore future landscape integrity and potential impacts to CEs through multiple measures of landscape change. First, we model future landscape condition using forecasts of the future human footprint. The future landscape condition was then used to inform future landscape intactness for an initial look at future landscape integrity. Additionally, we developed a tool to examine the cumulative impacts of all the CAs to begin identifying vulnerable landscapes. When compared to CE distributions, our assessment can provide insight into potential future ecological integrity.

5. Scope, Intent, and Limitations

With all landscape-level assessments, it is important to define the scope and intent of a study. REAs are designed to synthesize existing information to be used as a planning tool primarily at the regional level. Thus, results from this work are intended to guide general perceptions of issues, resources, and areas of greater and lesser concern, rather than implementation of site-specific management actions. We present here a synthesis of the current state of knowledge about how these ecoregions might change in the future so that land managers and other regional stakeholders can better plan for a changing environment.

While this report synthesizes the best available scientific knowledge about the ecoregion, many of the results presented are derived from incomplete information. Furthermore, no new data collection was permitted by the REA process, and data availability was limited for some CAs and CEs. Therefore information from outside of the REA was often used to develop and parameterize our models. Additionally, since theoretical and predictive models are simplified representations of complex ecological relationships, models do not incorporate all elements and relationships that are in fact operating on the landscape. The assumptions and limitations inherent in any modeling are important to understand, as these assumptions define the context in which the results are meaningful. We highlight the limitations and assumptions throughout this document to help the reader best understand the utility of these models. It is important to remember that model uncertainty can come from many different sources, including the raw data itself, and that interpretation should account for the regional-scale nature of this assessment.

Another key source of uncertainty is the inherent uncertainty in predicting future conditions. Specifically, human behavior and land use is very hard to predict, especially in the long-term. Thus, any future land use should only be considered as potential land uses. While we were able to leverage an ongoing and complimentary oil and gas development scenario project (see section E), this was limited to only oil and gas related development. A more robust approach of future land use would require an examination of multiple scenarios to bracket the uncertainty associated with all future human land use and development. This assessment is designed to provide a model of possible future conditions, but should not be considered a prediction, nor do we assign any probability or likelihood that any given land use would happen in the future.

Finally, it is important to note that information contained in this assessment is not meant to serve as management guidelines, or be interpreted as recommendations on specific policies. This assessment is intended to summarize the current state of this ecoregion, and identify ways in which the landscape, and the dependent species and habitats, may change in the future. We make no predictions about where specific species or habitats will be in the future. Maps and outputs derived from predictive models should be considered representations of general patterns.

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C. Abiotic Change Agents

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Summary

Section C. *Abiotic Change Agents* provides the detailed descriptions, methods, datasets, results, and limitations for the assessments of climate change, fire, and permafrost. The assessment of climate change includes cliomes and relationships to vegetation.

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1. Climate Change

This portion of the Technical Supplement addresses climate as a Change Agent in the North Slope study area, and is primarily concerned with assessing how climate may change over time. Climate variables assessed in this section include temperature, precipitation, snow day fraction, day of freeze, day of thaw, and climate clusters (“cliomes”) that are based on monthly temperature and precipitation data. Other strongly climate-linked factors, including fire and permafrost, are addressed in following sections.

Human effects on climate are global rather than proximal. Thus, for the purposes of this project, climate is considered a non-anthropogenic CA.

This section describes landscape-level model outputs, including the data sources, methods, and analysis. It also touches briefly on feedbacks between climate and other CAs (fire and permafrost), although more information on these feedbacks can be found in the applicable sections. The section also provides an overview of potential impacts to Conservation Elements. Further information on these interactions can be found in sections devoted to CEs (Sections G to J).

1.1. Introduction to Climate Change

The climate of far northern ecosystems is changing rapidly, resulting in thawing permafrost, altered hydrology, and shifting biological processes, and warming is predicted to continue to be more extreme at high latitudes than almost anywhere else on the planet. Predicting the magnitude and effects of these changes is crucial to planning and adapting (Hinzman et al. 2005). Not only are arctic and sub-arctic systems vulnerable to climate shifts, but they are also central to feedbacks important to global systems (Chapin et al. 2005).

Climate change will likely drive multiple types of change in the North Slope study area. Climate variables can directly impact coarse-filter and fine-filter CEs, but are also part of feedback loops with other CAs, such as fire and invasive species. Understanding the relationship between climate change and these elements is a complex problem, but ultimately a crucial one for decision-making by policymakers and land managers.

Computer models that simulate relationships between climate, vegetation, and fire are important tools for understanding and projecting how the future may appear (Rupp et al. 2007, Kittel et al. 2000). Here we employ simulation models to assess climate change in the context of historical, current, near-term (presented as a decadal average for the 2020s), and long-term (presented as a decadal average for the 2060s). Climate data were primarily derived from datasets created and managed by the Scenarios Network for Alaska and Arctic Planning (SNAP), with subsets of the available data selected based on the needs of the project.

Historical Climate

These ecoregions have an arctic climate, with long cold winters and brief summers. Climate varies depending primarily upon elevation and proximity to coastlines, with extreme cold at high elevations,

some seasonal moderation on the coast, and slightly warmer summers in the interior Arctic. With mean annual temperatures well below freezing in most areas, permafrost is almost continuous, except in isolated locations, typically associated with waterways.

Historical weather station data for the REA study area are limited, but can be augmented with interpolated data, as shown in Table C-1. Historical climate station data are available from the Alaska Climate Research Center, ACRC (<http://climate.gi.alaska.edu/>), with “Climate Normals” representing mean values for 1981-2010. Note that although winter temperatures and mean annual temperatures are warmest to the west, in Point Hope, summer temperatures tend to be warmer inland.

Table C-1. Measured and estimated historical mean monthly temperatures (°F). For some locations, no historical climate station data (Climate Normals for 1981-2010) are available from the Alaska Climate Research Center, ACRC (<http://climate.gi.alaska.edu/>).

Climate Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Anaktuvuk Pass*	-13	-15	-9	5	30	48	52	46	32	8	-6	-15	14
Atkasuk*	-18	-22	-17	-1	22	41	50	46	33	13	-6	-16	10
Barrow	-13	-14	-13	2	21	36	41	39	32	17	1	-8	12
Barrow*	-13	-18	-15	-2	20	34	39	38	31	14	-2	-11	10
Deadhorse*	-19	-18	-14	1	22	39	49	45	33	15	-10	-15	11
Kaktovik*	-15	-21	-16	-2	20	35	41	40	32	14	-2	-13	9
Kivalina	6	7	9	20	37	49	56	54	46	27	15	11	28
Nuiqsut	-15	-17	-15	2	24	43	50	45	36	18	-2	-9	13
Point Hope*	-2	-10	-6	6	26	40	47	47	39	23	8	-3	18
Point Lay*	-13	-24	-16	3	22	40	46	45	35	20	3	14	15
Prudhoe Bay	-10	-10	-7	9	28	45	53	50	39	22	2	-4	18
Wainwright	-12	-14	-14	2	23	40	46	44	35	20	2	-7	14

*Data come from interpolated baseline climate data (1961-1990) from the Scenarios Network for Alaska and Arctic Planning (SNAP). All others are ACRC Climate Normals.

Historical data for precipitation are available from the Alaska Climate Research Center, ACRC (<http://climate.gi.alaska.edu/>) only for Barrow, where monthly mean precipitation (in rainfall equivalent) ranges from 0.13 inches in January to 1.05 inches in August, with an annual total of only 4.5 inches.

Interpolated data also indicate dry conditions across the region, with lowest annual precipitation along the Arctic Coast, and slightly higher precipitation in the mountainous regions of the Brooks Range and foothills (for state-wide data see: <http://www.snap.uaf.edu>).

1.2. Methods

Given that REA projects must largely rely on preexisting data, we looked at available datasets at a range of scales that encompassed Alaska. While several global climate models offer data for the area, it is extremely coarse in resolution, and not validated specifically for Alaska. The finest-scale and most reliable climate models and data were found via The Scenarios Network for Alaska and Arctic Planning (SNAP), at the International Arctic Research Center at the University of Alaska Fairbanks.

SNAP Climate Data

SNAP projections focus on the five available Global Circulation Models (GCMs) that perform best in the far north. Global Climate Models (GCM) are developed by various research organizations around the world. At various times, the United Nations Intergovernmental Panel on Climate Change (IPCC) calls upon these organizations to submit their latest modeling results in order to summarize and determine the current scientific consensus on global climate change. There have been five assessment reports from the IPCC (in 1990, 1995, 2001, 2007, and 2014). In support of the more recent reports, the Coupled Model Intercomparison Project (CMIP) was initiated. Although the Fifth Assessment Report contains the most contemporary estimates of climate change, the data were not available prior to the beginning of this assessment. Therefore, we utilized the CMIP3 model outputs from the IPCC's Fourth Assessment Report (AR4) for this assessment.

SNAP obtains GCM outputs from the Lawrence Livermore National Laboratory Program for Climate Model Diagnosis and Intercomparison (PCMDI) data portal. PCMDI supports Coupled Model Intercomparison Project (CMIP) and is dedicated to improving methods and tools for the diagnosis and intercomparison of Global Climate Models that simulate global climate. SNAP utilizes the first ensemble model run and the historical 20C3m scenario as well as the projected B1, A1B, and A2 datasets for downscaling, representing optimistic, mid-range, and slightly more pessimistic (but not extreme) emissions scenarios (IPCC SRES 2000).

SNAP climate datasets have been downscaled using the Delta method (Fowler et al. 2007, Prudhomme et al. 2002) to 771 meter resolution using PRISM (Parameter-elevation Regressions on Independent Slopes Model) interpolated data (Daley et al. 2008), which takes into account slope, elevation, aspect, and distance to coastlines. This downscaling uses a historical baseline period of 1971-2000. This baseline was carried over for use in the North Slope REA for consistency across REAs in Alaska.

Outputs derived from these climate datasets include temperature and precipitation data at monthly resolution. These data have also been analyzed to create multiple derived climate datasets. Based on interpolation of running means, we created datasets estimating the date at which temperatures cross the freezing point in the spring and fall (termed "thaw date" and "freeze date"). In addition, we used temperature data to create spatial estimates of monthly estimated snow fraction.

Although this project focused on the A2 emissions scenario, several recent studies shows that many risks now appear greater than they were originally calculated to be for the scenario, including biological and geological carbon-cycle feedbacks and actual measurable increases in greenhouse gas emissions, which

have accelerated recently (Fussler 2009). Although the IPCC's most recent report, the fifth Assessment Report (AR5), refers to four Representative Concentration Pathways (RCPs) rather than the scenarios described in the Special Report on Emissions Scenarios (SRES) published in 2000, the slightly older model outputs used in this analysis are still relevant within the new framework. The A2 scenario outputs fall between those of RCP 6 (a mid-range pathway in which emissions peak around 2080, then decline) and RCP 8.5, the most extreme pathway, in which emissions continue to rise throughout the 21st century (Rogelj et al. 2012). The A2 scenario describes a heterogeneous world with high population growth, slow economic development, and slow technological change. As such, it ultimately predicts high carbon emissions, as less developed nations are driven to higher burning rates of dirty fuels, with few population checks or cleaner technologies to temper these emissions. However, the most rapid change does not occur until later in this century, with considerable lag time, since slow economic development suggests few immediate increases in worldwide fuel use.

For this project, an average of the five downscaled GCMs was used in order to minimize uncertainty due to model bias. We used decadal averages, as opposed to data for single years, in order to reduce error due to the stochastic nature of GCM outputs, which mimic the true inter-annual variability of climate. Thus, the project used climate data for the 2020s rather than just 2025, and the 2060s decade rather than the single year 2060.

Source Datasets

For the purposes of addressing both the MQs and the core analysis (i.e., examining the relationship between climate and selected CEs), we provided both primary and derived climate data as described above and as listed below in Table C-2. These datasets were used in general discussion and analysis of climate change. A subset of these data were also selected to analyze the potential impacts of climate change on CEs, based on attributes and indicators determined from the literature, as described in this document. These datasets were used in conjunction with maps of CE distribution as a basis for spatial analysis and for qualitative discussion.

Table C-2. Climate source data used in the REA analysis.

Dataset Name	Data source
Baseline temperature data, 1971-2000, 771 m resolution.	SNAP/PRISM
Baseline precipitation data, 1971-2000, 771 m resolution.	SNAP/PRISM
Monthly precipitation projections, CMIP3/AR4, A2 emissions scenario, 5-model average, 771 m resolution, decadal means, 2010s, 2020s, 2060s.	SNAP
Monthly temperature projections, CMIP3/AR4, A2 emissions scenario, 5-model average, 771 m resolution, decadal means, 2010s, 2020s, 2060s.	SNAP
Date of thaw (DOT) projections, CMIP3/AR4, A2 emissions scenario, 5-model average, 771 m resolution, decadal means, 2010s, 2020s, 2060s.	SNAP
Date of freeze (DOF) projections, CMIP3/AR4, A2 emissions scenario, 5-model average, 771 m resolution, decadal means, 2010s, 2020s, 2060s.	SNAP
Length of growing season (LOGS) projections, CMIP3/AR4, A2 emissions scenario, 5-model average, 771 m resolution, decadal means, 2010s, 2020s, 2060s.	SNAP
Monthly snow day fraction projections, CMIP3/AR4, A2 emissions scenario, single-model outputs for five models, 771 m resolution, decadal means, 2010s, 2020s, 2060s.	SNAP
Cliomes, 18-cluster data, 2 km resolution, based on SNAP monthly temperature and precipitation date	SNAP

Interpretation and Analysis

The process model of downscaled climate products (Figure C-1) demonstrates the linkages between source data, intermediate results, and final products or outputs. Fire, permafrost, and climate-biome models will be discussed separately. Outputs included under “Climate Model” are described below.

Temperature

All twelve months of temperature data have been provided as part of this project. However, given that it would be impractical to include all these datasets as map outputs in this document, we focused our analysis on outputs for the hottest month (July) and coldest month (December). Note that other months (or averages across months) were used as appropriate based on attributes and indicators when analyzing temperature in relation to specific CEs.

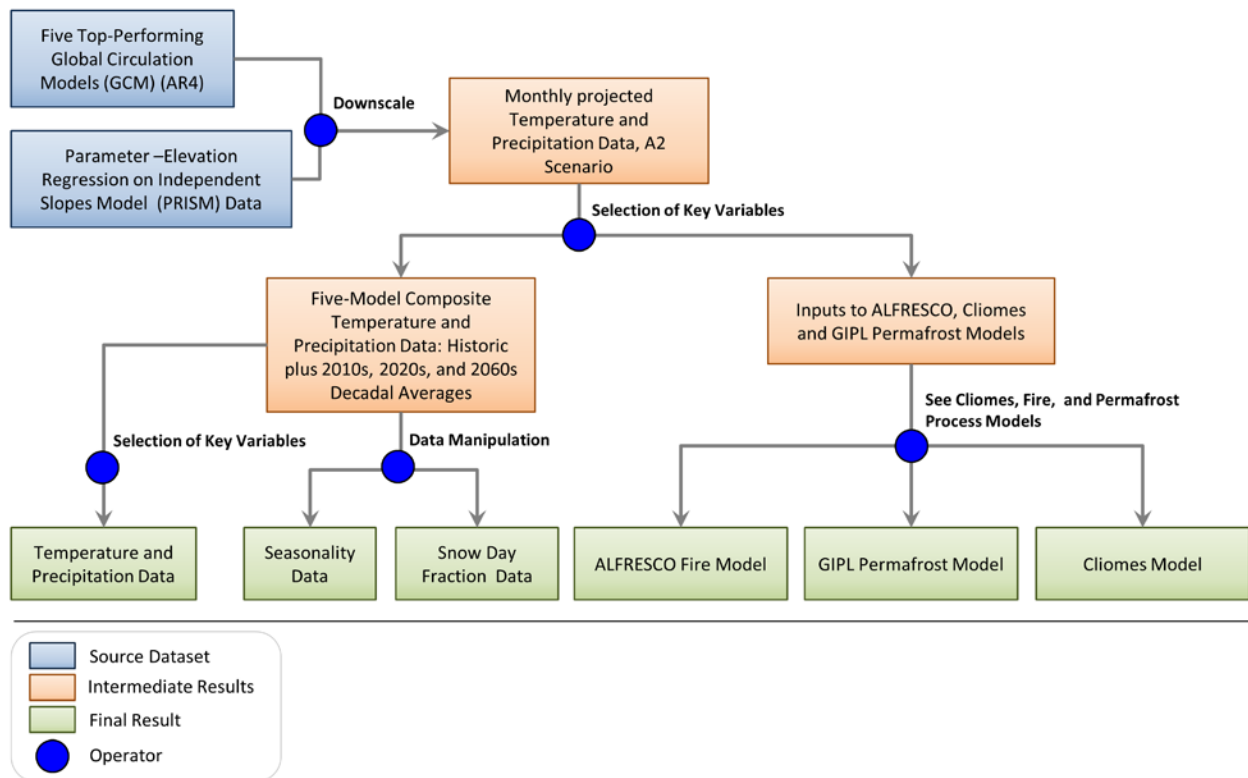


Figure C-1. Process model of downscaled climate products.

Precipitation and Snow-Day Fraction

We similarly focused our analysis of precipitation and snow-day fraction on a subset of the data. In this case, we present map outputs for three-month averages for summer (June, July, August) and winter (December, January, February) precipitation, as well as mean annual precipitation.

Precipitation data do not distinguish between rainfall and snowfall. However, assessing many crucial ecosystem effects and impacts to CEs requires clearer knowledge of snow patterns, particularly with regard to the total length of the snow season, the likelihood of rain-on-snow events, and potential changes in snow cover, snow pack, and timing and season of snowmelt and runoff. While some of these issues remain as data gaps, estimates of snow-day fraction (the percentage of days in which any precipitation that falls is likely to be snow, as opposed to rain, for a given month) helped inform the core analysis and address management questions for this REA. These estimates were produced by applying equations relating snow-day fraction to downscaled decadal average monthly temperature. In order to provide the greatest accuracy, separate equations were used to model the relationship between decadal monthly average temperature and the fraction of wet days with snow for seven geographic regions covering the entire state (McAfee et al. 2013).

Day of Freeze, Day of Thaw, and Growing Season

Estimated ordinal days of freeze and thaw are calculated by assuming a linear change in temperature between consecutive months. Mean monthly temperatures are used to represent daily temperature on the 15th day of each month. When consecutive monthly midpoints have opposite sign temperatures, the day of transition (freeze or thaw) is the day between them on which temperature crosses 0°C. The length of growing season refers to the number of days between the days of thaw and freeze. These calculations are only an estimate of the true occurrence of freeze and thaw. True transitions across the freezing point may occur several times in a year, or not at all. Moreover, it should be kept in mind that these metrics are not equivalent to notions of freeze and thaw (or “freezeup” and “breakup”) in common parlance, since these generally refer to the behavior of river ice, sea ice, or frozen soils. Lag times can be expected before these occurrences take place, and these lag times will vary based on characteristics of the water body in question.

1.3. Results

Here we examine the relationship between current, near-term, and long-term climate variables. We also address climate-specific MQs. Due to the formatting of climate data as decadal means, “current” data will be considered to be the decade 2010-2019, while 2020s will be represented by data from 2020-2029, and 2060s will be represented by data from 2060-2069.

Due to the resolution of the climate data and the most appropriate and manageable level to discuss and analyze it, given inherent uncertainties, some outputs are given at the resolution of sub-regions. These sub-regions were carefully selected, based on examination of the published literature and additional application of expert opinion, in order to capture east-west ecological zones as well as north-south delineations (Nowacki et al. 2001). Nine such sub-regions were defined within the REA region, as shown in Figure C-2.

Uncertainty and stochasticity are inherent to the predictive models used to create climate projections. Not only is prediction imperfect, but these models intentionally incorporate variability similar to the natural month-to-month, year-to-year and even decade-to-decade variability seen in real climate data. Model sensitivity will be discussed further below, in the separate Temperature and Precipitation sections.

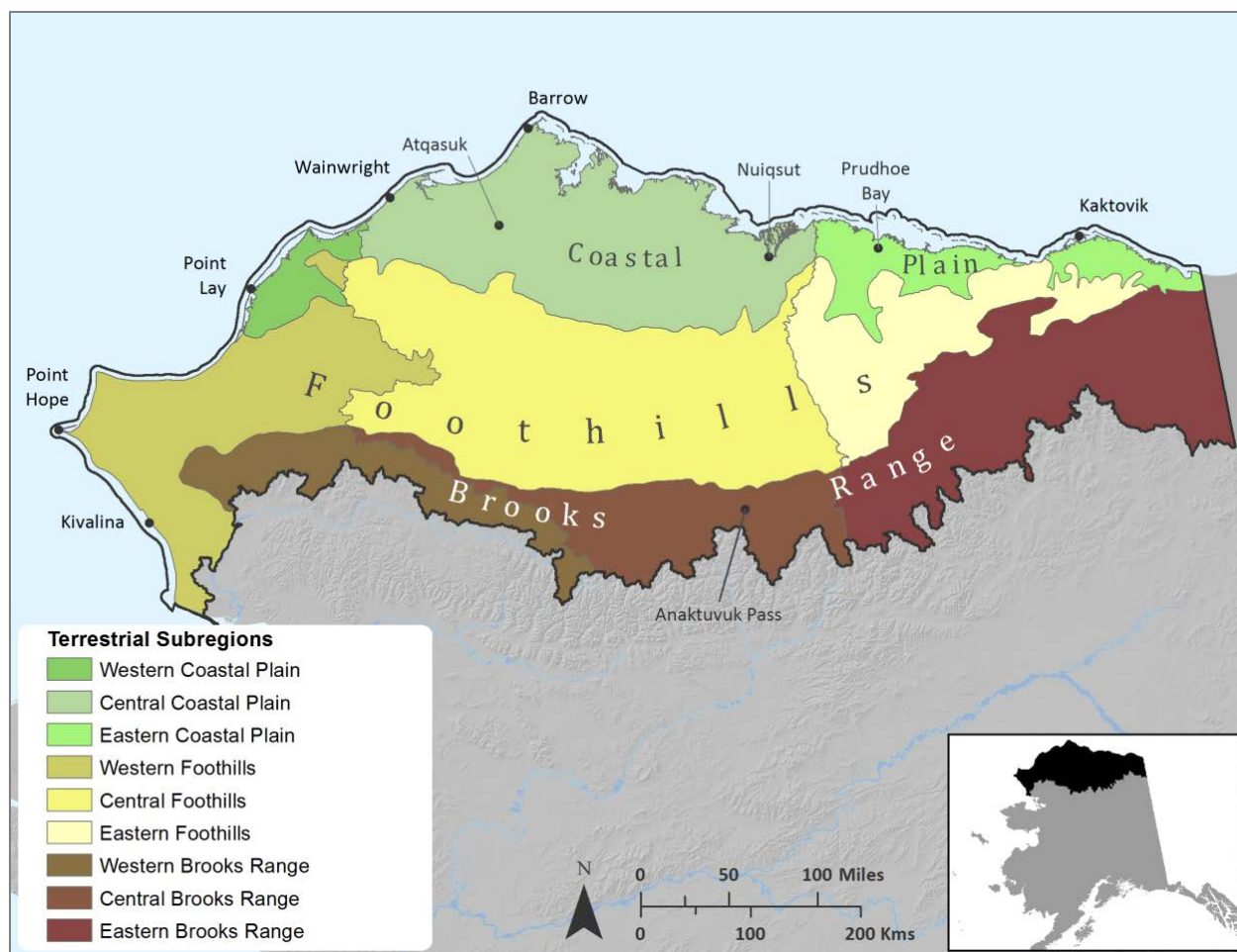


Figure C-2. Terrestrial sub-regions defined for the North Slope study area.

As previously noted, all data shown in the maps below has been served in raw form at 771 m resolution. It was determined that producing tabular output for all 5th-level HUCs would be cumbersome and of little use to managers. However, given the particular interest in changing climate in communities and immediately surrounding areas, we extracted data for all 5th-level HUCs that contain communities. Many of these outputs are presented in tabular form in the results, below.

Monthly, seasonal, and annual temperatures and precipitation are all expected to increase in the REA, with higher uncertainty associated with precipitation than with temperature. Temperature increase is expected to be relatively minimal in the near future. In the long-term, however, climate warming trends are clear and significant. Precipitation increases are more pronounced in the near-term, with the rate of change appearing to decelerate in the long-term.

Temperature Sensitivity Analysis

In order to provide a sensitivity analysis for the GCM model outputs used as the core of SNAP climate analyses, we analyzed the variability of model outputs across the five GCMs used to create the composite outputs used in this report. The standard deviation among these models can serve as a

measure of uncertainty, encompassing both the uncertainty associated with model calibration and accuracy, and the uncertainty associated with the natural stochasticity built into all GCMs. GCMs are designed and intended to replicate not only accurate mean values for climate variables, but also normal variability in weather patterns across short and long time periods (attributable to such factors as daily and monthly weather variations and longer-term fluctuations such as the Pacific Decadal Oscillation). Thus, assessments based on mean GCM values can be considered to be more robust if trends in those mean values fall outside at least one standard deviation of the means of multiple models.

Cross-model standard deviations for temperature are shown in Table C-3. These values are averaged across decades and across all pixels in the study area. According to this table the potential variation for any given cell is, on average, 1.3°C. Thus, projected shifts greater than 2.6°C from baseline temperatures can be considered statistically significant. Projected shifts of 1.3-2.6°C may still be significant, while changes of less than 1.3°C could be due to model variability and may not represent actual changes. However, this must be understood to be an estimate. As seen in Table C-3, inter-model variability appears to be higher in winter and spring months than in summer and autumn.

Table C-3. Inter-model standard deviations in projected monthly temperature, A2 emission scenario (°C).

Decade	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	mean
2010s	2.8	1.2	2.4	1.7	0.9	0.8	1.0	0.9	0.7	1.0	1.8	1.0	1.4
2020s	1.7	2.0	1.7	1.5	0.9	0.5	0.4	0.6	0.5	0.6	0.8	2.3	1.1
2060s	2.6	1.6	1.5	1.1	0.7	0.9	1.4	0.9	1.2	1.4	1.2	1.3	1.3
mean	2.4	1.6	1.9	1.4	0.8	0.7	0.9	0.8	0.8	1.0	1.3	1.5	1.3

Winter Temperature

Model outputs for January temperature (Figure C-3) show that warming is predicted throughout the North Slope study area in the coldest month of the year. As can be seen in Table C-4, January temperatures are expected to warm slightly more in the more eastern parts of the North Slope study area, with increases of about 4.5°C (8°F) by the 2060s. In the western areas, increases of about 4.0°C (7°F) are expected. Based on the above sensitivity analysis, this can be considered a significant trend over the long-term and a possibly significant trend in the near-term. Inclusion of minimum and maximum values for each decade shows that significant variability exists within each dataset, but that the trend for mean values is also the trend for maximum and minimum values.

Table C-4. January temperature projections by terrestrial sub-regions (°C).

Sub-region		Current	Near-term	Long-term	Change (2010s to 2060s)
Western Coastal Plain	mean	-23.1	-23.0	-19.2	3.9
	min	-24.9	-24.6	-21.2	3.7
	max	-21.0	-20.8	-16.8	4.2
Central Coastal Plain	mean	-25.0	-24.5	-20.8	4.2
	min	-27.2	-26.5	-23.1	4.1
	max	-22.4	-22.1	-18.4	4.0
Eastern Coastal Plain	mean	-24.6	-24.0	-20.1	4.5
	min	-25.5	-25.0	-21.2	4.3
	max	-23.4	-22.6	-18.6	4.8
Western Foothills	mean	-21.7	-21.4	-17.7	4.0
	min	-26.7	-26.3	-23.0	3.7
	max	-13.6	-13.5	-9.2	4.4
Central Foothills	mean	-24.7	-24.0	-20.7	4.0
	min	-28.1	-27.4	-24.0	4.1
	max	-19.1	-18.3	-15.1	4.0
Eastern Foothills	mean	-23.7	-23.0	-19.3	4.4
	min	-26.2	-25.6	-22.0	4.2
	max	-18.5	-17.6	-14.0	4.5
Western Brooks Range	mean	-22.0	-21.3	-18.1	3.9
	min	-25.1	-24.3	-21.1	4.0
	max	-14.6	-14.1	-10.6	4.0
Central Brooks Range	mean	-19.8	-18.9	-15.7	4.1
	min	-25.1	-24.1	-21.1	4.0
	max	-14.6	-13.6	-10.5	4.1
Eastern Brooks Range	mean	-20.5	-19.5	-15.9	4.6
	min	-28.4	-27.3	-23.7	4.7
	max	-16.3	-15.2	-11.8	4.5

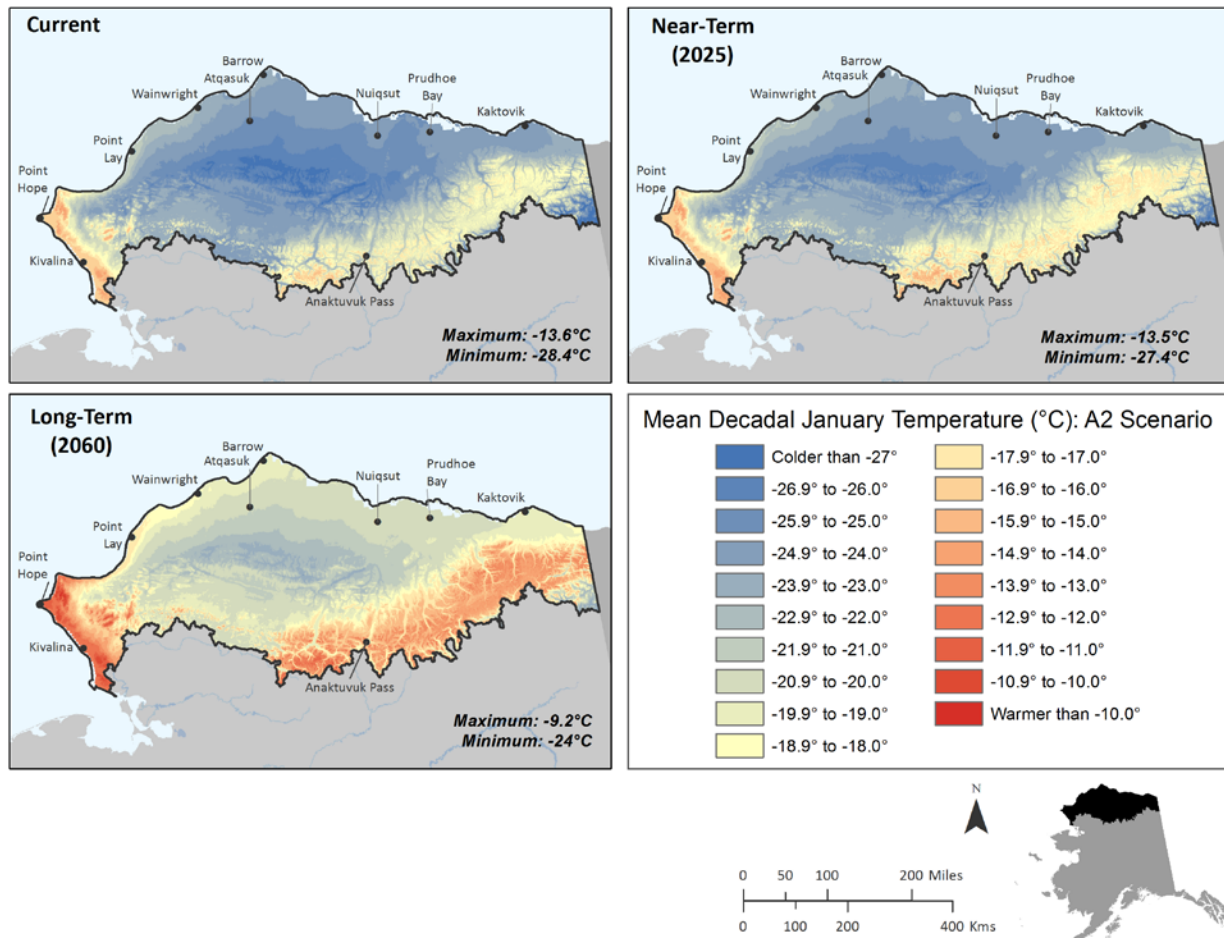


Figure C-3. Projected mean January temperatures.

Summer Temperature

These models show increased temperatures across the North Slope study area during the warmest month of the year by 2060. July temperature projections are shown in Figure C-4, and summarized in Table C-5. However, this warming trend is less pronounced than winter warming, and is not significant in the near-term. The tempered near-term summer warming is likely due to a combination of factors, including the inherent stochasticity and variability of the models, the short time frame, and the nature of the A2 emissions scenario, which tends to predict accelerating change later in the century. Significant summer warming is expected by the 2060s.

Summer warming is expected to follow a slightly different geographic pattern from winter warming, with greater changes in the inland part of the North Slope study area and less change along the coast.

Table C-5. July temperature projections by sub-region (°C).

Sub-region		Current	Near-term	Long-term	Change (2010s to 2060s)
Western Coastal Plain	mean	10.5	11.2	11.8	1.3
	min	5.5	6.1	6.5	1.0
	max	12.1	12.9	13.4	1.3
Central Coastal Plain	mean	7.7	8.4	8.7	1.0
	min	4.5	5.1	5.5	1.0
	max	11	11.8	12.3	1.3
Eastern Coastal Plain	mean	8.2	8.9	9.2	1.0
	min	5.1	5.6	5.7	0.6
	max	11.2	12.1	12.5	1.3
Western Foothills	mean	11.3	12.1	12.7	1.4
	min	7.4	8.1	8.9	1.5
	max	12.5	13.2	13.9	1.4
Central Foothills	mean	8.4	9	9.4	1.0
	min	7.2	7.7	8	0.8
	max	9.1	9.8	10.2	1.1
Eastern Foothills	mean	9.6	10.3	11.1	1.5
	min	1.7	2.4	3.2	1.5
	max	15.1	15.6	16.6	1.5
Western Brooks Range	mean	11	11.7	12.4	1.4
	min	2.8	3.3	4.3	1.5
	max	13.5	14.2	15	1.5
Central Brooks Range	mean	10.4	11.2	11.9	1.5
	min	7.4	8	8.6	1.2
	max	13.1	13.9	14.7	1.6
Eastern Brooks Range	mean	9.2	9.8	10.6	1.4
	min	-0.8	-0.1	0.5	1.3
	max	15.7	16.2	17.2	1.5

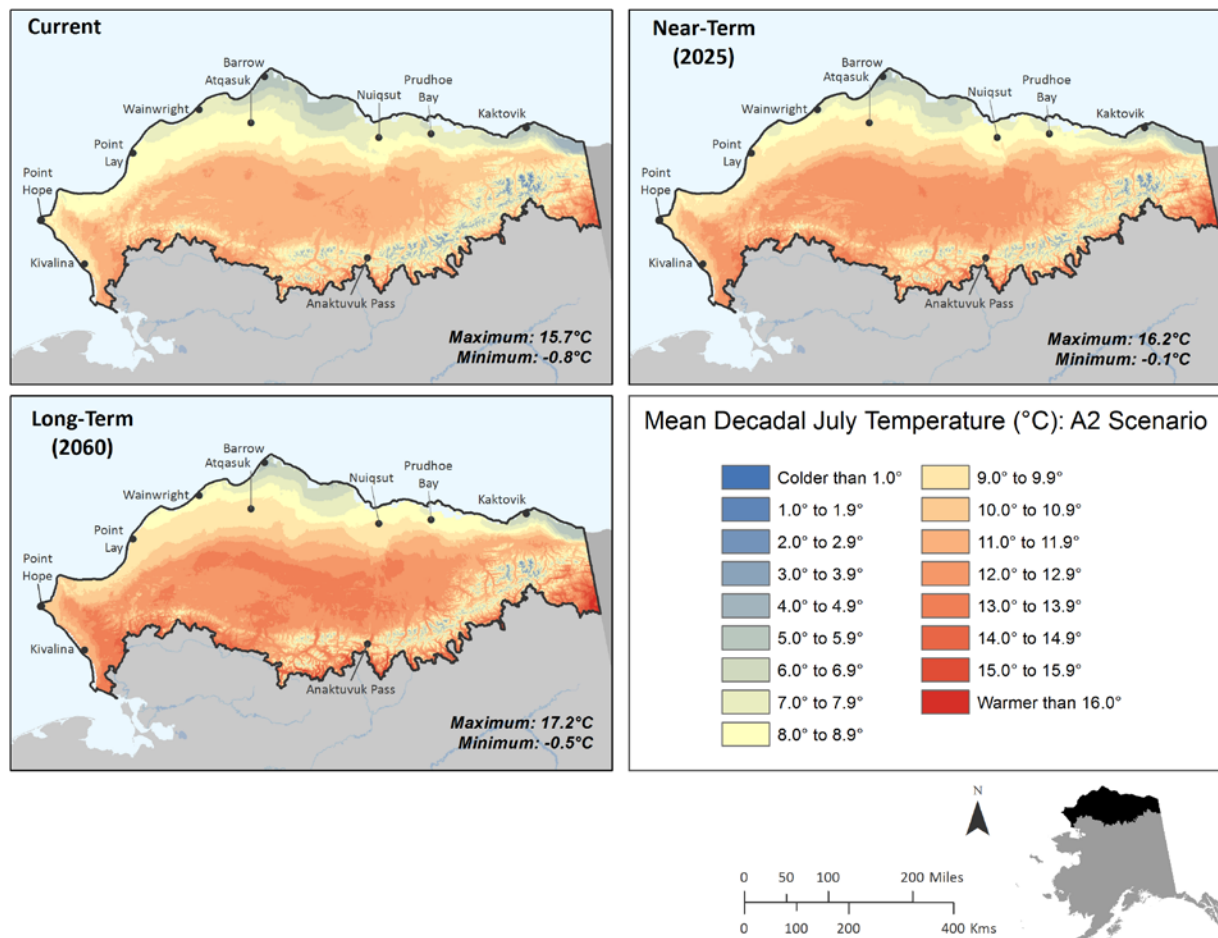


Figure C-4. Temperature projections for July (A2 Scenario).

Precipitation Sensitivity Analysis

Cross-model standard deviations for precipitation are shown in Table C-6. The rationale for producing these metrics is similar to that explained for temperature, above. Given that precipitation is more variable than temperature, across both space and time, standard deviations among models tend to be higher. Based on these values, variation in mean annual precipitation of less than 4.7 mm is not statistically distinguishable from baseline values. Projected shifts of 4.6-9.2 mm can be considered possibly significant, and a shift of more than 9.2 mm can be considered significantly different from baseline values.

Table C-6. Inter-model standard deviations in projected monthly precipitation, mm rainwater equivalent.

Decade	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	mean
2010s	3.8	3.3	2.1	2.2	1.8	5.9	7.1	6.2	7.1	3.5	2.7	2.9	4.1
2020s	4.7	2.6	2.7	3.1	2.5	6.5	5.1	12.6	5.1	4	3.3	5.2	4.8
2060s	6	3.7	3	3.8	1.8	6.2	8.6	8.9	6.1	5.4	3.9	5.6	5.3
mean	4.8	3.2	2.6	3.0	2.0	6.2	6.9	9.2	6.1	4.3	3.3	4.6	4.7

Annual Precipitation

General geographic patterns of precipitation are likely to remain unchanged across the REA, even as total precipitation increases slightly (Figure C-5). The southern mountainous part of the REA is shown to experience more precipitation, in some cases with more than twice the rainwater equivalent. However, more fine-scale variability in precipitation can be expected in areas with more complex topography. As can be seen in Figure C-6, those regions that currently receive the most precipitation (i.e. the Brooks Range) may see slightly greater increases than those that are currently drier.

Summer Precipitation

For some ecoregions within the REA, slight to moderate increases in summer (June, July, and August) precipitation are projected (Figure C-7; Table C-7), with no significant change in precipitation in the near-term, but a significant trend toward greater precipitation appearing by the 2060s. While mean summer precipitation is modeled to be lower for nearly all sub-regions in the near term, the projected decrease is not statistically distinguishable from baseline values. By the 2060s, precipitation may increase by as much as 8%, although model variability is relatively high.

The pattern of change for summer months shows greater increases to the south and east, and little or no change to the west, particularly on the coast. However, inter-annual variability is extremely high. This variability, which mirrors the true variability in seasonal rainfall, poses a challenge for land managers and local residents alike.

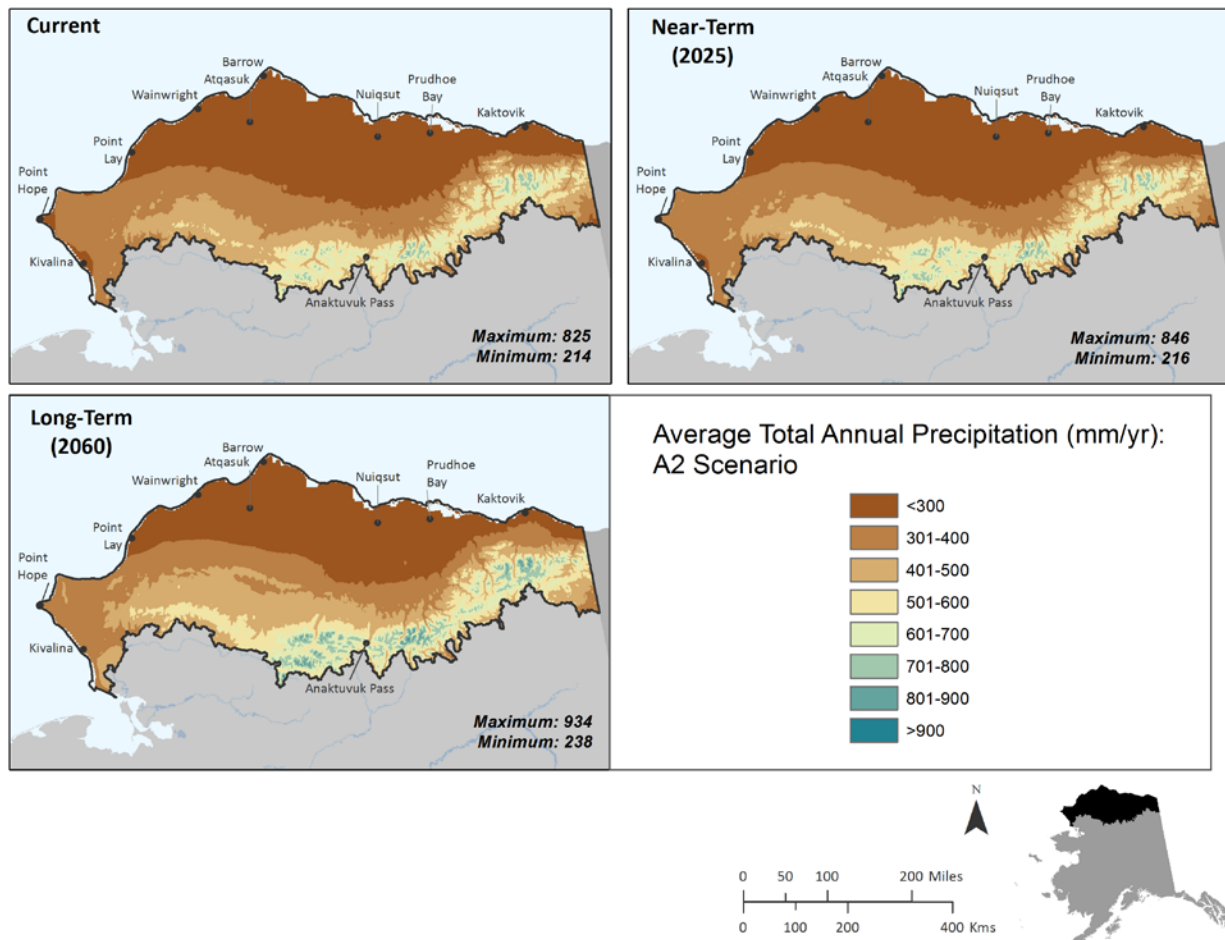


Figure C-5. Projected annual precipitation (mm, rainwater equivalent).

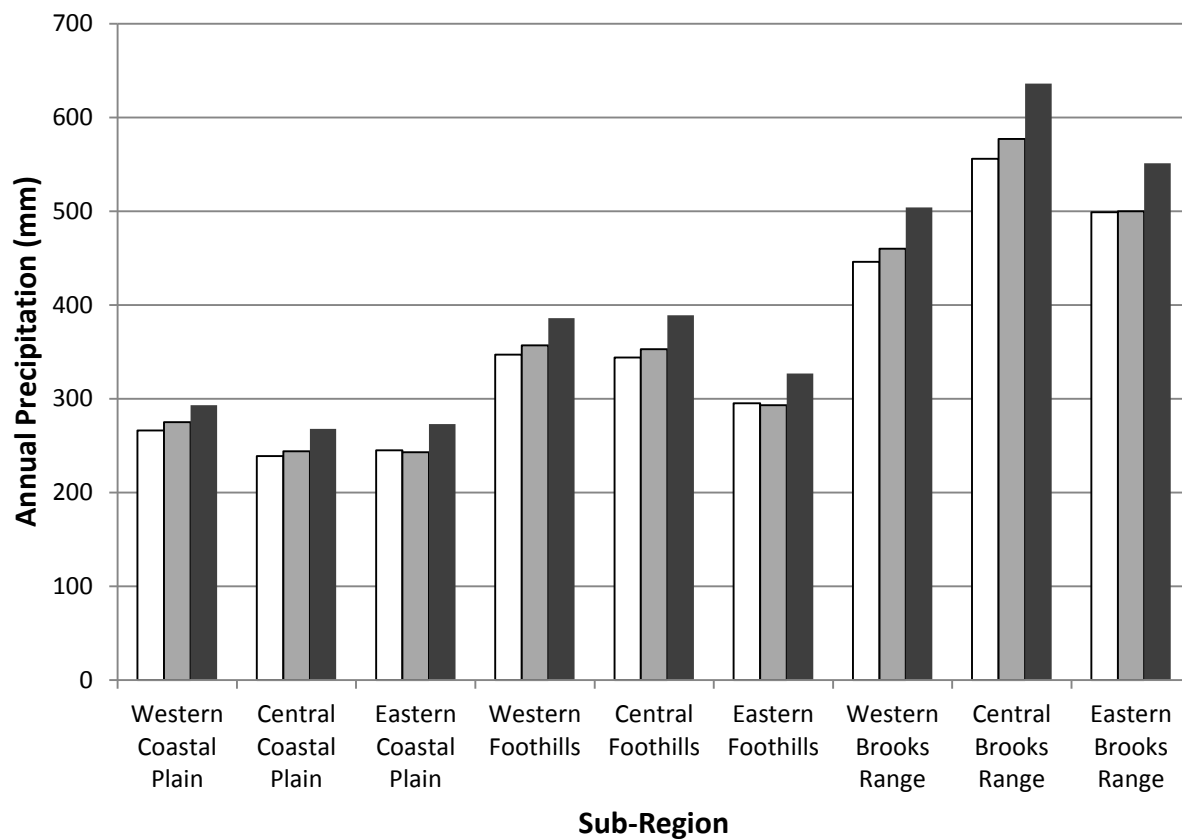


Figure C-6. Annual precipitation projections by terrestrial sub-regions (mm, rainwater equivalent). Current (white), near-term (light gray), and long-term (dark gray) time steps are shown.

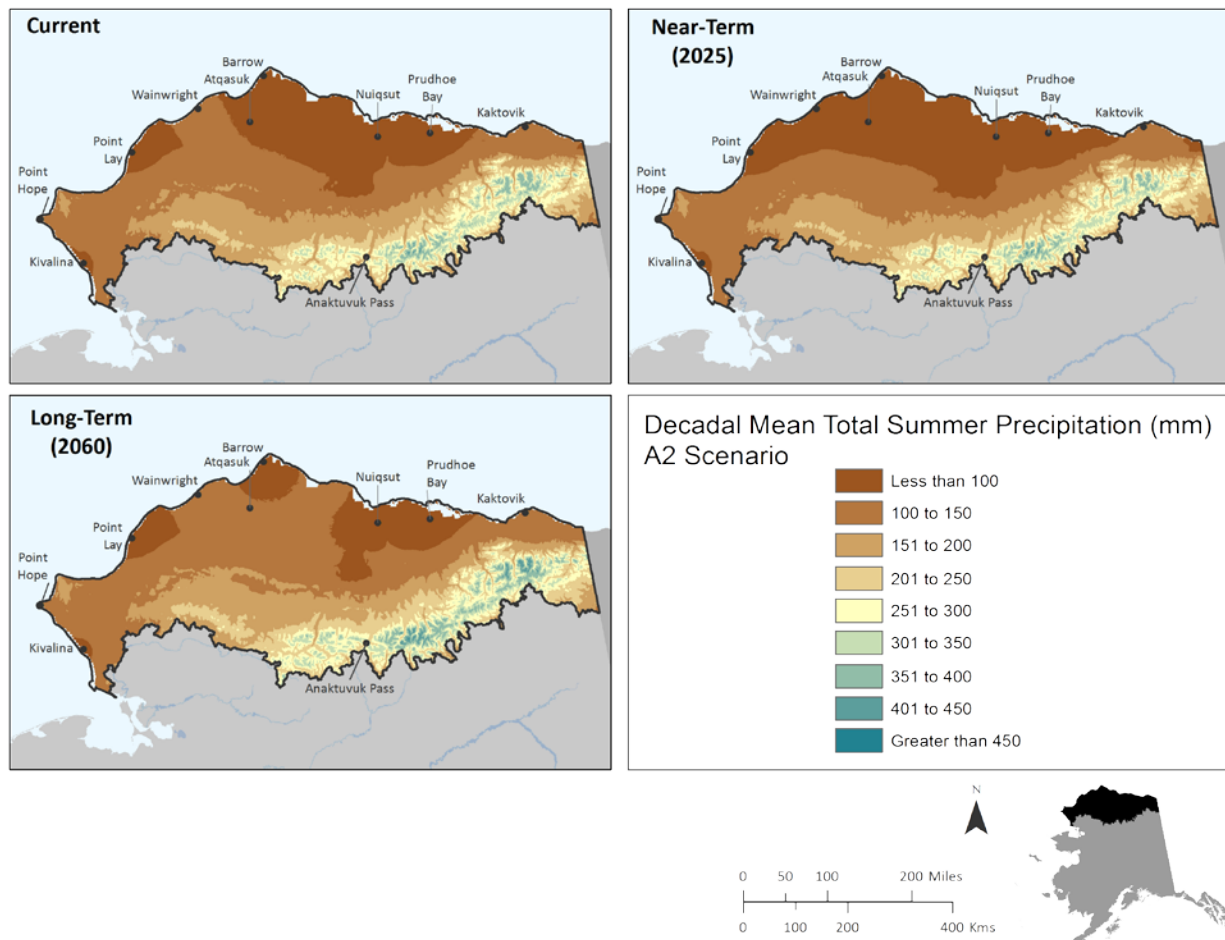


Figure C-7. Summer precipitation projections (mm, rainwater equivalent).

Table C-7. Summer precipitation projections by ecoregion (mm, rainwater equivalent).

Sub-region		Current	Near-term	Long-term	Change (2010s to 2060s)
Western Coastal Plain	mean	95	90	95	0.0
	min	88	83	87	-1.0
	max	109	102	109	0.0
Central Coastal Plain	mean	96	90	101	5.0
	min	76	69	80	4.0
	max	106	102	112	6.0
Eastern Coastal Plain	mean	97	89	102	5.0
	min	74	67	78	4.0
	max	132	121	140	8.0
Western Foothills	mean	131	127	134	3.0
	min	88	88	91	3.0
	max	198	190	205	7.0
Central Foothills	mean	143	139	152	9.0
	min	78	71	82	4.0
	max	271	272	294	23.0
Eastern Foothills	mean	140	132	148	8.0
	min	77	70	81	4.0
	max	273	266	292	19.0
Western Brooks Range	mean	178	175	187	9.0
	min	110	108	112	2.0
	max	344	348	373	29.0
Central Brooks Range	mean	251	253	271	20.0
	min	159	163	173	14.0
	max	426	429	462	36.0
Eastern Brooks Range	mean	256	248	272	16.0
	min	108	101	115	7.0
	max	422	426	458	36.0

Winter Precipitation

Unlike summer precipitation, winter precipitation is projected to increase across all sub-regions, although the projected change is greater in the same areas that are likely to see the greatest change in summer precipitation – that is, the Central Brooks Range sub-region. Changes in precipitation across both the near-term and long-term are only of moderate significance. That is, projected increases are greater than one standard deviation of inter-model variability, but for the most part less than two

standard deviations. It should be noted that the units (mm) in this section refer to rain-water equivalent, as “winter precipitation” does not necessarily mean snow (Figure C-8). Winter precipitation by sub-region is shown in Table C-8.

Variability from year to year is of greater magnitude than the projected trend associated with climate change. Moreover, the slight increases in winter precipitation predicted by these models may not result in increased snowfall or greater snowpack, since associated warming may mean that a greater percentage of this precipitation falls as rain, as discussed below.

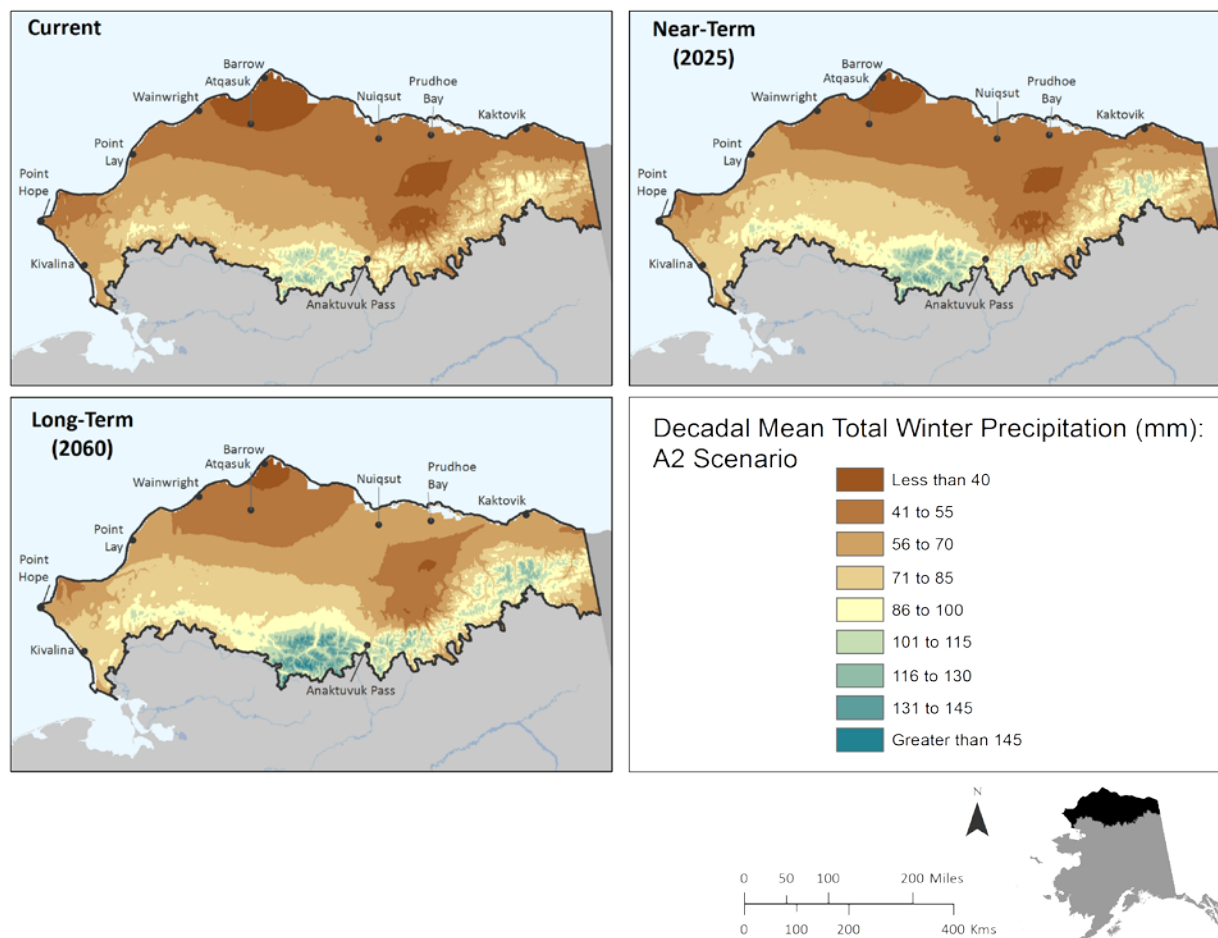


Figure C-8. Winter precipitation projections (mm, rainwater equivalent).

In terms of the hydrology of the region, results seem to indicate that the foothills may get drier, but the mountains might get slightly more precipitation. If this is the case, we might see hydrographs that increasingly look like arid systems throughout the western U.S.

Table C-8. Projected winter precipitation by ecoregion (mm, rainwater equivalent).

Sub-region		Current	Near-term	Long-term	Change (2010s to 2060s)
Western Coastal Plain	mean	53	60	61	8.0
	min	45	50	52	7.0
	max	61	68	70	9.0
Central Coastal Plain	mean	44	48	51	7.0
	min	32	35	38	6.0
	max	54	60	64	10.0
Eastern Coastal Plain	mean	48	52	57	9.0
	min	32	36	40	8.0
	max	55	60	66	11.0
Western Foothills	mean	63	72	73	10.0
	min	40	45	47	7.0
	max	92	103	104	12.0
Central Foothills	mean	61	68	73	12.0
	min	32	34	39	7.0
	max	106	117	129	23.0
Eastern Foothills	mean	45	49	55	10.0
	min	32	35	39	7.0
	max	75	82	91	16.0
Western Brooks Range	mean	79	90	92	13.0
	min	60	68	67	7.0
	max	136	152	165	29.0
Central Brooks Range	mean	91	100	111	20.0
	min	40	42	48	8.0
	max	131	146	161	30.0
Eastern Brooks Range	mean	70	77	86	16.0
	min	35	38	43	8.0
	max	106	115	130	24.0

Snow-Day Fraction

Snow-day fraction refers to the estimated percentage of days on which precipitation, were it to fall, would occur as snow as opposed to rain. Model outputs for all nine months of the year for the current decade (2010s) are shown in Figure C-9. Summer months (June, July, and August) are omitted, since projected snow for these months is absent or negligible.

Not surprisingly, clear spatial and temporal patterns are evident (Figure C-10). For all areas of the REA, all or almost all (> 90%) of precipitation is currently likely to fall as snow for all months from October to April, with the exception of small amounts of October rainfall in the area south of Kivalina. By 2060, although conditions in December to April are still expected to be completely snow-dominated area-wide, marked changes are expected in the fall (Figure C-11). Most notably, occasional October rainfall is to be expected across almost the entire Arctic coast, and even in November, precipitation may arrive as rain more than ten percent of the time around Kivalina and Point Hope.

Spatially, examining the shoulder season months of September, October, and May, shows that seasonal shifts from rain to snow and back again are more abrupt in inland high-elevation areas, and will continue to be so, but that shifts in snow day fraction are expected area-wide.

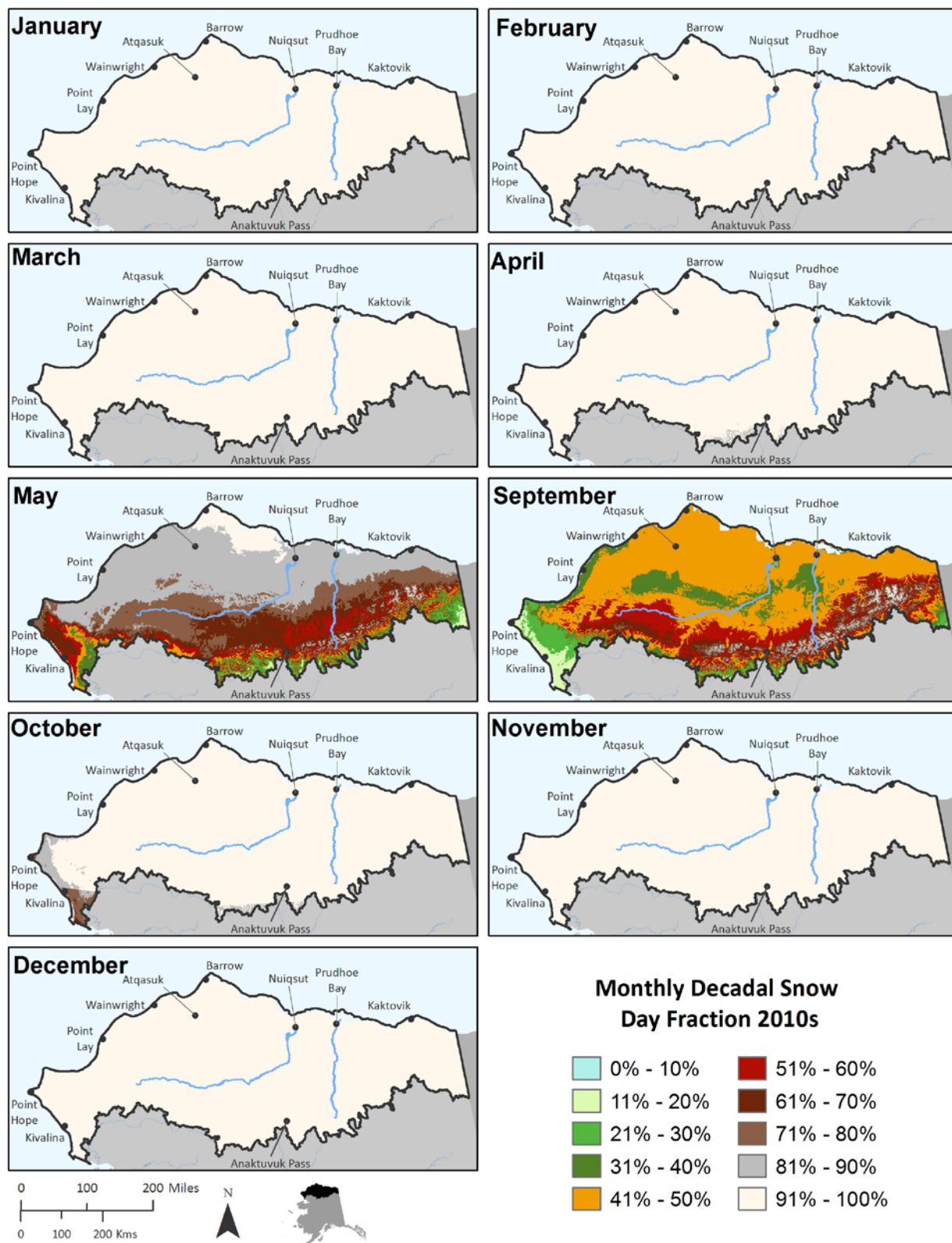


Figure C-9. Projected monthly snow-day fraction for winter and shoulder-seasons in the current decade.

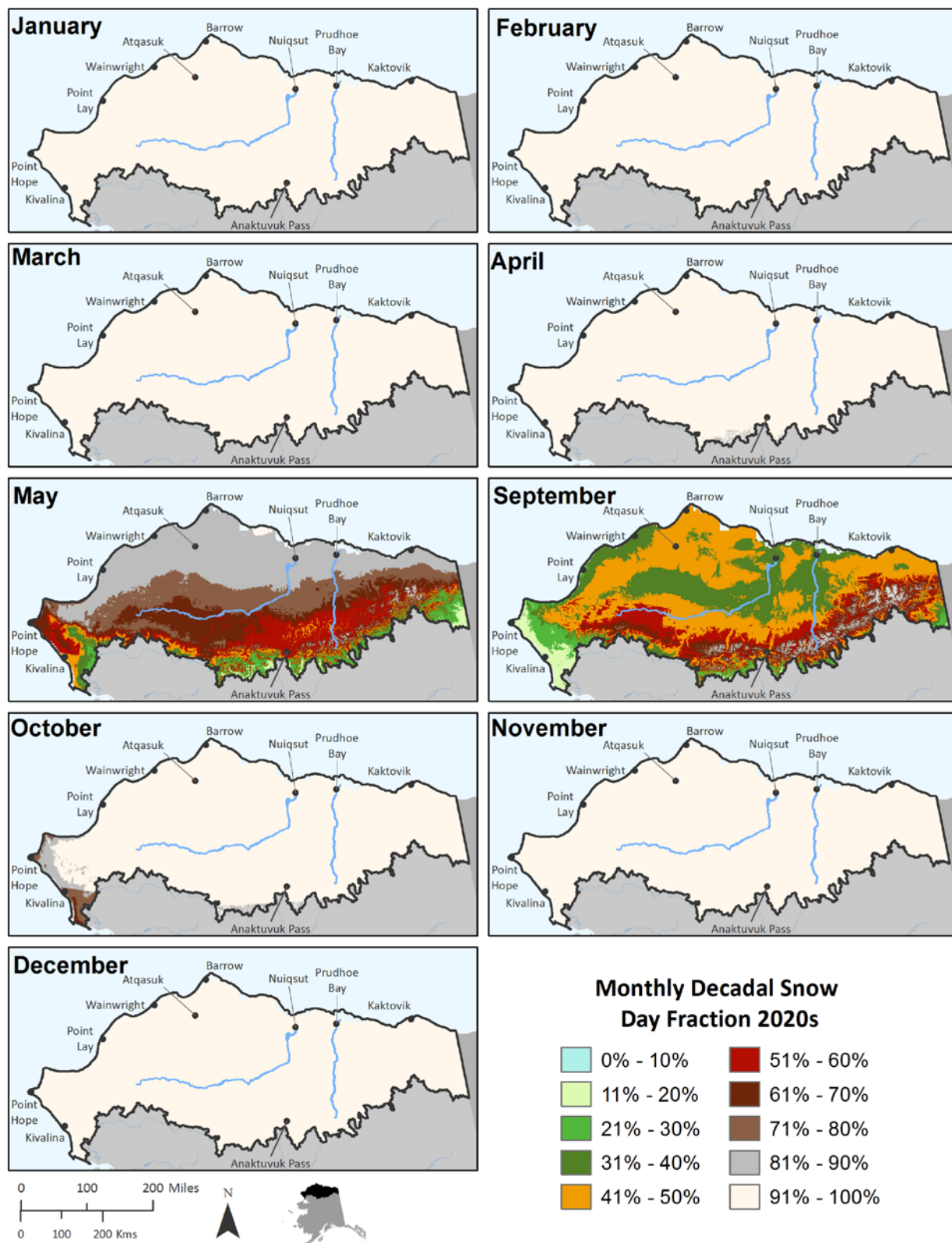


Figure C-10. Near-term projected monthly snow-day fraction winter and shoulder-seasons.

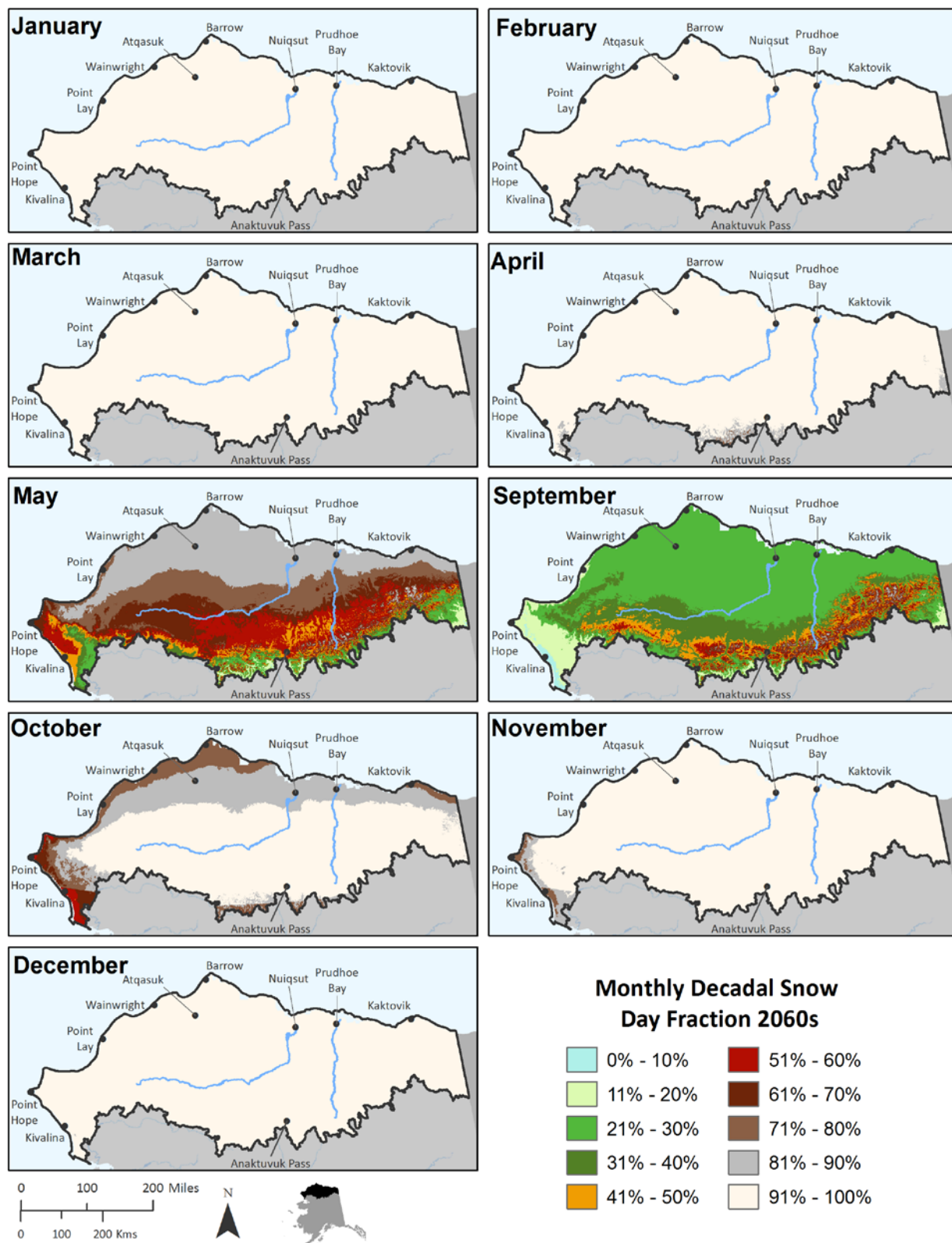


Figure C-11. Long-term projected snow-day fraction winter and shoulder-seasons.

Estimated Snowfall and Winter Rainfall

In order to further examine the complex relationship between precipitation and snowfall, we combined projections for precipitation in fall, winter, and spring with projections of snow day fraction during these seasons in order to estimate whether snowfall is likely to increase or decrease, spatially and temporally, as well as where and when shoulder season and winter rain may become more prevalent. These estimates were calculated by multiplying monthly precipitation values with monthly snow day fraction values by ecoregion and decade.

As can be seen in Figure C-12 and Figure C-13, this relationship is a complex one, varying both spatially and temporally. In general, near-term change (between the current decade and the 2020s) is minimal in all areas. Long-term change in snowfall tends to be highly positive in the fall (September), slightly positive in the winter months (in this case defined as all months from October to April, inclusive), and negative in the spring (May). Long-term change in non-summer rainfall is projected to vary widely by both season and sub-region.

This makes sense when we consider the input data. From October to April, almost all precipitation is snow, and it is expected to remain as such. The slight projected increases in precipitation will thus be experienced as increases in snow during these months. On the other hand, precipitation in May is expected to decrease in some areas, and is, moreover, offset by a much lower snow day fraction. In September, less change in snow day fraction is expected, and projected increases in precipitation are fairly high for some areas. Figure C-14 shows that when cumulative snowfall for the long-term is compared to cumulative snowfall for the current decade, increases are seen for most regions until late winter and early spring, when decreases in the seasonal cumulative total are seen for the Western Coastal Plain and Eastern Coastal Plain. Decreases in actual snowpack may be greater than decreases in cumulative total snowfall, since compaction, sublimation, and rain on snow events are all likely to increase as well.

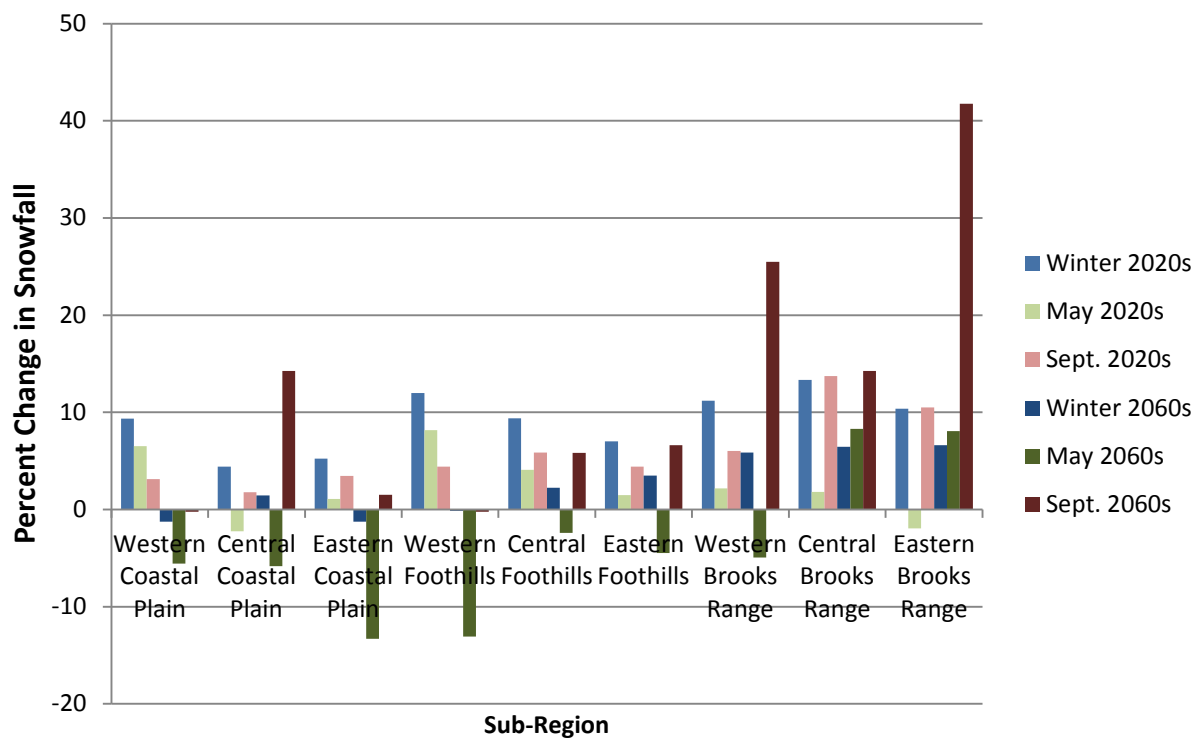


Figure C-12. Projected change in snowfall (as compared to the current decade) by sub-region. Values are based on projected precipitation and snow day fraction.

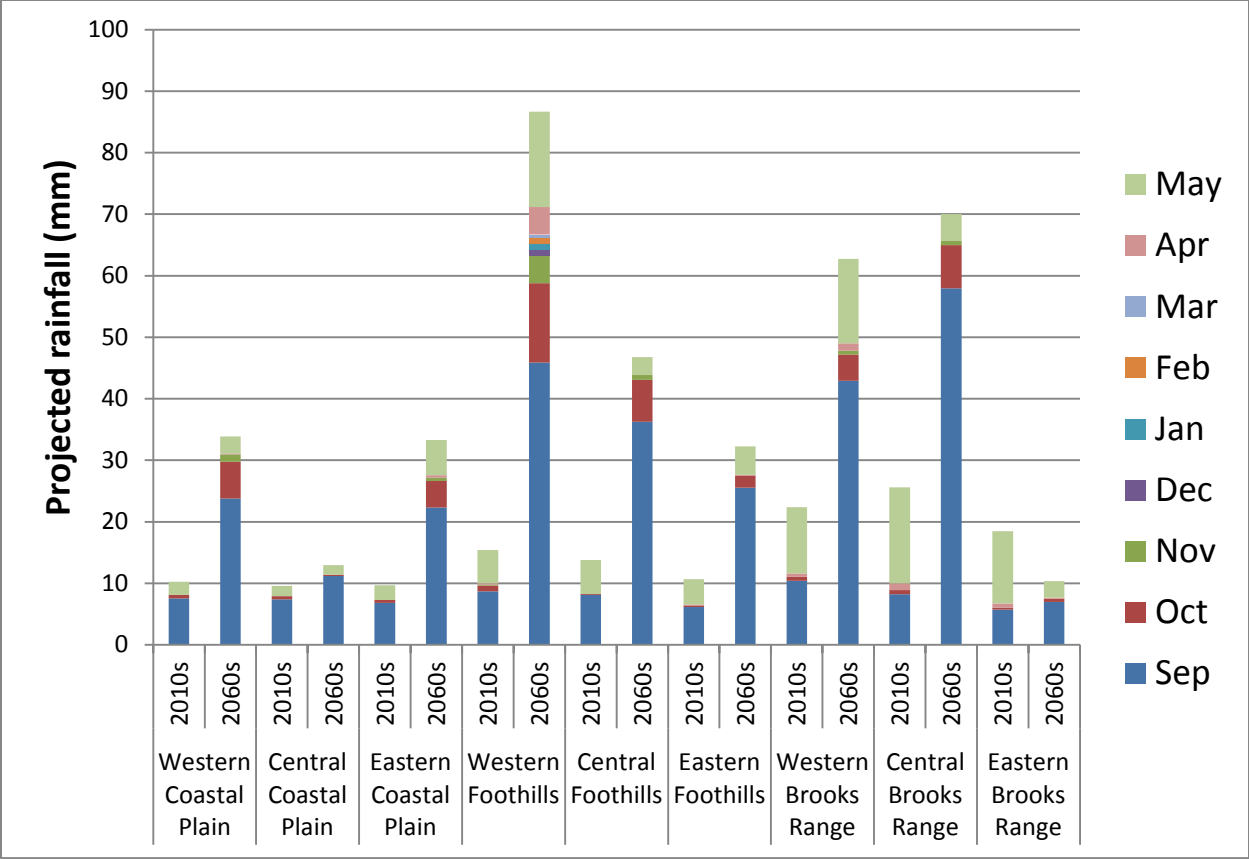


Figure C-13. Estimated current and long-term shoulder-season and winter rainfall by sub-region.

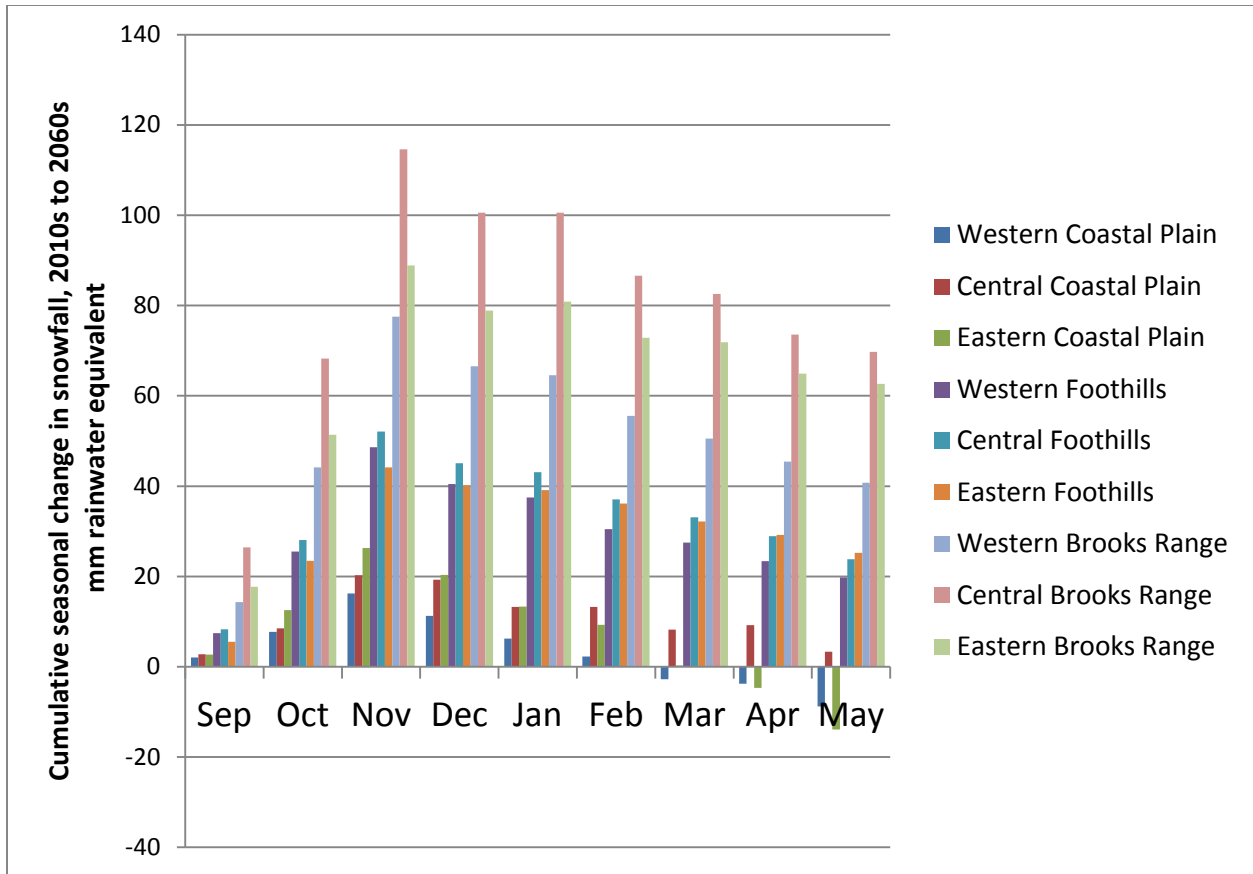


Figure C-14. Cumulative change in snowfall across the winter season for the long-term, as compared to the current decade.

Seasonal Timing and Growing Season Length

MQ TC 5	How is climate change affecting the timing of snow melt and snow onset, spring breakup and green-up, and growing season length?
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Day of Freeze (DOF) and Day of Thaw (DOT)

DOF refers to the interpolated day on which the running mean temperature crosses the freezing point in the fall. DOT refers to the equivalent day in the spring. Figure C-15 and Figure C-16 show trends in these two variables within the REA region.

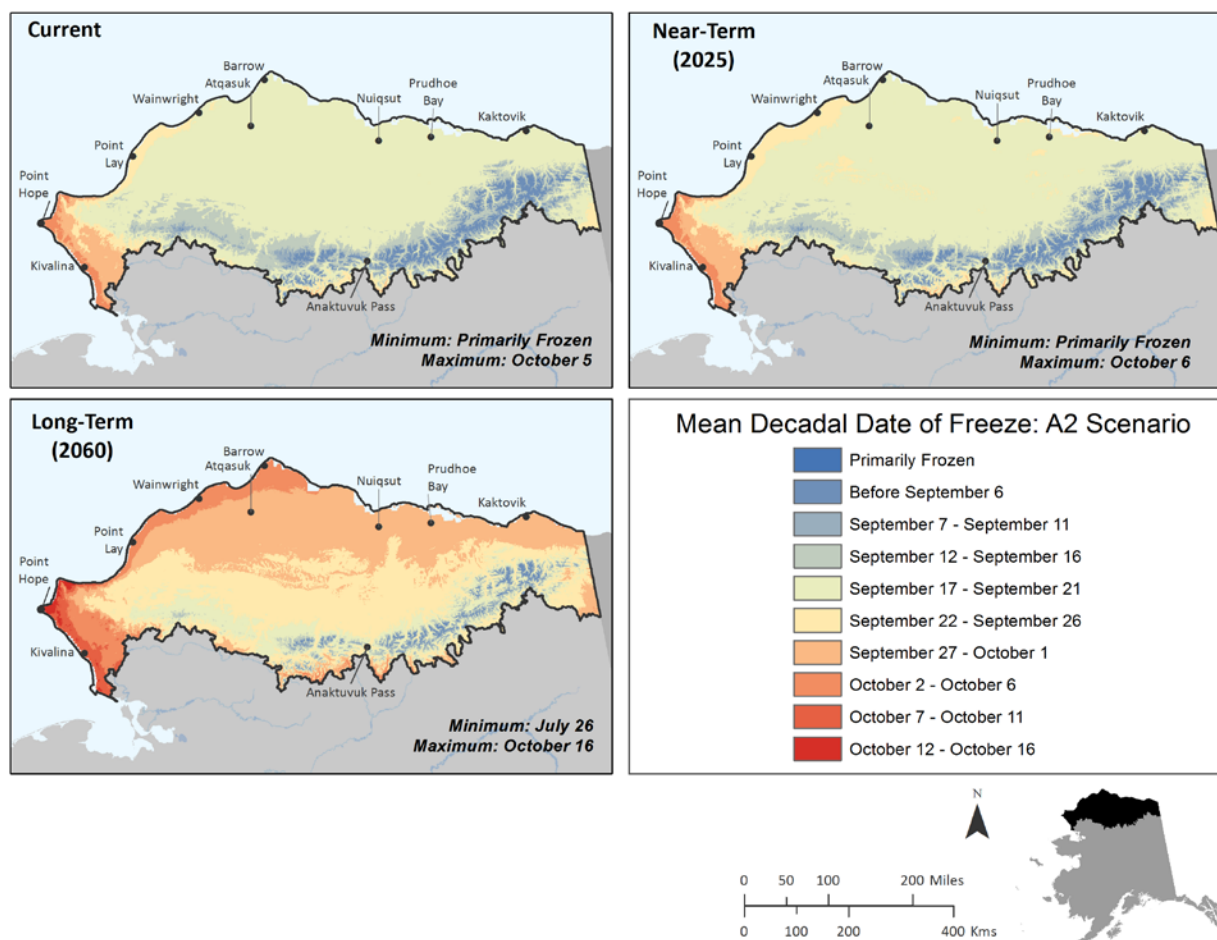


Figure C-15. Projected Date of Freeze.

As discussed above, DOF and DOT can be expected to correlate in general with the condition of ice on rivers, streams, and wetlands. Likewise, projected changes in the number of days between DOT and DOF cannot be expected to precisely reflect the number of ice-free days on any particular water body, but can serve as a reasonable proxy value of growing season or warm season length.

Table C-9 offers a tabular summary of DOF, DOT, and the current and projected number of days between these two dates. It also shows the projected change in the length of the warm season between the 2010s and the 2060s. The table is arranged by community, in order to give managers a sense of how these changes may affect people on the landscape. However, the values for each community are not point data; they represent the average values for the 5th-level HUC in which the community is located. Warm season length is projected to increase, on average, anywhere from 10 to 16 days across the North Slope study area, with the smallest increase seen in more southern and inland communities, and the greatest increase seen in coastal communities to the west, including Wainwright, Point Lay, Point Hope, and Barrow.

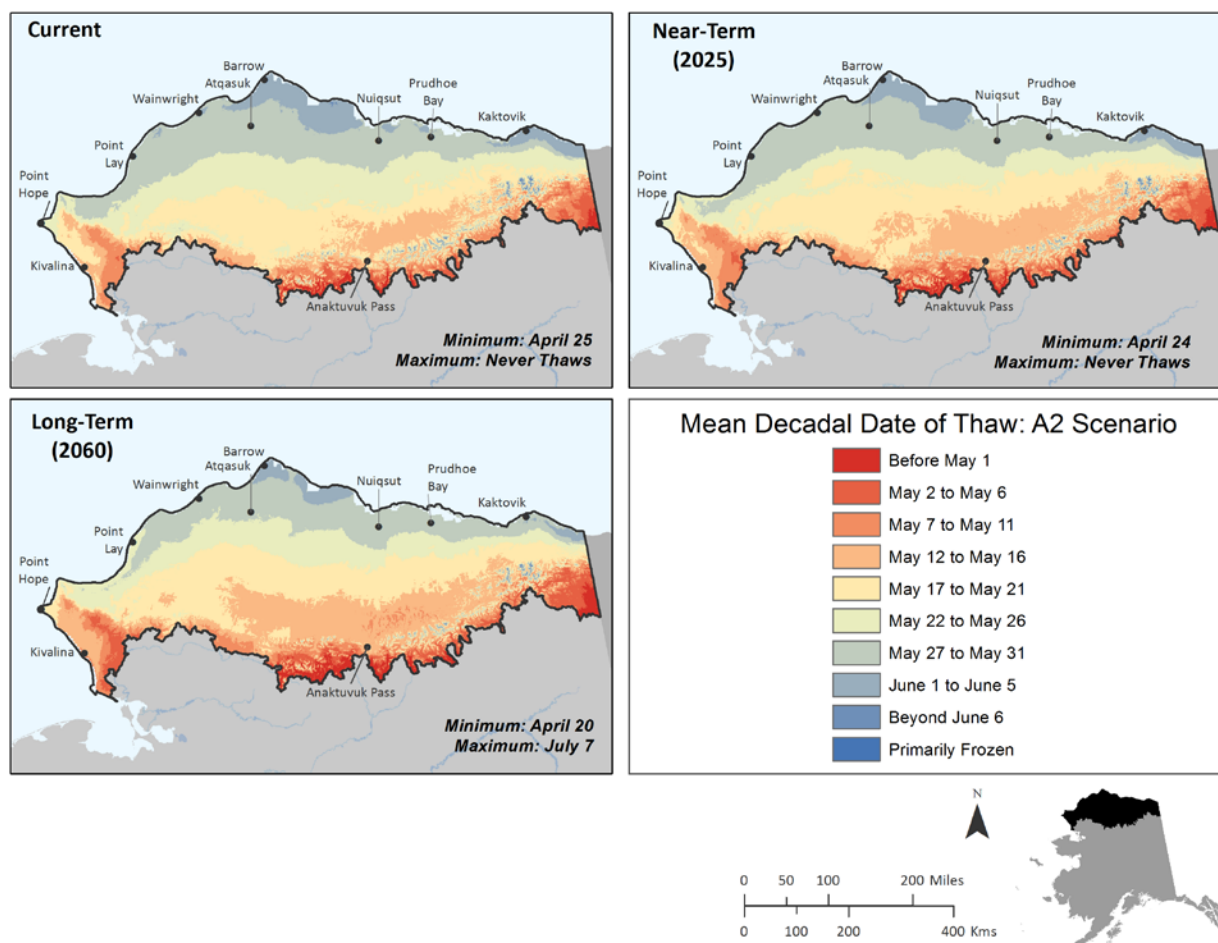


Figure C-16. Projected Day of Thaw.

Table C-9. Projected date of thaw and freeze and change in warm season length by community (based on mean values for local watersheds (5th level HUC).

Community	Date of freeze			Date of thaw			Warm season length (# of days)			
	2010s	2020s	2060s	2010s	2020s	2060s	2010s	2020s	2060s	Change
Anaktuvuk Pass	13-Sep	14-Sep	20-Sep	14-May	12-May	10-May	123	125	133	10
Kaktovik	20-Sep	20-Sep	30-Sep	2-Jun	1-Jun	30-May	110	112	122	12
Kivalina	2-Oct	3-Oct	10-Oct	15-May	13-May	11-May	140	142	151	11
Point Hope	1-Oct	2-Oct	11-Oct	23-May	21-May	19-May	131	134	145	14
Point Lay	23-Sep	24-Sep	3-Oct	30-May	29-May	27-May	116	118	129	13
Barrow	19-Sep	20-Sep	2-Oct	3-Jun	2-Jun	31-May	109	110	124	15
Nuiqsut	21-Sep	21-Sep	29-Sep	31-May	30-May	29-May	113	114	124	11
Atkasuk	20-Sep	21-Sep	28-Sep	28-May	27-May	26-May	115	117	126	11
Prudhoe Bay	20-Sep	21-Sep	28-Sep	29-May	28-May	27-May	114	116	124	10
Wainwright	21-Sep	22-Sep	4-Oct	31-May	30-May	28-May	113	116	129	16

Cliomes

Although this report offers detailed discussion of climate change modeling outputs in terms of changes in discrete climate variables (i.e., monthly temperature and precipitation), it can be difficult to view the impacts of 24 discrete variables on a complex system without additional synthesis. This section attempts to simplify this effort by offering maps and tables that depict all 24 of these variables grouped into clusters in order to define regions with strong similarities in overall climate, and to project how these clusters may shift over time (Figure C-17).

Climate-biomes or “cliomes” were initially created as part of a collaborative effort between multiple agencies in Alaska and Canada (SNAP 2012). At the core of the project was the idea of using progressive clustering methodology, existing land cover classifications, and historical and projected climate data to identify areas likely to undergo ecological pressure, given climate change. Cliome results and data are intended to serve as a framework for research and planning by land managers and other stakeholders with an interest in ecological and socioeconomic sustainability.

Using climate projection data from SNAP and input from project leaders and participants (SNAP 2012), the project modeled projected changes in cliomes. The eighteen cliomes used in this project were identified using the combined Random Forests™ and Partitioning Around Medoids (PAM) clustering algorithms, which are defined by 24 input variables (monthly mean temperature and precipitation) used to create each cluster.

This overview focuses on defining these clusters as characteristic climate types, rather than as vegetation –linked or biome-linked groupings, although managers may be able to draw some inferences with regard to the latter. Linking climate change to changes in vegetation, biomes, and ecosystems is complex. While climate is ultimately a key determinant of biome characteristics, biomes are also shaped

by spatial features (e.g., mountains and rivers). Moreover, time-delays occur between changing climate and changing biomes due to the mechanics associated with processes such as disturbance propagation and seed dispersal. Shifts in vegetation are occurring in the far north along with changes in climate; however, it is also clear that, the connections between these two variables are neither equal nor obvious. Studies show that shifts may occur as unstable, nonlinear threshold shifts rather than as smooth transitions (Scheffer et al. 2012).

Cliomes, as depicted in Figure C-18, are climate groupings that land managers – or others familiar with the current landscape – may associate with broad species assemblages or communities, although they are not directly biologically linked. However, projections from the Cliomes model serve as indicators of potential change and/or stress to ecosystems, and can be used as a proxy for the magnitude of climate change expected.

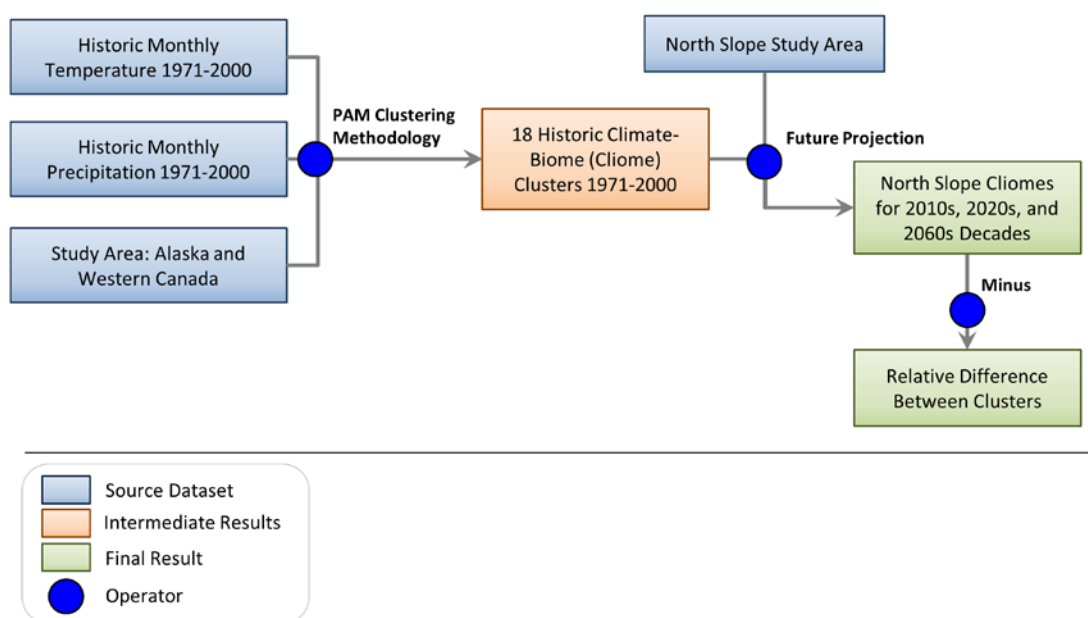


Figure C-17. Process model for cliome shift methodology.

A projected shift from one cliome to another indicates that systems are likely to experience stress due to significant changes in climate conditions. As a result, species assemblage may change, in terms of the percentages of various vegetation types. A one-to-one correspondence between these is not expected, since they represent very different ways of looking at habitat. As an example, land managers might understand what was meant by an “Interior Arctic Alaska climate” and might be familiar with the types of vegetation to expect in such a zone, although that vegetation would differ at a micro-scale according to slope, aspect, soil drainage, and other factors. Likewise, land managers would understand what was meant by “tussock tundra”. The two categories would certainly overlap, but are representative of different elements.

Cliome Descriptions

Cliomes were spatially compared to four different land cover designation systems (see SNAP 2012) to help define the prevailing conditions of each cliome. In addition, each cliome can be viewed in terms of the 24 input variables used to create it, and described in these terms.

The cliomes found in the North Slope study area are described as follows:

- **Cliome 1:** This cliome is the coldest and driest of all 18, with a mean annual temperature of -15.9°C , an above-freezing season length of only 73 days, and a total of 61 mm and 55 mm or rainfall-equivalent in the below-freezing and above-freezing months, respectively. As such it can be considered a high arctic desert. With only 216 Growing Degree Days (GDD) and 116 mm of precipitation, this cliome can be expected to be severely limited in the vegetation it can support.
- **Cliome 3:** This arctic cliome has an unfrozen season length of 110 days. Mean annual precipitation is 198 mm. The cold dry climate in this cliome is vegetation-limiting. However, less harsh winters might be expected to allow encroachment by species that would not be adequately cold-tolerant to survive in Cliome 1.
- **Cliome 4:** This cliome is characterized by dry conditions similar to other arctic cliomes. Winters are similar to cliome 3, with mean January temperatures of about -28°C . Summer temperatures are warmer however, with July mean temperatures of about 10°C , more than 5°C warmer than Cliome 1 and 2°C warmer than Cliome 3.
- **Cliome 5:** This arctic cliome shows some interior influences, with cold winters, late springs, and relatively warm summers. Precipitation is greater than in any of the preceding cliomes (about 20% higher than Cliome 4 and more than 100% higher than Cliome 1), and precipitation totals 243 mm annually. Fall precipitation accounts for most of this difference. The above freezing season is a mere 114 days, shorter than that of Cliome 4 and equivalent to that of Cliome 3.
- **Cliome 6:** This cliome displays slightly warmer and wetter interior-arctic climate conditions, with 12% more precipitation than Cliome 5 and a mean annual temperature 2°C warmer (-9.9°C). While the number of ice-free days in this cliome compares to that in Cliome 4, it exceeds all preceding cliomes in GDD by at least 18%, with a total of 945.
- **Cliome 7:** This climate grouping can be considered the first of the sub-arctic or boreal cliomes. These all feature summer temperatures that average about 10°C for all three summer months and precipitation exceeding 10 mm for all months. Warmer summers in these cliomes mean that about 60% of total precipitation is expected to fall as rain. Of cliomes 7-12, Cliome 7 has the coldest winters and driest summers), with January temperatures and July precipitation not dissimilar to Cliomes 3-6. However, spring comes much sooner in this cliome and, yielding April and May temperatures roughly 5°C warmer than any of the first six cliomes, and 1260 GDD.
- **Cliome 8:** This cliome experiences summers similar to those in Cliome 7, with mean temperatures of $9-13^{\circ}\text{C}$ typical in June-August, but milder winters and sharply increased precipitation, particularly in summer months. Variability in rainfall is high, however, and this cliome is still dry compared to most temperate regions. The mean annual temperature is -4.0°C , almost 4°C warmer than any of the preceding cliomes. Permafrost is still likely to be present

over most of this cliome, although given temperature variability, permafrost may be discontinuous.

- **Cliome 9:** Winters in Cliome 9 are slightly warmer than Cliomes 7 and 11 and slightly cooler than Cliomes 8 and 12. It is among the driest of the boreal cliomes, particularly in fall and winter, meaning that projected snowfall is very low — only 107 mm of rainwater equivalent for all below-freezing months combined. On the other hand, its GDD of 1349 is greater than all preceding cliomes by a margin of 89 GDD.
- **Cliome 10:** This cliome has distinctly milder winters than neighboring cliomes. It is distinct from others in the boreal zone by virtue of much higher precipitation (561 mm annually), the majority of which falls during winter. These characteristics are typical of coastal zones, with ocean-moderated seasons and significantly more rain than interior regions. Mild winters yield a longer period of above-freezing days (173), but GDD is lower than that of Cliome 9, due to cooler temperatures in June, July, and August. Notably, a mean annual temperature of -0.8°C suggests that permafrost in this cliome would be discontinuous.
- **Cliome 11:** This cliome matches Cliome 7 very closely for mean monthly temperatures, summer season length, and GDD, with cold winters (January mean = -28.4°C) and warm summers (July mean = 13.7°C). However, the rainfall and snowfall patterns of Cliome 11 are very different from that of Cliome 7 and other similar cliomes, with 390 mm annually as compared to 280 mm. Given that many boreal systems are water-limited during the growing season, we might expect to see distinct vegetative differences based on this difference in available moisture.
- **Cliome 12:** Cliome 12 is only marginally wetter than Cliome 11 in terms of precipitation, but is warmer in every month by a margin of $1\text{--}4^{\circ}\text{C}$. This cliome experiences an average of 1587 GDD, far exceeding all preceding cliomes, although the unfrozen season is slightly shorter than that of the ocean-moderated Cliome 10, and the mean annual temperature, at -4.0°C , is colder than that of Cliome 10. Nonetheless, we would expect some small areas of discontinuous permafrost within this cliome, e.g. on south-facing slopes.
- **Cliome 13:** Although contiguous with cliomes 11, 12, and 14 in our baseline maps, this cliome is distinct for its much colder conditions in all months and seasons — a difference that can be explained by elevation. The characteristics of Cliome 13 are typical of high-elevation zones, with unfrozen season length and GDD in the range of arctic cliomes 4-6. However, precipitation in Cliome 13 — 586 mm annually — is much higher than that of these cold arctic cliomes, and more similar to coastal Cliome 10. Unlike Cliome 10 however, the majority of precipitation in Cliome 13 is expected to fall as snow.

Although all 18 cliomes were created so as to be as mathematically disparate as possible, the difference between mean values (“medoids”) for any two clusters varies. A shift from cluster 1 to cluster 18 represents the greatest possible change, within the confines of the original clustering area. If this difference is defined by a value of approximately 1.0, the relative magnitude of all other possible shifts can be compared in terms of that difference. Table C-10 shows the relative distances between clusters.

Table C-10. Relative difference between 18 cliomes (climate clusters).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1																		
2	0.07																	
3	0.14	0.08																
4	0.17	0.11	0.05															
5	0.14	0.07	0.05	0.07														
6	0.19	0.12	0.07	0.06	0.05													
7	0.25	0.18	0.12	0.08	0.11	0.06												
8	0.36	0.29	0.22	0.19	0.23	0.17	0.13											
9	0.30	0.23	0.16	0.13	0.17	0.12	0.06	0.08										
10	0.49	0.42	0.35	0.32	0.35	0.30	0.26	0.13	0.21									
11	0.30	0.23	0.16	0.13	0.16	0.10	0.05	0.10	0.06	0.21								
12	0.38	0.32	0.25	0.21	0.25	0.19	0.13	0.07	0.09	0.16	0.09							
13	0.33	0.26	0.19	0.17	0.21	0.18	0.16	0.14	0.14	0.19	0.13	0.14						
14	0.61	0.54	0.47	0.44	0.47	0.41	0.36	0.24	0.32	0.11	0.31	0.24	0.27					
15	0.51	0.44	0.37	0.34	0.37	0.31	0.26	0.14	0.21	0.15	0.21	0.13	0.23	0.18				
16	0.47	0.40	0.33	0.29	0.33	0.27	0.22	0.13	0.17	0.15	0.17	0.08	0.17	0.19	0.07			
17	0.98	0.91	0.84	0.81	0.85	0.79	0.75	0.63	0.70	0.49	0.70	0.63	0.65	0.39	0.56	0.58		
18	0.58	0.51	0.44	0.41	0.44	0.39	0.33	0.22	0.28	0.16	0.30	0.21	0.32	0.17	0.10	0.17	0.53	

Cliome Results

Partially clipped results of this modeling effort are shown in Figure C-18 and Figure C-19. As can be seen in this figure, the North Slope study area has only a small subset of the eighteen clusters used in the original project. Cliomes are projected to shift over time, with northward movement of most cliomes. The colder arctic Cliome 3 along the north coastal margin is expected to decline substantially in area by the 2060s, while the more interior arctic Cliome 6 maintains a similar area, while shifting north. In addition to this northward movement, projections show notable increases in Cliomes 10, and 12 and decreased in Cliomes 3, 4, 5, and 9. Areas currently in Cliome 8, mostly in the western portion of the study area, are expected to shift to Cliome 10, a relatively damper and milder cliome with discontinuous rather than continuous permafrost. Reduction of cliomes 3, 4, and 5 in the far north suggests that much of the areas with the harshest, driest Arctic climates may become milder, with slightly warmer and wetter interior-arctic climate conditions. In general, greater changes in cliomes are expected in the Brooks Range and western Foothills ecoregions.

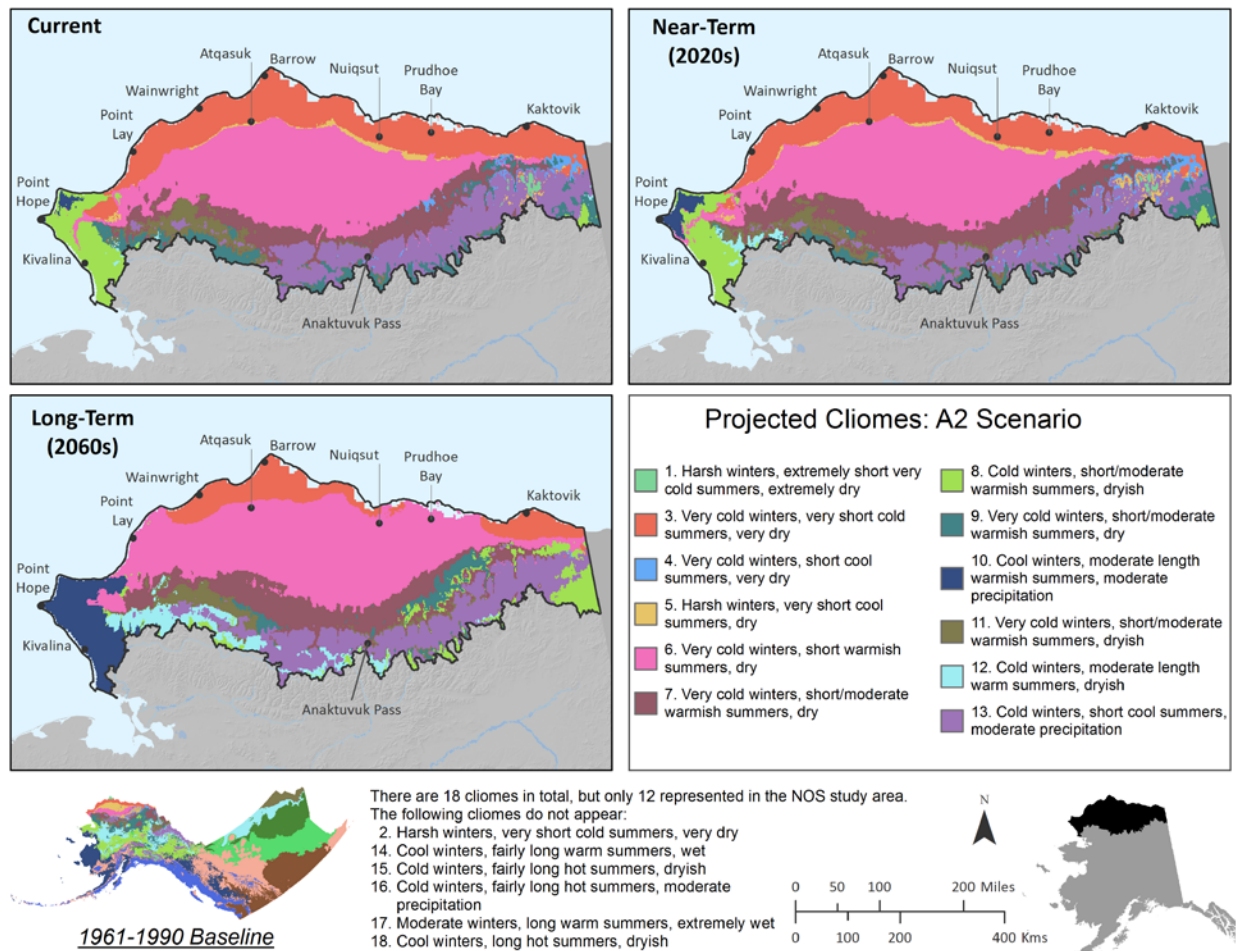


Figure C-18. Projected cliome shifts over time. Each color group represents an area of similar climate characteristic based on 12 month patterns of precipitation and temperature.

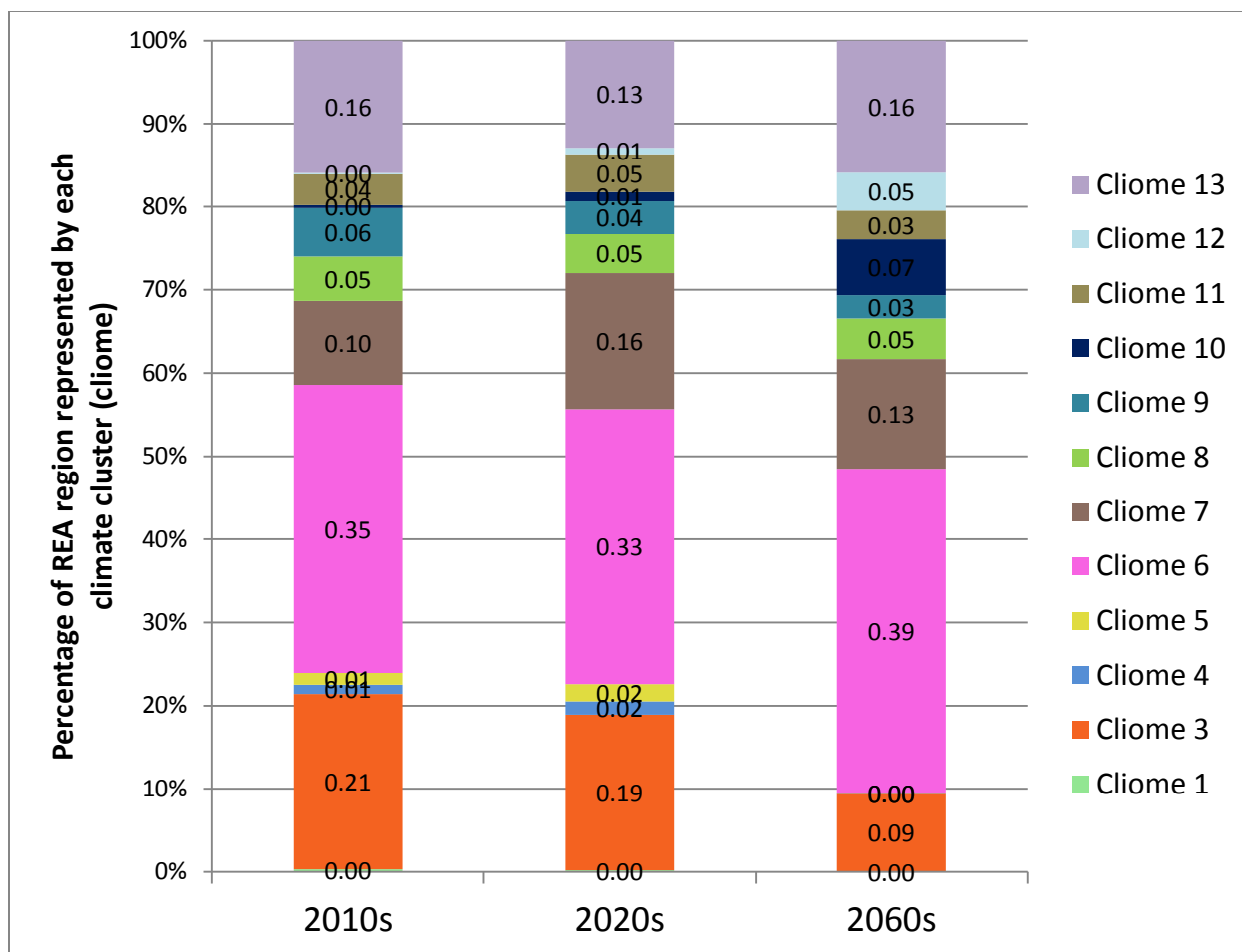


Figure C-19. Change in climate cluster (cliome) percentage over time across the REA.

1.4. Applications

In many cases, changing climate is likely to affect human uses of the landscape, either indirectly (e.g., as ecosystem changes alter subsistence harvest patterns) or directly (e.g., as longer summer seasons make travel across snow or ice impossible during shoulder seasons). For example, the slow freeze-up of rivers has lengthened the interval of unsafe river ice in autumn, an important season for operating fishing nets under river ice. Such changes are addressed in the sections of this report dedicated to social issues.

The cliomes approach (see Section C-2) offers a starting point for managers and researchers to develop more specific predictions regarding how vegetation and important habitats may change in the future. Additionally, projected shifts from one cliome to another may not be reflected by immediate vegetation change, but rather by increased stress to existing ecosystem components, or disconnections and asynchronies among species currently on the landscape and those best evolved for newly emerging weather patterns in the region. Projected shifts are likely to increase vulnerability at the landscape level. Conversely, areas projected to undergo little or no cliome change become candidates for climate refugia (Hope et. al 2013).

1.5. Limitations

While the baseline climate data used in SNAP's downscaling procedure (e.g. PRISM and CRU data) have been peer reviewed and accepted by the climate research community (Daley et al. 2008, New et al. 2002), and the downscaling has been validated by directly comparing twentieth century scenario (20C3m) GCM data to actual weather station data (WRCC 2011) and summarizing the outcomes in a validation report (SNAP 2008); nonetheless, data inputs, as well as subsequent analysis and interpretation, includes multiple sources of error. Thus uncertainty is inherent in all climate projections. Much of this uncertainty is addressed by using averages across multiple models and across decades. However, as described above, uncertainty with regard to human behavior leads to inherent uncertainty in selecting the most appropriate emissions scenario. Regardless, all projections must still be understood in the context of the methodology.

As described under Temperature sensitivity analysis and Precipitation sensitivity analysis, climate results are deemed significant when trends are outside the range of variability that can be expected within and between models. While between-model variability does not capture all sources of uncertainty, it serves as a reasonable proxy for model uncertainty.

Temperature

Available temperature data at the scale, coverage, and resolution necessary for this analysis were monthly rather than daily resolution. This imposed limitations, especially when trying to relate temperature change to communities, species and habitats. Extreme temperatures and temperature variability from day to day are sometimes more important variables than mean temperatures, when predicting the effects of heat stress, cold tolerance, and resilience.

Precipitation

Precipitation data do not differentiate between rain and snow; nor is any direct metric available for snowpack depth, rain on snow events, or other parameters that directly or indirectly impact certain CEs. However, we were able to add snow day fraction to the climate-related datasets in order to partially meet this need.

Snow-Day Fraction

Although the equations provide a reasonable fit to the data, model evaluation demonstrated that some weather stations are consistently less well described by regional models than others. Very few weather stations with long records are located above 500 m elevation in Alaska, so the equations were developed primarily from low-elevation weather stations, and thus may not be appropriate in the mountains. Finally, these equations summarize a long-term monthly relationship between temperature and precipitation type that is the result of short-term weather variability. In using these equations to make projections of future snow, we are assuming that these relationships remain consistent over time.

Day of Freeze and Day of Thaw

Day of freeze, day of thaw, and season length do not correspond to metrics of freeze and thaw for particular waterbodies or soils. Varied lag times apply. Change in DOF or DOT can reasonably be used as a rough proxy for related measures, however. For example, if DOT is projected to shift one week later in the area surrounding a wetland or lake, it is reasonable to expect that the wetland or lake would lose its ice cover approximately one week later, as compared to current averages. If land managers or local residents have a feel for what is “normal” then such metrics can prove useful for future decision-making.

Cliomes

Time lags can be expected between changes in climate and associated changes in vegetation. In some cases, climate-driven vegetation shift is limited by physical boundaries such as mountains or rivers. Hydrologic change based on warming temperatures may be driven more by thawing permafrost associated soil dynamics than directly by changes in air temperature.

Additional Data Gaps

Climate data, while relatively fine-scale, do not always match the scale of phenomena that affect CEs. Moreover, available data do not always match, in scale or detail, the climate-related attributes and indicators most closely linked to particular fine or coarse CEs. Even when linkages between CEs and climate variables are relatively clear, in many cases, the literature does not provide precise information regarding threshold values.

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2. Fire

This portion of the Technical Supplement addresses fire as a change agent in the North Slope study area and is primarily concerned with assessing how patterns of fire may change over time, as driven by changes in climate. This section links directly to the Climate Change section; climate modeling methods described there are not repeated here. Although some fires may be started by humans, fire is considered a non-anthropogenic CA here.

This section describes landscape-level model outputs, including the data, methods, and analysis. It touches briefly on feedbacks between fire and other CAs (climate and permafrost), though further information on these interactions can be found in the applicable sections. Here we also provide an overview of potential impacts to CEs, although further information on these interactions can be found in sections devoted to CEs.

MQ AB 1	Is the fire regime changing on the North Slope and what is the likely future fire regime (or range of regimes) based on climate projections and current knowledge of the relationships between climate and fire?
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2.1. Introduction to Fire

As a change agent, fire can be specifically examined in terms of changing fire dynamics on the landscape, driven by changing climate and ecosystem feedback loops. Fire is a natural, although relatively rare, feature of the landscape in this region and part of historical and existing ecosystem processes (Rocha et al. 2012).

Fire disturbance plays a key role in the interplay between vegetation and changing environmental conditions, because fire initiates cycles of secondary succession and creates opportunities for landscape change at the level of biomes or ecosystems (Johnstone et al. 2010, Higuera et al. 2011). A system that has been primed for change by shifting climate may not change gradually, but rather in a threshold shift after a fire event, as a novel successional pathway replaces the previous pathway.

Not only does fire play a crucial role in governing ecosystem processes in interior and arctic Alaska (Johnstone et al. 2010), but, driven by warming summers, fire appears to already be increasing in frequency (Kelly et al. 2013) and intensity (Genet et al. 2013), resulting in altered ecosystems and processes (Wolken et al. 2011). However, complex feedbacks between increased fire frequency, resulting vegetation shifts, and subsequent fire are poorly understood and require further study (Balshi et al. 2009). Data on vegetative regrowth after tundra fires are particularly scarce, given the relative rarity of such fires (Barrett et al. 2012). Moreover, tundra fires may be poorly recorded and understood (Jones et al. 2013).

Connecting Past, Present, and Future

Assessment of fire as a change agent includes both modeling potential change in fire behavior and linking that potential change to possible associated changes in landscapes and ecosystems. Thus, the effort may include several key components:

1. Analysis of spatially and temporally explicit historical fire data in order to ascertain what fire patterns have created the current assemblages of post-fire-successional landscapes, and can thus be considered historically typical;
2. Review of pertinent literature looking at post-fire succession and linking fire with landscape change and ecosystem change, allowing connections to be made between data on fire return intervals and data on ecosystem characteristics;
3. Creation and analysis of model outputs of projected fire frequency by region, on a spatial basis and/or a percentage/risk basis.
4. Direct modeling of potential vegetation change within the fire model.

The Role of Modeling

Modeling and analysis of changes in fire frequency can shed light on multiple aspects of future ecosystem function, including human/landscape interactions. Fire modeling allows for some assessment of impacts on terrestrial habitats (with mammals and birds secondarily influenced by habitat change, for example), including fire-induced changes in broad habitat types (deciduous forest, black spruce forest, white spruce forest, graminoid tundra, shrub tundra, wetland tundra, and snow/ice/rock), as well as in mean age or successional stage of each cover type. Fire modeling does not allow for assessment of impacts to most vegetation at the species level or at the level of fine-scale vegetation classifications used elsewhere in the project.

Fire modeling can also be coupled with analysis of fire impacts on permafrost, based on qualitative information from the literature on the influence of fire on permafrost, as is presented, in a limited way, here. This analysis does not include fire-linked spatial predictions of permafrost (see Section C-3).

2.2. Methods

Fire was modeled using ALFRESCO (Alaska Frame-based Ecosystem Code: Rupp et al. 2000; Barrett et al. 2012; Joly et al. 2012) in the larger context of a projected future fire regime and its effects on major vegetation classes. Climate projections, past fire history, and current vegetation patterns were used to model patterns of fire frequency across the landscape (Figure C-20).

ALFRESCO simulates the responses of vegetation to transient climatic changes. The model assumptions reflect the hypothesis that fire regime and climate are the primary drivers of landscape-level changes in the distribution of vegetation in the circumpolar arctic/boreal zone. Furthermore, the model assumes that vegetation composition and continuity serve as a major determinant of large, landscape-level fires.

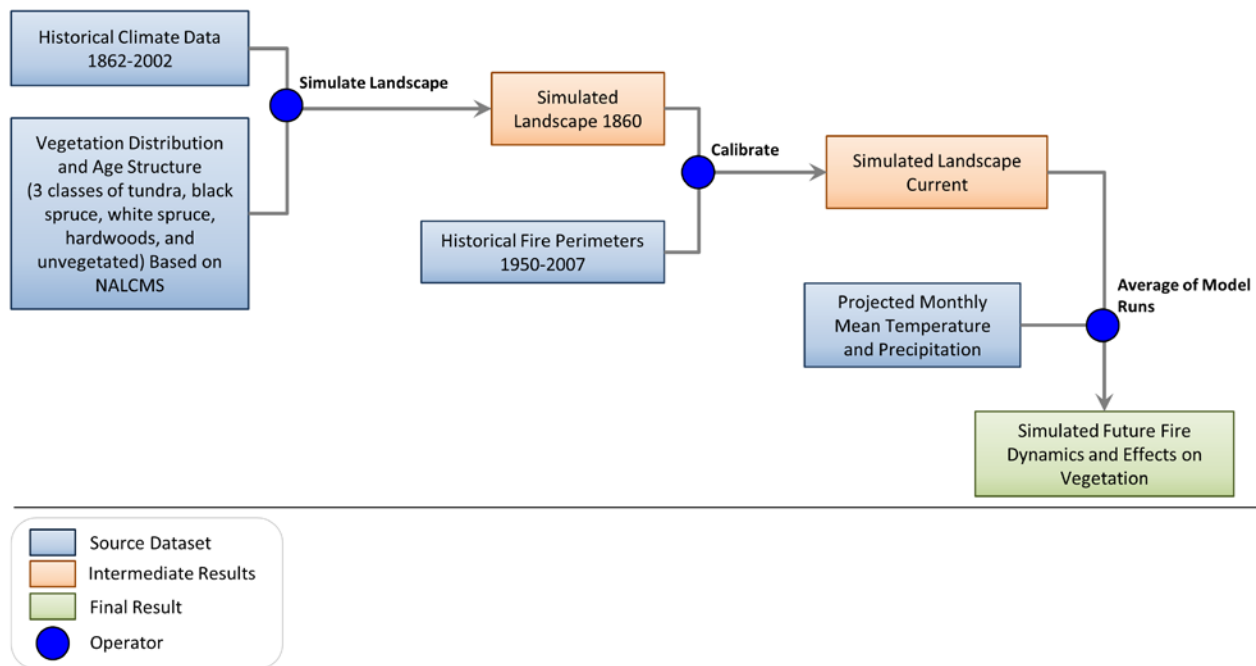


Figure C-20. Process model of ALFRESCO fire simulation methodology.

ALFRESCO operates on an annual time step, in a landscape composed of 1×1 km pixels. The model simulates a range of ecosystem types, including graminoid tundra, wetland tundra, shrub tundra, black spruce forest, white spruce forest, deciduous forest, and grassland-steppe.

ALFRESCO does not model fire behavior but rather models the empirical relationship between growing-season (May–September) climate (e.g., average temperature and total precipitation) and total annual area burned (i.e., the footprint of fire on the landscape). ALFRESCO was also used to model the changes in vegetation flammability that occur during succession through a flammability coefficient that changes with vegetation type and stand age (i.e., succession) (Chapin et al. 2003).

The model focuses on system interactions and feedbacks. The fire regime is simulated stochastically and is driven by climate, vegetation type, and time since last fire (Rupp et al. 2007). ALFRESCO employs a cellular automaton approach, where simulated fire may spread to any of the eight surrounding pixels. “Ignition” of a pixel is determined as a function of the flammability value of that pixel and starts are assigned randomly (Rupp et al. 2002). The flammability of each pixel is a function of vegetation type and age, meaning that ignitions will be concentrated in pixels with the highest fuel loads and the driest climate conditions. Fire spread depends on the flammability (i.e., fuel loading and moisture) of the receptor pixel. Some pixels, e.g., non-vegetated areas and large water bodies, do not burn and thus serve as fire breaks. Anthropogenic suppression activities were not simulated.

ALFRESCO has been calibrated using available literature regarding burn rates and stand compositions in a variety of forested land cover classes (Rup et al. 2007). More recently, it has been calibrated for tundra classes (Walker 2000; Jones et al. 2013; Breen et al. 2013). The model is calibrated through use of a “spinup” period of 1,000 years of simulated fire history, in order to match outputs as closely as possible

to historical fire patterns. The model parameters derived during this spinup period are then used to create future projections.

ALFRESCO outputs do not include fire severity (for which there is no data) or exact spatial/temporal predictions of future fires, since the stochastic nature of fire starts and fire behavior is better represented via averaging outputs across multiple model runs. Outputs also do not include historical or projected lightning, except in broadly qualitative terms based on literature review, due to lack of consistent past data and lack of reliable models for projected lightning.

ALFRESCO allows for vegetation shifts between classes (rather than merely between successional stages) after fire, as well as shifts when fire has not occurred. Vegetation parameters are described below under “Model Outputs”.

Model Stochasticity and Implementation

The “distribution” of varying fire frequencies is intimately tied to vegetation, as well as climate, but also involves stochastic elements such as the exact location of lightning strikes and the variability of weather patterns at finer time-scales than are available to modelers. Thus, multiple individual model runs yield varying results. Therefore, fire distributions per se were not modeled; rather we modeled projected average fire frequency and extent across the landscape. We also modeled some key changes in vegetation patterns and distribution. Some results are presented by ecological sub-regions derived from Nowacki et al. 2001. Outputs included projected average area burned per year across the target time periods and fire return intervals on a regional and sub-regional basis.

Table C-11. Source datasets used in the analysis of fire as a CA for the North Slope REA.

Dataset Name	Data source
Stochastic ALFRESCO model runs, mean of five separate models and 100+ runs, based on SNAP climate projections; vegetation outputs	SNAP
Stochastic ALFRESCO model runs, mean of five separate models and 100+ runs, based on SNAP climate projections; fire frequency outputs	SNAP
Fire Scar Map	BLM

Model Inputs

ALFRESCO inputs include elevation, slope, aspect, and slope complexity data obtained from the PRISM climate group, as well as climate and vegetation variables (Table C-11). Historical climate data are derived from Climate Research Unit (CRU) data, and projected climate data are derived from SNAP downscaled climate projections.

ALFRESCO is calibrated based on fire history grids (0 = no fire, 1 = fire) produced directly from the BLM Alaska Fire Service database and the Canadian National Fire Database. They are simply a 1 x 1 km raster representation of their fire history polygon database that can be obtained

from <http://fire.ak.blm.gov/predsvcs/maps.php> and http://cwfis.cfs.nrcan.gc.ca/en_CA/datamart. Fire history data is very unreliable before ~1950 in Alaska, so earlier data are not used.

ALFRESCO vegetation classes are based on NALCMS 2005 land cover map (<http://landcover.usgs.gov/nalcms.php>) although these vegetation classes are significantly re-grouped and adapted to meet the needs of the model, as described below. Original NALCMS classes found in the North Slope study area are:

1. Temperate or sub-polar needleleaf forest

Forests generally taller than 3 meters and more than 20% of total vegetation cover. This type occurs across the northern United States, Canada and mountainous zones of Mexico. The tree crown cover contains at least 75% of needle-leaved species.

2. Sub-polar taiga needleleaf forest

Forest and woodlands with trees generally taller than 3 meters and more than 5% of total vegetation cover with shrubs and lichens commonly present in the understory. The tree crown cover contains at least 75% of needle-leaved species. This type occurs across Alaska and northern Canada and may consist of treed muskeg or wetlands. Forest canopies are variable and often sparse, with generally greater tree cover in the southern latitude parts of the zone than the north.

5. Temperate or sub-polar broadleaf deciduous forest

Forests generally taller than 3 meters and more than 20% of total vegetation cover. These occur in the northern United States, Canada and mountainous zones of Mexico. These forests have greater than 75% of tree crown cover represented by deciduous species.

6. Mixed Forest

Forests generally taller than 3 meters and more than 20% of total vegetation cover. Neither needleleaf nor broadleaf tree species occupy more than 75% of total tree cover, but are co-dominant.

8. Temperate or sub-polar shrubland

Areas dominated by woody perennial plants with persistent woody stems less than 3 meters tall and typically greater than 20% of total vegetation. This class occurs across the northern United States, Canada and highlands of Mexico.

10. Temperate or sub-polar grassland

Areas dominated by graminoid or herbaceous vegetation, generally accounting for greater than 80% of total vegetation cover. These areas are not subject to intensive management such as tilling, but can be utilized for grazing. This class occurs across Canada, United States and highlands of Mexico.

11. Sub-polar or polar shrubland-lichen-moss

Areas dominated by dwarf shrubs with lichen and moss typically accounting for at least 20% of total vegetation cover. This class occurs across northern Canada and Alaska.

12. Sub-polar or polar grassland-lichen-moss

Areas dominated by grassland with lichen and moss typically accounting for at least 20% of total vegetation cover. This class occurs across northern Canada and Alaska.

13. Sub-polar or polar barren-lichen-moss

Areas dominated by a mixture of bare areas with lichen and moss that typically account for at least 20% of total vegetation cover. This class occurs across northern Canada and Alaska.

14. Wetland

Areas dominated by perennial herbaceous and woody wetland vegetation which is influenced by the water table at or near surface over extensive periods of time. This includes marshes, swamps, bogs, mangroves, etc., either coastal or inland where water is present for a substantial period annually.

15. Barren Lands

Areas characterized by bare rock, gravel, sand, silt, clay, or other earthen material, with little or no vegetation present regardless of its inherent ability to support life. Generally, vegetation accounts for less than 10% of total cover.

16. Urban and Built-up

Areas that contain at least 30% or greater urban constructed materials for human activities (cities, towns, transportation, etc.).

17. Water

Areas of open water, generally with less than 25% cover of non-water cover types. This class refers to areas that are consistently covered by water.

18. Snow and Ice

Areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.

For the purposes of ALFRESCO, classes were regrouped as shown in Table C-12.

Table C-12. Grouping of ALFRESCO land cover classes according to their North American Land Cover (NALCMS) class.

NALCMS category	ALFRESCO class
1. Temperate or sub-polar needleleaf forest	Spruce
2. Sub-polar taiga needleleaf forest	
5. Temperate or sub-polar broadleaf deciduous forest	Deciduous
6. Mixed Forest	
8. Temperate or sub-polar shrubland	Shrub tundra
10. Temperate or sub-polar grassland	Graminoid tundra
11. Sub-polar or polar shrubland-lichen-moss	Shrub tundra
14. Wetland	Spruce (bog)
15. Barren Lands	No vegetation
16. Urban and Built-up	
17. Water	
18. Snow and Ice	

The newly derived coastal wetland layer was further reclassified into wetland tundra or no vegetation using mean growing season temperate threshold of 6.5°C. Temperate or sub-polar shrubland was reclassified into deciduous or shrub tundra using the same threshold. Sub-polar or polar grassland-lichen-moss and Temperate or sub-polar grassland were reclassified into graminoid tundra or grassland based on this threshold. Spruce was divided into black or white spruce based on aspect (north vs. south facing slopes, respectively).

Vegetation transitions within ALFRESCO

Transitions from one vegetation class to another within ALFRESCO can occur post-fire, but can also be driven by climate variables, even in the absence of fire. The potential transitions, as well as the climate factors or other events that drive these transitions, are shown in Figure C-21.

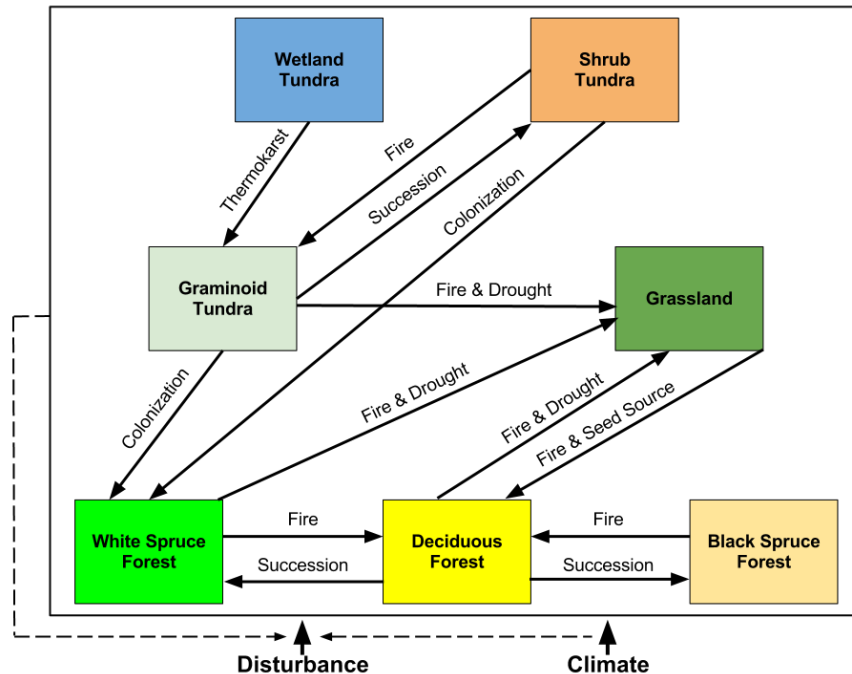


Figure C-21. Schematic of the ALFRESCO model showing potential vegetation transitions.

The variables and thresholds that drive these transitions are complex, and form a large part of the core of the code that is ALFRESCO (Epstein et al. 2004a; Epstein et al. 2004b). SNAP is working on making that code publicly available in its entirety. However, some general rules are summarized below. Transition rules between classes are built into ALFRESCO code, and calibrated based on hundreds of stochastic model runs. It should be noted that some of these transitions occur only post-fire, while others are climate driven, and can occur at other times, depending on complex algorithms described below. All transition arrows NOT labeled “fire” represent transitions that may occur at times other than post-fire (at age zero). Most transitions are probabilistic, based on the variables that govern the model as a whole and each cover type in particular.

In this model all Deciduous Forest is an early seral stage of White Spruce Forest or Black Spruce Forest. When any spruce pixel burns, the default trajectory is for that pixel to revert to Deciduous Forest (age zero). The transition back to spruce is variable, and differs from run to run, but might typically occur at about 40 years. White spruce pixels may instead start a new trajectory as grassland, under drought conditions (Roland et al. 2013).

Transitions from graminoid to shrub tundra are governed by multiple factors, including time since fire, mean July temperature, and Summer Warmth Index (SWI). SWI is defined as the sum of mean monthly temperatures > 0°C. Although tundra fire can promote shrub expansion (Racine et al. 2004), shrubification can also occur without fire (Naito and Cairns 2015).

The northern boundary of low shrub tundra occurs at approximately the 10°C mean July isotherm or an SWI of 20 (Walker 2000), while the greatest biomass of shrubs occurs at sites with a SWI of 25-30 (Walker et al. 2003). ALFRESCO is calibrated such that post-fire, shrub tundra transitions to graminoid

tundra. Approximately 30 years post-fire, graminoid tundra may transition to shrub tundra. If a fire occurred, there is a 5% chance of transition to shrub tundra (Racine et al. 2004). If a fire has not occurred, there is only a 1% chance of transition. When graminoid tundra transitions to shrub tundra, age is reset to 0.

Colonization of tundra by spruce is a two-step process consisting of seed dispersal and seedling establishment. Key variables include time since fire, burn severity, availability of seed sources, seed dispersal, July temperature, and SWI. These factors are calibrated using historical data to yield chances of transition of up to about 5%. During the past 50 years, 2.3% of treeless areas have been converted from tundra to forest in Alaska (Chapin et al. 2005). Therefore, it is reasonable to extrapolate that ~5% of tundra could transition to spruce over 100 years.

Fires of moderate to high severity are assumed to kill some or all trees, and to reset tundra-forest transition. Burn severity in ALFRESCO is a function of fire size and topographic index. Burn severity is a scalar, where low severity fire is “1”, low canopy, low surface moderate fire is “2” and kills 50% of established trees, and high canopy, low surface fire “3” or high canopy, high surface fire “4” kill 100% of trees.

Arctic treeline occurs at approximately the 12°C mean July isotherm and a SWI of 35 (Walker 2000). Thus, transition from tundra to forest begins with the establishment of seeds, which can occur if the decadal moving average July temperature is $\geq 12^{\circ}\text{C}$ and $\text{SWI} \geq 35$ and if a white spruce seed source exists within 1 km. The amount of seed dispersed is a function of the distance from the seed source; most dispersal is near the source and long distance dispersal is rare (Clark 1998).

Growth rate (accumulation of basal area) is a function of climate: Normal distribution bounded by 12-18°C, which are the mean July isotherms for the northern and southern limits of boreal forest (Larsen 1980). In the absence of fire, or after a fire of only low severity, basal area is assumed to continue to accrue, leading to eventual transition, White spruce average growth rate is 1 mm/year (Szeicz and MacDonald 1996), graminoid or shrub tundra transitions to white spruce forest when basal area is 20 m²/ha (Greene and Johnson 1999).

2.3. Results

Fire History

Historical data on fire in this region are available from the BLM, with reliable data starting in 1950. Given that remote sensing, GIS, and other fire detection and mapping technology has improved radically during the past 75 years, historical analysis of fire are limited to assessing overall size of burn scars. Although burn severity is a very important factor in determining long-term ecological outcomes post-fire, detailed information on patchiness of burns or severity of burns is largely unavailable.

In Figure C-22, fires are grouped by decade, from the 1940s to the 2010s (the current decade being incomplete). As can be clearly seen from this map, fires are extremely rare in the North Slope study area, except in the southernmost portions. Moreover, they are highly variable in both size and location,

and some decades saw markedly more fire activity than others. A single outlier – the 2007 Anaktuvuk Fire – is by far the largest tundra fire ever recorded in Alaska (Jones et al. 2009). This variability adds to the challenge of fire modeling, and means that model outputs must be viewed on a broad rather than a fine scale, both temporally and spatially. Nonetheless, it has been documented that tundra fires are indeed becoming more common (Rocha et al. 2012).



Figure C-22. Fire history, 1940 to the present, as shown via the BLM online map tool available at <http://fire.ak.blm.gov/predsvcs/maps.php>

Fire Frequency and Return Interval

Overall, ALFRESCO predicts increased fire frequency across the North Slope study area, although fire is likely to remain absent – or almost absent – from some sub-regions, as shown in Figure C-23. Indeed, most of the predicted fire activity is in the small portion of the study area to the south of the Brooks Range, and thus technically not part of the North Slope.

The fact that the ALFRESCO model predicts a higher rate of burn in the early part of this century than in the later part, for both the Western Brooks Range and Western Foothills is likely to be the result of the extremely high variability in the model, which reflects the high variability in the actual incidence of fire in the Arctic. In other words, variability is an artifact of the stochastic nature of the model. However, it should also be noted that when an area burns, it is less likely to burn again for many decades thereafter. Thus, if fire increases for a period of time, it will eventually stabilize at a new, shorter fire return interval. Historical evidence from the boreal region suggests that such a regime can persist under warm conditions (Kelly et al. 2013).

Most of the North Slope study area is likely to remain relatively free of fire, although sporadic tundra fires may occur in all sub-regions. Figure C-23 offers a spatial representation of relative flammability; this map is based on data from 1000 ALFRESCO runs from 2000 to 2100, and thus does not represent changing flammability over time, but rather the high variability of flammability across space given current and future vegetation patterns. Areas identified as highly flammable are all located south of the crest of the Brooks Range.

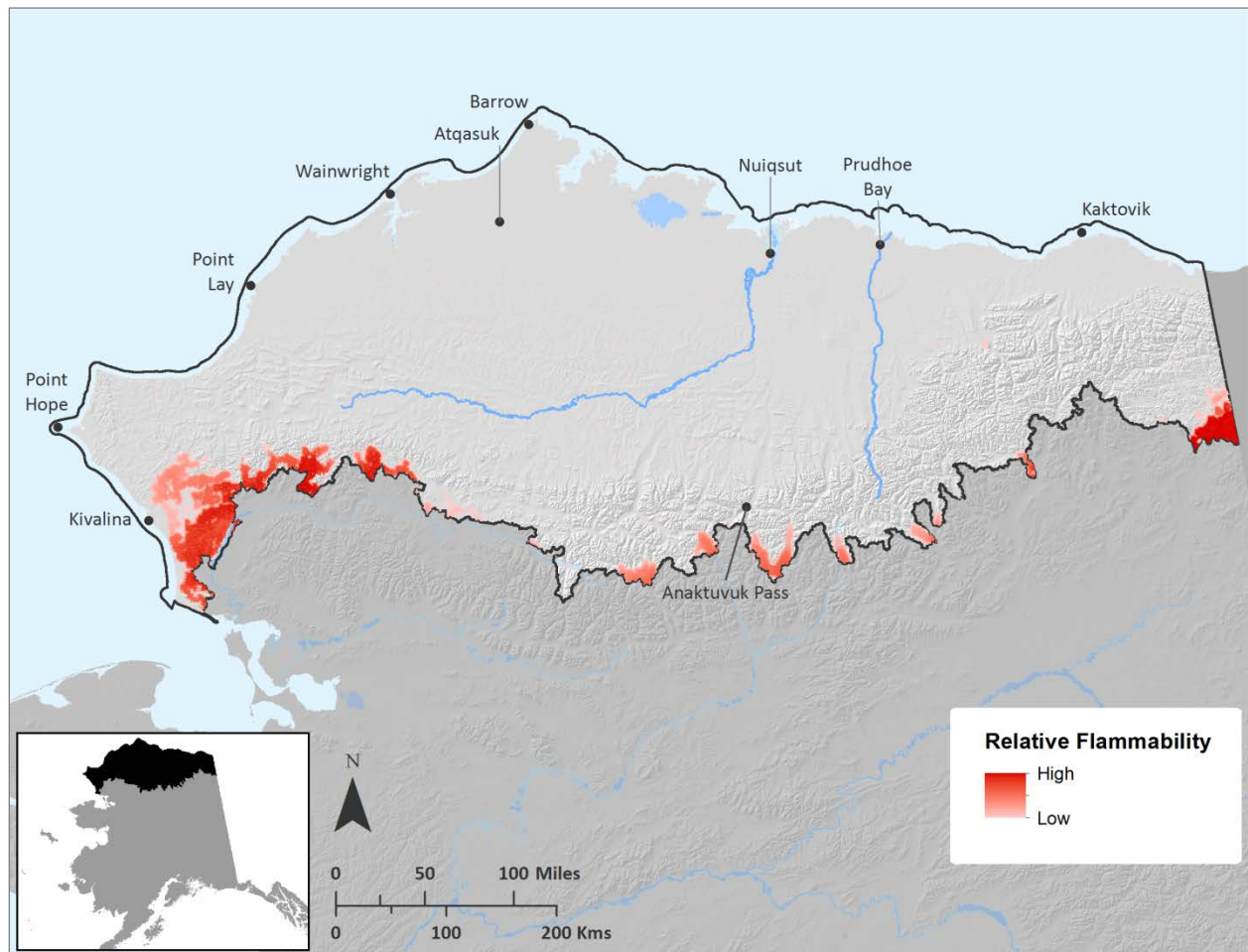


Figure C-23. Projected relative flammability across the North Slope study area.

Although the time period of interest for this project is current (2010s) to 2060s, a wider range of data (1900 – 2090) is displayed in Figure C-24 in order to better demonstrate long-term trends. Note that in some sub-regions, fire is almost absent.

While clear trends are evident for total area burned, the data are highly variable, and r-squared values are relatively low. This is to be expected, based on several factors intrinsic to fire in general, and fire in this region in particular. First, historical data support the fact that fires occur with extremely high inter-annual variability in terms of fire size and area burned, and are notoriously hard to predict. Second, much of the North Slope study area is tundra. Fire frequencies are exceedingly low in such areas

historically, meaning that a few rare large fires can further skew data, even when averaged across 1000 model runs.

Despite this high variability, model outputs do suggest that land managers could expect increased fire risk in coming decades in four of the sub-regions. While single events cannot be predicted, this anticipated increase may affect both humans and wildlife.

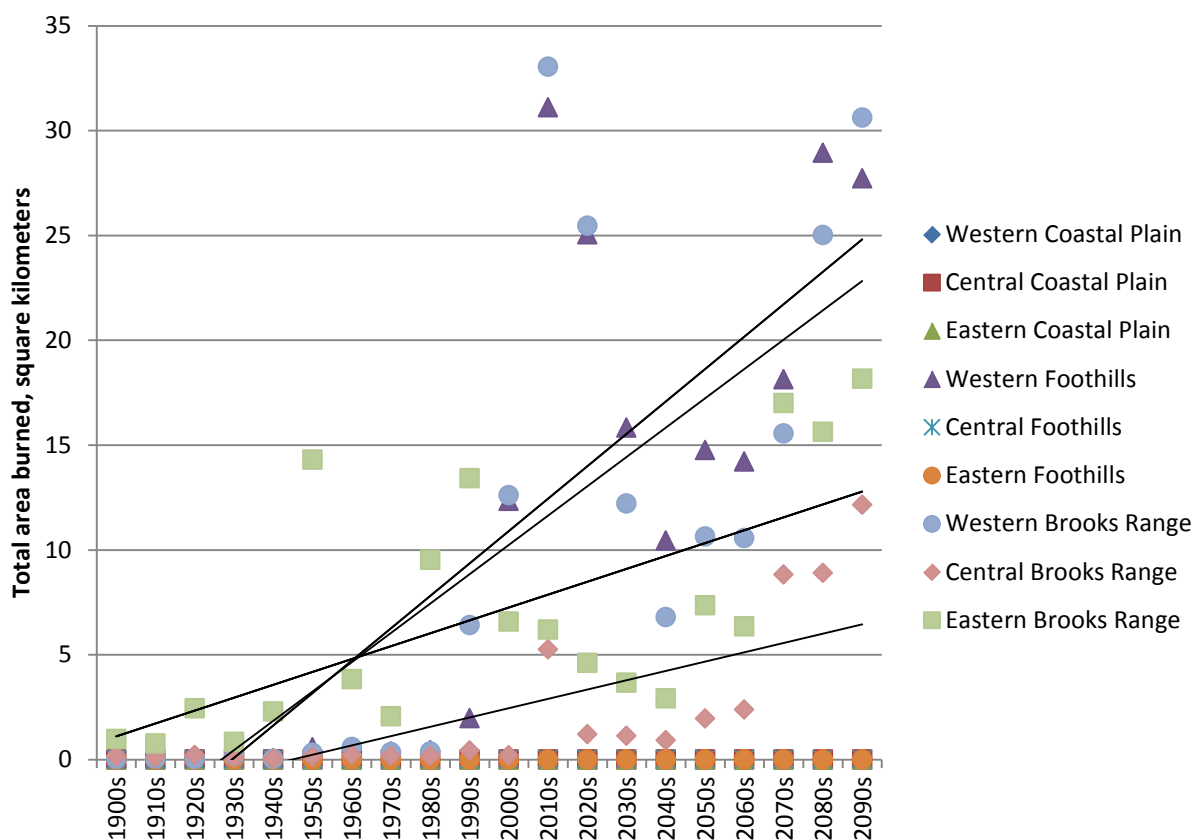


Figure C-24. Modeled mean decadal area burned (by sub-region) 1900s to 2090s.

Vegetation Change

Vegetation composition currently varies across the nine sub-regions in the North Slope study area. Some areas are expected to see little change, while in others, there may be a marked increase in shrub tundra and a corresponding decrease in graminoid tundra, and/or an increase in deciduous forest and white spruce, as shown in Table C-13. While the relative proportions of each vegetation class differs widely from region to region, ALFRESCO projects a general trend toward more shrubby vegetation. This can be attributed to climate-driven shrubification (Raynolds et al. 2013; Beck and Goetz 2011; Figure C-25 through Figure C-27).

Analyses suggest that changes in fire frequency on Alaska's landscapes may be driven at least as much by climate-induced changes in vegetation as they are by climate-induced changes in fire frequency

(Starfield and Chapin 1996). ALFRESCO is directly linked to both climate and vegetation, and is also capable of modeling shifts in between-fire and post-fire trajectories of succession that are climate-derived.

Table C-13. Projected vegetation percentages (based on ALFRESCO fire modeling) by sub-region.

Sub-region	Vegetation	2010s	2020s	2060s
Western Coastal Plain	Shrub tundra	15	15	15
	Graminoid tundra	75	75	75
	Wetland tundra	10	10	10
Central Coastal Plain	Shrub tundra	1	1	2
	Graminoid tundra	74	73	72
	Wetland tundra	26	26	26
Eastern Coastal Plain	Shrub tundra	1	1	1
	Graminoid tundra	89	89	89
	Wetland tundra	9	9	9
Western Foothills	Forest (all classes)	3	3	4
	Shrub tundra	67	67	68
	Graminoid tundra	29	29	28
	Wetland tundra	1	1	1
Central Foothills	Shrub tundra	73	74	75
	Graminoid tundra	27	26	25
	Wetland tundra	0	0	0
Eastern Foothills	Forest (all classes)	0	0	0
	Shrub tundra	31	31	33
	Graminoid tundra	69	69	67
	Wetland tundra	0	0	0
Western Brooks Range	Forest (all classes)	84	84	80
	Shrub tundra	53	54	58
	Graminoid tundra	43	42	35
Central Brooks Range	Forest (all classes)	30	30	29
	Shrub tundra	33	34	37
	Graminoid tundra	59	58	55
Eastern Brooks Range	Forest (all classes)	3	3	4
	Shrub tundra	29	29	33
	Graminoid tundra	69	68	63

The interplay between fire, vegetation, and other ecosystem variables is complex. Feedbacks with changes in soil thermal dynamics are not clear-cut, but are discussed further in the permafrost section of this report. Transitions may be abrupt following fire. Near tree-line, forests do not decline gradually in tree cover, but may instead shift rapidly into a sparse woodland or treeless state (Scheffer et al. 2012). The reverse may also be true as tree-line shifts upward in elevation and northward with climate change. Lloyd et al. (2007) posits that the northernmost range of black spruce may reflect an interaction between fire and substrate, such that the species may be restricted to sites that burn sufficiently to allow for establishment via sexual reproduction.

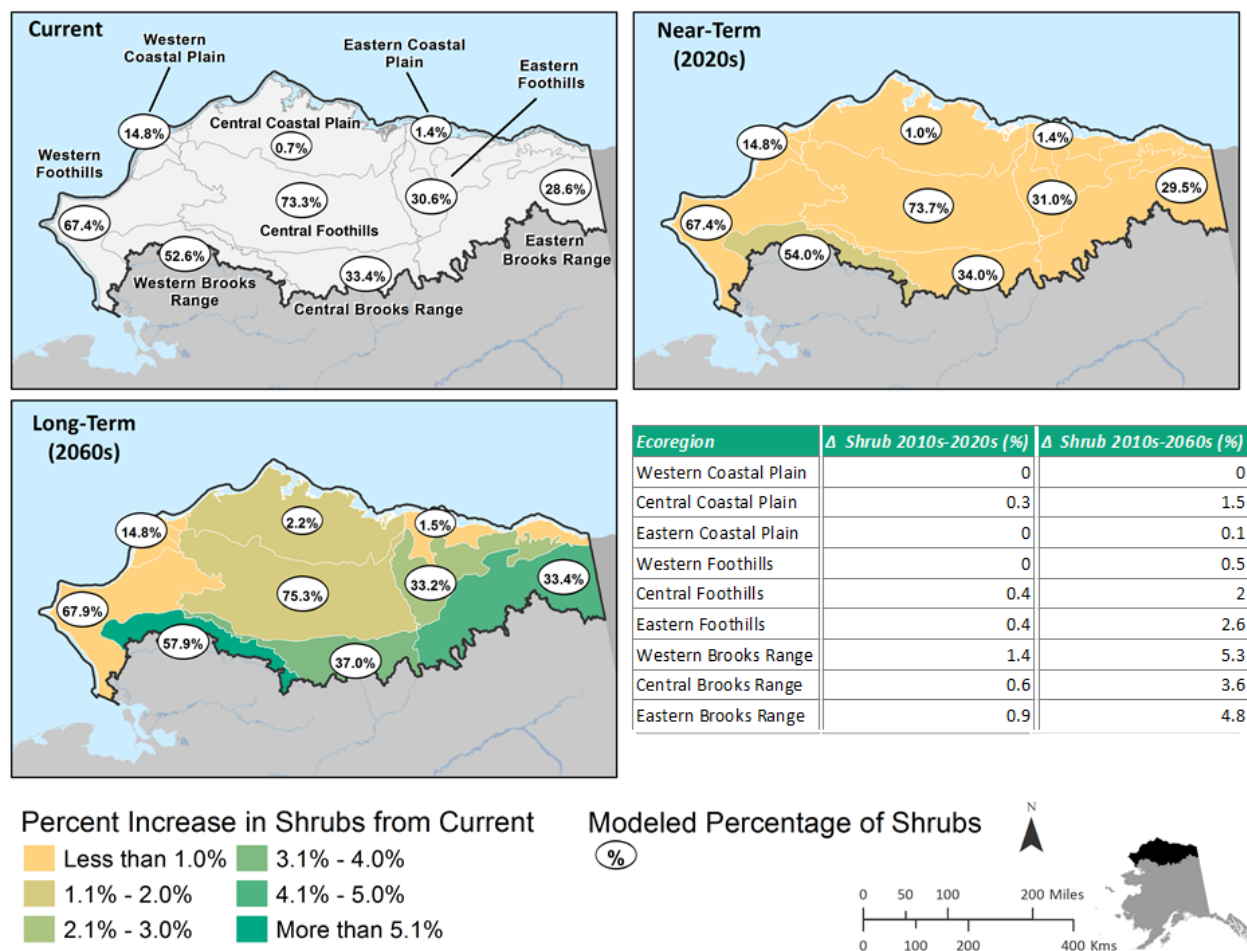


Figure C-25. Projected changes in shrub tundra by ecological sub-region.

In tundra systems, although frequent fires are expected, data on long-term effects are limited. Examination of post-fire succession in the North Slope study area suggests that partial replacement of tundra by shrub-dominated ecosystems is likely, with some modest shifts in treeline (Barrett et al. 2012, Breen et al. 2013). Tundra fires, when coupled with ongoing climate change, can trigger new successional pathways, thus facilitating the invasion of tundra by shrubs (Jones et al. 2013).

The literature shows that marked ecosystem change has been occurring in recent decades, particularly with regard to decreases in terricolous lichen ground cover and biomass. These changes are attributed

to disturbance by caribou and reindeer and to warming climate, which in turn affects fire and plant growth (Joly et al. 2009, Joly et al. 2012).

Since lichens are the primary winter food source for caribou herds in Alaska, decreases in lichen cover or a shift from lichens to shrubs may have strong repercussions for subsistence users. This relationship is further explored in Section G and Section H.

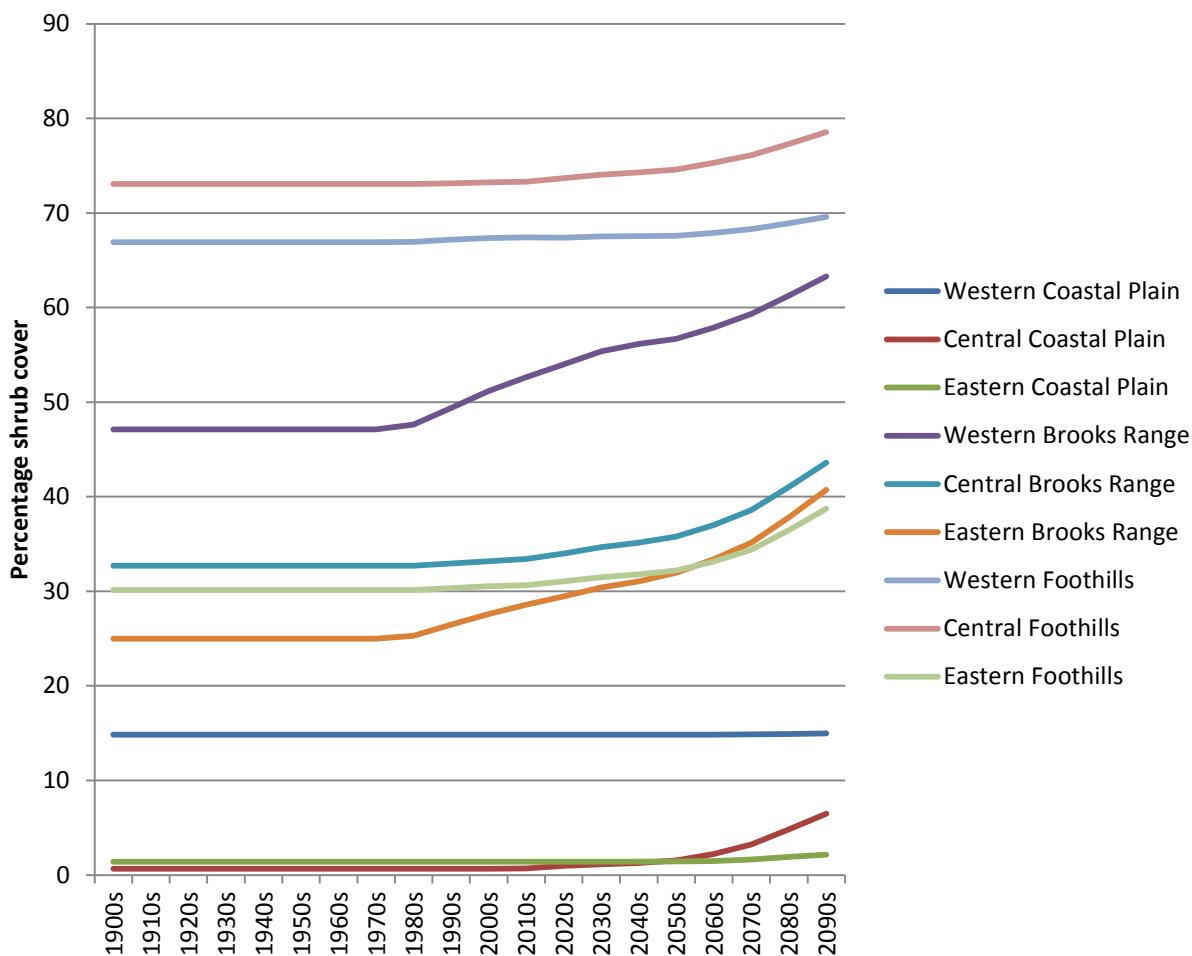


Figure C-26. Projected changes in shrub tundra by sub-region.

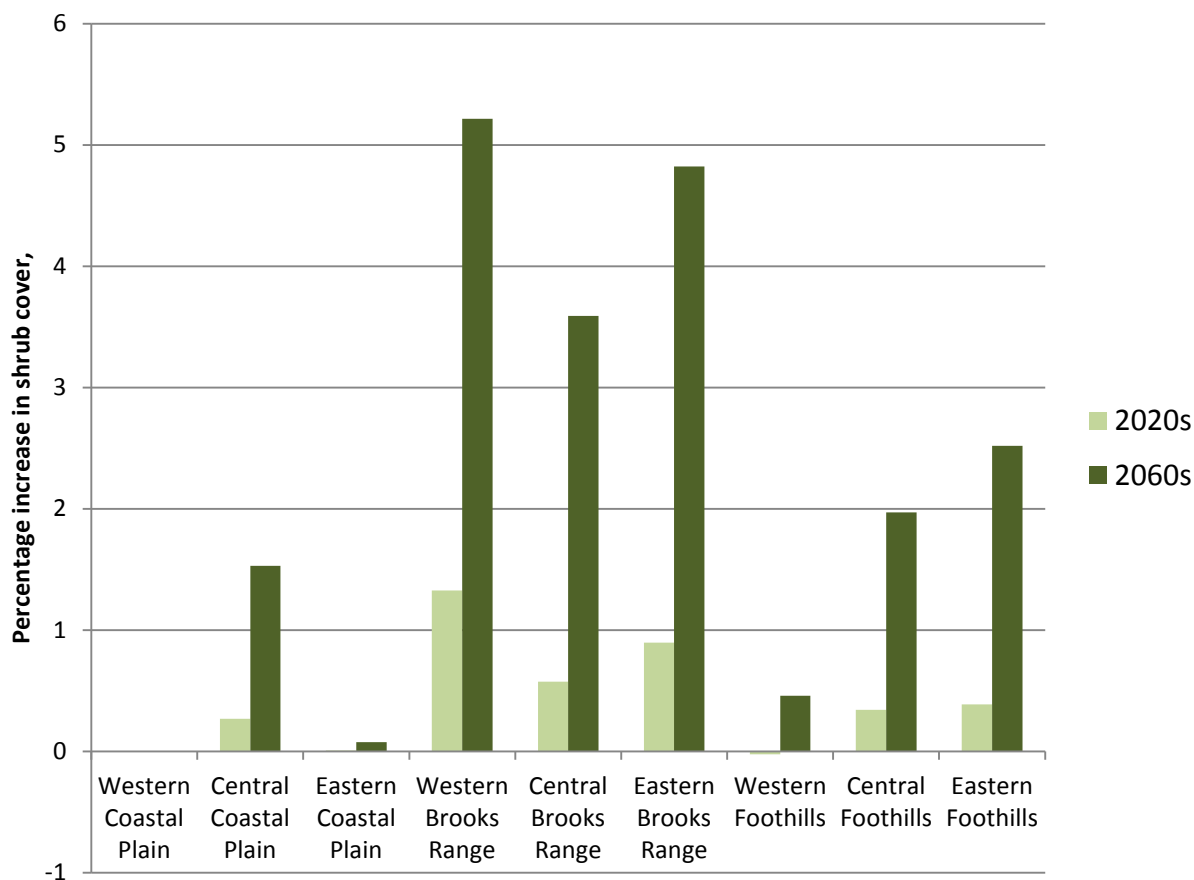


Figure C-27. Projected shrub expansion by sub-region in the near-term and long-term. (Increase, as compared to the current decade, in percentage total land cover).

2.4. Limitations

ALFRESCO is not suited to fine-scale analysis at either a temporal or spatial level, due to the stochastic nature of its outputs. Thus, interpretation should be considered more broadly, in terms of trends over time, rather than in terms of specific fire behavior at particular sites. Given that data were not available regarding fire severity, either in the historical data or via model outputs, we could not analyze the impacts of this important factor.

Because the ALFRESCO model is not directly linked to either the climate/vegetation (cliomes) model or the permafrost model used in this assessment, feedback between vegetation, fire, and soil thermal dynamics could be considered only qualitatively, not quantitatively.

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3. Soil Thermal Dynamics (Permafrost)

This portion of the Technical Supplement addresses permafrost and associated thermokarst as a Change Agent in the North Slope study area, and is primarily concerned with assessing how soil thermal dynamics may change over time. As such, it links directly to the Climate Change section of the Technical Supplement; climate modeling methods described there are not repeated here.

This section describes landscape-level model outputs, including the data, methods, and analysis involved in this modeling. It touches briefly on feedbacks between permafrost and other CAs (fire and climate). Additional information on these feedbacks can be found in the applicable sections. This section also provides an overview of potential impacts to Conservation Elements. Further information on these interactions can be found in Sections G, H, I, and J.

MQ AB 2	How will permafrost change spatially and temporally over the next two decades?
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3.1. Introduction to Soil Thermal Dynamics

Loss of permafrost, which is associated with thermokarst in ice-rich soils, can have profound effects on ecological systems as well as on human uses and economic endeavors (Stephani et al. 2014; Callaghan et al. 2004; Hong et al. 2014). Permafrost presence and absence cannot be directly assessed except by measurements (e.g., soil cores); modeling of soil thermal dynamics, however, can help estimate the state of permafrost across larger areas.

Assessments of soil thermal dynamics include estimates, based on models that use multiple input datasets, of existing and projected active layer thickness and mean annual ground temperature at 1 m depth, both at 1 km resolution. Based on these modeling efforts, it is possible to perform a regional-scale assessment of areas in which permafrost thaw may occur, and areas in which thaw is less likely (Luo et al. 2014).

Based on this permafrost modeling a broad regional assessment of the potential effects of these changes on hydrology is also possible. Such models can also be used to estimate the influence of permafrost thaw and associated hydrologic change on terrestrial habitats, with qualitative discussion of potential impacts, particularly with reference to hydrologic change (Frey and McClelland 2009).

Similarly, the influence on aquatic habitats can be estimated, including qualitative discussion of potential impacts to hydrologic change. However, such assessments do not include specific predictions at the pixel level of permafrost thaw or associated hydrologic change, impacts on terrestrial habitats, or influence on aquatic habitats.

Historical and current conditions

Current permafrost conditions vary within the North Slope study area (Kittel et al. 2011). Although permafrost dominates most of the landscape, in some areas permafrost is discontinuous, particularly

around water bodies, in coastal areas, and in the western coastal portions of the ecoregion. Coastal thaw has serious ramifications in terms of erosion, which can affect both human infrastructure and ecosystems (Kittel et al. 2011; Barnhart et al. 2014). Permafrost on the North Slope of Alaska has warmed 2.2–3.9°C (4–7°F) over the last century (Mars and Houseknecht 2007; NASA 2015).

Even in areas of continuous permafrost, active layer thickness varies on both a micro and macro level across the landscape. Indeed, the freezing and thawing of the active layer and the associated hydrologic dynamics are driving forces in shaping much of the topography of this region. Small differences in active layer thickness that are associated with changes in patterns of drainage (as in regions of topographic variability) can yield large differences in land cover and vegetation (McMichael et al. 1997). As such, soil thermal dynamics can be viewed as both a Change Agent and a Conservation Element in Arctic Alaska.

3.2. Methods

Soil thermal dynamics modeling for this project included permafrost modeling and secondary modeling of potential thermokarst. The thermokarst model, as will be described below, is based on outputs from the core permafrost model, as well as data on soils and ice content.

GIPL Permafrost Model

The main components of the permafrost model are represented in the general ecosystem conceptual model. As shown in Figure C-28, permafrost modeling incorporated both SNAP climate projections and the Geophysical Institute Permafrost Lab (GIPL) permafrost model for Alaska, which relies on spatial data related to soil, vegetation, and climate. GIPL model outputs include mean annual ground temperature (MAGT) and active layer thickness (ALT), linked by appropriate algorithms, as described below.

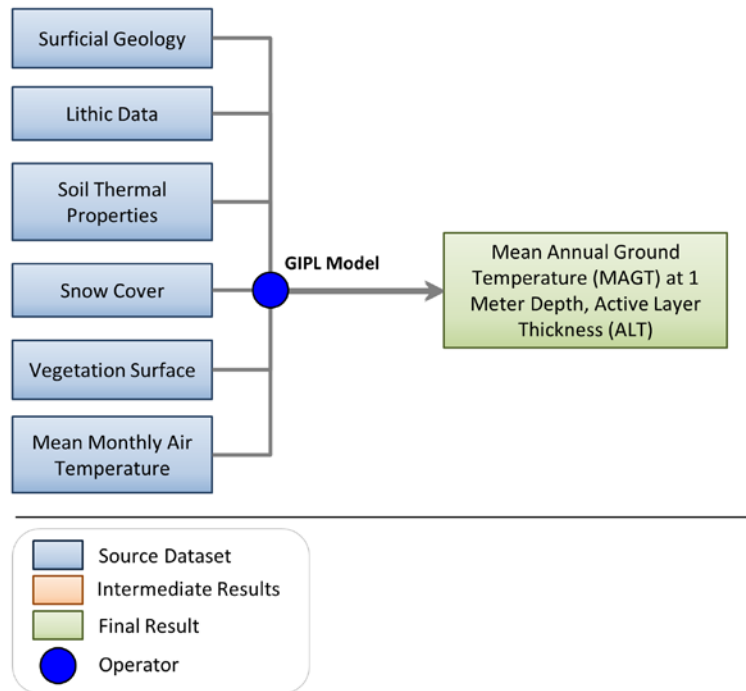


Figure C-28. Process model of permafrost modeling techniques.

The Geophysical Institute Permafrost Laboratory (GIPL) model was developed specifically to predict the effect of changing climate on permafrost. GIPL model is a quasi-transitional, spatially distributed equilibrium model for calculating the active layer thickness (the thin layer above permafrost that seasonally freezes and thaws) and mean annual ground temperature.

The GIPL permafrost model calculates permafrost extent, mean annual ground temperature, mean annual ground surface temperature, active layer thickness, snow warming effect, and thermal onset from data inputs relating to the geologic and soil properties, effects of ground insulating snow and vegetation layers, and predicted changes in air temperature and annual precipitation. The primary outputs used in this assessment are the mean annual ground temperature (MAGT) at one-meter depth, and the active layer thickness (ALT).

MAGT is a relatively straightforward metric, since temperatures below freezing represent permafrost and those above freezing indicate unfrozen ground. However, it should be noted that extensive deeper permafrost may still occur in areas projected to be thawed at one meter. Such deep permafrost has smaller impacts on vegetation and draining than shallow permafrost.

ALT is a more complex metric, in that it represents two different outputs: the depth of seasonal (summer) thaw, for areas with permafrost at one meter depth, and the maximum depth of seasonal (winter) freezing, for areas that are free of permafrost. In other words, for areas without shallow permafrost: how deeply does frost penetrate by the end of each winter? And for areas with shallow permafrost: how deeply does the thaw penetrate by the end of each summer? Since these two datasets are mutually exclusive, they can be shown on a single map. Both have strong implications for what plant

species can persist in a given area. Together, these properties (MAGT and ALT) delineate the presence and local extent of permafrost. The model is ground-truthed and validated using cores from around the state.

Algorithms to determine MAGT and ALT are dependent on calculations of the insulating properties of varying ground cover and soil types, as well as on climate variables, and vary spatially across the landscape at a resolution of 1 km. Surface vegetation data are derived from the Global Land Cover Characteristics Database, Version 2.0 (<http://edc2.usgs.gov/glcc/glcc.php>). Land cover categories used to define organic matter thermal properties are derived from the National Atlas of the United States of America, 1985, and soil types come from the U.S. Geological Survey 1997 Surficial Geology Map of Alaska. Outputs provide a general approximation of areas likely to undergo some degree of thaw and associated hydrologic changes.

The GIPL permafrost model provides a general and coarse approximation of permafrost conditions across the landscape. Despite the best available ground-truthing and validation of the GIPL model and the most reliable available climate projections from SNAP data, uncertainty is inherent in both models, and in the linked modeling of climate-induced permafrost change. Fine-scale changes in permafrost conditions at a scale of meters rather than kilometers cannot be accurately predicted by the GIPL model. For example, the GIPL model cannot predict the formation of specific thermokarst features or the drainage of specific lakes from permafrost thaw. However, the predicted changes in permafrost at the landscape level indicate where such phenomena will be most likely.

IEM Thermokarst Model

The Integrated Ecosystem Modeling Project is an ongoing collaborative effort aimed at creating a model that integrates vegetation succession, disturbance, hydrology and permafrost dynamics for Alaska and portions of western Canada by coupling the ALFRESCO fire and succession model, the biogeochemical Terrestrial Ecosystem Model (TEM), and the GIPL permafrost model. Spatial assessment of thermokarst risk is one output of this combined model.

The IEM thermokarst model relies on the hypothesis that thermokarst occurs in lowland peatland with ice-rich permafrost sites. Lowlands were defined as areas surrounding local elevational minima with a slope less than or equal to four degrees. These lowlands with minimal slopes encompass the majority (92.4%) of wetlands on the North Slope (Whitcomb et al. 2009).

The thermokarst model also relies on ice content maps and permafrost condition maps derived from Jorgenson et al. (2008) and Brown et al. (1998) and a map of histels from Hugelius et al. (2013). The model assesses the percent cover among histels in lowland and permafrost in areas with high to moderate ice content, and assigns an ice content class to all pixels, where pixels in the high to moderate ice class have a 100% chance of thermokarst, areas in the low or variable ice content class have a 10% chance of thermokarst, and areas in the null (glacier or unfrozen) category are not subject to thermokarst.

As such, outputs from the thermokarst model reflect the risk of thermokarst in the case of permafrost thaw (or partial thaw). Thus, when coupled with outputs of the GIPL model, these outputs can shed light on which areas of change may be most dramatically affected at the regional and landscape level. Datasets used in both of the above models are listed in Table C-14.

Table C-14. Source datasets for the analysis of permafrost and associated thermokarst as a CA in the North Slope REA.

Dataset Name	Data Source
GIPL model outputs for mean annual ground temperature at one meter depth (MAGT) based on GIPL core model and SNAP monthly temperature projections, CMIP3/AR4, A2 emissions scenario, 5-model average, 771m resolution, decadal means, 2010s, 2020s, 2050s, 2060s.	SNAP/GIPL
GIPL model outputs for active layer thickness (ALT) based on GIPL core model and SNAP monthly temperature projections, CMIP3/AR4, A2 emissions scenario, 5-model average, 771m resolution, decadal means, 2010s, 2020s, 2050s, 2060s.	SNAP/GIPL
Thermokarst risk model outputs.	SNAP/GIPL/IEM

3.3. Results

In general, results show warming of permafrost, but little loss of permafrost at one meter depth across the North Slope study area. In some areas, discontinuous permafrost may become more completely thawed, and colder permafrost may become discontinuous. These changes can be expected to vary at a fine spatial scale, but associated changes to hydrology and vegetation may occur more broadly.

Projected changes in MAGT between the current decade and future decades out to the 2060s are shown in Figure C-29. Although mean temperatures at one meter are below freezing across the map area, fine-scale variation is present that is not represented in the figure. Figure C-30 shows mean MAGT for 5th-level HUCs (small watersheds) surrounding communities within the North Slope study area. Even within these small areas, variability across 1km pixels is relatively high, as shown by the error bars.

It should be noted that true variability is even greater, since it also occurs at scales much finer than 1 km. For example, localized processes such as deep snow accumulation in riparian zones can allow for year-round liquid water below beaded stream pools, with the development of thaw bulbs or taliks (Arp et al. 2015). Around Kivalina and Point Hope, fine-scale thaw is likely, and it may occur even in colder regions.

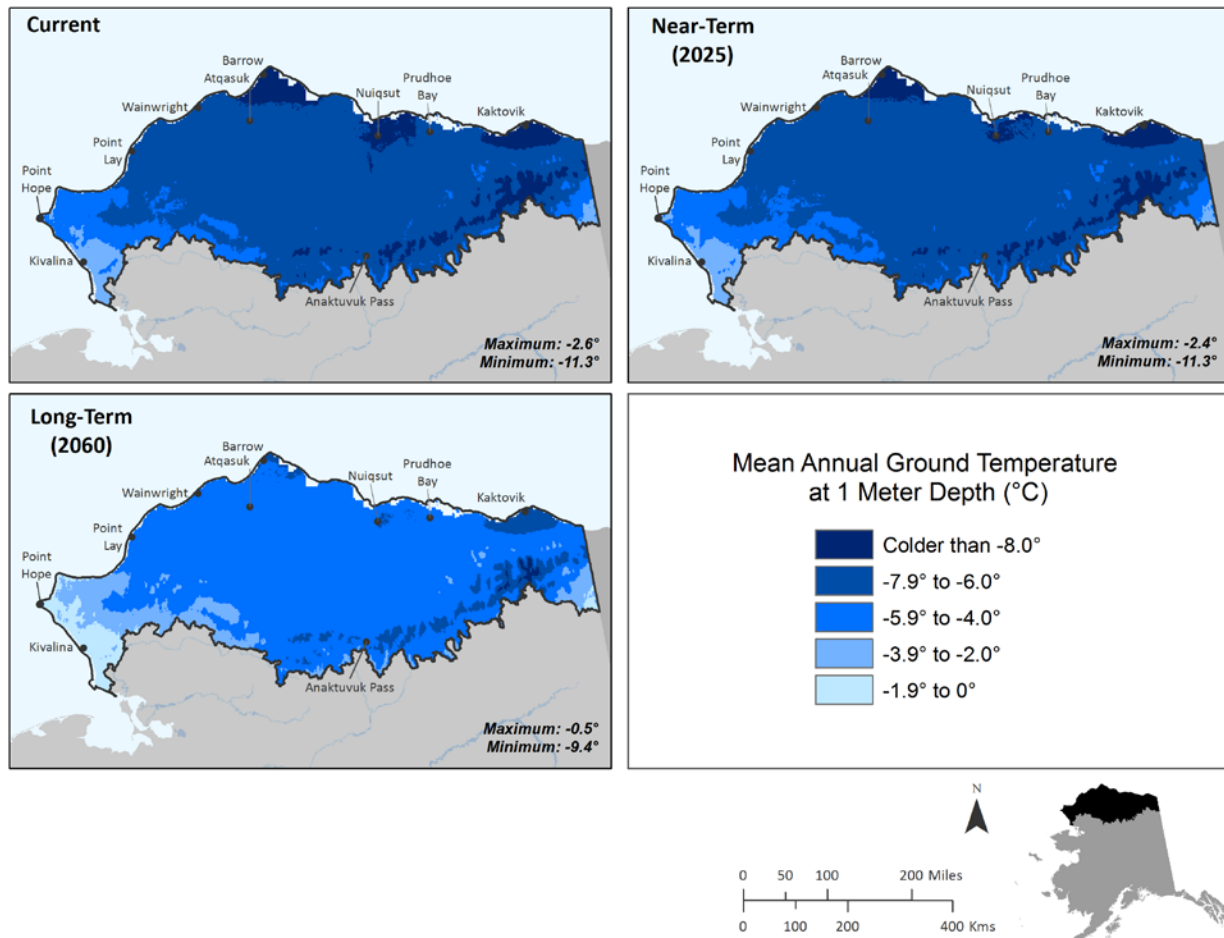


Figure C-29. Mean Annual Ground Temperature projections based on SNAP climate inputs into the GIPL permafrost model. Darker blue colors represent colder soil conditions.

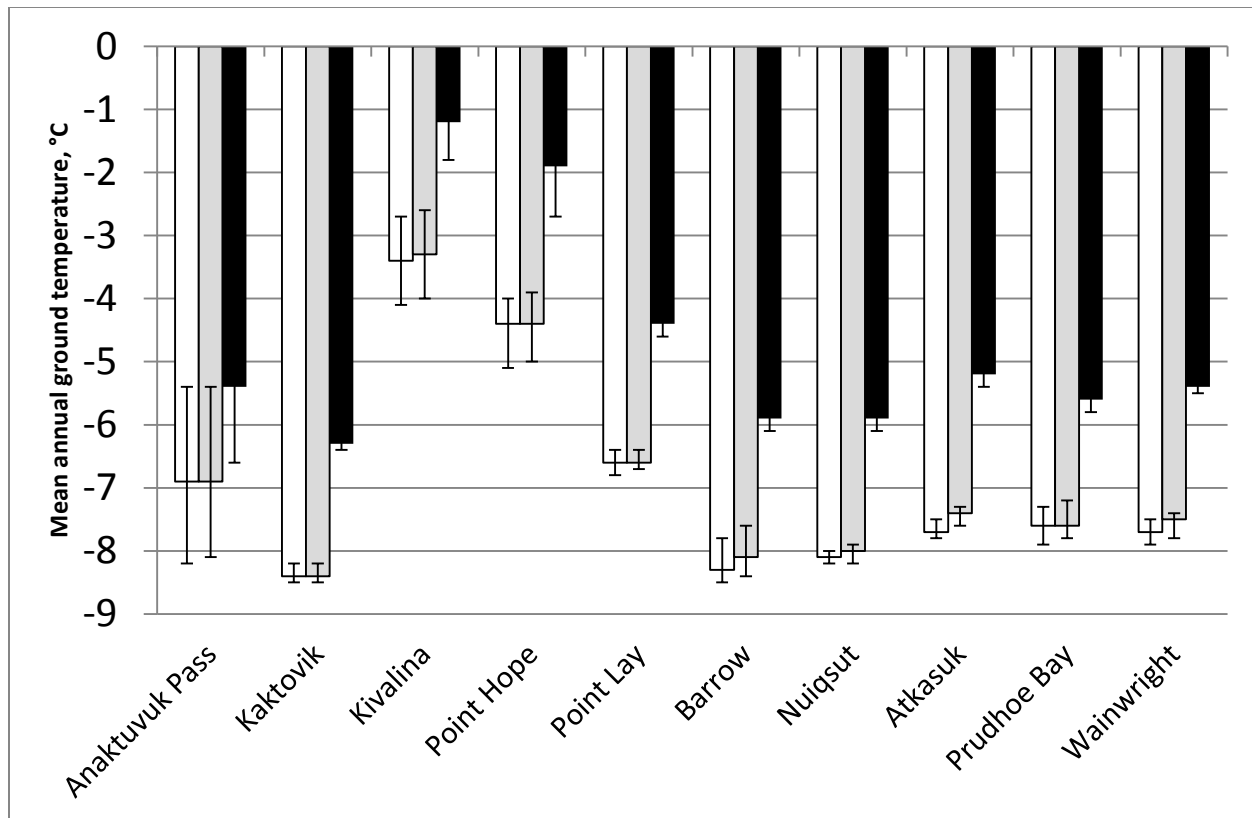


Figure C-30. Mean annual ground temperature (°C) at one meter depth (MAGT) for community watersheds in the North Slope study area. Current (white), near-term (light gray), and long-term (dark gray) time steps are shown. Active layer thickness is expected to increase across the North Slope study area (Figure C-31). Figure C-32 demonstrates the high ALT variability by sub-region, as well as within each sub-region. Maximum and minimum values are shown by error bars.

Some areas (Western Brooks Range, Western Foothills) show current or future pixels with values projected in excess of one meter, suggesting localized loss of shallow permafrost. Areas underlain by a sand sheet in the Central Coastal Plain show a greater depth and increase in area even by the 2020s. Most areas show modest increases in ALT, from about 0.5 to about 0.6 m by 2060. While such changes may seem small, they in fact represent a large percentage change in available rooting depth.

Active layer thickness is correlated closely with vegetation; even slight changes in active layer thickness can trigger threshold shifts from tundra to shrubland or from shrubland to forest, based on minimum rooting depths of the species in question. Thus, the projected changes in ALT may affect dominant vegetation, as well as the wildlife species that depend on this vegetation for forage or cover. These changes are complex in nature; they are linked not only to permafrost changes, but also associated changes in temperatures, snow cover, tundra fires, human development, and browsing behavior, all of which can affect shrub abundance (Myers-Smith et al. 2011).

Active layer thickness is also a strong predictor of hydrologic dynamics, with regard to water availability, stream flow, and formation or drainage of wetlands. Deeper active layers are generally associated with

greater drainage and drier surface conditions, but outcomes are highly site-specific. Thus, as permafrost thaws, water availability may become greater in some micro-sites and less in others. Shallow permafrost has more influence than deeper permafrost on long-term conditions in shallow aquifers, such that small changes can profoundly influence groundwater flow and changes in lake level evolution (Jespen et al. 2013).

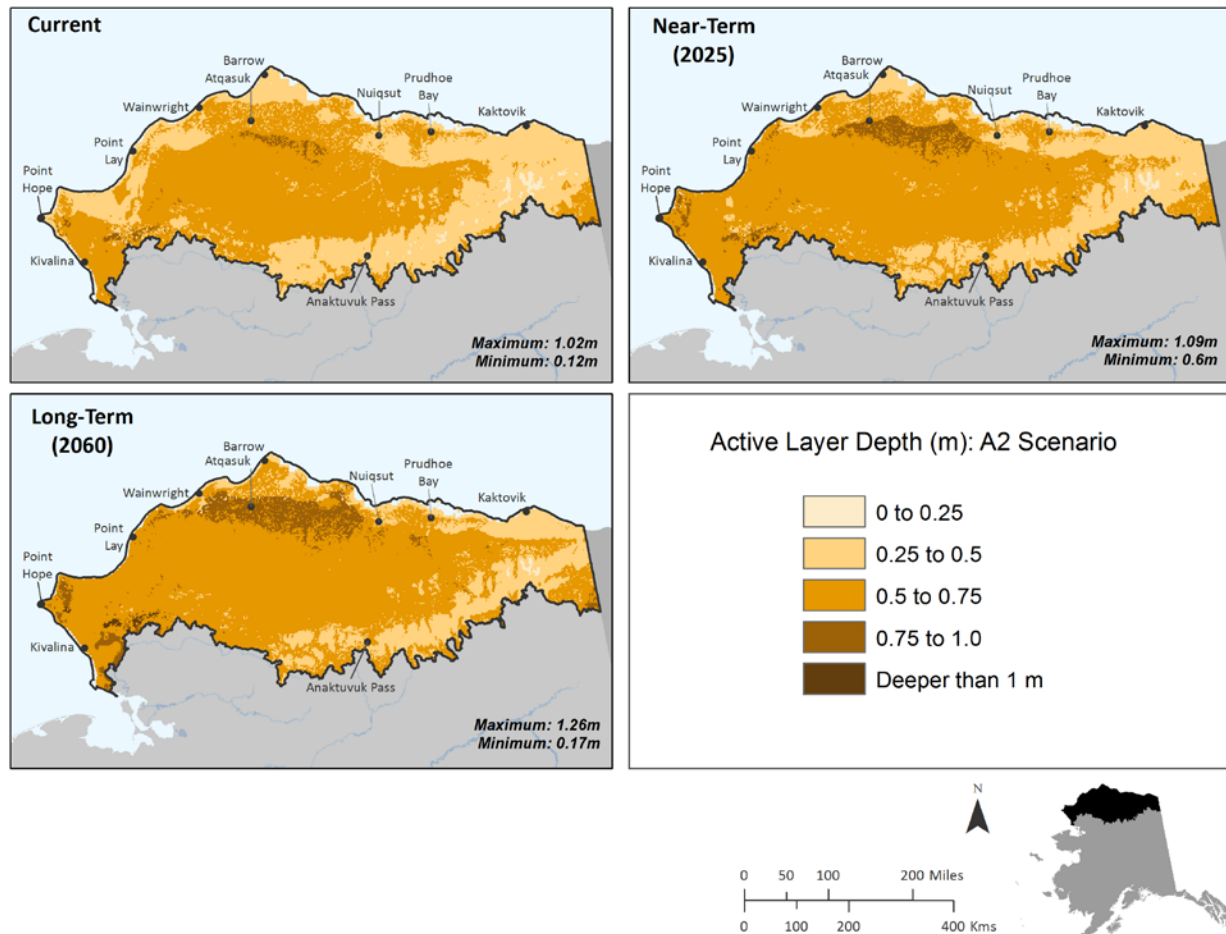


Figure C-31. Projected active layer thickness and depth of seasonal thaw. Darker brown colors indicate deeper active layer depths (m).

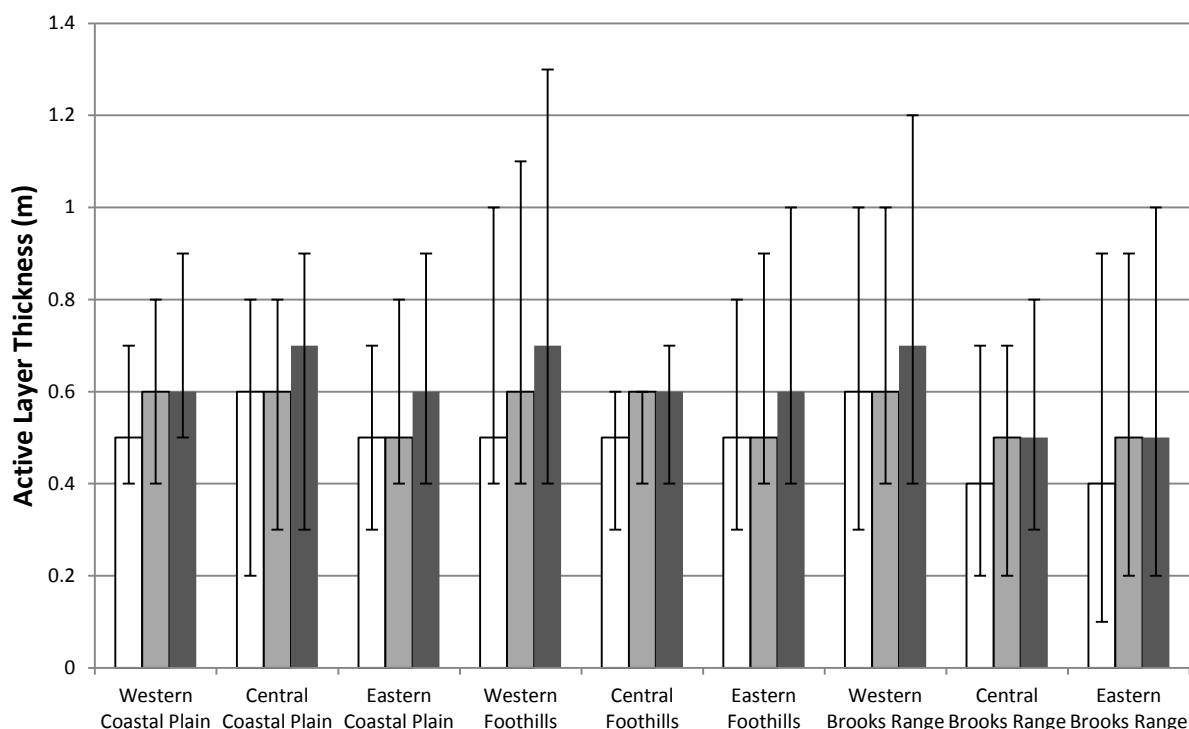


Figure C-32. Active Layer Thickness (ALT) projections by ecological sub-region. Current (white), near-term (light gray), and long-term (dark gray) time steps are shown. Error bars show minimum and maximum values for pixels in each sub-region.

Thermokarst susceptibility projections (Figure C-33) show regional variability across the North Slope study area with regard to potential slumping and structural failure in soils, should permafrost thaw. As might be expected, the potential for thermokarst is low to nonexistent in the Brooks Range, and high in flat low-lying coastal areas where soils are ice-rich.

Thermokarst can create lakes or lead to lake expansion, although these processes are dependent on the substrate and sediments under and around the lake (Hinkel et al. 2012). Although the physical changes caused by slumping are relatively localized, effects on vegetation and aquatic and terrestrial communities may be much more far-reaching. Downstream from thermokarst, concentrations of ammonium, nitrate, and phosphate were shown to be elevated, and that such increases in nutrient loading can stimulate primary and secondary production (Bowden et al. 2008). Increased sediment loading could also alter downstream ecosystem function.

Note that these projections are independent of climate, and reflect only the propensity for thermokarst, should thaw conditions occur. Thus, these outputs should be viewed in conjunction with projections for mean annual ground temperature and active layer thickness.

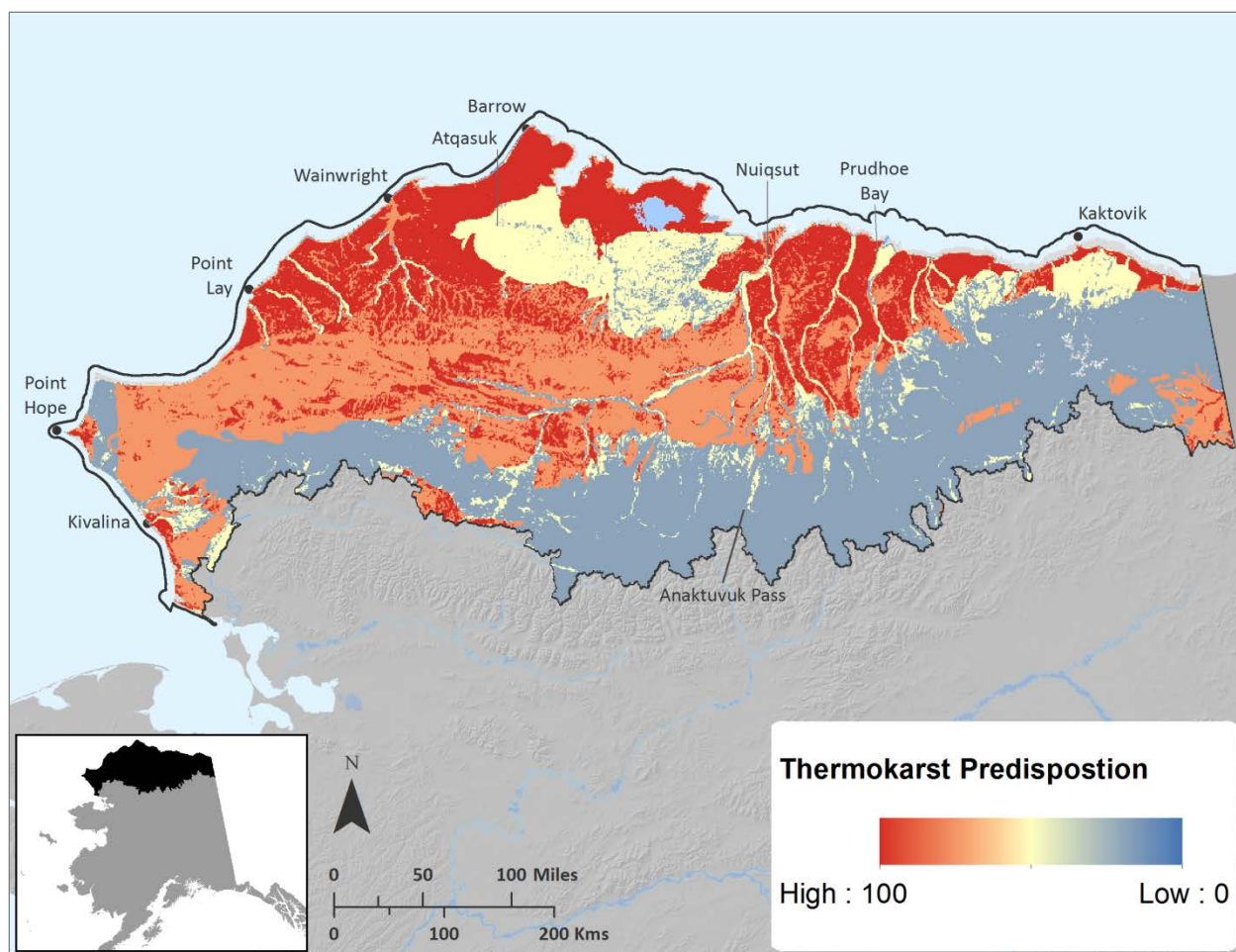


Figure C-33. Thermokarst predisposition based on topography and soil ice content. Warmer colors represent a higher thermokarst predisposition.

Permafrost thaw and associated thermokarst have been shown to lead to fundamental changes in vegetation, water storage and flow paths (Jorgensen et al. 2013). Around lakes and other water bodies, permafrost thaw has been shown to alter ecosystem dynamics. Retrogressive thaw slumping represents an important stressor to the biological communities of lakes, typically reducing nutrient availability (Thienpont et al. 2013). In upland areas, permafrost thaw may increase drainage to the point of creating drought stress for some species.

Although permafrost models are not directly linked with fire and vegetation models used in this study, the literature suggests that interaction between these variables may result in tree line advance in areas with increasing active layer thickness and drought risk in areas where drainage increases. Such changes in soil conditions may accompany a shift from coniferous forests to deciduous forests. The ability of species migration to keep pace with climate change has been questioned by some researchers (Garamvoelgyi and Hufnagel 2013).

Changes in permafrost may also affect human use and development, particularly in thermokarst areas. Engineering and planning in the Arctic require close attention to changes in permafrost, at a range of spatial and temporal scales (Stephani et al. 2014).

3.4. Limitations

The outputs of permafrost modeling and mapping are imperfect, despite being based on the best available data layers. Uncertainty is present at multiple levels, stemming from the inherent uncertainties of climate modeling and the uncertainty associated with linking climate to soil thermal dynamics.

The feedbacks between permafrost thaw and vegetation change are not always clearly understood. Moreover, these threshold dynamics are complicated by feedbacks between fire, vegetation, and climate. Permafrost can thaw very rapidly following fire, especially if the organic layer is consumed, but, stochastic models cannot predict the exact timing, location, or intensity of fires.

The joint SNAP/GIPL model represents, at best, data for climate, soils, insulating vegetation and other key variables at 1 km resolution. Discontinuous permafrost can vary at scales much finer than this, due to variable slope and aspect, drainage patterns, and numerous other factors. Managers should keep these fine-scale dynamics in mind when making management decisions that take into account changing soil thermal dynamics.

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4. Climate Change and Surface Water

MQ TC 3

How will changes in precipitation, evapotranspiration, and active layer depth alter summer surface water availability in shallow-water and mesic/wet tundra habitats and how reliable are these projections?

Changes in climate, including shifts in precipitation, evapotranspiration, and active layer thickness affect hydrologic dynamics. Water availability at specific locations is a function of snowfall and snowmelt; rainfall; surface and subsurface flow; evaporation and transpiration driven by temperature and dominant vegetation; stream flow; and formation or drainage of wetlands (Barichivich et al. 2014).

Mesic and wet tundra habitats, as discussed in Section G, include much of the REA, including (but not necessarily limited to) Coastal Plain Wetland, Coastal Plain Moist Tundra, Sand Sheet Moist Tundra, and Foothills Tussock Tundra. Shallow lakes are addressed under Aquatic Coarse Filter Conservation Elements. Specifically addressing how the above changes may affect water availability in all of these habitats requires assessment of how these components may interact. No comprehensive model of this interaction was available, but individual models of active layer and precipitation coupled with literature review sheds some light on possible outcomes.

As discussed under Climate, precipitation is expected to increase throughout the REA. However, shifts in the percentage that arrives as rain versus snow and changes in the timing of freeze and thaw may alter the timing of water availability. Moreover, greater total precipitation may be offset by increases in evapotranspiration. Shifts in precipitation are projected to be small enough that data uncertainty and methodological differences make predicting the direction of change difficult (McAfee 2013). Regionally and locally, slight drying or slight increases in moisture may occur.

Given the above, change in active layer is likely to have a greater effect on water availability than changes in precipitation and evapotranspiration. Deeper active layers are expected across the REA, as discussed under Soil Thermal Dynamics. Deeper active layers are generally associated with greater drainage and drier surface conditions, but outcomes are highly site-specific. Thus, as permafrost thaws, water availability may become greater in some micro-sites and less in others. Shallow permafrost has more influence than deeper permafrost on long-term conditions in shallow aquifers, such that small changes can profoundly influence groundwater flow and changes in lake level evolution (Jespen et al. 2013). Dry years cause deeper growing-season thaw depths in soils than wet years, which may partially offset potential moisture stress (Rouse et al. 1992). McMichael et al. (1997) found that there is no relation between active layer depth and NDVI in areas with little variation in relief, but that in areas where topography strongly controls the flow of water, the two variables were correlated.

Regardless of relative changes in water availability, Reyes and Loughheed (2015) and Harms et al. (2014) suggest that increases in thermokarst and active layer depth in Alaska's arctic may release substantial nutrients to downstream environments, resulting in significant future changes in nutrient cycling in this region.

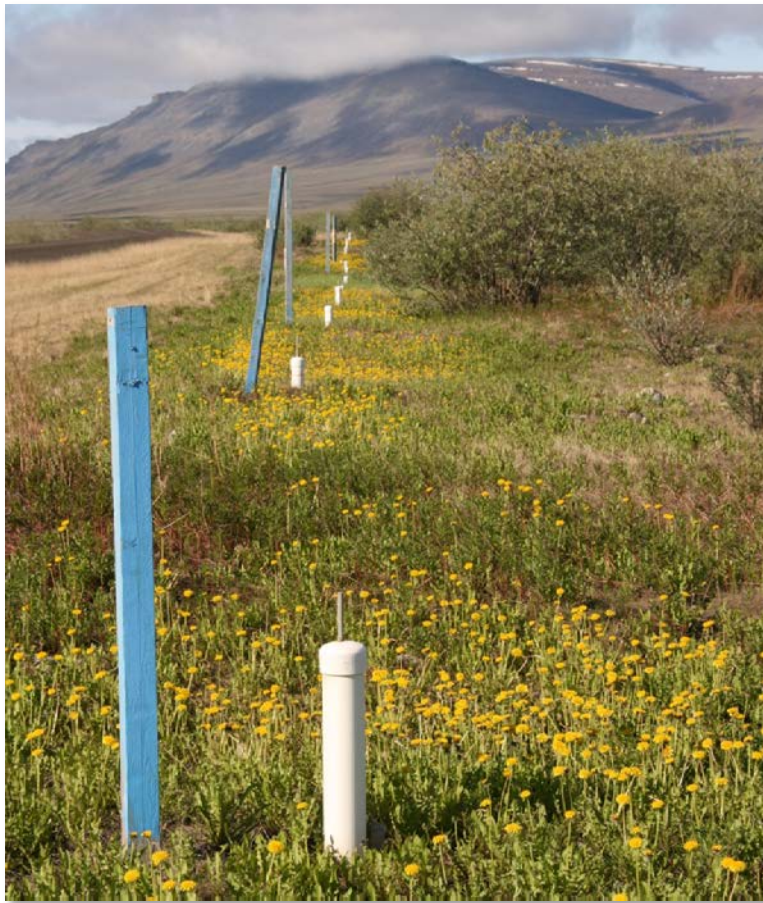
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D. Biotic Change Agents: Invasive Species

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Summary

Section D. *Biotic Change Agents: Invasive Species* provides the detailed descriptions, methods, datasets, results, and limitations for the assessment of current and future impacts of non-native plants in the North Slope study area.

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1. Introduction

Invasive species are included in this REA and all other BLM REAs due to their capacity to disrupt ecological processes and degrade biological resources. Invasive species are defined here in relation to the Executive Order 13112 definition: “as species not native to the ecoregion whose introduction does or is likely to cause economic or environmental harm or harm to human health.” Thus species native to the Arctic Coastal Plain but which have increased in abundance in recent decades, to the point of being considered pest (e.g., red fox and ravens), are excluded from consideration here. Nationally invasive species are recognized to be a major concern for resource management (Pimentel 2005; USDA 2013). In Alaska and the circumpolar North, invasive species are not known to have caused the degree of damage observed at lower latitudes (Carlson and Shephard 2007; Sanderson 2012, Lassuy and Lewis 2013). However, an increasing number of examples of ecological and economic harm are recognized in the state (Croll et al. 2005; Carlson et al. 2008; Spellman & Wurtz 2011; Nawrocki et al. 2011; Schwörer 2012). Infestations in Alaska are typically localized to areas on or adjacent to the human footprint (Bella 2011; Flagstad 2010; Carlson 2014), and while most non-native species populations are currently geographically restricted they may become more problematic with future changes in land-use and increases in temperature and growing season lengths (Carlson and Shephard 2007).

Short growing seasons and low summer temperatures are believed to limit the distribution of many invasive plants (Lassuy and Lewis 2013; Carlson 2014), as well as native plants in the Arctic (see Young 1971, Walker et al. 2010). Individual species are likely to respond to different climatic factors, such as cumulative summer warmth (growing degree days), probability of frosts during the growing season, maximum summer temperatures, etc.; however, variables such as the length of the growing season or mean July temperature are expected to integrate many of the climatic variables limiting the distributions of species. The high probability of continued warming in the Arctic and future climate amelioration, is expected to increase suitability of the region for many invasive species.

The ecologic and economic damage caused by invasive species requires three events: transportation of propagules, establishment of incipient populations, and subsequent increase in biomass. Invasive species will not become problematic if one of these three events does not occur, and increasing interest is being placed on managing pathways and nodes of invasion (Conn et al. 2008a; Davies and Johnson 2011; Mack 2003; Ruiz and Carlton 2003). The pathways that invasive species use to reach new areas are often predictable (Mack 2003). Understanding likely transportation routes is particularly critical in areas that currently have low levels of non-native species establishment, such as the North Slope study area. Monitoring potential vectors and management of incipient populations are likely to be the most cost-effective approaches to invasive species management (Conn et al. 2008a).

Pathways of invasive species across all groups of organisms closely follow the pattern of movement by humans, which are closely tied to levels and patterns of commerce (Hulme 2009). Both the volume and rate at which goods are shipped has increased dramatically in recent decades, which have facilitated the movement of invasive species (Hulme 2009).

The Dalton Highway and airports at regional hubs are undoubtedly the primary entry points for most non-native species propagules in the region. Large populations of invasive plants are common along the Dalton Highway south of the North Slope study area from Coldfoot south (AKEPIC 2014) and the high volume of tractor-trailer and personal vehicle travel would suggest that invasive plant seeds are being imported into the region. Vehicles are well recognized to contribute large numbers of non-native plant seed, often long distances (Lonsdale & Lane 1994; Van Der Lippe et al. 2007; Ansong & Pickering 2013). For example, approximately 67,500 viable seedlings per ton of dry sludge were estimated from car washes in Australia (Nguyen 2011, cited in Ansong & Pickering 2013). Once established at these ports of entry, access roads represent likely corridors for invasive species to further spread within and between oil fields and communities due to transportation of goods, vehicles, and people, or indirectly through non-native population expansion on the disturbed and connected habitats (see Hulme 2009). Additionally, non-natives may spread using natural dispersal mechanisms after reaching reproductive maturity. For example, the spread of the invasive ornamental tree *Prunus padus* from urban areas into semi-natural parklands in the Anchorage area appears to largely be mediated by waxwings, thrushes, and other passerines that are often observed eating fruits and seeds (Flagstad et al. in prep.).

The footwear of travelers is known to be a pathway of introduction of viable non-native seeds. The average traveler to the Arctic archipelago of Svalbard transports 3.9 non-native plant seeds on their footwear, with more than 40% of individuals transporting at least one non-native species (Ware et al. 2012). More than 25% of the seeds germinated in simulated arctic conditions (Ware et al. 2012). Similar levels of transport have been recorded from visitors to Antarctica (Lee and Chown 2009). Grasses represent the largest percentage of introduced seeds in these contexts. Scientists have been shown to carry more seeds on their footwear than tourists and other groups (Ware et al. 2012) and the high frequency of exchange among scientists in the circumpolar north suggests that scientific field stations and hubs (Toolik Field Station and Barrow) are vulnerable to importation of non-native plant propagules. Additionally, a large number of caribou hunters travel to the region from other regions of the state and out of state. While most non-native plants imported from this user group are expected to be deposited along the Dalton Highway, pullouts, and formal and informal campsites, hunters using firearms are required to travel five miles from the highway. River floodplains are most frequently used by hunters and hikers for transportation to avoid saturated soils. The majority of unimproved airstrips are also found in floodplains (D. Tirrell pers. com.). In the southern half of the state, invasive waterweed (*Elodea* spp.) appears to be spreading as a contaminant on the floats of aircraft; this species however, is not known to occur in arctic regions of the world (GBIF 2015) and therefore considered unlikely to establish in the North Slope study area. Thus regional hubs, primary highway corridors, and to a lesser degree floodplains, in the North Slope study area are expected to be the most likely sites of introduction.

Increases in shipping traffic to and from arctic ports and ports to the south are a potential source of invasive marine and terrestrial animals to the region (see Lassuy and Lewis 2013 for discussion). Such increases in shipping, subsurface resource exploration, and shoreline development, coupled with environmental change may greatly increase invasions at high latitudes (Ruiz and Hewitt 2009). While the REA process excludes the marine zone and is not therefore not addressed here, marine shipping could

introduce invasive species such as the brown rat (*Rattus norvegicus*) that are well-known to cause significant ecological impacts, particularly to nesting seabird colonies.

While non-native plant seeds are surely being imported into the region, established populations are very uncommon. Despite surveys in Dead Horse, Barrow, and other high-use areas mature non-native plants have not been recorded. Plant ecological work off of the human footprint has not detected any populations of non-native plants. This pattern is strongly suggestive of climatic factors limiting non-native plant establishment.

Invasive species in this REA are concentrated into two thematic areas:

- 1) The current state of invasive species in the North Slope study area and identification of areas and resources which are most at risk, and
- 2) The predicted future state of invasive species in the North Slope study area in near-term (2020s) and long-term (2060s). No management questions were proposed to specifically address invasive species.

This section describes the current status of non-native species and landscape-level model outputs, including the data sources, methods, and analysis involved in the modeling. Invasion vulnerability was assessed in the context of current, near-term (2020s), and long-term (2060s). Invasive species data were derived from Alaska Exotic Plant Information Clearinghouse Database (AKEPIC 2014) and the Pacific Northwest Consortium of Herbaria (<http://www.pnwherbaria.org/>); anthropogenic data were garnered from diverse sources and summarized by the Institute for Social and Economic Research; climate data were produced by the Scenarios Network for Alaska and Arctic Planning. We briefly discuss relationships between non-native plant establishment, climate, and development.

2. Methods

The first theme of current state of invasive species was addressed by summarizing known locations, densities, diversities, and perceived ecological impacts of non-native species in tabular and cartographic forms. Based on the known ecology and distribution of the non-native plant species present in the North Slope, we review potential CEs that may be impacted by the non-native species that are present.

To summarize the current status of non-native plant species in the region we queried the AKEPIC weed database in December 2014 (see <http://aknhp.uaa.alaska.edu/botany/akepic/> for updated data). Additionally, we downloaded all electronically databased botanical records from the Consortium of Pacific Northwest Herbaria (<http://www.pnwherbaria.org/>), the most regionally comprehensive database available, and extracted the non-native species (Table D-1). Current status of invasive species was evaluated by overlaying the North Slope study area with the spatially explicit AKEPIC data and extracting all relevant records. The spatially explicit statewide AKEPIC records were used to classify all non-native plants by their minimum growing season length. Figure D-1 displays an overview of methods and approach.

Table D-1. Source datasets for analysis of invasive species.

Dataset Name	Data source
Alaska Exotic Plants Information Clearinghouse (AKEPIC)	AKNHP
Consortium of Pacific Northwest Herbaria	University of Washington

To identify possible future invaders to this region and to generate invasion vulnerability maps, we used the North Slope 2060 maximum predicted growing season length as a proxy for cumulative summer growing conditions and identified which species across Alaska are currently associated with that threshold value and/or values of lower magnitude (a shorter growing season length than 170 days). Growing season length is defined as the length of time mean temperatures are above freezing (i.e., between when the running mean temperature crosses the freezing point in the spring and again in the fall, see Section C). Thus, we predict that species that are able to grow and reproduce in less than 170 days would be able to persist in at least the warmest areas of the region by 2060. This approach used spatially explicit climate models from Scenarios Network for Alaska and Arctic Planning to identify maximum growing season length values. Localities that currently have those values or those of lower magnitude were identified and overlaid with non-native plant locations of all 282 non-native plants currently tracked in the state (list of state species see AKEPIC 2014). We individually reviewed records for non-native species with five or fewer recorded locations from 170 growing days or less; species with apparently erroneous records were removed (e.g., records in which the description of the location did not match the latitude and longitude and likely was a due to data entry errors).

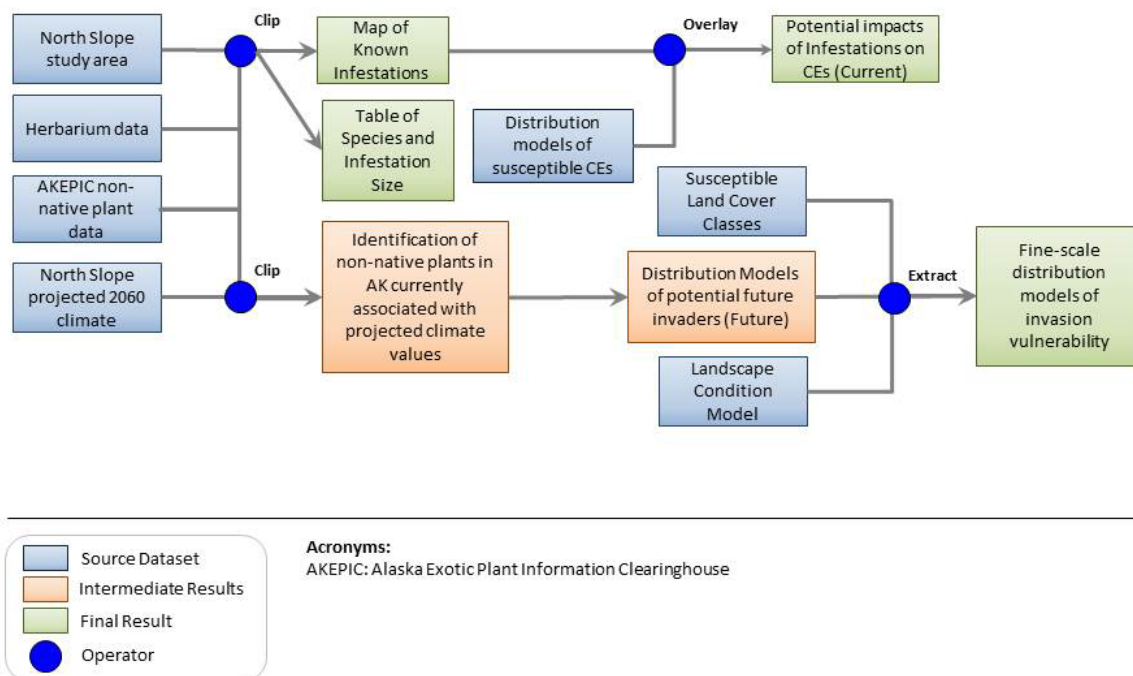


Figure D-1. Process model of invasive species current and predicted future condition methodology.

We divided the non-native plant flora with the minimum cold tolerance threshold of the projected long-term (2060) North Slope study area into five categories based on their minimum growing season length (Table D-2). Those species with known populations in areas with growing seasons of 120-130 days were defined as “extremely cold tolerant”, 131-140 days were defined as “highly cold tolerant”, 141-150 days were defined as moderate-highly cold tolerant”, 151-160 days were defined as “moderately cold tolerant”, and 161-170 days were defined as “weakly cold tolerant”. Figure D-2 shows histograms of the number of infestations relative to growing season length of three example species to illustrate the process of screening those species that are only associated with warmer regions of the state.

Table D-2. Non-native plant cold tolerance categories based on associations of infestation locations with minimum Growing Season Length.

Growing Season Length threshold (days)	Tolerance Definition
120-130	Extremely cold tolerant
131-140	Highly cold tolerant
141-150	Moderate-highly cold tolerant
151-160	Moderate cold tolerant
161-170	Weakly cold tolerant

Invasion vulnerability within the North Slope study area was then outlined by identifying those areas associated with non-native plants of the five cold tolerance categories. This approach is intended to illustrate potential changes in non-native plant invasion vulnerability at the broad-scale. The probability

of non-native plant propagules reaching most of these areas is low and the majority of habitats (e.g., foothills tussock tundra) are expected to be very resistant to establishment of invasive plants.

To address potential changes in invasion vulnerability at the finer scale, we delineated the overall area vulnerable to the most cold-tolerant non-native plants into areas of higher and lower suitability based on the probability of propagule importation and specific land cover classes most susceptible to invasive plant establishment. The Land Condition Model (LCM) was used as a proxy for probability of non-native propagule importation and establishment primarily on imported, or otherwise disturbed, substrates. The non-native plant species in all the cold-tolerance categories are primarily associated with sparsely vegetated, mineral substrates within the North Slope and elsewhere in the state. Floodplain shrublands and barrier islands were identified as the two sparsely vegetated terrestrial Coarse-Filter CEs most susceptible to invasion. Areas associated with the minimum suitable growing season length and overlapping with the LCM and two landcover classes were then identified.

Future fine-scale invasion vulnerabilities were then explored based on growing season lengths at short-term (2020s) and long-term (2060s) under both moderate and high LCM Scenarios.

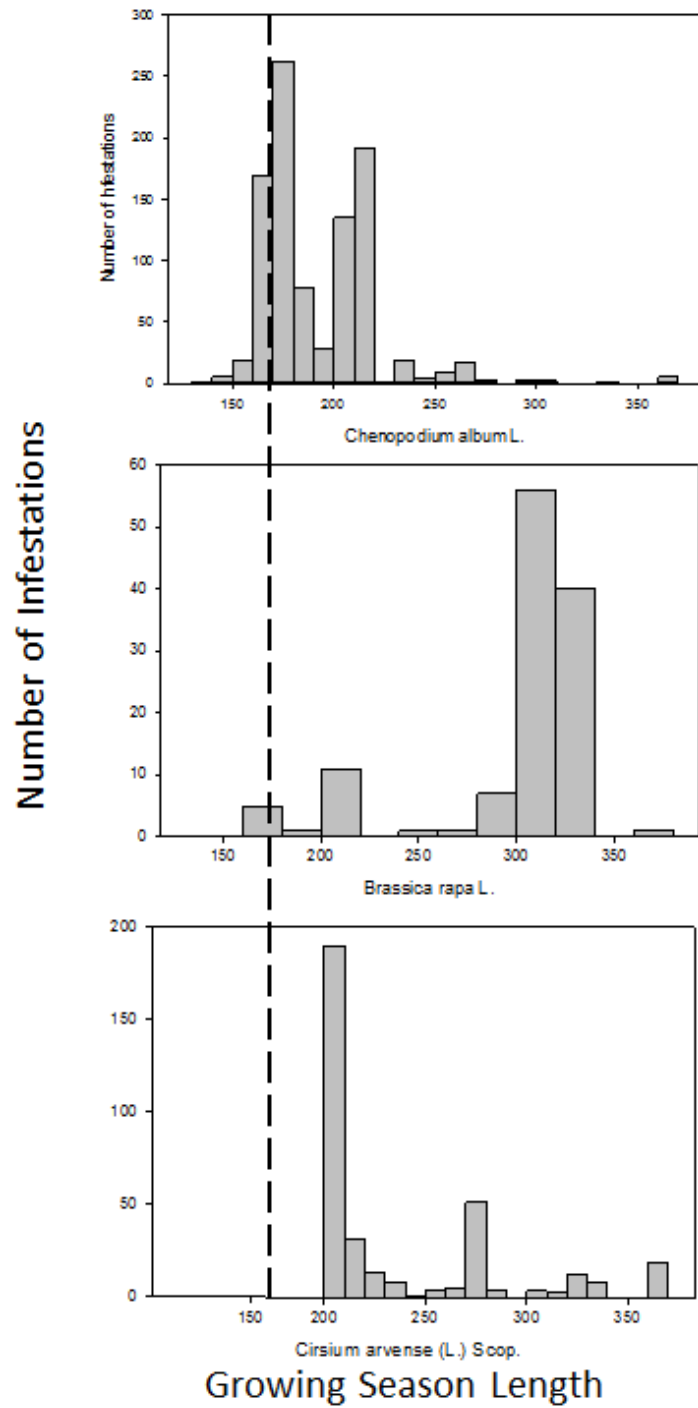


Figure D-2. Example histograms of number of infestations relative to growing season length for three non-native plant species in Alaska. The dashed line represents the maximum predicted growing season length present within the REA region by 2060. Species with recorded infestations at or below this growing season threshold (such as *Chenopodium album* and *Brassica rapa*) are included in the discussion here, while species such as *Cirsium arvense* is omitted from further discussion.

3. Results

Nine non-native vascular plant species were documented from 39 infestation records, encompassing only 24.3 total acres (Table D-3). The record of *Descurainia sophia* is likely a misidentification of the native *Descurainia sophioides* that often behaves weedy and is known in the region and in which most taxonomic keys used in the state do not appropriately distinguish. These records account for an exceedingly small percentage of the total North Slope land area (0.00000037%). Surveys of an additional 195 sites, encompassing 2,080 acres, did not detect non-native plant species. Additionally, exhaustive plant surveys in other remote areas and localities that would likely harbor non-native plant infestations such as Barrow, Wainwright, Deadhorse, the roadsides and gravel pits along the northern 120 miles of the Dalton Highway have not detected non-native species. Figure D-3 displays the spatial distribution and density of known infestations in the North Slope study area. Most non-native plant infestations are associated with warmer areas of high human use/traffic, specifically along the portion of the Dalton Highway at the southern boundary of the REA and villages in the south-central region of the REA. The Dalton Highway on the south side of the Brooks Range has the highest density of species and infestations. A smaller number of non-native species are found along the Dalton Highway north of Atigun Pass on the roadside or areas of construction and ground disturbance. The villages of Anaktuvuk Pass and Umiat both have records of non-native plants present. A small number of *Hordeum jubatum* plants were observed on imported fill at the BLM camp and airstrip at Inigok.

Table D-3. Non-native vascular plant species present, total area infested and number of infestations by each species in the North Slope study area, and Invasiveness Rank (see Carlson et al. 2008 for discussion of ranking criteria).

Species	Total Infested Acres	Number of Infestations	Invasiveness Rank
<i>Brassica rapa</i> (field mustard)	NA	1	50
<i>Chenopodium album</i> (lambsquarters)	0.01	1	37
<i>Descurainia sophia</i> * (herb sophia)	1.0	1	41
<i>Hordeum jubatum</i> (foxtail barley)	16.63	21	63
<i>Lepidium densiflorum</i> (common pepperweed)	NA	1	25
<i>Matricaria discoidea</i> (disc mayweed)	1.01	2	32
<i>Plantago major</i> (common plantain)	1.52	4	44
<i>Polygonum aviculare</i> (prostrate knotweed)	1.01	3	45
<i>Taraxacum officinale</i> (common dandelion)	2.5	4	58

*Indicates the non-native species was identified, but was likely a misidentification of the native *Descurainia sophioides*.

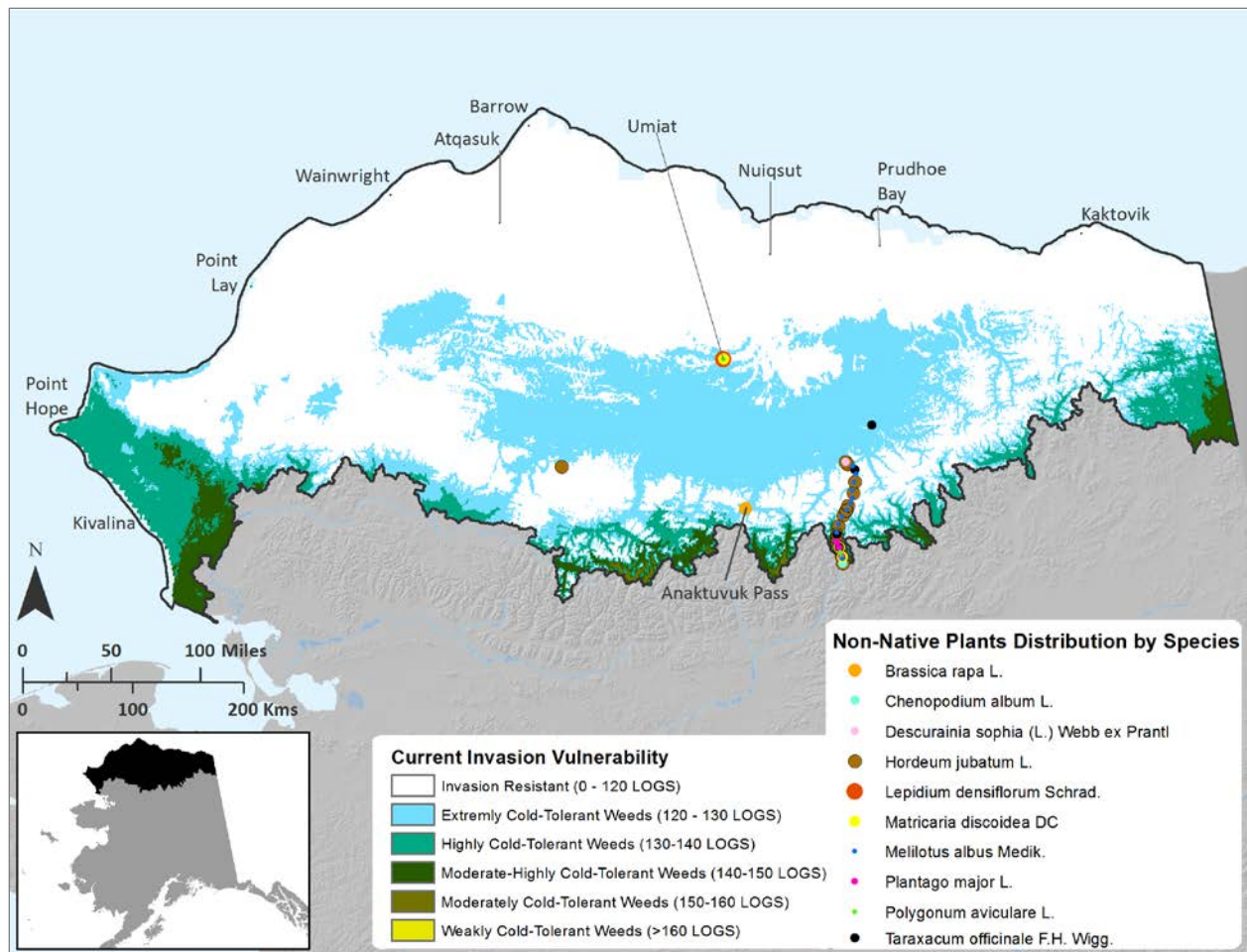


Figure D-3. Distribution of non-native plant infestations in the North Slope study area (circles). General plant invasion vulnerability is illustrated by the colored polygons. Areas with a Length of Growing Season (LOGS) of less than 120 days are predicted to be invasion resistant (white); areas in blue represent regions vulnerable to invasion by extremely cold-tolerant plants; and warmer colors represent areas predicted to vulnerable to less cold tolerant species.

All the species documented in the study area currently are not regarded as significant threats to the regional ecology. The species with the greatest perceived ecological risk is the grass *Hordeum jubatum* that is considered “moderately invasive” (see Carlson et al. 2008 for discussion of perceived ecological risks). The nativity of *Hordeum jubatum* in Alaska is equivocal. This species may have been present in the state at the time of contact; however herbarium records indicate that it was a common contaminant in straw and agricultural seed and has spread dramatically in recent decades. *Hordeum jubatum* is a common colonizer of disturbed mineral substrates, such as roadsides and floodplains. This species is also capable of spreading in upper reaches of tidal marshes elsewhere in the state. The most commonly occurring species are the disturbance specialists: *Chenopodium album*, *Matricaria discoidea*, *Plantago major*, and *Taraxacum officinale*. With the exception of *Taraxacum officinale*, these species typically require continued ground disturbance to persist in Alaska and are unlikely to establish in large numbers in natural areas outside of active floodplains or barrier island habitats.

3.1. Current and Future Invasion Vulnerability

Current invasion vulnerability across the region suggests that the northern and high elevation regions of the North Slope study area are resistant to invasion even by the most cold-tolerant non-native plant species (Figure D-4). The Brooks Range foothills and south side of the Brooks Range west to Point Hope are predicted to be vulnerable to the extremely to moderately cold-tolerant species currently. By the 2020s modest changes in invasion vulnerability are predicted, with expansion of the region potentially suitable to the extremely cold-tolerant suite of species occurring primarily northward and westward. By the 2060s however, the area expected to be resistant to non-native plant invasion becomes dramatically reduced. The region is expected to become vulnerable to invasions of the extremely cold-tolerant species primarily. Vulnerability of the landscape to less cold-tolerant suites of species is expected to occur in the Brooks Range foothills, and particularly on the south side of the Brooks Range and the region from Hotham Inlet to Cape Lisburne.

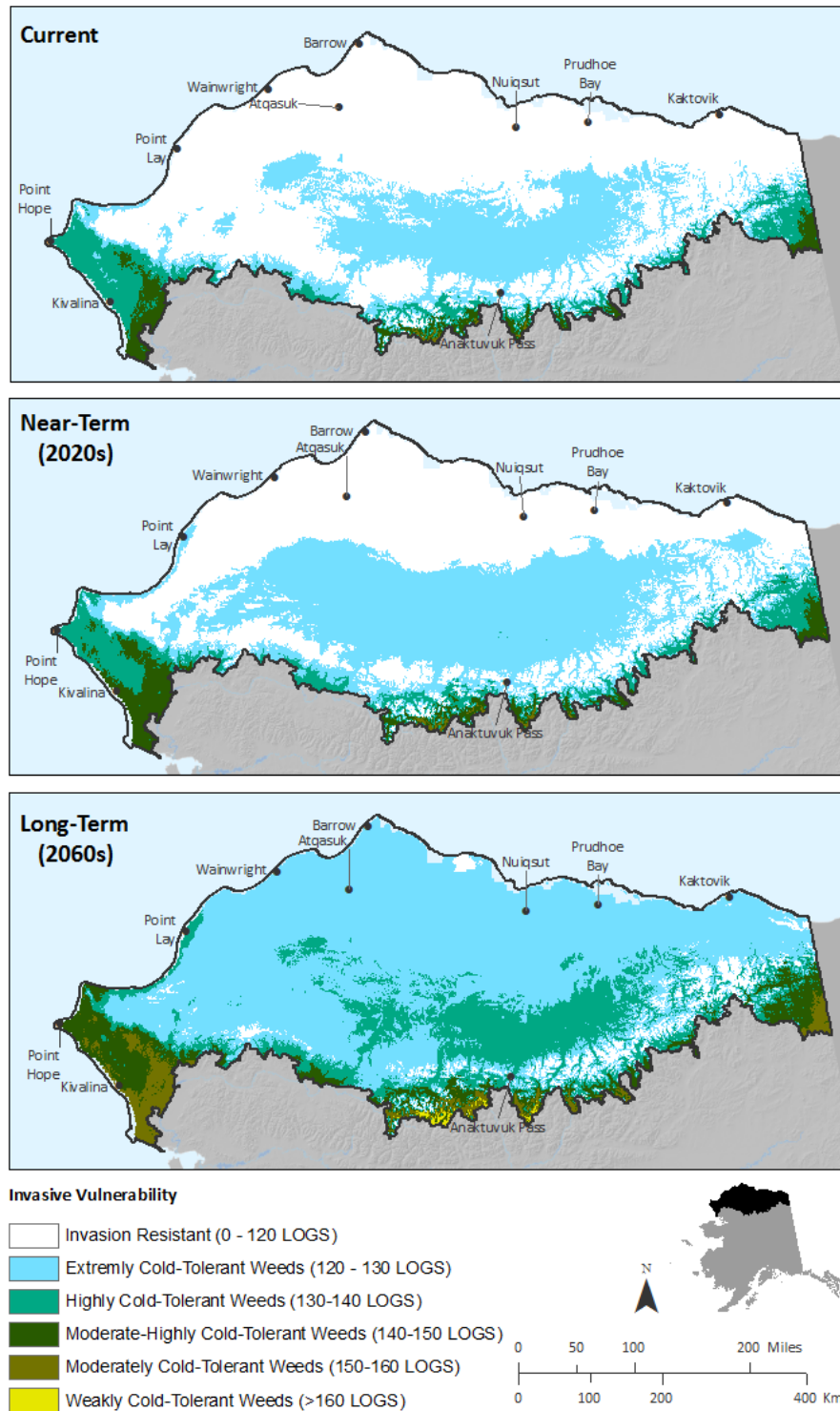


Figure D-4. General plant invasion vulnerability is illustrated by the colored polygons. Areas with a growing season of less than 120 days are predicted to be invasion resistant (white); areas in blue represent regions vulnerable to invasion by extremely cold-tolerant plants; and warmer colors represent areas predicted to vulnerable to less cold tolerant species.

The fine-scale invasion vulnerability model, combining higher probability sites for non-native plant importation and establishment, suggests that the region currently and into the near term is likely to have a non-native plant species restricted to a very small area (

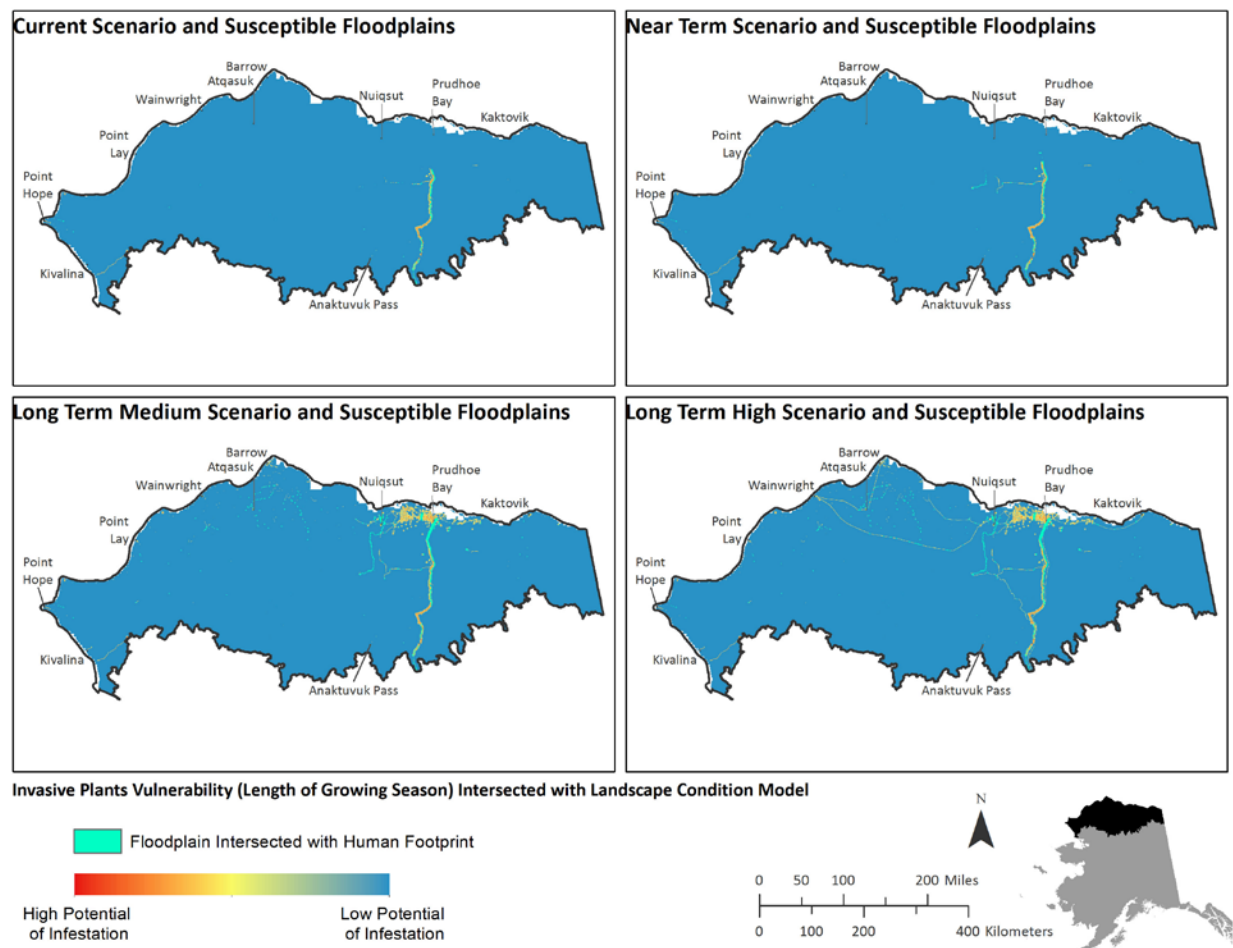


Figure D-6). By 2060 however, all villages and the human footprint associated with the oil fields is expected to increase in probability of non-native plant invasion. Additionally, numerous floodplain shrubland habitats that intersect current or proposed future right-of-ways or infrastructure is expected to warm to the degree that is likely to make them vulnerable to invasion by the extremely cold-tolerant species.

Non-native plant species that may be able to establish in the region by 2060 are shown in

Table D-4. Only two species known from the region currently (*Hordeum jubatum* and *Taraxacum officinale*) are associated with growing seasons of less than 130 days, i.e., extremely cold-tolerant. Nine species are considered highly cold-tolerant with evidence that populations can persist with between 131 and 140 growing season days. This suite of species tends to be weakly invasive and associated with habitats with frequent disturbance. Six species, including the more ecologically threatening grass, *Bromus inermis* are associated with minimum growing seasons of 141-150 days. Fifteen species are associated with minimum growing seasons of 151-160 days, including the highly invasive *Melilotus*

albus, *Vicia cracca*, and *Prunus padus*. These three species are known from the region south of the North Slope study area (although control efforts have been initiated to eliminate the *Prunus padus* from within Gates of the Arctic National Park) and are known to be highly invasive with a potential of altering ecological processes (Carlson et al. 2008; Spellman and Wurtz 2011; Conn et al. 2008b; Conn et al. 2011; Schneller et al. in prep.). *Vicia cracca* and *Melilotus albus* are both common along the Dalton Highway from Coldfoot south and it is likely that seeds are being dispersed into the region on vehicles and fill. *Melilotus* seeds can remain viable for over 80 years (Klemow & Raynal 1981). *Melilotus albus* has invaded a number of floodplain habitats in interior Alaska. *Vicia cracca* is known to aggressively spread in forests and woodlands of the interior (including on the Koyukuk River near Bettles). Both of these species pose a significant threat to the southern boundary of the North Slope study area by 2060. Based on our assessment of its current patterns of cold-tolerance however, plants in this category of cold-tolerance do not seem likely to invade north of the Brooks Range by 2060.

3.2. Current and Future Vulnerabilities

Our assessment suggests that floodplain habitats of the Sagavanirktok River are currently vulnerable to establishment by *Hordeum jubatum* and *Taraxacum officinale* (Figure D-5). By the 2020s the potentially vulnerable portion of the Sagavanirktok is expected to extend northward and a small portion of the Colville River downstream of Umiat is expected to increase in invasion vulnerability. Portions of the Kukpuk and Noatak also are expected to increase in vulnerability by the 2020s. By the 2060s the entire Sagavanirktok River and the lower half of the Colville River floodplains are expected to increase in invasion vulnerability. The upper Sagavanirktok River is anticipated to become increasingly vulnerable to the highly cold tolerant suite of species by 2060. Additional areas expected to increase in vulnerability to the extremely cold-tolerant species include the Ikpiuk, Meade, Kuk, and Kukpowruk River floodplains. The Barrier Islands CE is not anticipated to be vulnerable to invasion currently or in the near term, but nearly all Barrier Island areas are expected to increase in invasion risk by 2060, although only a small portion of this CE overlaps with the anthropogenic footprint. The salt-tolerant and disturbance-associated species, *Hordeum jubatum*, is an invasive species that is expected to be a more likely colonist on the Barrier Islands CE.

As current and future effects of invasive plants in this study area are expected to be relatively minor and geographically restricted, we do not anticipate significant impacts to terrestrial and aquatic fine-filter CEs. Discussion of potential effects of invasive species to individual terrestrial and aquatic fine-filter CEs is therefore speculative and therefore omitted.

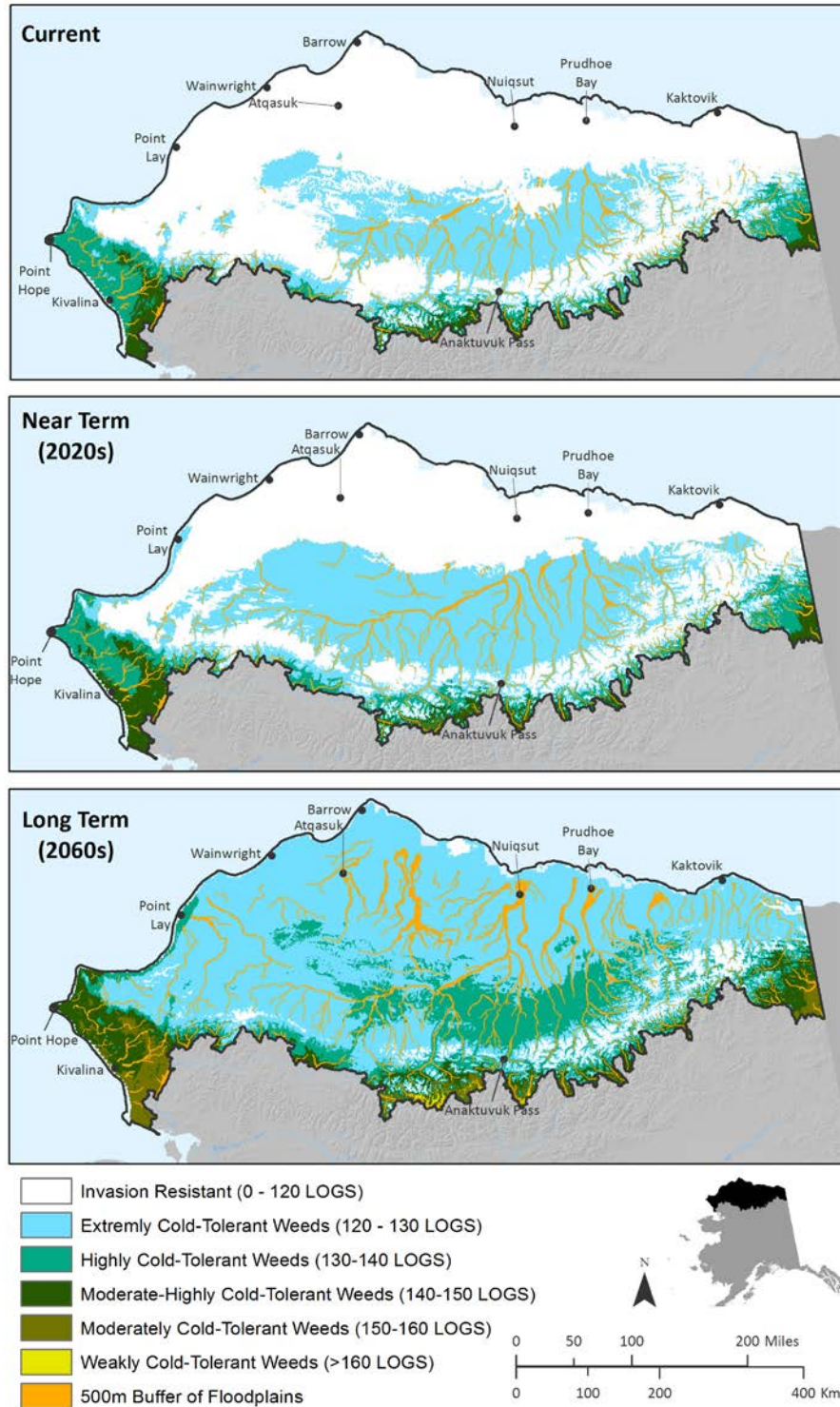


Figure D-5. General plant invasion vulnerability is illustrated by the colored polygons overlaid with the most susceptible habitats in floodplains (orange). Areas with a growing season of less than 120 days are predicted to be invasion resistant (white); areas in blue represent regions vulnerable to invasion by extremely cold-tolerant plants; and warmer green to yellow colors represent areas predicted to vulnerable to less cold tolerant species.

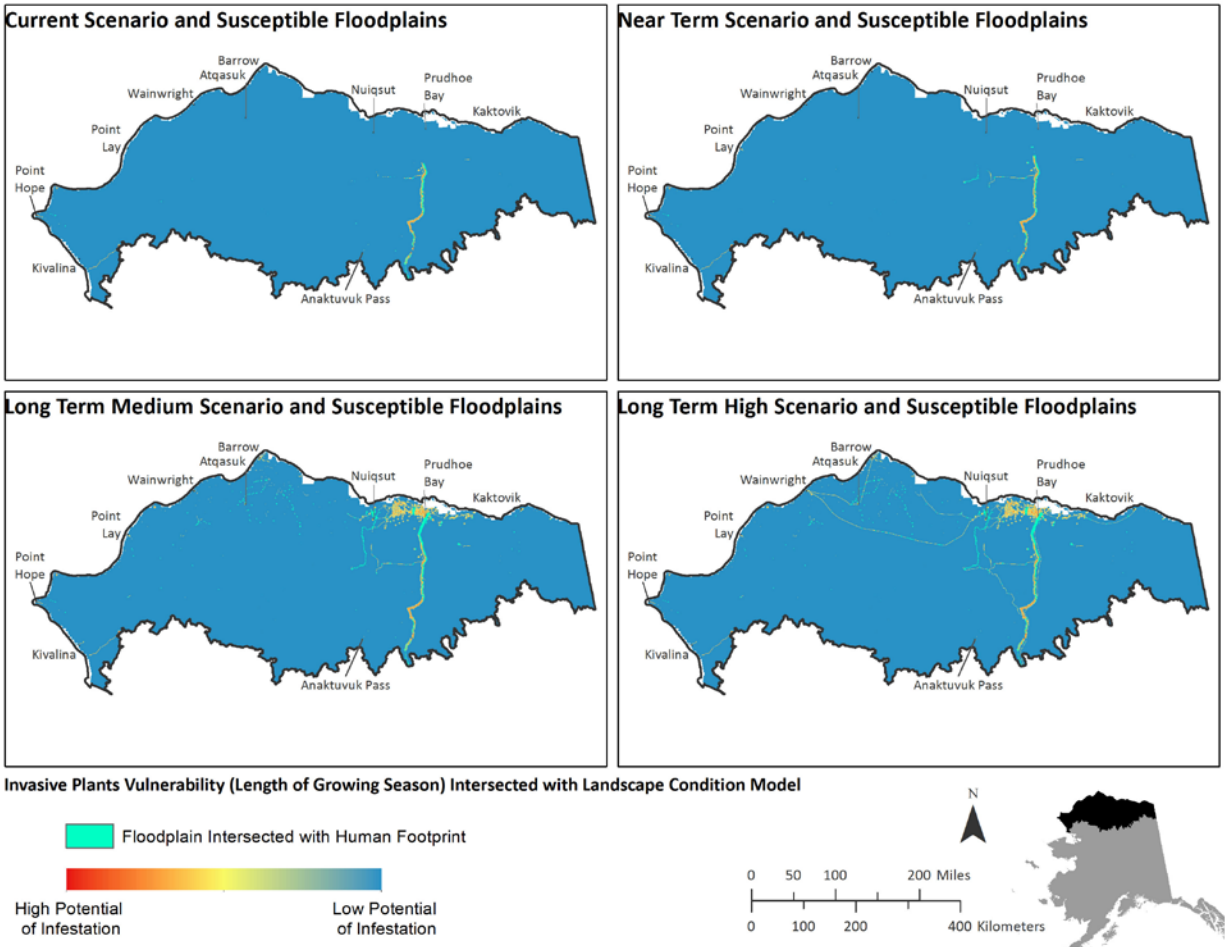


Figure D-6. Modeled infestation vulnerability in the North Slope for clockwise from upper right: current (a), near-term (b), long-term medium development Landscape Condition Model (LCM) scenario (c), and long-term high development LCM scenario (d). Areas predicted to have higher probabilities of invasion potential by at least the most cold-tolerant suite of species are shown in warmer colors. Invasion vulnerable Floodplain Shrublands and Barrier Island CEs overlapping with the LCM are shown in turquoise.

Table D-4. Non-native plant species in Alaska grouped by minimum growing season length (cold-tolerance) categories. Invasiveness Rank indicated perceived impacts to natural habitats and ecology in Alaska (species with no perceived impact would rank 0, while the most invasive species would rank 100).

Species	Cold-Tolerance Group (Growing Season Days)	Invasiveness Rank
<i>Hordeum jubatum</i> *	Extreme (120-130 days)	63
<i>Taraxacum officinale</i>	Extreme (120-130 days)	58
<i>Matricaria discoidea</i>	High (131-140 days)	32
<i>Plantago major</i>	High (131-140 days)	44
<i>Poa annua</i>	High (131-140 days)	46
<i>Lepidium densiflorum</i>	High (131-140 days)	25
<i>Chenopodium album</i>	High (131-140 days)	37
<i>Stellaria media</i>	High (131-140 days)	42
<i>Polygonum aviculare</i>	High (131-140 days)	45
<i>Crepis tectorum</i>	High (131-140 days)	56
<i>Trifolium repens</i>	High (131-140 days)	59
<i>Capsella bursa-pastoris</i>	Moderate-High (141-150 days)	40
<i>Descurania sophia</i>	Moderate-High (141-150 days)	41
<i>Galeopsis tetrahit</i>	Moderate-High (141-150 days)	50
<i>Phleum pratense</i>	Moderate-High (141-150 days)	54
<i>Elymus repens</i>	Moderate-High (141-150 days)	59
<i>Bromus inermis</i> *	Moderate-High (141-150 days)	62
<i>Poa pratensis irrigata</i>	Moderate (151-160 days)	52
<i>Cerastium fontanum</i>	Moderate (151-160 days)	36
<i>Triflorum pratense</i>	Moderate (151-160 days)	53
<i>Triflorum hybridum</i>	Moderate (151-160 days)	57
<i>Leucanthemum vulgare</i> *	Moderate (151-160 days)	61
<i>Melilotus albus</i> **	Moderate (151-160 days)	81
<i>Hieracium umbellatum</i>	Moderate (151-160 days)	51
<i>Alopecurus pratensis</i>	Moderate (151-160 days)	52
<i>Vicia cracca</i> **	Moderate (151-160 days)	73
<i>Papaver croceum</i>	Moderate (151-160 days)	39
<i>Linaria vulgaris</i> *	Moderate (151-160 days)	69
<i>Prunus padus</i> **	Moderate (151-160 days)	74
<i>Spergularia rubra</i>	Moderate (151-160 days)	34
<i>Senecio vulgaris</i>	Moderate (151-160 days)	36

Species	Cold-Tolerance Group (Growing Season Days)	Invasiveness Rank
<i>Lappula squarosa</i>	Moderate (151-160 days)	44
<i>Tripleurum inodorum</i>	Weak (161-170 days)	48
<i>Medicago sativa</i> ssp. <i>sativa</i>	Weak (161-170 days)	59
<i>Lotus corniculatus</i> *	Weak (161-170 days)	65
<i>Prunus virginianum</i> **	Weak (161-170 days)	74
<i>Trollius europeus</i>	Weak (161-170 days)	NR
<i>Hordeum vulgare</i>	Weak (161-170 days)	39
<i>Medicago sativa</i> ssp. <i>falcata</i> *	Weak (161-170 days)	64
<i>Melilotus officinalis</i> *	Weak (161-170 days)	69
<i>Caragana arborescens</i>	Weak (161-170 days)	74
<i>Collomia linearis</i>	Weak (161-170 days)	NR
<i>Thalaspi arvense</i>	Weak (161-170 days)	42
<i>Plantago lanceolata</i>	Weak (161-170 days)	NR
<i>Persicaria maculosa</i>	Weak (161-170 days)	47
<i>Lolium multiflorum</i>	Weak (161-170 days)	41
<i>Lolium perenne</i>	Weak (161-170 days)	52
<i>Cerastium glomeratum</i>	Weak (161-170 days)	36
<i>Silene noctiflora</i>	Weak (161-170 days)	42
<i>Fallopia convolvulus</i>	Weak (161-170 days)	50
<i>Galeopsis bifida</i>	Weak (161-170 days)	50
<i>Convolvulus arvensis</i>	Weak (161-170 days)	56
<i>Triticum aestivum</i>	Weak (161-170 days)	NR
<i>Aegopodium podagraria</i>	Weak (161-170 days)	57

*Indicates the non-native species with moderate invasiveness scores (> 60) and ** indicates highly invasive species with scores (>70).

3.3. Applications

Overall, we anticipate that invasive plant establishment will be geographically restricted under near- and long-term scenarios and that most CEs will not be strongly impacted by this CA. We expect that only a small number of non-native plant species will be able to form self-sustaining populations and these will most likely be restricted to the human footprint and floodplains or barrier islands and beaches that intersect with the human footprint. Thus the Sagavanirktok and Colville River floodplains, particularly by 2060, are deemed vulnerable to invasion. The most ecologically threatening species appear to be less cold tolerant and are anticipated to remain restricted to the warmest portions of the North Slope study area by 2060, particularly on the south side of the Brooks Range and the area from Hotham Inlet to Cape

Lisburne. Sparsely vegetated habitats adjacent to road corridors (Dalton Highway, road to Red Dog) and villages are expected to be most vulnerable.

While we expect that the ecological impacts of invasive species will remain limited in the region, we do anticipate a worsening condition. These results can assist managers in targeting the limited resources on surveys and control efforts in the most appropriate areas. Second, we have identified those non-native species that are present and expected to be able to establish in the study area currently and in the future, facilitating the development of conservation goals (i.e., which species should be the highest priority for control). Last, we view the products developed in this section as a starting point for more specific testing of abiotic and biotic limitations for the establishment of non-native plants in the Arctic.

3.4. Limitations and Data Gaps

Survey points for invasive plants are not random and many species are only recently introduced; therefore it is possible that documented locations do not represent the true breadth of their climate niche space. Individual plant species are expected to display different sensitivities to climatic variables. However, such studies have not been conducted on the non-native flora of Alaska and we are additionally limited by the spatial data sets available. Growing season length is likely to integrate many climatic variables controlling non-native plant establishment; however development of growing degree days above 4° C and probability of summer frosts, for example, are likely to assist in future invasion vulnerability assessments. Additionally, the probability of invasive species establishment is largely driven by anthropogenic variables, such as human population size and road density, elsewhere in the state. With so few invasive species in the Arctic region, however, we are unable to determine the influence of anthropogenic factors on invasion probability per se.

Future infestation vulnerabilities are based on scenarios of climate change and development that are inherently uncertain (see Section B-1) and caution should be exercised in interpretation of those outputs. Other disturbances such as herbivorous insect outbreaks and tundra fires are expected to increase the probability of non-native plant establishment; however, we are unable to incorporate these factors in a meaningful spatial context. Areas subjected to wildfire in remote areas of the interior rarely have non-native plants present and typically require close proximity to roads or human habitation before non-native infestations are observed (Greenstein and Heitz 2013). We suggest disturbances within regions known to harbor infestations or predicted to harbor infestations are more likely to experience expansions of existing populations.

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E. Anthropogenic Change Agents

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Summary

Section E. *Anthropogenic Change Agents* provides the detailed descriptions, methods, datasets, results, and limitations for the assessments of changes due to human activities including natural resource extraction, infrastructure, and subsistence.

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1. Introduction

Anthropogenic Change Agents assessed in this project include several human activities ranging from oil production and mining, to livelihood activities such as subsistence. This section describes the current extent of human activity in the North Slope study area and attempts to assess potential changes in these factors projected into the future.

Anthropogenic activities in the North Slope study area are diverse. Although natural resource extraction dominates the footprint, subsistence as a competing use is an important activity for consideration in making land use decisions. Small communities separated by large distances, located primarily along the northern coast, are vulnerable to changing climate conditions, which creates complex challenges for near and long-term regional management. Ownership and control of land is fragmented among several federal agencies, state, and local bodies. Ecoregional boundaries cross jurisdictional boundaries, thus creating the need for robust inter-agency cooperation and coordinated management of resources. With subsistence being a critical part of the local social, cultural, and economic fabric, local participation in resource management is, and will continue to be, critical in sustainable management practices.

Owing to the breadth of such factors, this section is necessarily limited to general information, guided by the MQs, and covers the following:

- **Subsistence:** All communities in the region depend on subsistence resources. Species harvested for subsistence include various species of fish, birds, plants, and big game animals (primarily caribou), and marine mammals. Development of any kind impacts the land available for subsistence. People in the region constantly strive to balance these two priorities, allowing them the ability to have both a subsistence lifestyle and a cash economy.
- **Natural Resource Extraction:** Prudhoe Bay is home to the largest oil field in the United States and produces approximately 40% of the oil extracted in Alaska. Oil extraction has substantial impacts on transportation infrastructure, energy supply, community populations, employment, and subsistence. Additionally, mining activities are either proposed or currently exist in a smaller part of the study area.
- **Transportation and Communications Infrastructure:** The majority of the transportation infrastructure is related to oil industry activities. Other community transportation infrastructure – existing and planned – is small in comparison to the oil industry’s activities, as well as small in comparison to other U.S. communities. Transportation infrastructure includes local roads, airports, ports, and local summer and winter trails. Communication infrastructure includes broadband and cellular service towers.
- **Recreation:** This includes visitors to remote lodges and dispersed and centralized facilities in state and national recreation areas. Visitors to this region are mostly seasonal.
- **Community Energy Development:** Diesel generators are the main source of electricity in communities, with an increasing emphasis on renewable sources of energy. Renewable energy projects in this region are small scale and designed to replace some of the energy produced by

diesel generators. Lack of transmission infrastructure and a small customer base limit the size of these projects.

In addition to assessing the current and future anthropogenic activities, we also provide a social and economic profile of the region. Assessing the extent of anthropogenic activities required an extensive process of discovery, collection, and cleaning of data on various social and economic indicators from multiple data sources, and mapping and analyzing the various types of activities in the region. This section also identifies various data sources used in the analysis, and identifies various limitations to availability and accessibility of required data. The ecoregions correspond closely to the administrative boundaries of the North Slope Borough with the exception of two communities, Kivalina and Noatak, and the Red Dog Mine, all located in the Northwest Arctic Borough (NWAB).

Although the BLM requests project results to be reported at the 5th-level hydrologic unit, social and economic data are only available by political and administrative jurisdictions and do not correspond to HUCs. Where possible and meaningful, data were aggregated to the 5th-level hydrologic unit, but most data were presented at their native resolution.

1.1. General Land Status

With almost 70% of the land in the North Slope study area monitored and regulated by federal agencies, federal government is the largest landowner in the study area (Table E-1). More than half of this federal land is regulated/monitored by the Bureau of Land Management (BLM), including the National Petroleum Reserve – Alaska (NPR-A). Overall, the BLM is the largest landowner/regulator in the North Slope study area, regulating 38.98% (97,364.321 sq. km) of total land in the study area.

Table E-1. Distribution of land ownership in the North Slope study area.

Land Ownership	Area (km ²)	Percent of Total Study Area
Bureau of Land Management	97,364	39%
State Patent or TA	49,493	20%
US Fish and Wildlife Service	45,834	18%
National Park Service	29,165	12%
Native Patent or IC	23,134	9%
State Selected	3,009	1.2%
Native Selected	1,674	0.7%
Military	81	0.03%
Private	0.05	0.00%
Total	249,754	

Data Source: Bureau of Land Management.

The State of Alaska with 19.82% (49,493.086 sq. km) is the second largest landowner in the study area. This was part of the land entitlement accrued as part of the Alaska Statehood Act. Approximately

174,015 km², or 42% of the state's entitlement (a total of 415,005.13 sq. km.) was transferred and patented by the state as of 2004 (Brooks 2005). This selection includes 149,976 km² of land that was tentatively approved for selection (Bradner 2013). The State selected areas it believed would provide the necessary resources for the state's development, and to convey control over the state's internal affairs from the federal government. These selections were based on the principles of encouraging development and settlement, development of natural resources, and development of recreational uses of land (Alaska Department of Natural Resources 2000). Much of the oil development in the North Slope study area is on state-owned land. Figure E-1 shows land ownership in the study area.

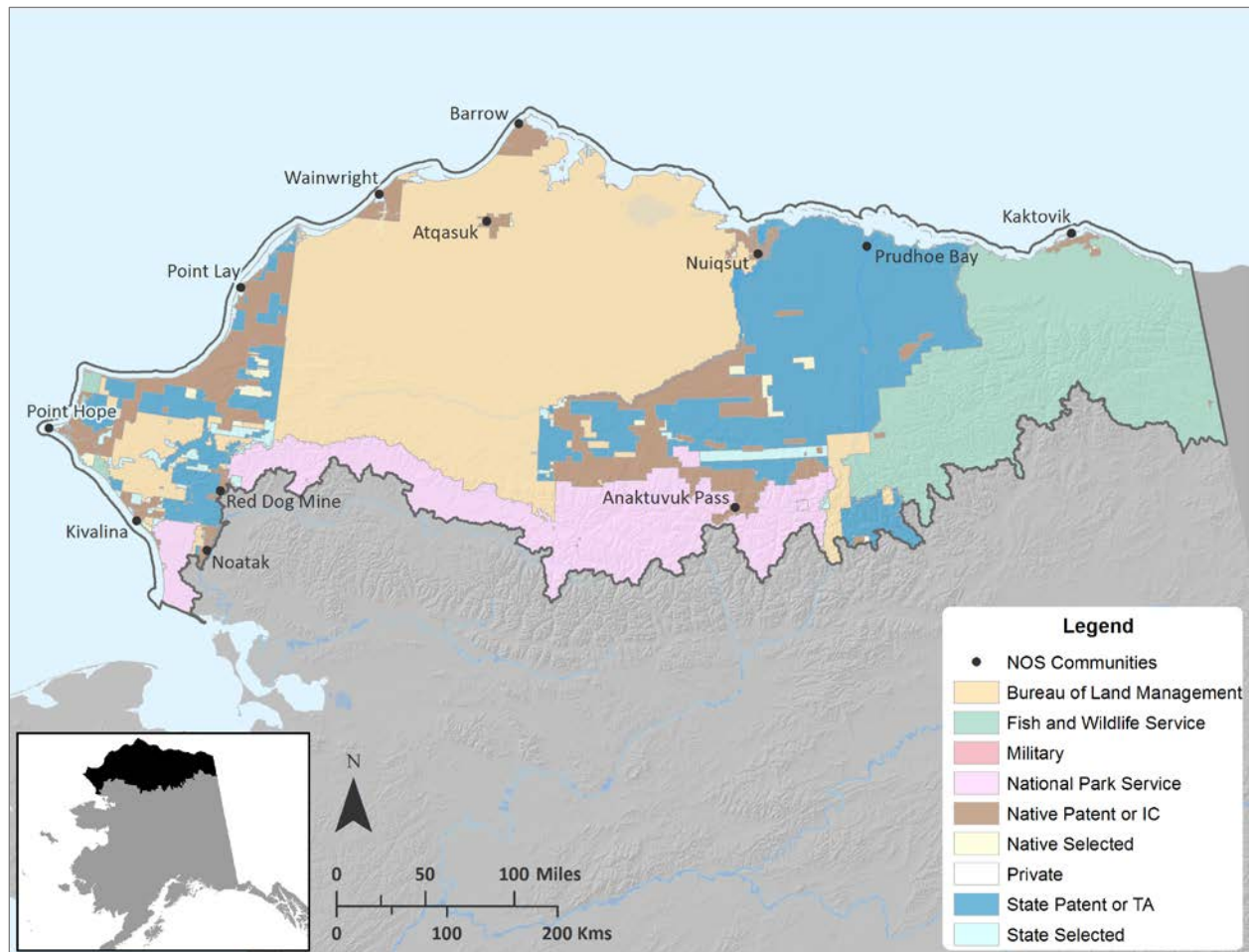


Figure E-1. Land status in the North Slope study area. Data Source: Bureau of Land Management.

In addition to the State Patent or Temporarily Approved (TA) selection, the State of Alaska also selected lands that are yet to be approved by the federal government, and has not yet been conveyed either through a patent or temporary approval. Approximately 3,008.827 sq. km of land is marked as state selected lands in the North Slope study area, not all of which may be eventually conveyed under the authorizing legislation. While the state files a claim and the land is marked as "state selected", the land is closed for federal mining claims, however, the State of Alaska accepts mining claims on this land. There is considerable risk associated with such claims since the federal government may restrict such

claims or may decide not to convey the selected land to the state (Alaska Department of Natural Resources 2014).

Similar to the state selection, Alaska Native corporations were entitled to land selections through the Alaska Native Claims Settlement Act of 1971. A total of 23,133.629 sq. km² of land is either conveyed or in interim conveyance (IC), and another 1,674.189 sq. km of land was selected but yet to be conveyed. Recipients of conveyances under ANCSA are a mixture of regional and Alaska Native village corporations, and the majority of this land will be conveyed as private landholdings to them. A small portion of this land is to be conveyed as a land base for communities. These conveyances for community lands (up to 1200 acres) will first be transferred from local Alaska Native corporations to the state, in trust for a future municipal body to be incorporated under state law. Upon incorporation of such a municipal entity, these conveyed trust lands will be conveyed to the local municipal entity. Such lands are selected by each community through an extensive public process involving members of that community and other stakeholders in the lands around that community. Most communities in the North Slope study area region have not completed their land selections.

The ten communities in the study area have a combined footprint of 22.485 sq. km. While the area occupied by each community is extremely small compared to any other landowners in the area, subsistence activities of the resident population require a significantly large area, potentially extending to the entire study area. As shown in Figure E-2, the resident population has camps and cabins throughout the region, mostly along the rivers and other water bodies. The data obtained from the North Slope Borough's Traditional Land Use Inventory (TLUI) does not include camps and cabins used by residents of Kivalina and Noatak, and thus is limited to just the residents of North Slope Borough. This dispersion indicates the significant use of the land, albeit seasonal. Although the region's population is relatively small, and concentrated in communities that are far from each other, their reliance on subsistence requires the use of such vast areas. The majority of trails outside the vicinity of Prudhoe Bay are used to access subsistence resources of the region. Despite the density of camps and cabins, the remoteness of the region and sparse population mean relatively low impact of this use on the ecological resources.

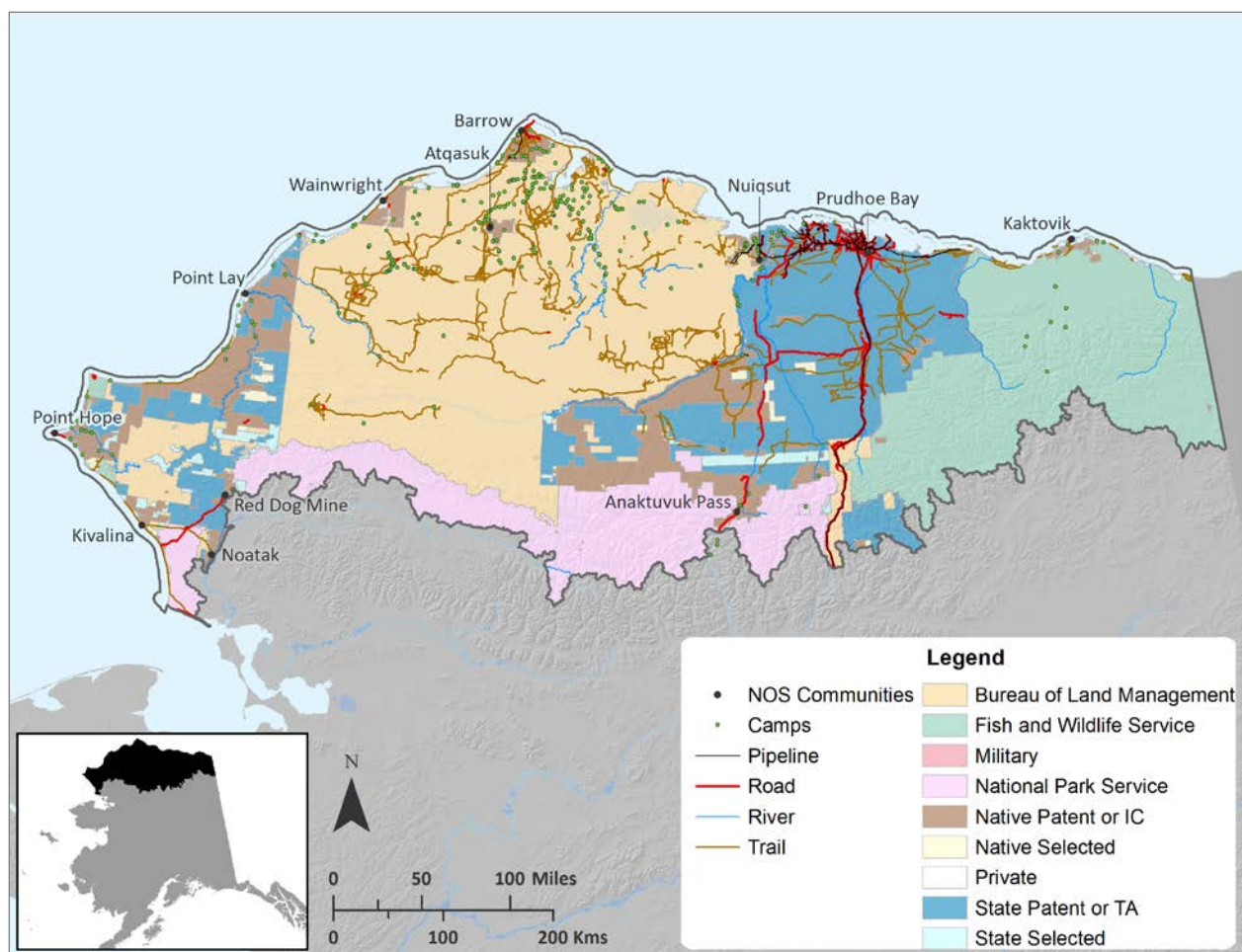


Figure E-2. Locations of camps and cabins in the North Slope study area. Data Sources: Bureau of Land Management; North Slope Borough; USGS; ADNRR; ADFG; Mapmakers Alaska; UAA-ISER; UAA-AKHNP.

2. Current Human Footprint

This section describes the current human footprint in the North Slope study area. Human activity in this area dates back centuries. However, this narrative is limited to the recent human footprint beginning with the military installations following World War II. Many trails used for inter-village transportation and access to subsistence existed far before any contact with non-residents of this region. These access and transportation routes changed over time, and documentation of such routes is a relatively recent effort.

Ten communities, two industrial complexes with substantial transient populations, a number of fishing camps, around the Teshekpuk Lake and along all rivers, transportation routes (trails, roads, and river transportation routes), oil fields, pipelines and associated infrastructure, and mines comprise the bulk of the current human footprint. In addition, this region saw increased activity during the heady days of the Cold War, with several military installations that still dot the landscape. Radar sites at Barrow, Oliktok, and Barter Island are active North Warning System Long Range Radars. The region is home to some of the largest parks and preserves in the nation, and abundant natural resources.

2.1. Methods

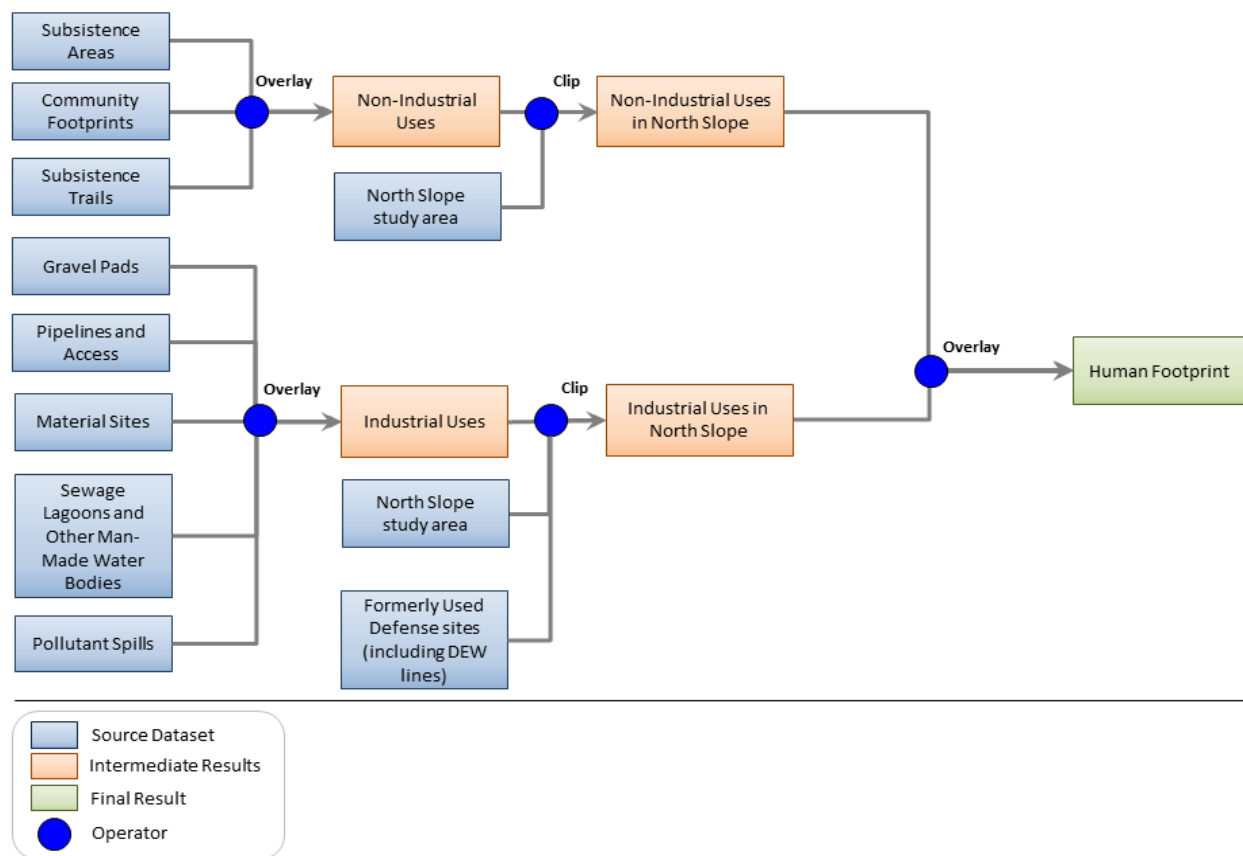


Figure E-3. Process Model for computing human footprint in the North Slope study area.

The human footprint includes all major human activities ranging from individual community footprints, subsistence use areas, transportation networks, defense installations, and industrial infrastructure. We identified current human footprint in the region by using several data layers. Figure E-3 shows the process model for computing the current human footprint in the region.

Datasets

Table E-2 lists the datasets that were included in computing the human footprint in the region. All original datasets were cropped to the North Slope study area boundary. A combined human footprint map was used to generate the Landscape Condition Model, and was produced by overlaying all individual layers described below. Some of the datasets that were more challenging are also described below.

Table E-2. Source datasets for analysis of current and future human footprints.

Dataset Name	Data Source
Community Footprints	Digitized from aerial and satellite imagery
General Land Status - October 2013 - All Attributes - Clipped to 1:63,360 Coastline	ADNR Information Resources Management
Alaska DNR RS2477 Trails	ADNR Information Resources Management
Alaska Roads 1:63,360	ADNR Information Resources Management
Rolligon Routes	Bureau of Land Management
Ice Roads	Bureau of Land Management
Alaska Resource Data File (ARDF)	U.S. Geological Survey
Mineral Potential Data	U.S. Geological Survey
Federal Mining Claims in Alaska	Bureau of Land Management
Alaska DNR State Mining Claims	ADNR Information Resources Management
Alaska DNR State Prospecting Sites	ADNR Information Resources Management
Renewable energy infrastructure	Alaska Energy Authority (AEA)
Contaminated sites program database	Alaska Department of Environmental Conservation
Oil and gas infrastructure, transportation infrastructure, camp sites	Mapmakers Alaska
Distant Early Warning sites and Formerly Used Defense Sites (FUDs)	U.S. Army Corps of Engineers
Subsistence Use Areas	Bureau of Land Management
Kivalina evacuation route	Digitized from reports prepared by WH Pacific, a private consulting engineering firm

All uses of the land are broadly classified into industrial and non-industrial use areas. Industrial use areas include all infrastructure associated with oil, gas, and mining industries in the North Slope study area. Non-industrial use areas include community footprints and subsistence use areas. There is an obvious overlap between industrial and non-industrial uses. While several facilities in Prudhoe Bay and surrounding oil and gas fields are strictly used for residential purposes, these are classified as industrial uses for two reasons: (1) these facilities are expected to be temporary, and (2) only serve the needs of the workforce and do not serve any permanent population in the study area. Within the community footprints, there can be several facilities that could be classified under industrial uses. However, since all these facilities are located within community footprints, and the individual footprint of these facilities is relatively insignificant, they are classified as non-industrial.

Communities

Community footprints were produced by digitally tracing the built areas from satellite imagery. This was done to represent the actual footprints more accurately than would have been possible from the U.S. Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) files. TIGER files are geospatial files with information on several political and administrative units. These shapefiles include polygon boundaries of geographic areas and features, linear features including roads and hydrography, and point features. The communities in Alaska were released as a polygon shapefile, with each community's boundary identified. However, there were two major concerns with this file:

- i. Community boundary polygons represent the legal boundaries and not the actual developed areas. The actual developed area for each community in the region is much smaller than its legal boundary. Moreover in many instances, boundaries as identified in TIGER files are not legal boundaries recognized under state law. Therefore, these polygon boundaries are not accurate representations of existing communities, and over-represent the actual community footprints.
- ii. Many of the maps produced for this project show community-level social and demographic information. For better representation in such maps, a point file was used instead of a polygon file to identify communities. Generation of a point file from a polygon file is done by locating the point at the center of gravity of the polygon. Given the large polygons in the community TIGER file, centers of gravity are often well outside the actual community footprints.

As a result, Census TIGER files were not used in identifying community footprints. Instead, each community's footprint was digitized from satellite imagery. Communities in the North Slope study area are small and their footprints are concentrated in small areas with some activities scattered around each communities' central location. Population in each community is low and activity beyond identified footprint boundaries is limited to subsistence-use and inter-community trails.

Total population numbers from the years 1990 to 2013 were used. Population in Prudhoe Bay was counted as resident population of the North Slope starting with the Census 2010. Since Prudhoe Bay numbers are unavailable for prior years, we excluded Prudhoe Bay population from 2010 to 2013. Decennial population data (for the years 1990, 2000, and 2010) were obtained from U.S. Census. Data for other years were obtained from estimates provided by the AK-DOLWD.

Table E-3. Population projection models considered for projecting population of the North Slope study area.

Model Name	MAPE	Adjusted R-square
Trend Linear Regression (Method1)	3.97%	
Holts Exponential Smoothing (Method2)	1.40%	
Time Series Decomposition (Method3)	0.96%	
Multiple Regression with Method1, Method2, and Method3	0.89%	96.01%
Multiple Regression with Method2 and Method3	0.88%	96.06%

Data Source: Estimated by ISER.

Three different models (Table E-3) were used - Trend Linear Regression, Holts Exponential Smoothing, and Time Series Decomposition. Mean Percentage Absolute Error (MAPE) was used for individual and combination of models to identify the model that provides the best projection. Multiple regression with Holts Exponential Smoothing and Time Series Decomposition had the highest adjusted R-square of 96.06% and lowest Mean Absolute Percentage Error (MAPE) of 0.88%, and therefore this method was selected for the base population projection.

Community Energy Infrastructure

Both gas and diesel are used to produce electricity in the North Slope study area. Alaska Energy Data Gateway (AEDG) maintained and managed by the Institute of Social and Economic Research (ISER) is a comprehensive source of data on production and consumption of energy from all sources in the state. The AEDG was explored to obtain relevant data for this project. Energy infrastructure in the study area includes several diesel power plants and some gas powered generators.

Renewable energy infrastructure includes several types of energy production installations: wind, hydro, thermal, and biomass. Through multiple waves over the last decade, the Alaska Energy Authority - Renewable Energy Fund funded, or is considering funding, several of these installations. All renewable energy sites are small scale and are within community footprints. Future potential for renewable energy in the region was obtained from the Alaska Energy Atlas produced by the Alaska Energy Authority.

Transportation Infrastructure

The transportation network in the region includes airstrips, few paved or gravel roads within communities, and a network of trails to subsistence use areas and those that connect communities. Most communities in the region are located along the northern coast of Alaska, with Noatak, Nuiqsut, Prudhoe Bay, and Atkasuk located inland, along rivers. Travel to and from communities in the region is largely limited to air travel. While many rivers in the region are navigable, these are not treated as regular transportation routes. The transportation data used in the North Slope study was obtained from two sources – North Slope Borough Planning Department and Alaska Department of Natural Resources (ADNR). Alaska trails from Revised Statute (RS) 2477 of the Mining Act of 1866 are rights-of-way for the construction of highways over public lands, not reserved for public uses. The Act granted public right-of-way across unreserved federal land to guarantee access as land transferred to state or private

ownership. Rights-of-way were created and granted under RS 2477 until its repeal in 1976. The combined dataset used for this project does not include subsistence access trails on Native land.

Natural Resource Extraction

As of 2003, there were more than 4,800 exploratory and production wells, 223 production and exploratory drill pads, over 500 miles of roads, 28 production plants, gas processing facilities, seawater treatment plants, and power plants on the North Slope and in the adjacent Beaufort and Chukchi Seas (National Research Council 2003), and approximately 989 miles of flowline and oil transmission pipelines (Robertson et al. 2010). Although no comprehensive listing of facilities supporting the oil and gas industry was available, several sources list the following as common industrial facilities associated with the North Slope oil and gas industry:

- Drill Site
 - Well Pads
 - Ice Pads
 - Production Pads
 - Injection Pads
- Wells
 - Exploratory
 - Development (exploitation or production)
 - Disposal
- Production facilities (NPR-A, 2013)
 - Docks and bottom-founded structures
 - Seawater treatment plants
 - Material sites such as gravel and sand pits
 - Temporary platforms
 - Pump stations
- Processing facilities
 - Above-ground oil storage tanks
 - Building modules
 - Facility oil piping
 - Crude oil transmission pipeline
 - Drilling mud plant (2014 GMT1 EIS)
 - Flow lines
 - Pipelines
- Maintenance Complex
- Emergency response center
- Warehouse facilities
- Vibroseis (thumper truck)
- Transportation
 - Gravel roads
 - Ice roads
 - Airports
 - Bridges
 - Power plants
 - Refineries
 - Residential centers
 - Solid waste

Data on mining activities in the region were obtained from the Alaska Resource Data File (ARDF), a compilation of mining activity maintained by the U.S. Geological Survey (USGS). It is a subset of the National Mineral Resource Data System (MRDS), "a collection of reports describing metallic and non-metallic mineral resources throughout the world" (U.S. Geological Survey 2014). All mines, prospects, and mineral occurrences are recorded with descriptions, types of minerals and ores, last reported date, current status of the site, and location.

The following process was followed to prepare the ARDF mining dataset to be included in the human footprint:

1. Main data file had quadrangle codes, and quadrangle code descriptions were given in another file (<http://ardf.wr.usgs.gov/explain.pdf>). The quadrangle code descriptions have been added in the main dataset.
2. Address the considerable uncertainty in several key fields in the dataset.
 - a. 'Site status' had the following values: 'active,' 'active?,' 'inactive,' 'inactive?,' 'probably inactive,' 'not determined,' 'undetermined.' These were recoded and defined as follows:
 - i. Active (some work was reported at the time of last report date) - 'active', 'active?'
 - ii. Inactive (no work was reported at the time of last report date)– 'inactive' 'inactive?,' 'probably inactive'
 - iii. 'undetermined' (no information was available) – 'undetermined', 'not determined,' 'undetermined' and blank cells
 - b. 'Site type' refers generally to the current status or potential for the site to yield a mineral. Three distinct values seem to be valid – 'mine', 'occurrence', and 'prospect'. This classification of reporting mineral occurrences is not congruent with the industry standard set by the Society for Mining, Metallurgy & Exploration (SME), or other international organizations. No certain definitions could be obtained from USGS. This field had the following recorded values: 'mine', 'mine?', 'mines', 'mine (?)', 'occurrence', 'occurrence(?)', 'occurrence?', 'occurrences', 'prospect', 'prospect(?)', 'prospect?', 'prospects(?)', 'prospect', 'mine', and 'mine and prospect'. These were recoded and defined as follows:
 - i. Mine (where a mineral was or is being extracted) – 'mine', 'mine?', 'mines', 'mine (?)'
 - ii. Occurrences (a location where a useful mineral or material is or was found) – 'occurrence', 'occurrence(?)', 'occurrence?', 'occurrences'
 - iii. Prospect – (prospect is any occurrence that has been developed to determine the extent of mineralization) – 'prospect', 'prospect(?)', 'prospect?', 'prospects(?)', 'prospect; mine', and 'mine and prospect'.
 - c. Commodities or minerals at each site were recorded in two separate columns – 'commodities-main', and 'commodities-other':
 - i. 'Commodities-main' is the main mineral resource that was, is or is expected to be mined at the site. Multiple commodities (up to 21) were listed in this column for many sites.
 - ii. 'Commodities-other' are ancillary minerals that may be extracted depending on the technological and economic feasibility. There were more than one commodities listed in this column.

- d. 'Deposit model' field contained a brief description of the deposit. These descriptions indicated if a particular site was a placer gold mining site. If the site listed gold in the 'commodities-main' field, these sites were marked as placer gold mining sites, whether in the past, present, or in the future.
- e. 'Production' field recorded any production activity at each site as of the last reported date. A variety of values were used. They were all recoded into the following options:
 - i. 'No' – 'No', 'None'
 - ii. 'Yes' – 'Small'; 'Yes', 'Large', 'Yes', 'medium', 'Yes, small', 'Yes, Very small', 'Yes: small', 'Yes: large', 'Yes, medium', 'Yes, small?', 'Yes: unknown', 'Yes?'
 - iii. 'Undetermined' – 'Undet.', 'Undetermined', 'Unknown')
- f. 'Last report date' is the only date field in the dataset. This field reports the date of last update on any activity at each site. Date of last update on each site varies, and not all sites are updated annually or periodically.

The ARDF file is not updated in a systematic way. Data contained in the ARDF are largely a result of voluntary reporting and collection efforts. The last report date for the ARDF file are between 2001 and 2012 have been considered in the final data set. There were only four (4) prospects that had a report date prior to 2001, all were last updated on May 4, 1999.

Mineral potential data was available for the eastern part of the study area from the BLM. Six mineral deposit models were used to generate the data:

- 1) REE-Th-Y-Nb deposits associated with peralkaline to carbonatitic intrusive rocks,
- 2) Placer and paleoplacer Au,
- 3) PGE (-Co-Cr-Ni-Ti-V) deposits associated with mafic-to-ultramafic intrusive rocks,
- 4) Carbonate-hosted Cu (-Co-Ag-Ge-Ga) deposits,
- 5) Sandstone U (-V-Cu) deposits, and
- 6) Sn-W-Mo (-Ta-In-fluorspar) deposits in specialized granites.

12-digit HUC areas were used to display the data. Each polygon contains an estimate of potential and uncertainty of a particular mineral deposit model to be found in that polygon. Estimates are based on the proximity of certain favorable geologic conditions found in multiple statewide datasets.

2.2. Results

Communities

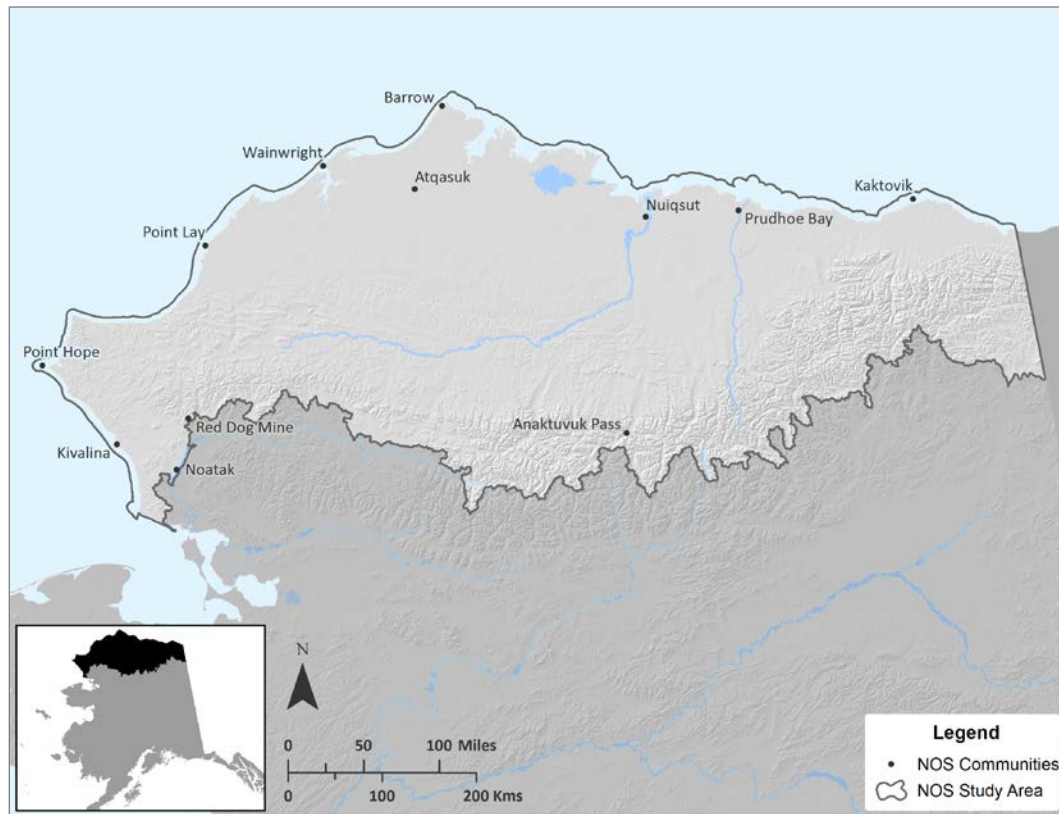


Figure E-4. Footprints of communities and populated places in the North Slope study area. Prudhoe Bay and Red Dog are not treated as communities, and their footprint is discussed in a separate section. Data Source: U.S. Census; UAA-ISER.

Table E-4. Total population counts of communities and group quarters in the North Slope study area.

Community	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
North Slope Borough														
Anaktuvuk Pass	282	302	308	326	311	321	314	293	303	309	324	324	344	358
Atkasuk	228	236	234	232	224	233	245	231	229	212	233	243	235	248
Barrow	4,581	4,450	4,449	4,428	4,388	4,201	4,095	4,067	4,082	4,171	4,212	4,324	4,445	4,514
Kaktovik	293	273	295	280	265	252	259	252	237	245	239	247	245	262
Nuiqsut	433	427	445	419	436	415	422	408	389	410	402	427	428	452
Point Hope	757	708	699	706	706	694	703	666	646	660	674	668	668	683
Point Lay	247	250	245	248	232	218	208	216	218	196	189	184	196	215
Wainwright	546	560	532	546	526	511	506	525	519	536	556	571	565	543
Northwest Arctic Borough														
Kivalina	377	380	374	374	372	363	365	366	370	370	374	384	402	402
Noatak	428	438	456	469	451	475	471	490	515	490	514	547	568	562
Group Quarters (data available since 2010)														
Prudhoe Bay											2,174	2,174	2,174	2,174
Red Dog Mine											309	309	309	309
Total	8,172	8,024	8,037	8,028	7,911	7,683	7,588	7,514	7,508	7,599	10,200	10,402	10,579	10,722

Data Source: U.S. Decennial Census: 2000 and 2010 population; Alaska Department of Labor and Workforce Development: 2001-2009 and 2011-2013.

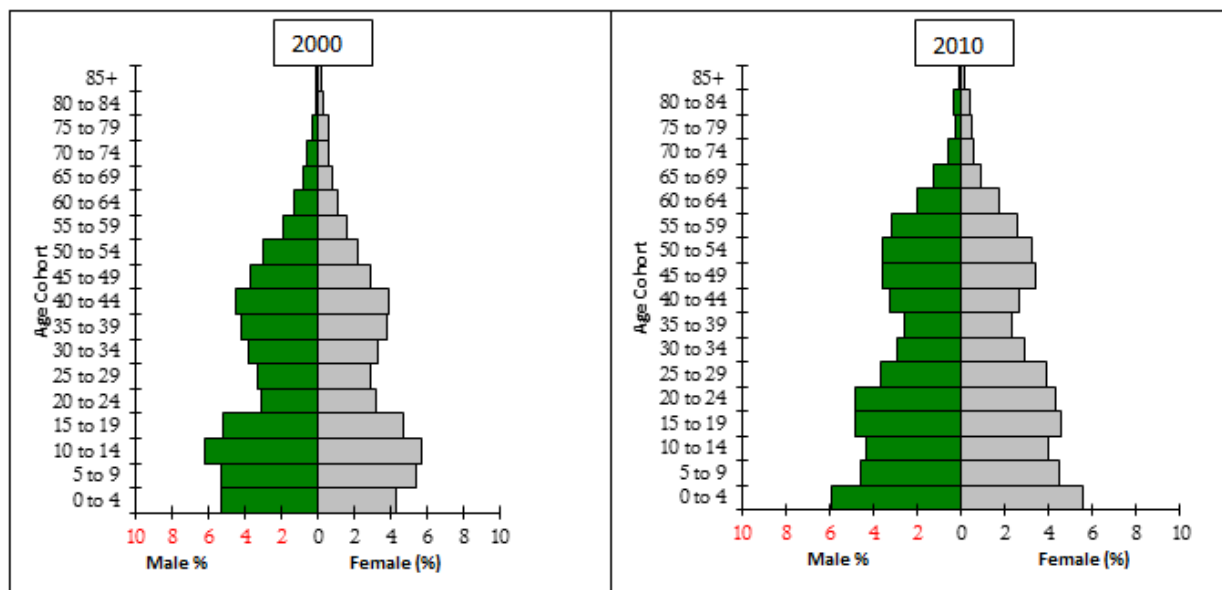


Figure E-5. Population structure of the North Slope study area (excluding group quarters; 2000 and 2010). Data Source: U.S. Census.

Figure E-4 shows the locations of communities. Table E-4 shows Barrow (pop. 4,514 in 2013), with the largest population, which also has the largest footprint among the communities in the region. Remaining communities' populations range from 683 in Point Hope to 215 in Point Lay. All communities except Noatak in the Northwest Arctic Borough, and Atkasuk, Anaktuvuk Pass, and Nuiqsut in the North Slope Borough are located on an island off the coast, or on the coast. Figure E-5 shows the gender and age distribution of the population in the study area excluding Prudhoe Bay and Red Dog Mine for the years 2000 and 2010. Although the total population in 2000 (pop. 8,172) is less compared to 2010 (pop. 7,717), higher proportion of younger cohorts in 2010 indicates likely sustained growth in the future. Total estimated resident population of the study area, excluding Prudhoe Bay and Red Dog Mine, in 2013 is 8,239. If the present trends continue (Table E-5; Figure E-6) the region's population is likely to be more than 9,500 by year 2025 and over 12,000 by year 2050. Alaska Natives comprise approximately 70% of the local resident population in the region, and more than 90% of the population in a majority of the communities (Figure E-7).

Table E-5. Projected population for the North Slope study area (excluding Prudhoe Bay and Red Dog Mine).

Year	Base Projection	Low Projection	High Projection
2020	9,047	9,001	9,137
2025	9,500	9,452	9,595
2030	10,028	9,978	10,129
2035	10,529	10,477	10,634
2040	11,038	10,983	11,149
2045	11,486	11,429	11,601
2050	12,017	11,957	12,137
2055	12,518	12,456	12,644
2060	13,028	12,963	13,158

Data Source: Estimated by ISER.

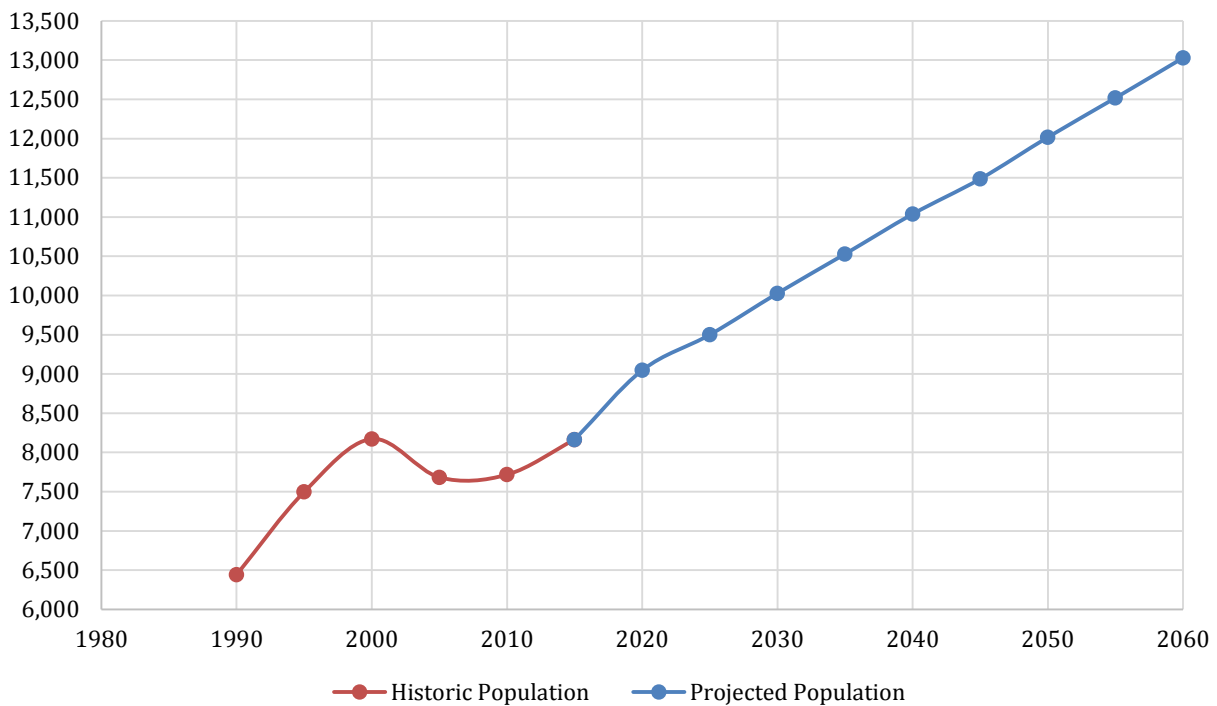


Figure E-6. Population projection of the North Slope study area (excluding Prudhoe Bay and Red Dog Mine). Data Source: Estimated by ISER

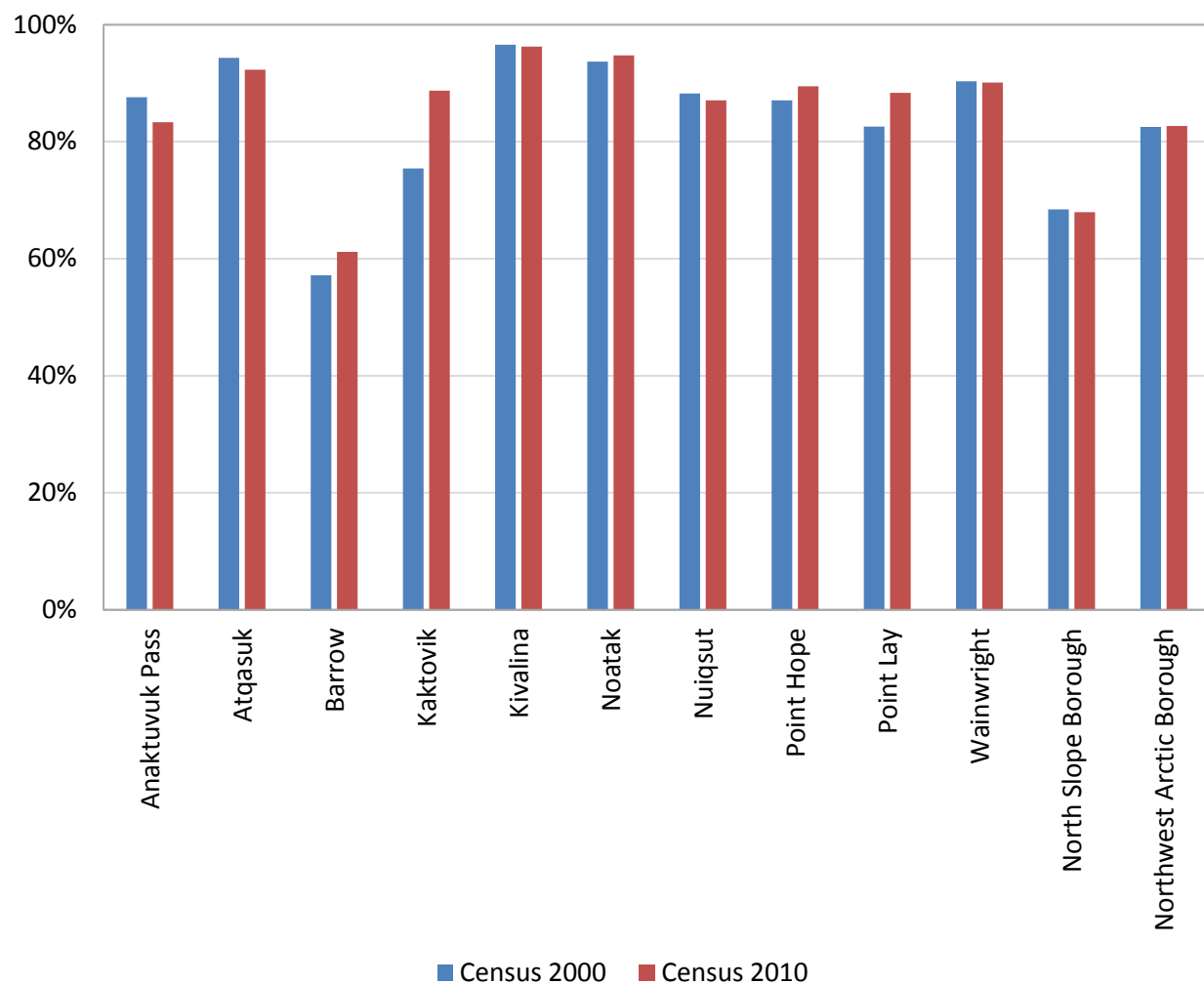


Figure E-7. Percentage of population reported as Alaska Native in each community in the North Slope study area.
Data Source: Estimated by ISER.

Prudhoe Bay and Red Dog Mine are large industrial developments. Prudhoe Bay (pop. 2,714 in 2013) is home to the largest oil industry complex on the North Slope. Several oil fields in the vicinity also operate their logistics from Prudhoe Bay. Red Dog (pop. 309 in 2013) is a zinc and lead mine. Population in these industrial developments is entirely composed of transient workers on a two-week or three-week shift. Residential facilities built to serve this population include large hotels and lodges owned or contracted by oil companies. No permanent residence is allowed in either place. Population from both places is excluded from the population projections above.

Community Energy Infrastructure

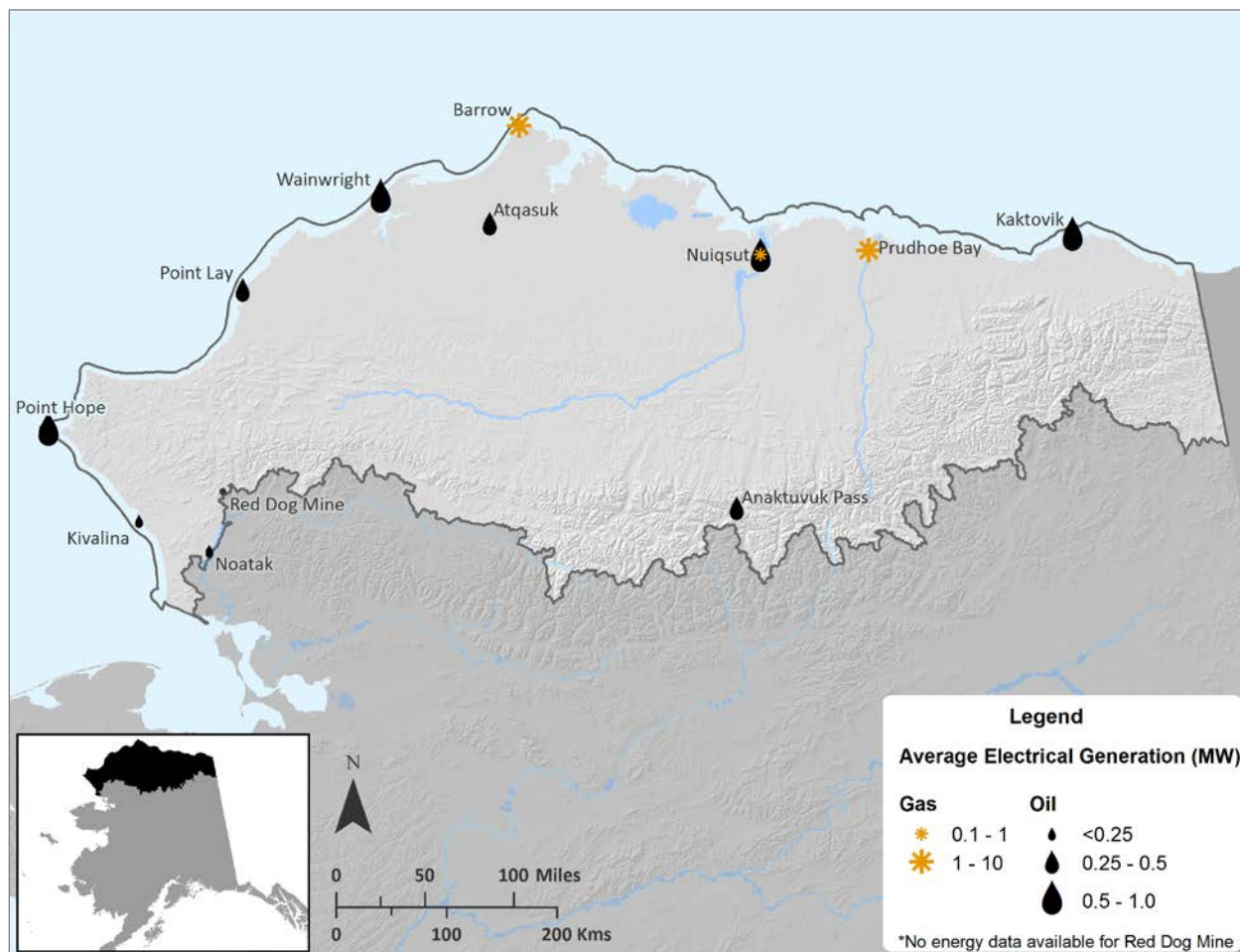


Figure E-8. Electricity generation capacity and source for each community in the North Slope study area. Data Source: Alaska Energy Authority (AEA).

This section only covers the energy infrastructure serving the region's resident communities, and does not discuss the energy infrastructure of Prudhoe Bay oil and gas industry complex in any detail. Each community in the study area is served by an isolated grid, with its own generation and distribution infrastructure. All energy infrastructure in each community is within the community's footprint. Barrow and Prudhoe Bay, the two largest population centers, rely completely on natural gas for generating electricity. Nuiqsut relies both on natural gas and diesel. Other than Barrow and Prudhoe Bay, all other communities have small demand loads, and thus only generate less than a megawatt. Figure E-8 shows the locations and generation capacity of electricity infrastructure in the North Slope study area.

Renewable energy infrastructure includes several types of energy production installations: wind, hydro, thermal, and biomass. Through multiple waves over the last decade these projects were funded or are being considered for funding by the Alaska Energy Authority - Renewable Energy Fund. All renewable energy sites are small scale and are within community footprints (Figure E-9). We obtained the data for

the area's renewable energy potential from the Alaska Energy Atlas produced by the Alaska Energy Authority (Figure E-10).

While several renewable energy projects are in the planning stages, the only active project is a heat recovery system in Point Lay. Most proposed projects use wind energy for electricity generation; they are all small scale, with the capacity to meet only a fraction of the local energy demand in their respective communities.

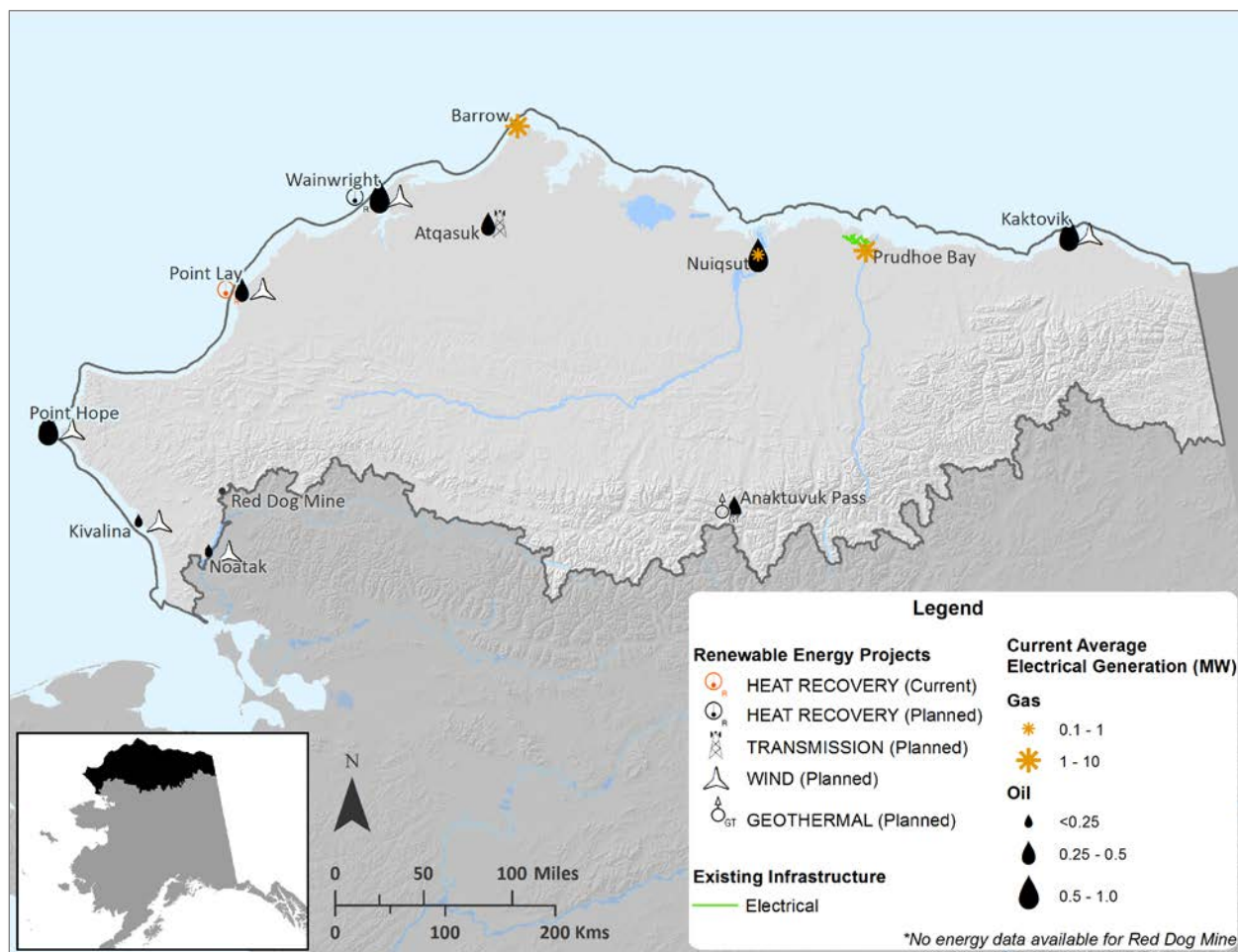


Figure E-9. Planned renewable energy projects in the North Slope study area. Data Source: Alaska Energy Authority (AEA).

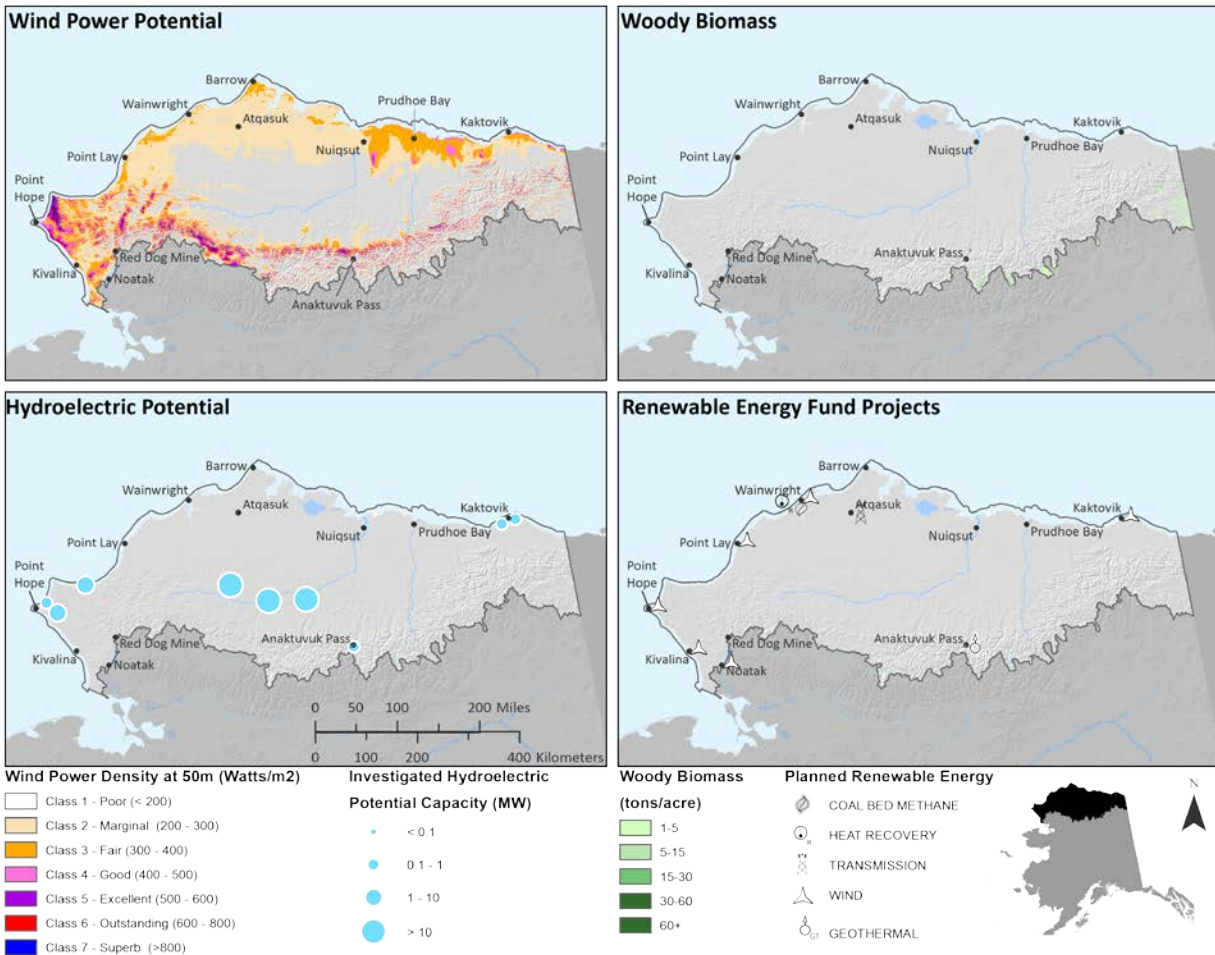


Figure E-10. Renewable energy potential in the North Slope study area. Data Source: Alaska Energy Authority (AEA).

Transportation Infrastructure

Although a complex network of trails, roads, and other ground transportation infrastructure exists in the study area, they are not useable year-round. All resident communities are remote and isolated, and rely on air transport services. Every community has an airstrip within its community boundary. Barrow, the largest community in the region, serves as the commercial and services hub for the region. The communities of Point Hope, Kivalina, and Noatak are served from Kotzebue due to better logistics.

The Dalton Highway connects Prudhoe Bay to Livengood, 75 miles north of Fairbanks, and parallels the Trans-Alaska Pipeline carrying crude oil from Prudhoe Bay oil fields to the Port of Valdez located on the Gulf of Alaska. The Highway is 28 ft. wide with an average of 3-6 ft. of gravel surfacing. The majority of traffic on the Highway is commercial freight trucks serving the oil and gas industry in and around Prudhoe Bay. The Highway was opened to public use in 1995. Summer traffic counts are substantially higher than during winter months. Another major gravel road in the North Slope study area with high

usage is the 52-mile road connecting the Red Dog Mine to its port site on the Chukchi Sea. Ore is trucked to the port for export during the 100-day open shipping routes.

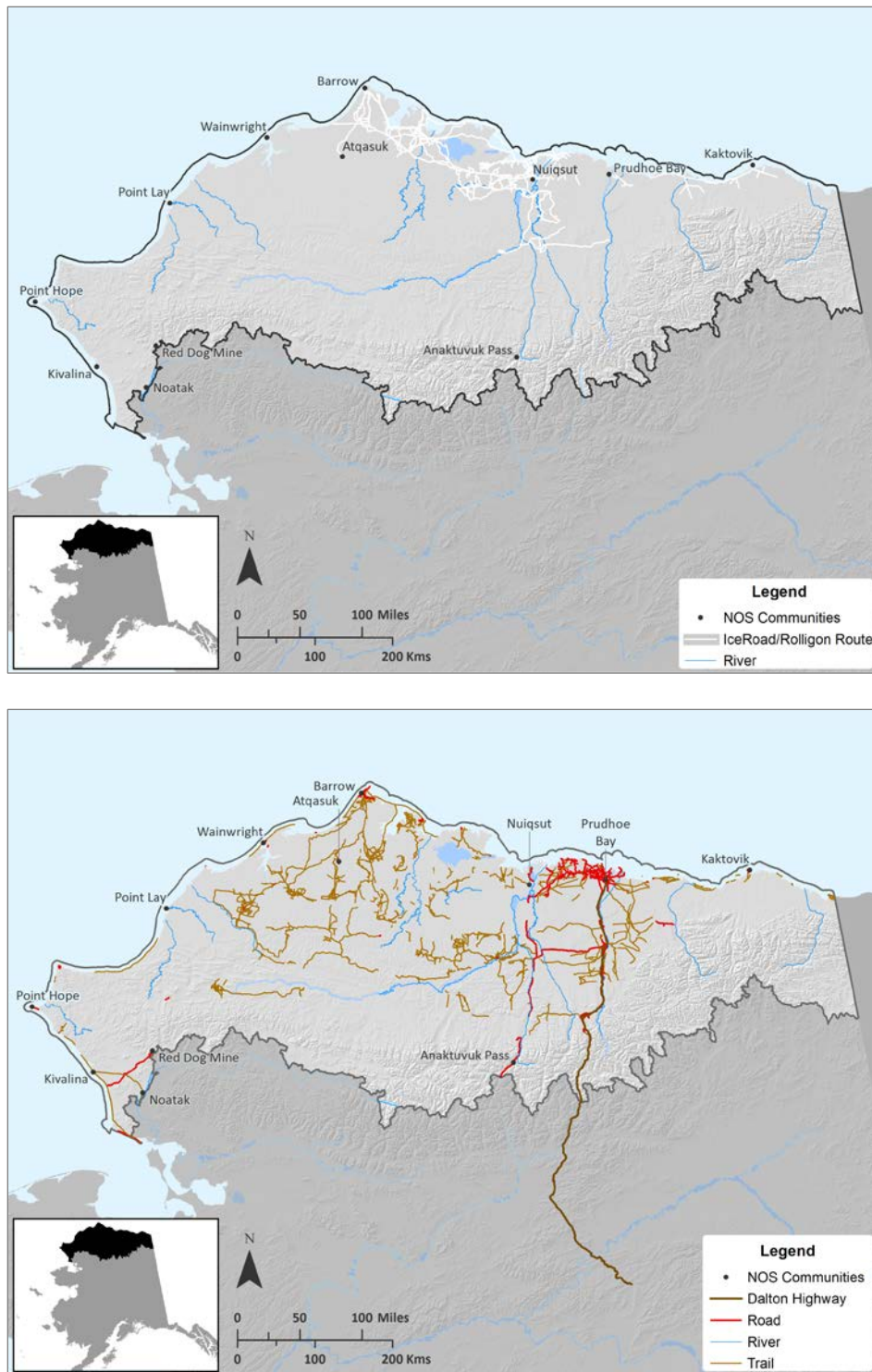


Figure E-11. Transportation infrastructure in the North Slope study area. Data Source: BLM; North Slope Borough; USGS; ADNR; ADFG; ADOT; Mapmakers Alaska; UAA-ISER; UAA-AKHNP.

In addition to the Dalton Highway, Prudhoe Bay oil fields are also served by three major airstrips – a state owned and operated airport at Deadhorse and two privately owned airstrips. The Deadhorse airstrip is 6,500 ft. long and 150 ft. wide, and accommodates large aircraft. This airport is served by several scheduled flights operated by commercial airline companies. The two privately owned airstrips are of similar capacity at Deadhorse, and are exclusively served by Shared Services, a joint flight operation of ConocoPhillips and British Petroleum. The Wiley Post-Will Rogers Memorial Airport in Barrow is also state-owned and is similar in capacity to the Deadhorse Airport. Barrow is also served by commercial airline companies from Anchorage and Fairbanks. Kotzebue’s Ralph Wien Memorial Airport is also state-owned, and is 5,900 ft. long to accommodate large aircraft. Nuiqsut, Wainwright, and Atkasuk are the other primary airports in the region with approximately 4500 ft. long gravel airstrips, and are also state owned.

Table E-6. Extent of transportation routes in the North Slope study area.

Type of route	Length in km
Trails	9916.14
Ice Roads/Rolligon Routes	4975.71
Rivers	4568.92
Secondary Roads	1221.37
Pipelines access roads	1671.10
Dalton Highway	333.37

Data Source: Calculated by ISER

In addition to the Dalton Highway and the airstrips that serve the most major transportation needs in the region, an extensive trail network developed over generations plays a significant role for inter-community travel and for access to subsistence use areas. As shown in Table E-6, the total length of the trail system far exceeds the other modes of transportation in the study region. This trail network includes several that were built to access various infrastructure facilities in the oil and gas fields around Prudhoe Bay. Work on assessing long-term impacts of these trails is still underway. Figure E-11 shows the extent of various transportation infrastructure facilities in the North Slope study area.

A major concern in the study area is the disturbance caused by activities on trails associated with increased seismic exploration requiring ground transport. During the early days of oil exploration, when concerns of environmental impacts were not acute, exploration activities were not as regulated. Damages to the slow-growing tundra and permafrost can still be seen 60 years later. Better land management practices and regulations starting in the 1970s minimized further damages to a large extent. Short-term (2-8 years) studies did not find any major impacts, and thus activities as conducted now, during winter months when the ground is frozen, are considered harmless. However, increased exploration activities both in frequency and geographic extent during the last decade brought back concerns of their impact. The cumulative impacts of seismic exploration are considered higher than all other human activities combined (National Research Council 2003). There is an increased effort to assess these long-term impacts (Janet et al. 2010).

The almost 5,000 km. long network of ice roads/Rolligon routes is used to serve the oil and gas infrastructure facilities in the study area. State of Alaska regulations allow ice roads to be built in areas with 6" to 9" of snow depth and with soil temperature of -5C at 30cm depth. The short-term impacts on the environment have been studied, and the impacts are reported to be more severe than seismic trails (National Research Council 2003). Rolligon trails are pioneered in the study area to transport freight to remote drilling sites, and for travel between Barrow and Atkasuk and Nuiqsut. These trails are built for special vehicles called Rolligons, equipped with large inflatable bags for wheels. Rolligons can carry large loads (approximately 40 tons) and can travel for up to 250 miles at 12 mph. An inconclusive study in 2004 reported some impacts from insufficient data (Roth et al. 2004). Many rivers and streams in the region are navigable. They are used for access to subsistence use areas, and recreation purposes. However, given the sparse population and remoteness of the region, rivers are not major transportation routes in the region. None of the rivers in the region offer inter-community connectivity.

Natural Resource Extraction

The natural resource economic potential from the North Slope of Alaska is well recognized. Continuous exploration for and extraction of oil, gas, and minerals had a sustained impact on the region's ecosystems throughout last century. While such activities were limited in scope before the discovery of oil at Prudhoe Bay, the region has experienced phenomenal growth in these activities since. Landscape-scale disturbances are due to an accumulation of a number of smaller, related activities over a long period of time. For example, an oil field can have one small gravel pad with an access road, and this likely does not have a perceivable impact as an isolated activity. However, when there are a number of these activities, such as gravel pads, access roads, associated pipelines, transportation infrastructure including trails, vehicular traffic, dust accumulation, material sites, gravel mines, sewage lagoons, reserve pits, small and large pollutant spills, seismic trails, and snow pads, they can have a sustained impact on the natural ecosystem.

By 2001, the total area covered by oil and gas infrastructure in the North Slope study area was approximately 17,354 acres. This estimate includes areas affected by year-round structures and does not include seasonal and occasional activities such as ice roads or off-road travel. While technology improvements over the last three decades have decreased the amount of year-round infrastructure being built, it still remains high. In addition to extensive presence of oil and gas deposits, there are rich deposits of some of the best grade coal, and several minerals. Similar data is not readily available for mining as they are for oil and gas activities in the region (National Research Council 2003).

Patterns of land ownership in the North Slope study area are unique, and play a major role in the patterns of natural resource extraction. The study area can be broadly classified into state owned/controlled, federally owned/controlled, native regional corporations-which are privately controlled-tribally owned/controlled, and other private land. Federal ownership and control dominates the region. Approximately 70% of the land is owned and controlled by the federal government through its various agencies. Most oil and gas development is concentrated between the National Petroleum Reserve – Alaska (NPR-A) and the Arctic National Wildlife Refuge (ANWR), between the Colville River in the west and Canning River in the east. This land is largely owned by the State of Alaska and is

subdivided into two lease zones: the North Slope (20,639 sq. km.) and the North Slope foothills (30,756 sq. km.). A third leasing zone consists of the territorial waters of the Beaufort Sea. Owing to the scale used in this report, this section only discusses the dense development of oil and gas infrastructure present on the state-owned land. Several past attempts at exploration in the NPR-A were included in the human foot print section.

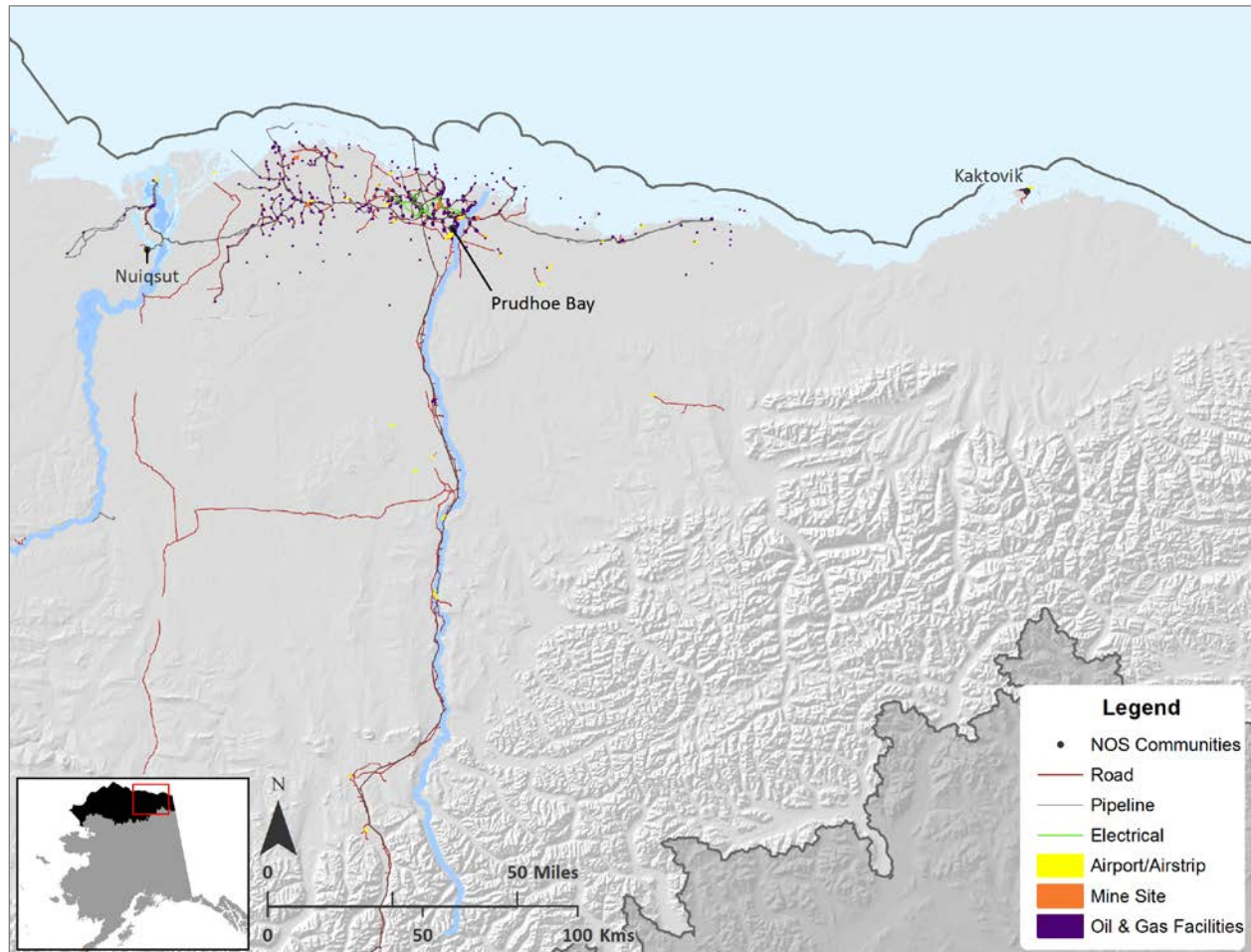


Figure E-12. Oil and gas infrastructure in the North Slope study area. Data Source: Mapmakers Alaska.

Although exploration in the region began in the 1920's, economically feasible extraction began in the late 1970's after the completion of the Trans-Alaska Pipeline System (TAPS) and the Dalton Highway. Natural resource development in the North Slope study area can be described as approximately 423 miles of gravel road/causeway, 189 miles of peat roads, tractor trails, and exploration roads, 166 miles of TAPS, 491 miles of other pipeline, 336 miles of power transmission lines, 400 facility pads, 13 airstrips, gravel mines covering 21.7 sq. km., 2,037 culverts, 27 bridges dot the landscape directly disturbing 74.2 sq. km. of land in this region (Hillmer-Pegram 2014). Figure E-12 shows the footprint of this infrastructure.

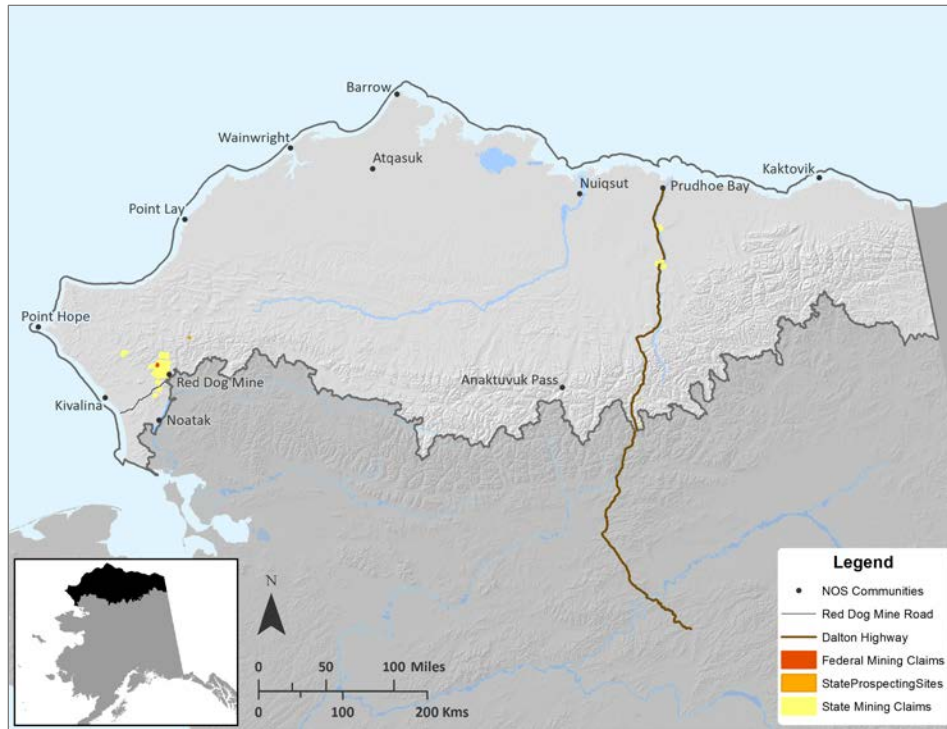


Figure E-13. Mining claims in the North Slope study area. Data Source: BLM; ADNRR.

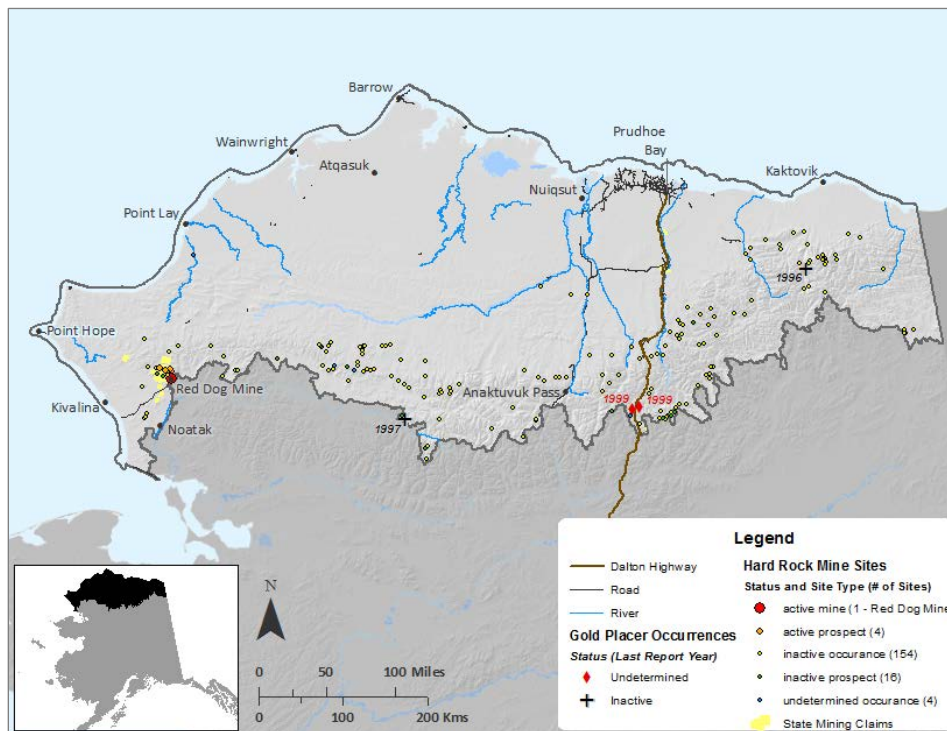


Figure E-14. Placer and hard rock mine sites from the Alaska Resource Data File (ARDF). Data Source: Alaska Resource Data File (ARDF).

Mining in the North Slope study area can be discussed in two primary parts. The first part, mining for precious minerals, is mostly restricted to Red Dog Mine in the western part of the region. Several areas in the region-particularly in the foothills of the Brooks Range-are rich in several valuable minerals. However, the economic feasibility of mining these materials is low, limiting current exploration and extraction. The second part is mining for gravel. Gravel is used to construct everything from drilling pads to roads, community facilities, and airports. A substantial amount of gravel is mined in the North Slope study area.

Gravel mining at substantial levels in the region parallels the development of oil and gas industry in the region. During the first decade of oil industry development, gravel was primarily mined from active river waterbeds. There was little monitoring and the permitting process was weak. Gravel mining and water withdrawal from active rivers and overwintering lakes caused concern, resulting in new regulations in late 1970s restricting such use between the Canning and Colville Rivers. This led to innovative multiuse deep gravel pits that supplied gravel for the numerous needs of the oil and gas industry operations in addition to serving as deep lakes for overwintering of fish. Studies over the years by ADF&G found that the winter water quality of these lakes is very conducive for healthy fish habitat (Ott et al. 2014).

Mining in the region is limited to the Red Dog Mine in the Northwest Arctic Borough. It is an open pit zinc and lead mine, and uses the truck and shovel method. The mine site is accessed year round by air. Mine facilities include the main Red Dog pit, Aqqaluk pit, tailings pond, mill, and the personnel accommodation complex (PAC). The DeLong Mountain Transportation System (DMTS), the transportation network around the mine, includes several access roads to various facilities at the site, a terminal port on the Chukchi Sea coast, and a 52-mile gravel road connecting the mine site with the port.

In addition to the mining claims around the Red Dog Mine, there are minor active mining claims along the Dalton Highway (Figure E-13). The Alaska Resource Development File (ARDF) mine site database displayed in Figure E-14 shows several inactive occurrences all along the northern foothills of the Brooks Range. Very few of these potential mine sites, principally in the vicinity of the Red Dog Mine, are located on active mine claims.

Data on mineral potential in the study area was available from the U. S. Geological Survey (USGS) (Jones III et al. 2015). This data was compiled as part of a mineral resource potential study for the Bureau of Land Management Central Yukon Planning Area. Data was compiled on six selected deposit groups:

- Rare Earth Elements (REE): Th-Y-Nb deposits associated with peralkaline to carbonatitic intrusive rocks
- Placer and Paleoplacer Gold: Gold
- Platinum Group Elements (PGE): Co-Cr-Ni-Ti-V deposits associated with mafic-to-ultramafic intrusive rocks
- Carbonate-hosted Copper Deposits: Cu-Co-Ag-Ge-Ga
- Sandstone Uranium Deposits: U-V-Cu

- Tin-Tungsten-Molybdenum-Fluorspar deposits: Sn-W-Mo-Ta-In-fluorspar deposits in specialized granites

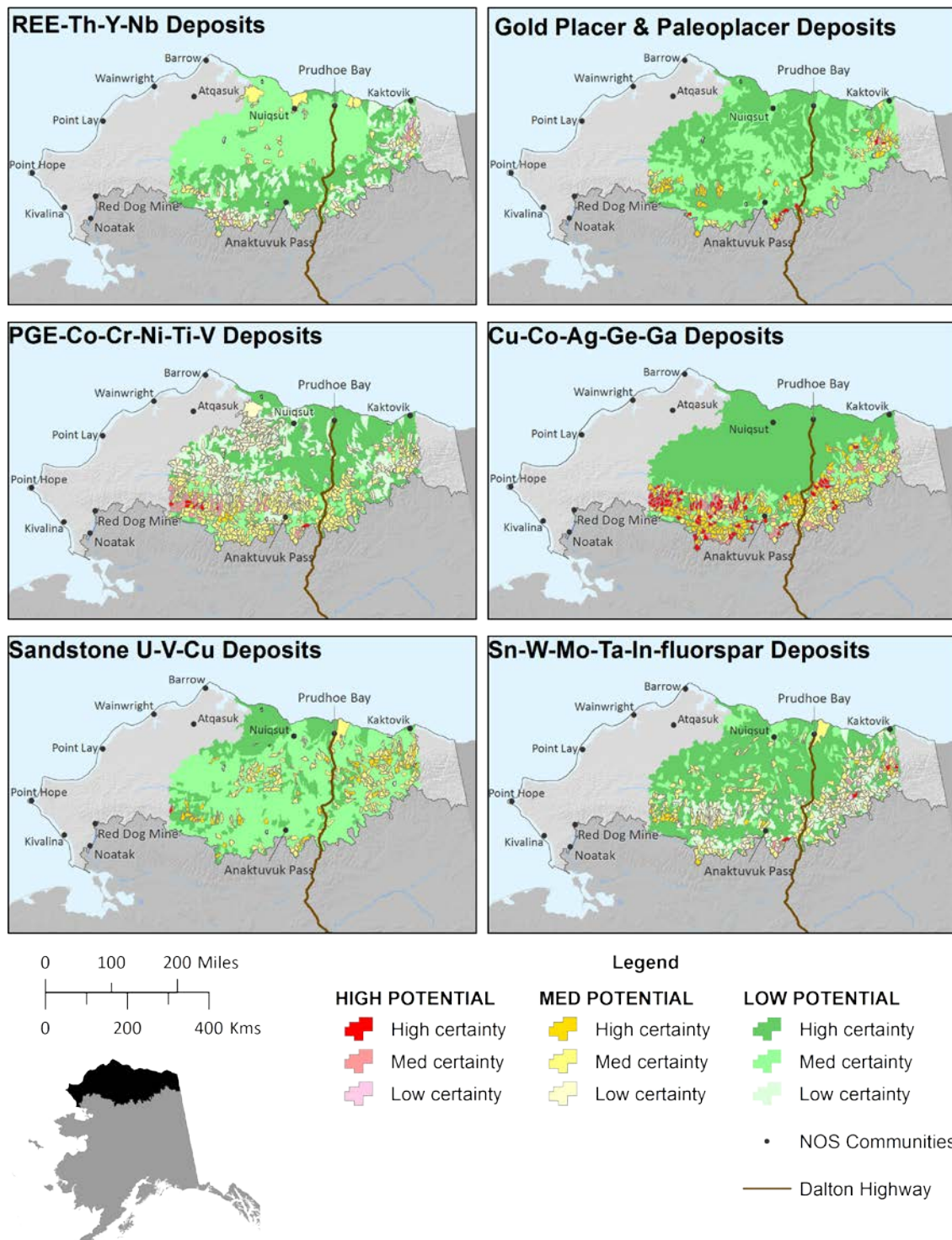


Figure E-15. Mineral potential for six deposit groups in the eastern part of the North Slope study area. Data Source: USGS.

Based on proximity of certain geologic conditions found in multiple state-wide datasets, potential for various deposits was estimated in polygons and displayed at a 12-digit HUC level. The intensity score of occurrence depended on a variety of characteristics: the presence of certain elements in sediment geochemistry; the presence of samples of each type in the ARDF; igneous indices for ASI (aluminum saturation index), $10,000 \cdot \text{Ga}/\text{Al}$ (gallium over aluminum) or displacement of Fe#; presence of ARDF samples of Th/K from aerorad data set. Figure E-15 shows the potential for each deposit group.

Large deposit of coal in the region has been known for a long time. The largest coal field in the state (77,700 Sq. Km.) is located in the northwest part of the state, along the north slope of the Brooks Range (Meyer 1987). A more recent report describes five major coal fields spread across western portion of NPR-A extending into the west of NPR-A to the shores of Chukchi Sea. The estimated coal deposit is more than a third of the nation's coal potential (Rothe 2007):

- Colville Group – marine, delta, and fluvial formations
- Nanshuguk group – swamp, delta and shallow marine deposits
- Kukporuk field just south of Point Lay
- Deadfall Syncline just east of and north of Cape Beaufort
- Lisburne Field extending from Cape Lisburne to Point Hope

In addition, the Kobuk basin coal province is a poorly defined coal field in the Ambler district. BHP Billiton Energy Coal explored the Deadfall Syncline from 2006 through 2009 but terminated their operations citing economic conditions (BHP Billiton 2009).

The potential for future mining of any of the minerals is distinct from the potential for existence of a mineral deposit. The economic and regulatory environments are significant drivers in the feasibility of mining. Several non-local factors including the international market dynamics for a mineral influences the feasibility of mining. Assessing the potential for a mine is nearly impossible without extensive data collection and is well beyond the scope of this project.

3. Future Human Footprint

3.1. Methods

The future human footprint of the region was developed concurrent to the REA through the North Slope Science Initiative (NSSI) Scenarios Project (NSSI 2015). The primary goal of the project is to identify plausible future development scenarios on Alaska's North Slope and adjacent seas using a stakeholder driven approach. Since the project is ongoing the development scenarios should be considered interim products and may change. Additionally, the NSSI Scenarios Project is focused just on oil and gas development scenarios; no future residential or commercial development is considered. Given the opportunity to integrate with a more robust approach to future human development, we utilized the scenario project for future human development estimates. More information about the project can be found on the North Slope Science Initiative's website (<http://northslope.org/scenarios/>).

3.2. Results

Geospatial data for three scenarios were delivered to us showing plausible oil and gas development futures (low, medium, and high scenario). The low scenario was not considered in the REA as it depicted the removal of oil and gas infrastructure, and while that future is certainly plausible, we did not feel it provided value to the REA process. Future oil and gas infrastructure associated with the medium development scenario includes development in part of the Greater Moose's Tooth region of NPR-A, and further expands the development currently at Point Thompson (Figure E-16). Drilling pads at Liberty are expanded, and there is a new pipeline built connecting offshore activities to the Point Thompson region. In addition to the oil and gas development, we also included the road and relocation of Kivalina in the medium development scenario.

The high development scenario included all the same infrastructure of the medium development scenario, but expanded the Greater Moose's Tooth development to include a pipeline connecting to Smith Bay, a pipeline and road from the potential Chukchi Sea facilities, and a pipeline connecting Umiat to other oil and gas infrastructure (Figure E-17). Although offshore activities are included in the NSSI scenarios, we did not include those developments given our terrestrial focus. If built, the pipeline crossing the NRP-A from the Chukchi Sea to the Trans Alaska Pipeline System is likely to have significant impact on the caribou habitat in the region. Additionally, we assumed all current oil infrastructure would continue to operate into the future. Given the uncertainty in future human footprint models, especially in the high development scenario, the results should be considered representative of potential changes in human land use and development.

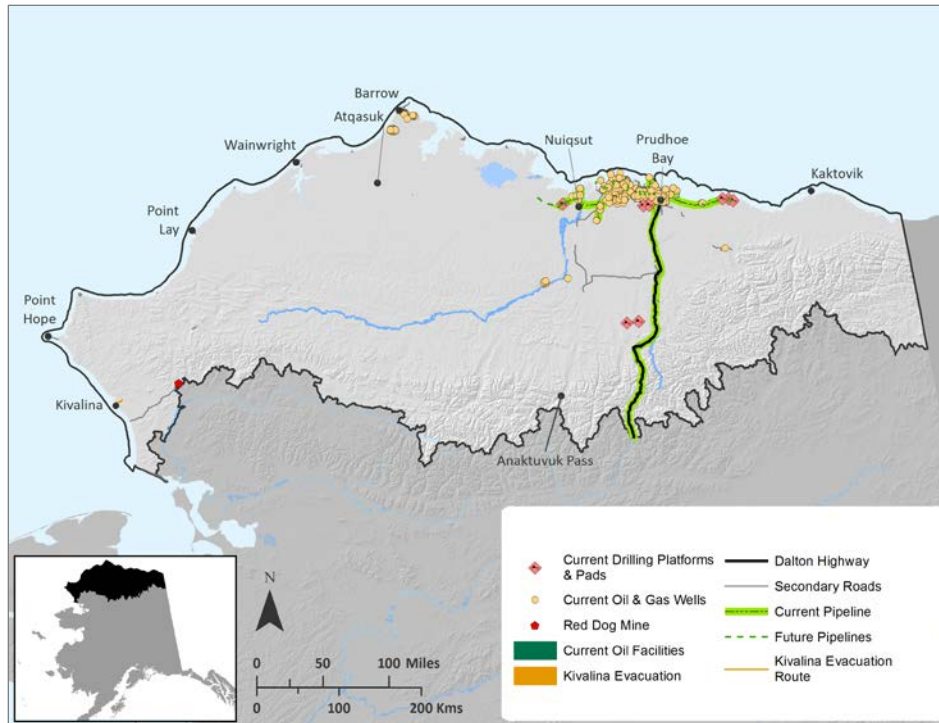


Figure E-16. Medium development scenario (2040) showing changes in oil and gas activity in the North Slope study area. Data Source: North Slope Science Initiative Scenarios Project.

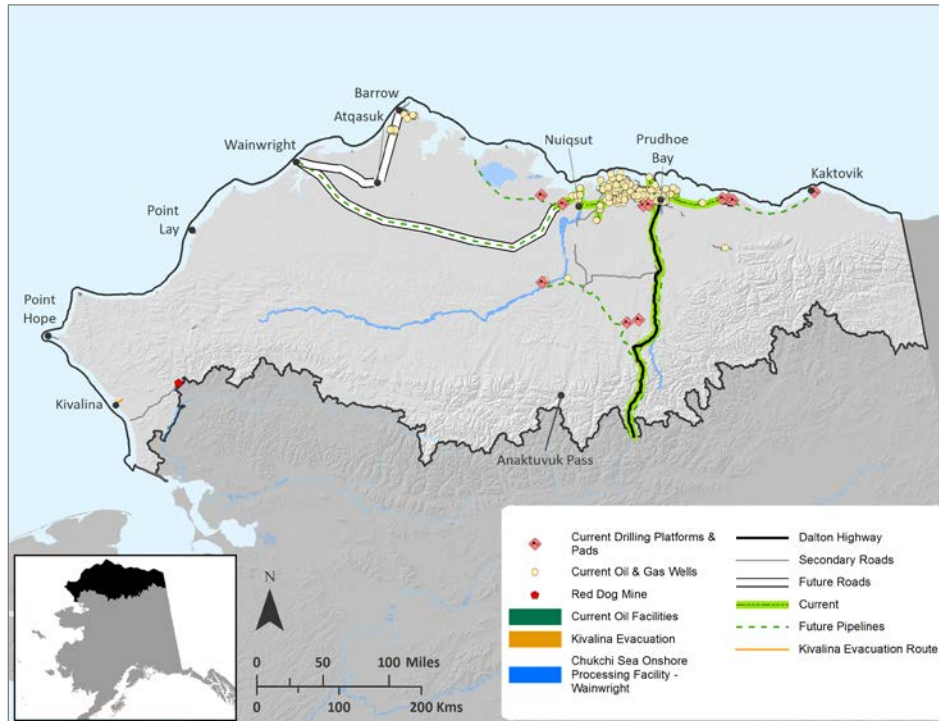


Figure E-17. High development scenario (2040) showing changes in oil and gas activity in the North Slope study area. Data source: North Slope Science Initiative Scenarios Project.

4. Social and Economic Conditions

4.1. Methods

We attempted to assess the social and economic conditions of the North Slope study area and individual communities using a framework developed for the Arctic Social Indicators (ASI) Report (Larsen et al. 2013). Data in the ASI include commonly used, publicly available sources. Most of the literature used in the ASI is gray literature, such as ADF&G community harvest studies, newspaper articles, and reports from individual research grants.

A comprehensive index of various indicators was attempted to describe the socioeconomic conditions of the region. Such an index would allow relative comparisons between this region and other similar regions in the state. The ASI Report identified a list of indicators organized into seven domains of life in the Arctic. Domains were identified through extensive interviews across the circumpolar north to reflect the lifestyle circumstances of the region. The seven domains are: health, population and demographics, material wellbeing, closeness to nature, cultural wellbeing, education, and fate control. Several indicators identified are relevant to multiple domains. We reorganized the list of indicators identified to represent these overlaps. Figure E-18 shows the reorganized list of ASI domains and indicators, and intersections between domains.

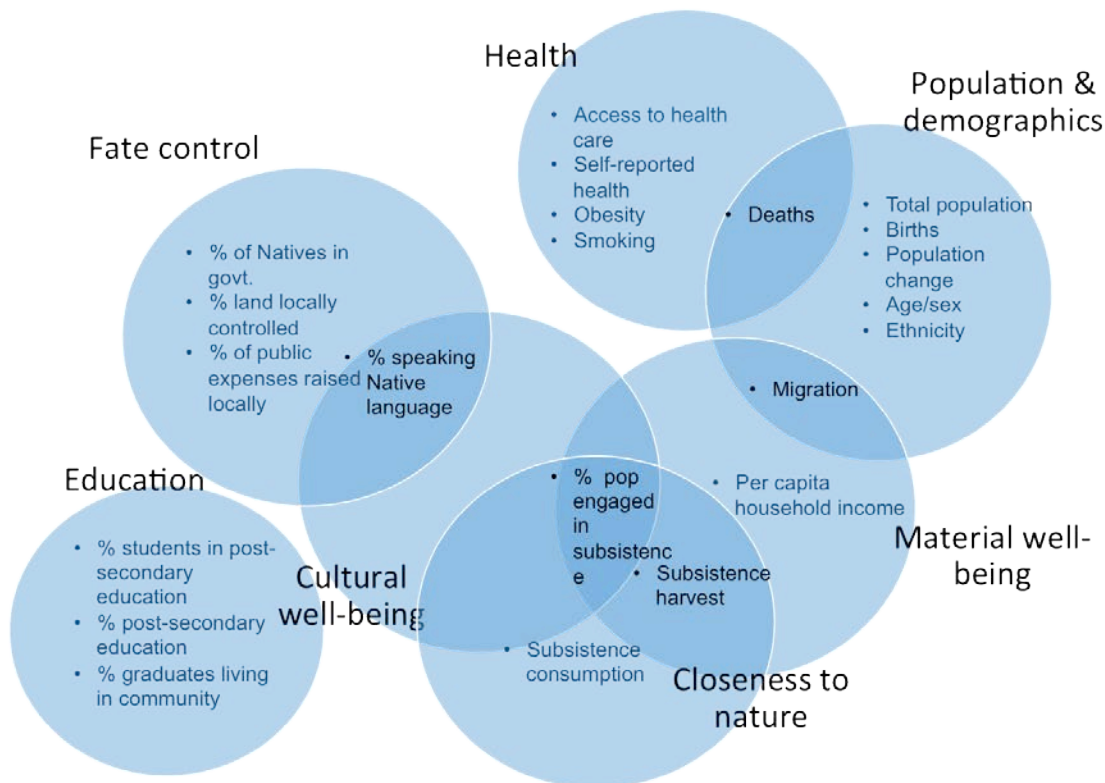


Figure E-18. Arctic Social Indicators (ASI) organized into seven domains. Data Source: Arctic Social Indicators (ASI) Report.

Table E-7 identifies all domains and indicators suggested by the ASI Report, whether or not data are available, and suggested proxy variables. While the ASI report identified six domains, we separated population and demographics into its own domain because data was most available on these indicators. The ASI Report suggested a single variable per domain that would best represent each of the seven domains; these variables include such statistics as infant mortality rate for the health domain, net migration rate for population/demography domain, per capita income for material well-being, ratio of students successfully completing post-secondary education for the education domain, and language retention for the cultural well-being domain. Data for several variables are not systematically collected in Alaska. We identified proxy variables for only a few.

Table E-7. Indicators identified in ASI Report. Key variables that according to the ASI report best represent the domain are indicated with an asterisk.

Domain	Variables suggested by Nordic Council	Community level data available	Used
Health	Access to health care	Unavailable.	N
	Self-assessed health		
	Smoking rate		
	Obesity rate	Community level data are confidential.	
	Child mortality rate		
	Infant mortality rate*		
	Suicide rate		
Population/ Demography	Total population	Alaska Department of Labor and Workforce Development (AK-DOLWD) and U.S. Census	Y
	Population growth or decline rates and projections	Calculated	
	Number of births	Annual community level data are not available. We assumed that these rates do not vary significantly among communities.	N
	Age/sex/ethnicity composition of the population including age and sex ratios		
	Birth rates		
	Mortality rates		
	Infant or child mortality rates		
	Net migration*		
	Number of death		
Material Well-being	Per capita household income *	ACS 2006-2010 moving average.	Y
		Proxy variable: Per capita income (past 12 months) for total population and for AIAN (ACS 2006-2010).	
		AK-DOLWD estimates of annual per capita earnings by community.	

Domain	Variables suggested by Nordic Council	Community level data available	Used
	Per capita gross domestic product	GDP data for Alaska is available at U.S. Government Federal Reserve.	
	Unemployment rate	AK-DOLWD–ALARI provides unemployment insurance claimants by community.	
	Poverty rate	Community level data are not available.	
	Subsistence harvest per person	ADF&G subsistence harvest data are not collected every year in every community, nor for every species in every year. However, they are available for nearly all of the North Slope communities.	
	Net migration rate	Community level data are not available. State and census area level are available.	
	A composite index that takes into account three sectors: Per capita household income, Net migration rate, Subsistence harvest	Lacking complete data.	
Education	Proportion of students pursuing post-secondary education	Proxy variable: Proportion of students pursuing secondary education (Alaska Department of Education and Early Development (AK-DEED); National Center Educational Statistics (NCES).	Y
	Ratio of students successfully completing post-secondary education*	Proxy variable: Ratio of students successfully completing secondary education (AK-DEED; NCES).	
	Proportion of graduates who are still in their own community (or have returned to it) 10 years later	Unavailable.	N
Cultural Well-being	Cultural autonomy	Unavailable.	N
	Do laws and policies recognize institutions that exist to advocate for cultural autonomy or national minority populations?		
	Do institutions representing national minority cultures exist?		
	What is the proportion of such institutions to minority peoples, e.g. are all peoples represented through such organizations?		
	Are resources available to such institutions?		
	Are funding policies in place and how well-resourced are they?		

Domain	Variables suggested by Nordic Council	Community level data available	Used
	Language retention* (e.g. what percentage of a population speaks its ancestral language?)	Proxy variable: Multiple variables from community level language data from US Census.	Y
	Belonging (e.g. what percentage of people are engaged in recreational or subsistence activities?)	ADF&G subsistence harvest data report the number of people attempting to harvest, successfully harvesting, and using each species. However, data are not available for all communities.	N
	A composite index that takes into account above three sectors	To be computed but data unavailable.	
Closeness to Nature	Harvest of country foods*	Partial subsistence data available from ADF&G.	Y
	Consumption of country foods*	Partial subsistence data available from ADF&G.	
	Number of people or households engaged in the traditional economy	ADF&G subsistence harvest data report the number of people attempting to harvest, successfully harvesting, and using each species. However, data are not available for all communities.	
Fate Control	Percentage of indigenous members in governing bodies (municipal, community, regional) relative to the percentage of the indigenous people in the total population	Proxy variable: native corporations' earnings.	Y
	Percentage of surface lands legally controlled by the inhabitants through public governments, Native corporations, and community governments*	Acres of land owned by native corporations.	
	Percentage of public expenses within the region (regional government, municipal taxes, community sales taxes) raised locally	Proxy variable: Municipal taxation, State of Alaska Department of Commerce, Community and Economic Development (AK-DCCED), Alaska Taxable.	
	Percentage of individuals who speak a mother tongue (whether Native or not) in relation to the percentage of individuals reporting corresponding ethnicity	U.S. Census collects the data that shows how many people speak only English in the community.	

Data Source: Arctic Social Indicators (ASI) Report

*Key variables to use as indicators – According to authors of the Arctic Social Indicator report.

Many of the domains share indicators. For example, subsistence is a component of three different domains. Because of this overlap we used available data in a principal components analysis and attempted to identify similar but mutually exclusive domains. We compiled the available data and conducted a principal component analysis (PCA) to identify factors that would explain the economic and social conditions of various communities. However, the data was not sufficient to meaningfully interpret the results. For meaningful results, the number of items or variables in a PCA should be sufficiently large

in comparison to the number of cases, or communities in this situation. The general convention is 15 cases for each variable. We had only 12 communities in the North Slope study area. We tried the analysis with all rural communities in the state to increase the number of communities in the analysis. However, due to lack of consistent variables across communities, the results were not meaningful to interpret. Therefore, we resorted to a descriptive analysis of the social and economic conditions of communities in the region.

Datasets

Data on most indicators identified by the ASI Report are not available at the community level. For the purposes of the North Slope REA, we retained the domains as a conceptual framework and identified proxies for indicators, for those variables where local level data were available.

Data from diverse sources were compiled for the North Slope REA. Table E-8 lists the datasets and sources. Much of the demographic data was obtained from the U.S. Census and the Alaska Department of Labor and Workforce Development (AK-DOLWD). The decennial census from the U.S. Census collects only demographic information (age, sex, and race/ethnicity of household members). Starting with Census 2000, the Census Bureau eliminated the long form, which contained questions about income, occupation, education, migration, language use, and disabilities. The census long form was replaced by the American Community Survey (ACS), which is used to collect long form equivalent information every year. ACS is a sample survey, with a sample size of less than 10,000 for the entire state, and as such is highly unreliable for small population centers. To compensate for this, data are pooled over a 3-year or 5-year period. However, margins of error on the estimates are often larger than the estimates. AK-DOLWD uses data from the Permanent Fund Dividend records to estimate population for inter-censal years and reconciles these numbers with the decennial census numbers. AK-DOLWD numbers are used to compute several demographic details of the North Slope REA study area.

Table E-8. Source datasets for analysis of community socio-economic conditions.

Dataset Name	Data Source
Demographic information – population, gender, race (2000-2010)	U.S. Census Bureau, Alaska Department of Labor and Workforce Development (AK-DOLWD)
Status of distressed communities 2013	Denali Commission
Employment by industry in the private sector (2001-2013)	Alaska Department of Labor and Workforce Development (AK-DOLWD)
Employment by sector and gender	Alaska Department of Labor and Workforce Development (AK-DOLWD)
Total employment by quarter (2010)	Alaska Department of Labor and Workforce Development (AK-DOLWD)
Percentage of workers by annual per capita wage income (2001-2010 average)	Alaska Department of Labor and Workforce Development (AK-DOLWD)
Average household size	U.S. Census
Communities under risk of erosion	U.S. Army Corps of Engineers
Fuel prices by community	Division of Community and Regional Affairs (DCRA)
Alaska visitor statistics	McDowell Group
Alaska Game Management Units (GMUs)	Alaska Department of Fish and Game (ADF&G)
Sport harvest of sheep and moose in the North Slope study area (1970s – 2010s)	Alaska Department of Fish and Game (ADF&G)
Subsistence use areas	Bureau of Land Management (BLM)
Alaska harvest statistics	Alaska Department of Fish and Game (ADF&G)

The Denali Commission releases a status list of communities every two years, identifying if a community is economically distressed. This rating was used in assessing social and economic conditions of the communities in the region. The Alaska Fuel Price Projections are developed for the Alaska Energy Authority (AEA) to assist in evaluating the economic feasibility of proposed renewable energy projects.

4.2. Results

Current socio-economic conditions in North Slope communities were shaped by three major events during the late 1960s and early 1970s: discovery and commercial production of oil starting in the late 1960s, the Alaska Native Claims Settlement Act (ANCSA) enacted in 1971, and the establishment of the North Slope Borough in 1972. This profile provides an overview about the demographic structure and economy of the region and sets the context regarding the impact of development on key ecological elements in the region.

ANCSA established 12 regional land-based share-holding corporations across the state and distributed rights to 44 million acres of land along with almost a billion dollars in cash compensation in exchange for aboriginal land rights. A thirteenth regional corporation was established in 1975 for Alaska Natives who

live outside of Alaska. Two of these corporations are located in the North Slope study area: the Arctic Slope Regional Corporation (ASRC) and NANA, Inc. These corporations received surface and subsurface rights. ASRC received subsurface rights to nearly 5 million acres of land (the combined acreage is about the size of Massachusetts), and NANA¹ Inc. received subsurface rights to approximately 2.3 million acres. A local village corporation was created in each village and rights to surface estate was conveyed to the corporation. ASRC began paying biannual shareholder dividends in 1972. The corporation's 2014 shareholder base is approximately 11,000, about three times more than the 3,700 in 1971. In 2014, dividends were \$50 per share. Shareholders owned 100 shares each, on average. Since 1972, ASRC has paid out over three quarters of a billion dollars in dividends (Alaska Business Monthly 2014). NANA paid out approximately \$9.4 million to its more than 13,600 shareholder in 2014.

Both North Slope Borough and Northwest Arctic Borough (NWAB) used their taxation authority to levy taxes on the natural resource extraction industries located on borough land. NWAB receives an annual payment from the Red Dog mine in lieu of taxes. To quickly generate cash however, the North Slope Borough issued bonds, and over time used tax revenue to repay them. Bond revenues provided funding for major infrastructure improvement projects in the North Slope Borough area. Since its inception, nearly all residents have worked for the North Slope Borough rather than directly for oil companies or oil support industries. Local and borough government jobs allow for subsistence leave and schedule work around community calendars. Fuel subsidies provided by the North Slope Borough are an additional source of economic support. These subsidies do not apply to NWAB villages of Kivalina and Noatak.

Abundance of oil and the ability to tax its production through the establishment of the North Slope Borough created a much more robust local economy over the last four decades than in most rural Alaska areas. Until the advent of the oil industry, the region's economy was dominated exclusively by external interests. Commercial whaling was the economic driver in the western Arctic during the years when baleen and whale oil were in high demand before the 1920s. However, residents of the region had minimal participation in the industry. Demand for whale oil collapsed in the 1920s as whale oil was replaced by petroleum products. At the same time, high demand for fur in the 1920s drove the economy into the fur trade, which at times proved more profitable than whaling. During and immediately following World War II, there was a federal infusion of cash from heightened military activities. Inupiat, the majority population group in the North Slope study area, adapted well over the last century and a half to the external changes that brought major local economic impacts. Local populations actively engaged in economic opportunities presented by each boom period, and reverted back to their traditional economy and subsistence during the bust periods characterized by severe unemployment (Northern Economics 2006).

During postwar years prior to statehood, and through some major political and administrative reorganization of the state and its economic contours after statehood, the region's population had a major and most direct stake in the region's natural resources and its development. Statehood paved the way for three major structural changes – passing of ANCSA (1971), formation of North Slope Borough

¹ Northwest Arctic Native Association was NANA's predecessor, and played a key role in the enactment of ANCSA.

(1972), and the construction of the Trans Alaska Pipeline System (TAPS) (mid-1970s) – that fundamentally transformed the region’s economy, and allowed for greater self-determination. Although North Slope Borough initially borrowed against future revenues, it also accumulated surplus revenues over the years. This allowed North Slope Borough to strengthen its local village economies through infrastructure development, local jobs, and considerable energy subsidies. The North Slope Borough is the largest employer of residents in the North Slope study area, with unique provisions for subsistence leave. This has several positive effects such as higher employment rates, higher earnings, and lower rates of out-migration than in any other parts of rural Alaska.

This fundamental transformation of the economic structure also affected the social structure. Despite the adoption of modern life styles (ex: standard housing and settled communities), economic behaviors (ex: consumerism and wage employment) and cultural traits (ex: mainstream American sports and other popular entertainment), the local population continued their reliance on subsistence and retained their traditional worldview. This is illustrated by one of the leaders in the region referring to ANCSA as a harpoon, meaning that this recent federal law has had significant socio-economic impacts, much like the ancient whaling weapon effective enough to hunt and kill one of the largest known mammals in the world (Northern Economics 2006).

Employment

The majority of the employment in the North Slope study area is provided by the oil and gas industry – the oil companies themselves, and the many supporting service organizations. While a majority of the jobs in the region are in the oil industry, most of these jobs are filled by non-residents who commute from outside the region. Approximately 10 - 15% of the local residents are directly employed by the oil and gas companies or their contractors. Both the North Slope oil industry and the Red Dog Mine provide employment and earnings for other Alaskans and others who live outside the state. Unlike the North Slope oil industry, NANA, Inc. owns the mineral rights to the region where Red Dog mine is located. The mine is operated by Teck Alaska. Nana, Inc., in partnership with the Mine’s operator Teck Alaska, implements preferential policies to hire NANA shareholders ahead of non-shareholders (Haley and Fisher 2012). Not all NANA shareholders who work at the mine live in the region. Both Prudhoe Bay and Red Dog Mine are equipped with large airports, allowing easy commute for workers who live elsewhere in the state and the nation.

Despite the natural resource industry and other associated supporting employment sectors, local government is the largest employer of the resident population, accounting for approximately 50%-60% of the total jobs held by residents of the region. Trade, transportation, education, health services, professional services form the major private sector employers. Figure E-19 shows the distribution of employment by sector for the years 2001-2014. A substantial percentage of the workforce continues to be employed in trade, transportation, and utilities and construction sectors. Jobs in the educational, health, professional and business services increased over the same period.

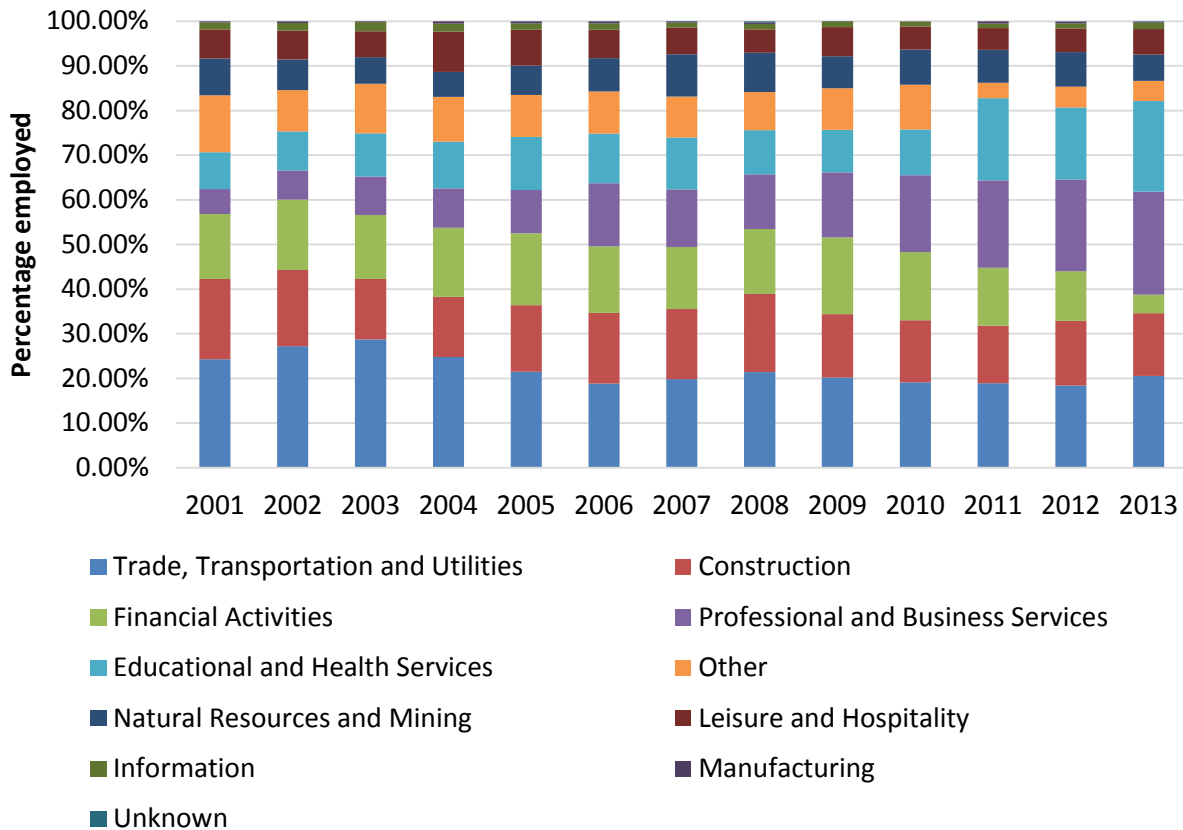


Figure E-19. Employment by industry in the private sector – North Slope study area including the oil industry and Red Dog Mine (2001-2013). Data Source: Alaska Department of Labor and Workforce Development (AK-DOLWD).

The majority of the jobs outside Prudhoe Bay and Red Dog Mine are located in Barrow. The North Slope Borough government and the school district are the community's largest employers, accounting for almost half the workforce in the community (Table E-9). Other major employers include Alaska Native for-profit corporations, regional non-profit corporations, and several state and federal agencies with offices in Barrow. During the period from 2001 through 2013, Barrow accounted for over 50% of all local government jobs in the North Slope study area. The other 50% of local government jobs were distributed among the other communities. Point Hope and Wainwright accounted for 10% and 7% respectively over the same period. Although several federal and state government agencies have offices in the regions' communities, employment in this sector is minimal compared to all other sectors identified in this report.

The gender distribution among those employed in the region varies by sector. Education and health services being dominated by women; while the financial services, leisure / hospitality, and professional services are fairly balanced. And predictably, construction trades, transportation, utilities, and information sectors are dominated by male employees.

Table E-9. Total employment by quarter (2010), by community.

Community or Political Entity	Jan-Mar	April-June	July-Sept	Oct-Nov	All 4 quarters
Alaska	253,557	270,292	269,839	256,722	213,657
North Slope-study area (excluding Prudhoe Bay and Red Dog Mine)	2,994	3,245	3,313	3,066	2,394
North Slope Borough	2,701	2,919	2,981	2,750	2,175
Anaktuvuk Pass city	135	138	146	131	101
Atkasuk city	86	97	99	86	67
Barrow city	1,673	1,816	1,829	1,715	1,407
Kaktovik city	111	114	125	120	94
Nuiqsut city	153	176	175	158	106
Point Hope city	260	273	292	259	182
Point Lay CDP	85	90	99	86	63
Wainwright city	185	202	204	183	143
Northwest Arctic Borough*	2,372	2,558	2,667	2,499	1,818
Kivalina city	122	136	135	124	83
Noatak CDP	184	203	209	204	148

*Employment figures for Northwest Arctic Borough includes a number of jobs located in Kotzebue and other communities outside the North Slope Study Area. Jobs within the communities of Kivalina and Noatak are listed above.

Data Source: Alaska Department of Labor and Workforce Development

Revenue and Income

Revenue sources for local governments in the North Slope study area are dominated by taxes from the oil and gas industry. Other major sources of revenues include federal funds for health and education services, and revenue sharing funds from the state. Civic infrastructure built since the mid-1970s have largely been within the boundaries of the communities. Figure E-20 shows the percentage of workers in the North Slope study area by their annual per capita wage income. This does not include dividends and other non-employment income. Approximately 45% of the workforce earned less than \$20,000. With an average household size of 3.59 in 2010, and based on per capita wage income only, a substantial amount of the population may have lived below the poverty line.

In addition, regional for-profit corporations ASRC and NANA provide dividend income from their earnings. Dividend payout policies vary widely among corporations. NANA paid \$6 per share in 2014, and projected to pay \$14 per share in 2015. ASRC pays out quarterly dividends, and paid \$12.50 per share in the first quarter of 2014. Dividends contribute considerably to the personal and family incomes in the region.

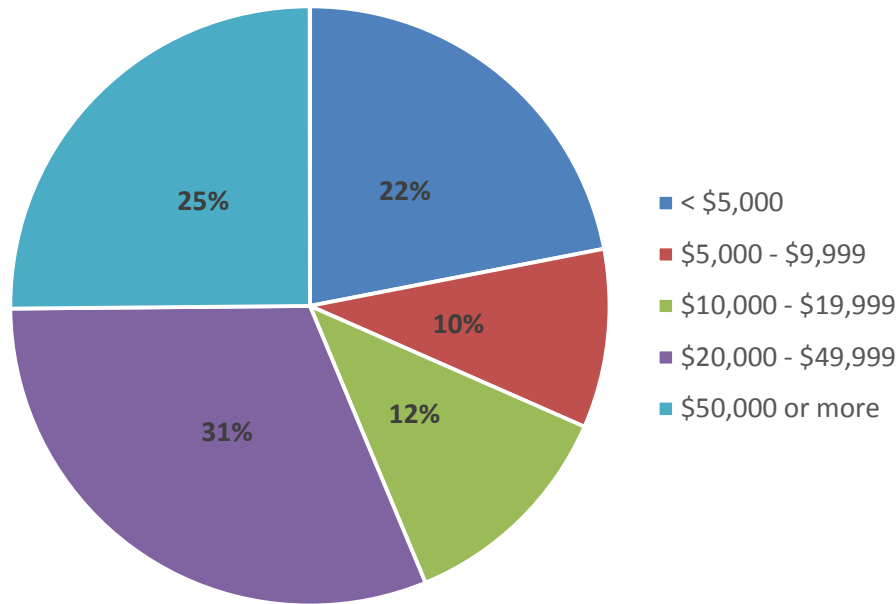


Figure E-20. Percentage of workers by annual per capita wage income (2001-2010 average) in the North Slope study area. Data Source: Alaska Department of Labor and Workforce Development (AK-DOLWD).

Socio-economic conditions can also be understood using the designation of ‘distressed communities’ as defined by the Denali Commission (Denali Commission 2013). Distressed communities meet at least two of three criterion: (1) Average market income in 2012 less than \$16,120 (half-time employment at \$7.75 minimum wage); (2) More than 70% of residents 16 and over earned less than \$16,120; and (3) Less than 30% of residents 16 and over worked all four quarters of 2013. Increased revenue for the borough/regional governments, and increased per-capita incomes are reflected in the ‘distressed communities’ classification of communities in the region. Based on this criterion, Kivalina is the only community in the North Slope study area categorized as distressed.

Kivalina has been identified by the U.S. Army Corps of Engineers as being at risk from erosion damage and will need to move or implement major projects to mitigate damage from erosion and permafrost thaw. The U.S. Army Corps of Engineers estimates that without major mitigation efforts Kivalina will remain above ground for 10-15 years. Relocation will be expensive, at an estimated \$400 million, and could disrupt cultural traditions, limit access to subsistence and other resources, and require complicated government agency and community coordination (Glenn Gray and Associates 2010).

Planning has started for an evacuation road. The community has had three emergency evacuations in the past five years. Currently, planes or boats are the only evacuation means. An evacuation road is also a first step in relocation. Residents have identified a site eight miles inland as the location for a new school and destination for the road.

Energy Prices

The energy picture in rural Alaska can be best understood as comprised of three key components – electricity, heating, and transportation.

Costs of electricity in most rural Alaska communities are prohibitive due to the high fuel prices, primarily driven by the cost of delivery, and are indicative of the severe economic conditions and high cost of living. Alaska had 2,197 MW of installed capacity for electricity generation and approximately 6.6 million MW-hours of electricity were generated. While a majority (58%) of the state's electricity is generated with natural gas, almost all of this was consumed in the rail belt region (Wilson et al. 2008). Most remote rural communities were eligible for the Power Cost Equalization (PCE) program in 2014. PCE was instituted by the state to offset the high fuel prices in rural Alaskan communities. “The PCE assistance payment is determined by a formula that covers 95% of a utility’s cost between a base rate (the weight average rate for urban centers of Anchorage, Fairbanks, and Juneau) and a ceiling (that changes periodically) for the first 500 kilowatt-hours consumed by residential customers” (Fay et al. 2013). However, the program has not been fully funded by the Legislature in 15 out of its 25 years of existence, and electricity rates in rural Alaska with PCE are still higher than in urban Alaska (Fay et al. 2013). Due to this, the PCE program increases the economic vulnerability of rural households to changes in state spending. “Alaskans in small remote rural places that rely on fuel oil had the most expensive electricity — with prices from roughly 30 cents more to more than \$1 per kilowatt-hour in 2011. The only exceptions are rural communities on the North Slope, where rates are significantly lower than in most rural communities; that region has a flat rate structure among its communities, and two have access to natural gas” (Fay et al. 2013).

Heating houses and other buildings is a necessity in Alaska. Communities across the state rely on a variety of fuel sources for heating: natural gas, diesel, electricity, wood, and other sources such as geothermal energy. Saylor and Haley (2007) reported 79% of the houses in remote rural Alaska are heated using diesel fuel. Between 2000 and 2005, cost of diesel for home heating increased by 83% in these remote rural communities. While natural gas is not available for transport to most rural Alaska communities, especially those beyond the railbelt, the primary fuel source for heating in two of the North Slope communities, Barrow and Nuiqsut, is natural gas. On average, outside of the North Slope Borough, heating fuel retailed at \$5.71 per gallon (Table E-10) shows fuel prices in the North Slope Borough communities in 2015 (Division of Community and Regional Affairs 2015).

Transportation consumes both gasoline and diesel. Although outside of the North Slope study area, in a survey of 54 households in Norton Sound, Schwoerer (2013) reported that on average each household travels 774 miles on snow machines, 416 miles on boats, and 172 miles on all-terrain vehicles (ATVs), one-way to access subsistence resources. These households consume approximately 1,291 gallons of gasoline per year. In addition, these households also consume 886 gallons of diesel oil and four cords of wood per year for various other purposes.

North Slope Borough village corporations provide heating fuel, charging only a per-gallon delivery fee. This is possible due to fuel subsidies provided by the North Slope Borough. However, the North Slope

Borough does not subsidize heating fuel for commercial use. These subsidies do not apply to NWAB villages of Kivalina and Noatak. Price of fuel in rural communities is periodically recorded by the State of Alaska Division of Community and Regional Affairs (DCRA) through a survey of a sample of communities. Table E-10 shows the 2015 fuel prices for communities where data was available. Noatak, Kivalina, and Point Lay were not included in the sample during 2015. However, anecdotal information suggests that the price of fuel in Noatak was \$10.00 per gallon in 2014. The Red Dog mine also sells limited amount of fuel oil on set days to local residents at a lesser cost.

Table E-10. Fuel prices by community in the North Slope study area.

Community	Community Retailer	Residential	Commercial	Gasoline
Anaktuvuk Pass	Nunamiut Corporation	\$1.55	\$9.25	\$9.49
Atkasuk	Atkasuk Corporation	\$1.40	\$4.10	\$4.10
Barrow	BUEC, Inc.	Natural Gas	Natural Gas	\$7.00
Kaktovik	Kaktovik Inupiat Corporation	\$3.00	\$9.00	\$7.50
Nuiqsut	Kuukpik Corporation	Natural Gas	Natural Gas	\$5.00
Point Hope	Tigara Corporation	\$1.99	\$7.99	\$5.76
Wainwright	Olgoonik Corporation	\$1.50	\$7.30	\$6.87

Data Source: DCCED, DCRA 2015. Alaska Fuel Price Report, January 2015. Data for Noatak, Kivalina, and Point Lay are not available for the year 2015.

With perhaps an exception in 2014-15, there has been a recent dramatic increase in fuel prices throughout Alaska. Looking only at changes from 2000 through 2006, Saylor and Haley (2007) used census data to document total utility costs – including heat, electricity, water, and sewer – paid by residents of remote Alaska communities increased from a median value of 6.6% of total income to 9.9% of total income. By comparison, the median amount spent by Anchorage households increased from 2.6% to 3.1% of household income during this same period.

5. Non-Industrial Activities

5.1. Methods

All non-industrial activities result from general living of the local population in the region. The 2010 Census reports a total of 10,200 people live in the North Slope study area, including 2,174 workers at Prudhoe Bay. The remaining population lives in ten different communities. Barrow, the largest community, with a population of 4,212, serves as the regional communication, transportation, and administrative hub. Point Hope, with 674 people, is the next largest and Atkasuk, with 233 people, is the smallest. Few communities are connected by ground transportation but all can be reached by air year-round. More than 80% of the population in all communities are Alaska Native, with the exception of Barrow. In Barrow, Alaska Natives comprise 61% of the population. While wage employment is higher in the region compared to other parts of rural Alaska, reliance on subsistence is high. Subsistence is of both economic and cultural value to the population. Non-industrial activities are generally confined to the community footprints. They include general community infrastructure such as housing units, transportation facilities such as roads and airports within the community footprint, and commercial and public facilities. Subsistence and recreation access trails extend beyond the community boundaries to reach hunting and fishing camps. Rivers provide access to interior regions. Although the acreage under industrial development is large (approximately 2,500 sq. km.), it is much less than the area required for subsistence. All four herds of caribou that range in the region are harvested for subsistence uses. Additionally, several other animal and bird species, plants, and berries are harvested.

Subsistence use areas are computed from data obtained from the Bureau of Land Management (BLM). Spatial data was collected through surveys by private contractors for various projects, and was made available for this project. The Alaska Department of Fish and Game (ADF&G) also collects similar data during their community household subsistence surveys. However spatial data for subsistence use areas for communities in the North Slope study area were not available from ADF&G in time for this report. Thus, we relied on survey data collected for specific projects such as environmental impact statements of various development proposals in the region.

Data were obtained through household surveys conducted during sporadic years over a long period of time. For example, data for Atkasuk is from 1978. Data for Nuiqsut dates as far back as 1985, and is more substantial than for any other community. Only a small sample of households is interviewed during these survey attempts, thus raising questions about the sample size and representativeness of the sample. One household member in a household is typically asked to identify the areas and locations that the household hunted or fished during the previous year. These areas and locations are digitized and combined with responses from other households in the community. Such data is collected for each major subsistence species.

We used this data to compute subsistence use areas for the North Slope study area. We computed areas and locations by species, and by community. Thus we derived a polygon file for each species for each community. We then overlapped each community's polygon file for a particular species. Respondents from multiple communities sometimes identified common areas and locations. Overlaps are rated by

the number of such overlaps. Areas with respondents from only one community were assigned a rating of 1, areas with two communities were assigned a rating of 2, and areas with three communities were rated as 3. All maps are color coded. Thus, subsistence use area maps represent a simple use intensity for each species across the study area.

Additional data was collected over the years for each of the ten communities through various surveys for specific projects. While this data is available, it is not in a useable format for the purposes of the REA. We only used data that is available, and accessible in a digital data format, not in a PDF format, as required by the REA guidelines. This assessment is to identify such digital datasets. Therefore, much of the useful data from surveys in various communities could not be used in this assessment.

5.2. Results

Recreation

Recreation in the North Slope study area is distinct from what is considered recreation elsewhere. The region is remote and much of it is inaccessible by major modes of transport. Much of the region is not connected by roads, and recreational visitors either arrive by air, or use the trails and rivers. Recreation activities in the region include wildlife viewing, camping, and sport hunting.

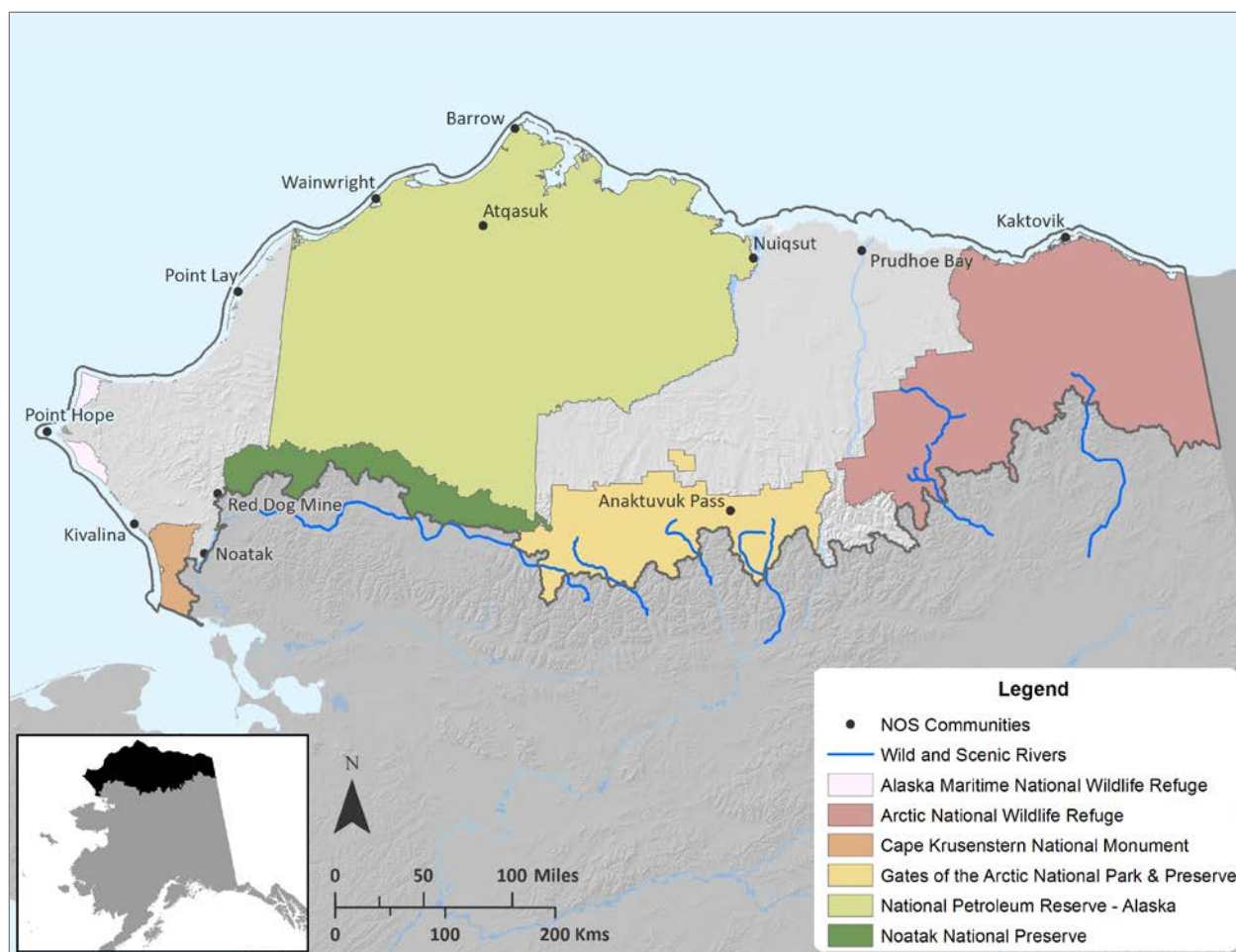


Figure E-21. Federal protected areas in the North Slope study area. Data Source: BLM; ADNRR; U.S. Dept. of the Interior.

Tourism in the region is minimal although there is increased interest in recent years. The tourism visitor statistics program of the State of Alaska does not provide detailed visitor statistics for any place within the study area. The most recent assessment of tourism development needs in the North Slope Borough was conducted by the Arctic Development Council in collaboration with the State Department of Commerce in 1997, and identified the lack of facilities in the region and along the Dalton Highway. Several independent touring companies offer tours of specific communities or custom planned trips to remote parts of the region for wildlife viewing, camping, river travel, and sport hunting. There is a general lack of data available regarding the number of visitors to conduct an analysis. Figure E-21 shows all the protected areas in the study area. While NPR-A is not a recreational park, it is a protected area from most other development.

Sport hunting data is available at a game management unit level for the region. Sheep are most harvested around Anaktuvuk Pass and Kaktovik. Moose are most harvested around the Northwest Arctic Borough communities of Kivalina, Noatak, and Red Dog Mine (Figure E-22). Caribou are mostly

harvested around Prudhoe Bay and along the Dalton Highway corridor. Muskox, brown bear, and black bear are other species harvested by sport hunters in the region.

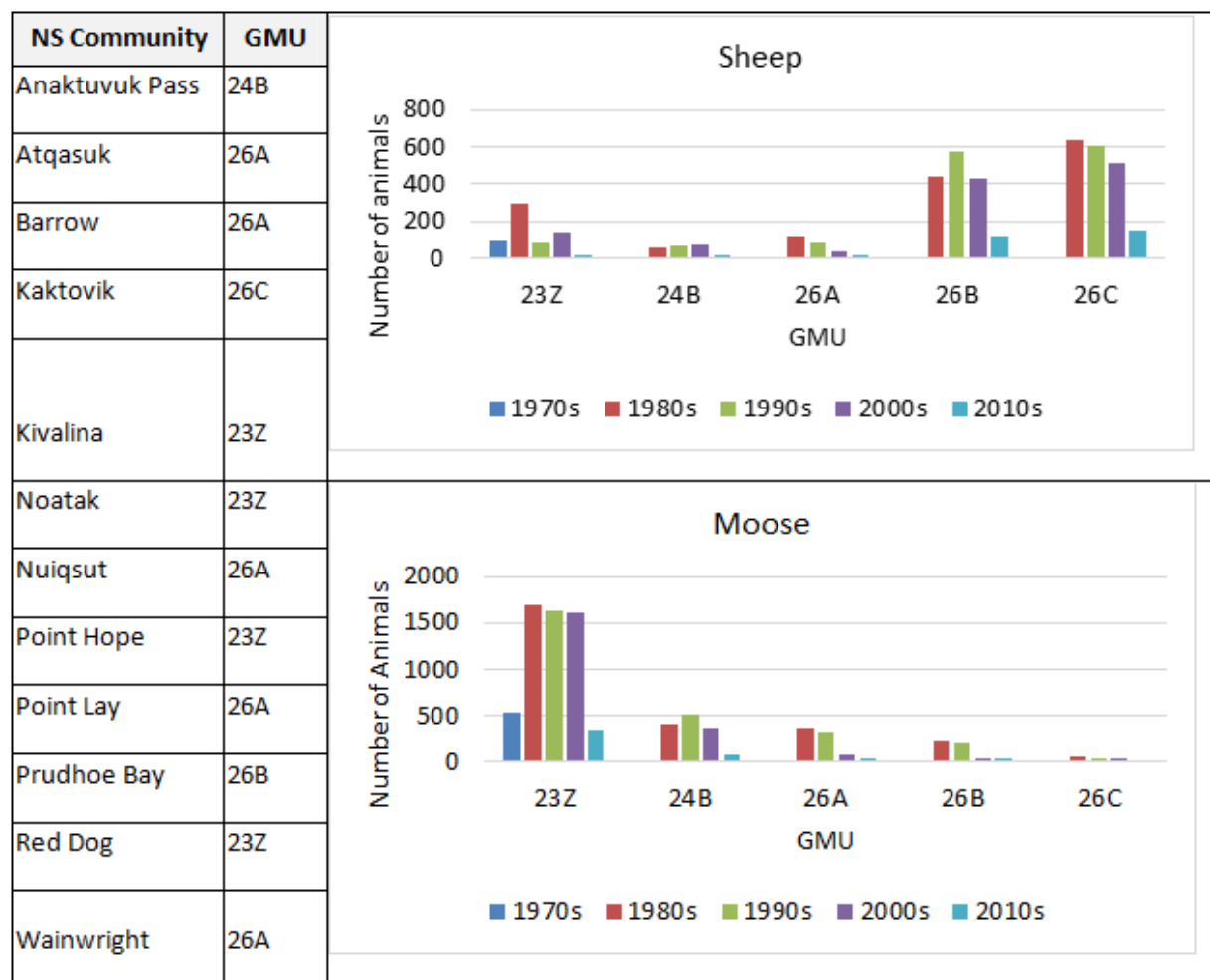


Figure E-22. Sport harvest of sheep and moose in the North Slope study area (1970s – 2010s). Data Source: Alaska Department of Fish and Game (ADF&G).

Subsistence

Subsistence practices are closely linked to the natural cycles of the environment. Such practices include hunting, fishing, and gathering of various animal and plant species in the region. The majority of the population in remote rural Alaska depends substantially on subsistence to supplement their wages (Goldsmith 2007). Fishing and hunting are essential parts of local livelihoods in the North Slope study area. Subsistence forms a substantial part of the household and community economy in the region. As shown in Table E-11. Annual cycle of subsistence activities in the vicinity of Anaktuvuk Pass., local population in the study area uses a large portion of the region’s land for subsistence. We computed subsistence use areas from survey data collected for other projects and data available from the Bureau of Land Management.

Subsistence foods are a large part of household food consumption. According to the Survey of Living Conditions in the Arctic, subsistence foods make up between half and three-quarters of all food consumed by Alaska Native households (Martin 2012). Higher income households are also high subsistence-producing households, and have been termed "super households" (Wolfe et al. 2009). This report identified what has become known as the "30:70 rule," where 30% of households produce 70% or more of a community's subsistence food. Even though only 30% hunt, nearly everyone reports using subsistence foods, illustrating widespread sharing and the significance of the role hunters have as part of a community's holistic system. Subsistence traditions connect people to each other, the animals, and land they have used for thousands of years. This is especially true of Alaska Natives, who are among the very few aboriginal groups in the world that have not been displaced from their traditional lands.

Many species are harvested by the local population. Among the Conservation Elements considered for this REA, the following are frequently considered subsistence species:

- Caribou – *Rangifer tarandus* – Tuttu
- Greater White-Fronted Goose – *Anser albifrons* – Nibliq
- Willow Ptarmigan – *Lagopus lagopus* – Aqargiq
- Dolly Varden – *Salvelinus malma* – Iqalukpik
- Broad Whitefish – *Coregonus nasus* – Aanaakliq
- Chum Salmon – *Oncorhynchus keta* – Iqalugruaq
- Arctic Grayling – *Thymallus arcticus* – Sulukpaugaq
- Burbot – *Lota lota* – Tittaaliq
- Arctic Fox – *Vulpes lagopus*

While all the above species are harvested, only a few of them are harvested in significant amounts, and are discussed below. Data on subsistence harvest is limited. Available ADF&G surveys are dated, and some of it was useable for REA purposes. Information on all species was not always collected.

Table E-11. Annual cycle of subsistence activities in the vicinity of Anaktuvuk Pass.

Species	Winter					Spring		Summer			Fall	
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Caribou												
Sheep												
Moose												
Grizzly Bear												
Ptarmigan												
Furbearers												
Fish												
Berries												
	No to very low levels of subsistence activity											
	Low to medium levels of subsistence activity											
	High levels of subsistence activity											

Data Source: Estimated by using data available from BLM.

Table E-12. Annual cycle of subsistence activities in the vicinity of Barrow.

Species	Winter					Spring		Summer			Fall	
	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Fish												
Birds												
Berries												
Furbearers												
Caribou												
Polar Bear												
Seals												
Walrus												
Bowhead Whale												
	No to very low levels of subsistence activity											
	Low to medium levels of subsistence activity											
	High levels of subsistence activity											

Data Source: Estimated by using data available from BLM.

Animal and plant species used as subsistence resources may vary from community to community and from year to year. Each community has a general seasonal cycle of harvest, informed by tradition, personal experience of elders in the community, and observations of harvesters during the current and

immediate previous harvest seasons. Natural and human factors such as river conditions, ice, weather, migratory patterns, species abundance, technology, economic opportunities, and other factors have an impact on the harvest cycles (Georgette and Loon 1991). Table E-11 shows the seasonal cycle of subsistence activities for Anaktuvuk Pass, a community at the foothills of the Brooks Range, far from the coast. Almost all subsistence harvest in the community is land-based. On the other hand, Table E-12 shows the seasonal subsistence cycle for Barrow, a coastal community. Marine mammals are a substantial source of subsistence foods for this community.

Regardless of the location in the region, all communities rely heavily on some common species. Caribou are harvested by all communities across the study area. The only harvest data available for this study area was from ADF&G household subsistence surveys. The survey data is sporadic, with data missing for many years for each community. Only eight out of the ten resident communities were ever surveyed. Of those surveyed, the earliest available data is from 1982. Kaktovik was surveyed eight times, most among the ten communities. Wainwright, Point Lay, Nuiqsut, and Barrow were each only surveyed twice during the three decades since 1982. Therefore, this analysis is severely limited by the sparse data available on subsistence harvest amounts in the region.

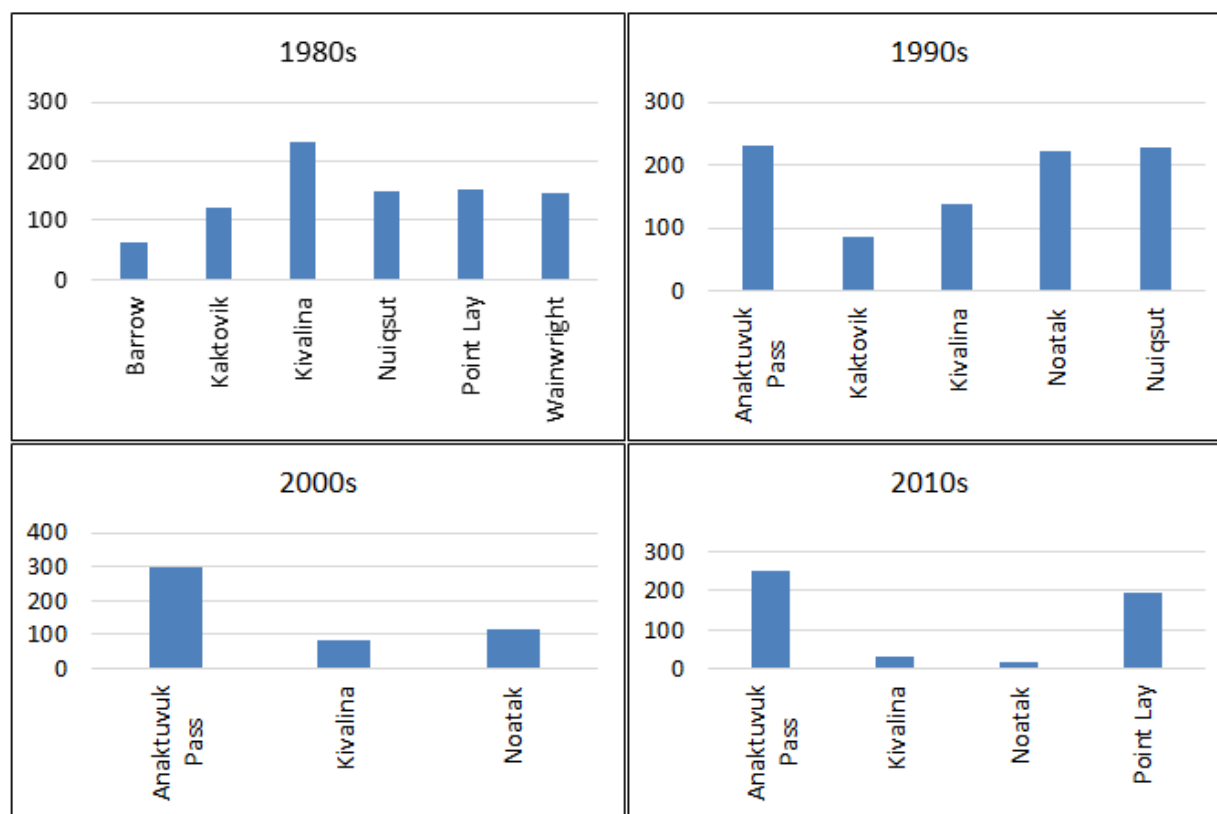


Figure E-23. Average per capita subsistence harvest of caribou (in pounds) for communities surveyed (1982 – 2013). Data Source: Alaska Department of Fish and Game (ADF&G).

Figure E-23 shows the per capita caribou harvest in pounds across eight communities, over three decades. The numbers represent average amounts over the years for which data was available during

the decade. Since data was available only for a few years for any community, these numbers are very limited and do not represent the average harvest amounts. Variation in per capita harvest amounts can be due to many reasons associated with harvesters or the species being harvested. Factors influencing subsistence harvests were explored in response to MQ TF 3. However, sparseness of the available data severely limited our ability to explore possible explanations of observed variability in per capita subsistence harvests. ADF&G data available for grayling, with similar limitations, is presented in Figure E-24.

While ADF&G data is very limited, the North Slope Borough has been working diligently for more than two decades to collect and compile subsistence harvest patterns and practices. The Subsistence Harvest Documentation Project (SHDP) (North Slope Borough 2015) is part of a larger 4-part Subsistence Harvest Documentation Project initiated in 1994. The larger project includes mapping, migratory bird survey, and hunter education, and is designed to collect, compile and analyze subsistence data to inform management practices. SHDP is designed to collect survey data from each household in each community within the North Slope Borough every six months. Due to Barrow's relatively large population, a sample of households is randomly picked for the survey.

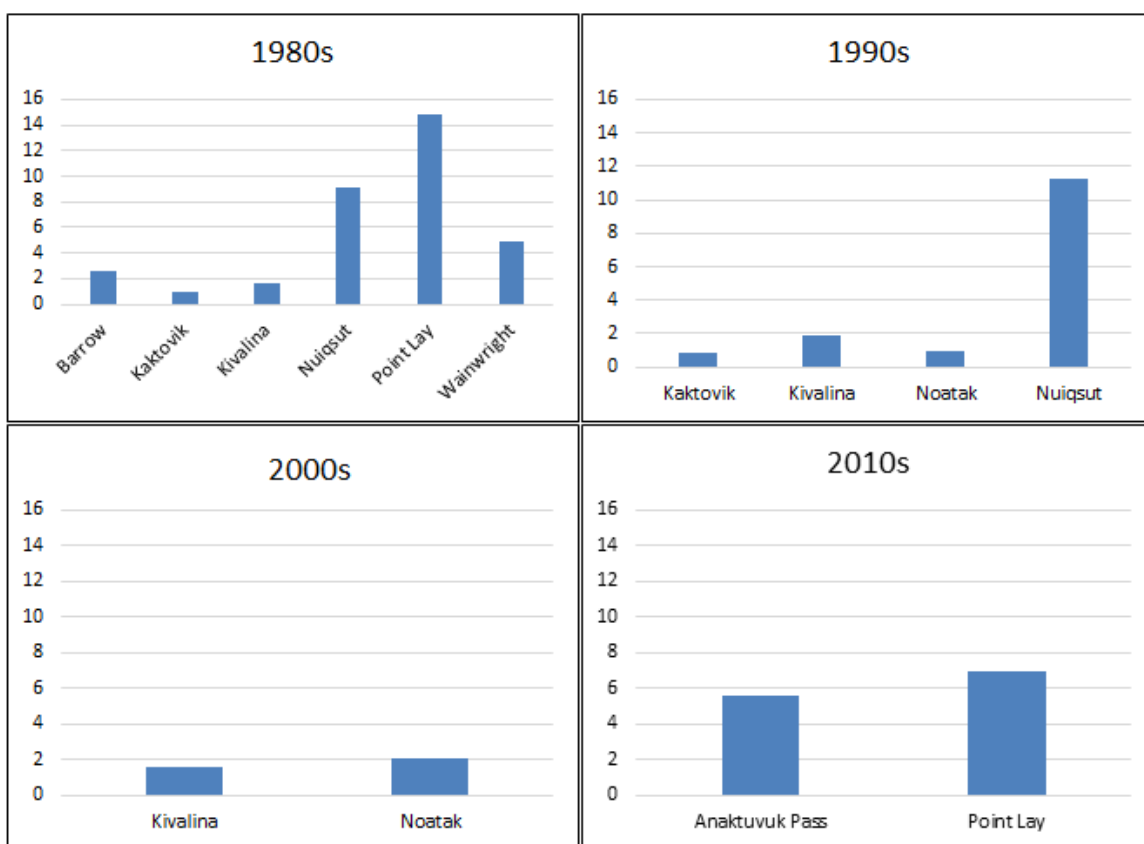


Figure E-24. Average per capita subsistence harvest of grayling (in pounds) for communities surveyed (1982 – 2013). Data Source: Alaska Department of Fish and Game (ADF&G).

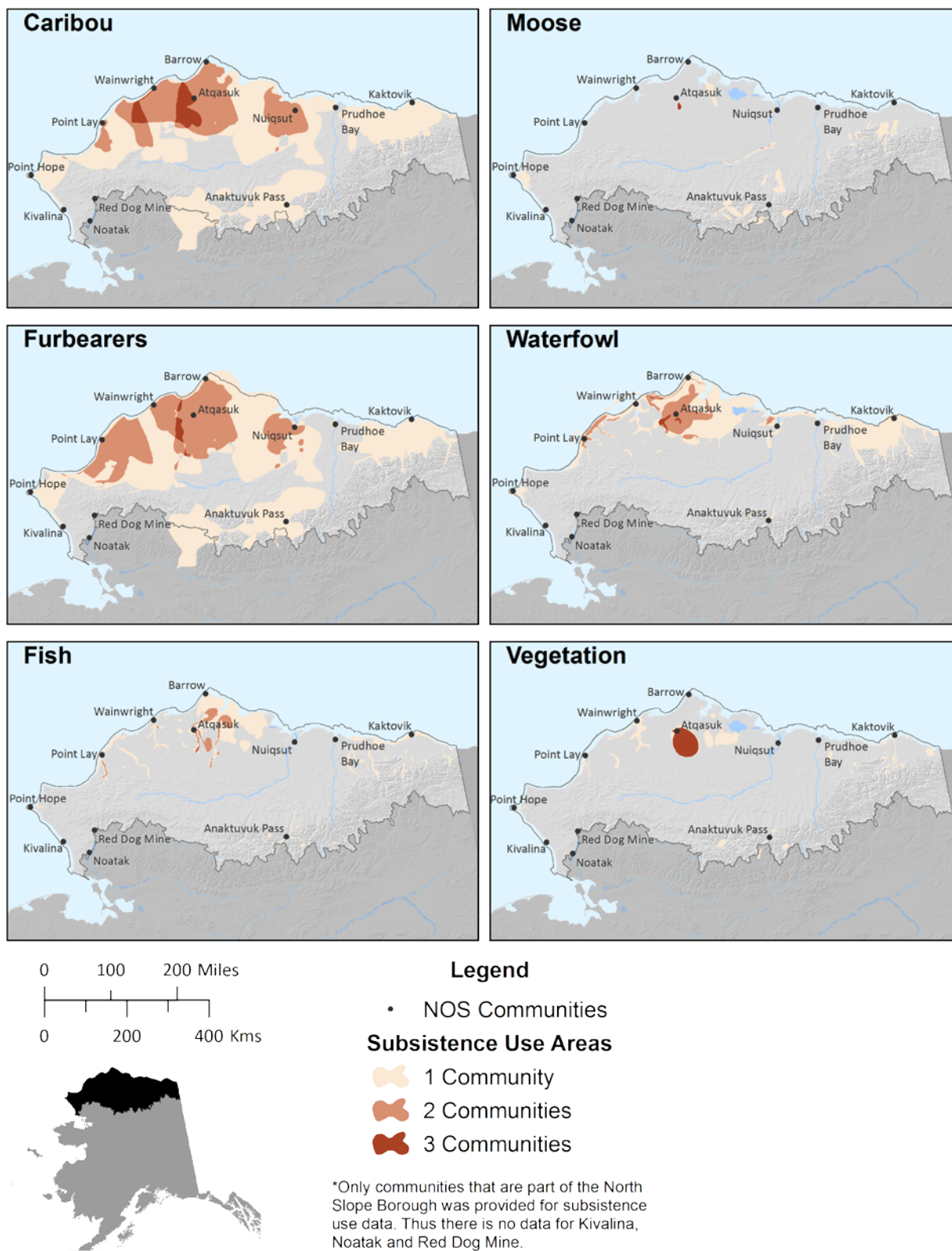


Figure E-25. Subsistence use areas within the North Slope study area. Data Source: North Slope Borough.

Bacon et al. (2011) report subsistence harvest numbers between the years 1993 and 2003 from the data collected through the SHDP. SHDP conducted two surveys in each village – a one year recall survey, and a six-month recall survey. During the period between 1994 and 2003, only 13 one-year surveys and 17 six-month surveys were conducted in the eight communities of the North Slope Borough, indicating challenges in conducting subsistence surveys. Other limitations of this data included difficulty in identifying the right species, non-availability of households for the survey, inaccuracy of recall. All these errors are not uncommon in similar efforts such as the ADF&G surveys. The SHDP data was not available to be analyzed for the North Slope REA.

Other disparate efforts to collect similar survey data include attempts by independent contractors to conduct surveys as part of a specific proposed or current development project. Data from these one-time projects may extend over a few years, are often proprietary, and are not available in public domain. The Bureau of Land Management shared spatial data from such projects for the purposes of this study. This data was utilized to compute subsistence use areas in the North Slope study area. This data is very limited in several ways. Some of the data is not dated, leading us to believe it is quite old. Nevertheless, we developed a method to spatially identify areas that may be valuable for subsistence. This data is limited to communities in the North Slope Borough.

Figure E-25 shows subsistence use areas for caribou, moose, vegetation, fish, furbearers, and wildfowl. The largest concentration of human population in the region is in the communities of Barrow, Atkasuk, and Wainwright. The region surrounding these communities seems most used for subsistence purposes. However, it should be noted that the level of use is a simple overlapping count of the number of communities that identified a particular area as important for subsistence use. The number of hunters that identified a particular area, or the count or pounds of subsistence harvest is not considered in preparing these maps. This is a severe limitation considering the distances between the communities.

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7. Measurable and Perceived Impacts of Development

The North Slope study area includes three distinct but overlapping management questions regarding impacts of development on subsistence resources. All three questions are addressed in this section. Although the resource of focus differed between TF 3 and AF 2, both questions were very similar, with similar methodologies and results. Limitations to access (AP 1), whether physical or perceptual, are closely related to the impacts of development. Many of the impacts identified in TF 3 and AF 2 are adverse, and are either real or perceived barriers to access.

MQ TF 3	What are the measurable and perceived impacts of development on subsistence harvest of caribou?
MQ AF 2	What are the measurable and perceived impacts of development on subsistence harvest of fish?
MQ AP 1	What physical and perceptual limitations to access to subsistence resources by local residents are caused by oil/gas activities?

Impacts due to measurable factors and perceived factors may have similar effect on subsistence outcomes whether measured in pounds harvested or access to subsistence. However, both sets of factors are distinct and owing to the methodological differences in identifying them, are discussed separately in response to these question.

7.1. Definitions

Subsistence: Alaska National Interest Lands Conservation Act (ANILCA) defines subsistence as “the customary and traditional uses by rural Alaska residents of wild renewable resources for direct personal or family consumption as food, shelter, fuel, clothing, tools, or transportation”. Subsistence as an important component of the food supply chain as well as an integral part of the population’s cultural identity and social life (Woods 2013). Therefore, subsistence can mean a diverse set of activities that contribute to the physical, emotional, social, and cultural wellbeing of the population.

Measurable impacts: Measurable impacts are interpreted as anything that could be quantified.

Subsistence harvest: Although ‘subsistence harvest’ can be defined quite broadly, we used a narrow definition to allow measurement – per capita harvest of caribou in pounds.

Factors affecting subsistence: There are many different factors that can affect subsistence harvests including land use restrictions by the local, state, and federal authorities; restriction of access to subsistence areas due to development activities; contaminations due to oil spills and other development activities; fuel cost; wage earning jobs; available time for subsistence activities; subsistence equipment costs; distance to travel for harvests; change of animal migration patterns; total population number and population density of both the humans depending on subsistence and the resource being harvested; distance of the villages from the urban markets; vehicular traffic and other noises due to development activities; water quality and water withdrawal for oil and gas and other development activities; and loss

of vegetation due to contamination and space used for development activities. We limited our analysis to factors relevant to development activities.

Development: Many types of development are identified in the literature – principal among them are social development, economic development, and physical development. Each type of development has several, often overlapping sets of indicators. Social development indicators may include population demography, life expectancy, infant mortality rate, maternal mortality rate, literacy rate, percentage of population with post-secondary education, etc. Economic development indicators may include real wages per worker, unemployment rate, local revenues from taxes and fees, new businesses created, new jobs created, mean and median income, etc. Physical development indicators may include road (paved) length per square kilometer of surface area; railroad length per square kilometer of surface area; per capita electricity consumption; annual fresh water withdrawal for domestic, agriculture, and industrial use; secure internet servers (per 1 million people), etc. We considered physical, social, and economic indicators.

7.2. Methods

Measurable Impacts

Figure E-26 shows the process model to assess the measurable impacts on subsistence harvest of caribou. Two primary elements impact subsistence harvest: physical alterations to landscape, and social and economic factors of the population that enhance or hinder their abilities to harvest. Physical alterations include any development activities such as construction of roads or industrial infrastructure. Social and economic factors include increased income that may allow hunters to acquire new and more efficient modes of transport that can enhance their ability to harvest while also leaving them less time for subsistence activities, impeding their ability to harvest.

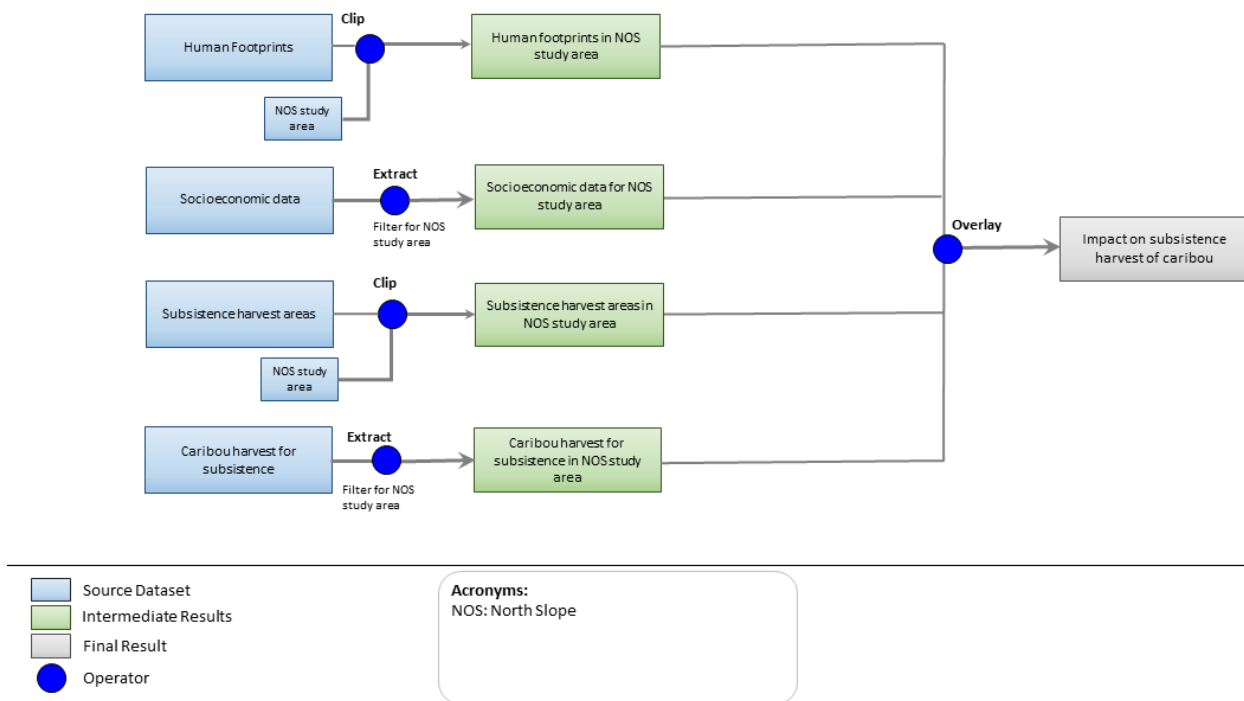


Figure E-26. Process model identifying measurable impacts of development on subsistence harvest.

Several agency reports and peer-reviewed journal articles were retrieved from multiple sources. 'North Slope Alaska', 'Subsistence', 'Socioeconomics', 'Oil and Gas' were used as search terms singularly and in combination. We identified the following variables (and corresponding data availability) as having an impact on subsistence harvest:

- **Per capita harvest amount in pounds (available):** Data were obtained from the Alaska Department of Fish and Game subsistence harvest surveys. These surveys are conducted sporadically in various communities across the state.
- **Distance from Subsistence Use Areas (unavailable):** Subsistence use areas for various species. Use areas may change over time, and thus temporal data is important. From the use area maps we intended to calculate the distance between each community (hunter's home) to the nearest subsistence area by species.
- **Intensity of Contamination (unavailable):** An overlay of the map showing intensity of contaminants and subsistence use area maps would yield the proportion of the subsistence use areas impacted by contamination.
- **Human Traffic and Vehicular Traffic (unavailable):** Number of people and vehicles passing by the subsistence use areas during the harvest season each year. Number and type of aircrafts flying by the subsistence use areas, their altitudes and noise levels during the harvest season each year.
- **Animal Migration Pattern (available):** Number of animals (caribou) moved in the harvest area and moved out of the harvest area; i.e. net migration number or net migration rate.

- **Physical Barrier (available):** Physical infrastructure (ft² or m²) between the community and subsistence use area.
- **Transportation Infrastructure (available):** Road access from the community to subsistence use area (in mile or meter), paved road or ice road during harvest season.
- **Road Network (available):** Distance of the community from the major road network.
- **Price of Store Bought Foods (available):** Community level commodity price index or consumer price index.
- **Animal Count (available):** Number of caribou per square meter (before harvest) in subsistence use area.
- **Number of Substitute Species (partially available):** Number of other CE species per square meter (before harvest) in subsistence use area.
- **Urban Market Distance (available):** Distance to the closest urban market (hub community) from the rural community.
- **Population (available):** Ratio of native population to total population.
- **Income (available):** Per capita aggregate income or income from wages (per capita).
- **Available Time (available):** Number of employees who worked all 4 quarters of a year in relation to the total population of those age 16 and over.
- **Fuel Price (available):** Diesel fuel price, based on cost per gallon.

We used the subsistence per capita harvest of caribou in pounds as the dependent variable and used several combinations of the above variables as independent variables in a multiple regression to examine the impacts of each variable on per capita subsistence harvest amounts. Several independent variables had to be eliminated from the analysis due to co-linearity.

Perceived Impacts

Perceived impacts of development on subsistence were assessed using qualitative methods. A review of literature combined with content analysis of primary sources revealed factors perceived by the local population that impact subsistence harvest.

At the first Assessment Management Team (AMT) meeting on June 27, 2013 we were advised to closely examine the meeting minutes of the Subsistence Advisory Panel (SAP) for the National Petroleum Reserve-Alaska (NPR-A) to identify specific species or habitats of interest to the North Slope study area. A two-phase project was designed. Phase I consisted of an exploratory survey of the SAP documents for key issues and themes using frequency and co-occurrence analyses. Phase II entailed a more in-depth examination of those themes and issues identified during Phase I, in order to identify substantive knowledge components potentially useful in answering management questions. Although Phase II of the analysis was abandoned in light of the findings of Phase I, the results of Phase I analysis are applicable to management questions addressing perceived impacts to fish and/or caribou.

- Reading the entire set of transcripts
- Simple Text Retrieval – frequency count for every term used in the documents

- Identifying search categories – picking out potential CEs, CAs. We used preliminary list of CEs, and CAs from the North Slope REA to identify search categories. This list included variants of the stated CEs and CAs.
- Coding – The entire document set was searched using each of the items in the search category list. Blocks of text containing the search term was filtered for coding based on the following rules:
 - Speaker identity and role – the speakers were self-identified subsistence users in the region, devoid of their official role with any organized agency or private entity operating in the region, or as industry representatives.
 - Context of the conversation – Conversations initiated by subsistence users and not in response to comments, reports and/or presentations made by industry or agency representatives were coded.
- Frequency Analysis – Each code in the above step was counted.
- Co-occurrence Analysis – Pairings of CE-CA codes were counted.

During the coding process, specific attention was paid to comments initiated by subsistence users. If a person acted in multiple capacities (i.e. as a subsistence representative in the industry but also as a participant in workshops and meetings), only those comments made in the context of meeting/workshop participation were included. This was because the reports made by these individuals in their official capacities as subsistence representatives were reflective of the context of their employment, and were considered biased by that context. There was a risk of skewing the data based upon term repetition within single comments. To account for this, terms were searched as single hard returns, rather than exact word-matches. Thus, when the same category was mentioned multiple times in the context of a single comment-response interchange, that conversation was coded as a single occurrence.

In addition to the above, some identified categories were referenced in-text using variants, misspelled in transcription, or identified within a specific subgroup. Those identified during the initial reading process were organized as additional search terms and sorted as subcategories within the established categories. For example, specific caribou herds mentioned by subsistence users (Teshekpuk Herd, Central Arctic Herd, etc.) were coded using the broader category “caribou”.

Following coding, the retrieval process consisted of both frequency and co-occurrence analyses, employed to identify the relative importance of particular categories based on repetition and also to assess which categories aligned more frequently than others. For purposes of presenting these analyses, similar categories were grouped together. The appended tables reflect select categories (presented by group), their term frequency as established in Phase I, and their filtered frequency after the coding scheme was applied.

For the purposes of this analysis, each of the issues and recommendations in the document were reviewed for pertinence to fish, caribou, or access. In addition, the issues/recommendations were also associated with CAs identified in the North Slope study area where possible.

Further supplementing the above analysis, and following it, an extensive review of the extant literature was conducted:

- Consortium Library database search (peer-reviewed journal articles) and Google Scholar and Google (articles and webpages) were conducted using these search terms alone and in combination
- Following terms were used in the context of caribou: “oil, production, gas, subsistence, perceived, perceptual, perception, mental, sensed, observe, observed, observation, resources, activities, barriers, development, exploration, extraction, pipeline, hunters, villagers, Alaska Natives, impacts, harvest, caribou, Teshekpuk Herd, Central Arctic Herd”
- Following terms were used in the context of fish: “oil, production, gas, subsistence, perceived, perceptual, perception, mental, sensed, observe, observed, observation, resources, activities, barriers, development, exploration, extraction, pipeline, hunters, villagers, Alaska Natives, impacts, fish, fishing, harvest, dolly varden, broad whitefish, chum salmon, arctic grayling, burbot”
- Following terms were used in the context of access to either fish or caribou: “access, oil, production, gas, subsistence, perceived, perceptual, perception, mental, sensed, observe, observed, observation, resources, activities, barriers, development, exploration, extraction, pipeline, hunters, villagers, Alaska Natives, impacts”
- Special attention was paid to the following documents (identified either for the comprehensive nature of the documentation or the importance of the document to community/communities in the region:
 - Full-text review and bibliographic search of “Synthesis: Three Decades of Research on Socioeconomic Effects Related to Offshore Petroleum Development in Coastal Alaska” (Braund and Kruse 2009)
 - Full-text review and bibliographic search of “Subsistence Mapping of Nuiqsut, Kaktovik, and Barrow” (Braund and Associates 2010)
 - Full-text review and bibliographic search of “Impacts and Benefits of Oil and Gas Development to Barrow, Nuiqsut, Wainwright, and Atkasuk Harvesters” (Braund and Associates 2009)
 - Full-text review and bibliographic search of “Aggregate Effects of Oil Industry Operations on Inupiaq Subsistence Activities, Nuiqsut, Alaska: A History and Analysis of Mitigation and Monitoring” (Braund and Associates 2013)
 - Full-text review of “The Inupiat View. National Petroleum Reserve in Alaska 105(c) Final Study, Volume 1(b)” (Inupiat Community of the Arctic Slope 1979)

7.3. Results for Measurable Impacts

The final dataset consisted of very few records mainly due to the small number of communities in the North Slope study area. Because only 10 communities were surveyed sporadically over the last several decades, there were only 17 records. To increase the power of the analysis, we included all rural communities in the state, and all resources instead of just caribou. The final regression model included

four independent variables – wage per capita in nominal dollars, percentage of American Indian and Alaska Native population, diesel fuel price in nominal dollars, and Gini index. These variables were chosen because of data availability.

A backward step-wise regression tested five different models, each subsequent model with one variable removed. Unfortunately, none of the models were a good fit. Nevertheless, the variables identified were considered to have a significant impact on the subsistence harvest of species, and would have yielded meaningful results with sufficient data.

Impacts of physical development

Impacts of development on the natural environment have been documented extensively. Development activities may create noise, contamination, and land use restriction due to regulation or alteration of physical features. All these may cause loss of vegetation area, loss or transformation of natural habitat, change in migration pattern, and other changes that affect subsistence harvests (Bureau of Ocean Energy Management 2011, Braund et al. 2009, Woods 2013).

For example, migration patterns of caribou near Noatak had an unusual pattern in 2009 and 2010 - narrow along the east-west corridor centered on the Anisak River drainage. Harvest numbers for Kotzebue, Kivalina, and Noatak during those years were lower (Braem and Kostick 2014). Similarly, residents of Nuiqsut, surrounded by oil development on the North Slope, reported traveling longer distances for subsistence hunting: “A few residents also reported hunting substantial distances east and west of the community, although several people commented that hunting has declined east of the community due to activities associated with oil and gas development. Respondents commonly indicated that they look for caribou while hunting wolf and wolverine by snow machine over a large expanse. Residents generally did not travel past the Sagavanirktok River to the east in search of caribou, but one individual reported venturing as far west as Barrow in the last 10 years” (Braund et al. 2010).

In addition to these immediate affects, changes in migration patterns may have long-term negative impacts on subsistence harvest due to loss of calving grounds and consequent decline in herd (U.S. Army Corps of Engineers 1980). Changes in migratory pattern may prove fatal to very old or very young members of a herd due to unfamiliar conditions (Tetra Tech, Inc. 2009). Central Arctic Herd (CAH) of caribou in the North Slope is the most affected herd due to the expansion of industrial activities around Prudhoe Bay oil fields. “The CAH traditionally calved between the Colville and Kuparuk Rivers on the west side of the Sagavanirktok River and between the Sagavanirktok and the Canning Rivers on the east side. During the 1990s, the greatest concentration of caribou calving in the western portion of Unit 26B shifted southwest as development of infrastructure related to oil production [began] in what was originally a major calving area” (Braem et al. 2011). Other studies documented similar patterns. Continued expansion of the Prudhoe Bay oil field eastward displaced caribou further eastward toward the coast, affecting their calving habitat as well as their migration route and grazing areas (Bureau of Ocean Energy Management 2011, Pedersen and Caulfield 1980).

In addition to physical barriers, development is a major source of contaminants that affects habitat and individual species. Most common sources of contaminants in the North Slope include oil spill and

fugitive dusts, affecting both land and water (Tetra Tech, Inc. 2009, Bureau of Ocean Energy Management 2001) through multiple pathways (Galginaitis and Patterson 1990, Alaska Native Science Commission 2009).

Impact of social and economic development

Short and long-term development activities create opportunities for wage-paying jobs (Pedersen and Caulfield 1980). The economy of North Slope communities transformed since the beginning of the oil and gas industry in the region, with dramatic rise in per capita incomes. Increased incomes have both positive and negative impacts on subsistence harvests. Time available for subsistence hunting is limited due to obligations of a paid job. People with full-time well-paying jobs may be limited to weekends, after hours, or vacation time. Time restrictions often force shorter commutes to subsistence harvest areas. On the other hand, the ability to purchase hunting and fishing tools, including transportation vehicles such as ATV's or snow machines is often greatly improved. Barrow residents tend to fish at Elson Lagoon, Chipp, Ikpikpuk, and/or some other local rivers where they catch salmon, whitefish, Arctic grayling, least cisco, burbot, and some other fish as opposed to established subsistence harvest areas (Carothers 2013).

Table E-13. Factors impacting subsistence harvest in the North Slope study area.

Caribou	Fish
Noise	Contamination (i.e. oil spill, fugitive dust): death of fish, destruction of fish habitat
Road traffic, human traffic, air traffic	Change of migration patterns due to contamination and water withdrawal for development activities
Contamination (i.e. oil spill, fugitive dust)	Access to subsistence area: legal restriction, transportation infrastructure, distance to subsistence area
Change of animal migration pattern	Income from wages
Access to subsistence area: perception/belief, legal restriction, physical barrier, transportation infrastructure, distance to subsistence area	Available time
Loss of vegetation area and calving habitat	Material inputs: Oil price, hunting gears, snow-machines
Income from wages	Price and availability of substitute store foods
Available time	Legal restriction imposed by local, state, and federal authorities on fishing specific species
Material inputs: Oil price, hunting gears, snow-machines	Availability of substitute harvest species
Price and availability of substitute store foods	Access/distance to urban markets
Legal restriction imposed by local, state, and federal authorities on hunting specific species	Number of total people
Availability of substitute harvest species	Number of native people
Access/distance to urban markets	Water withdrawal for development activities
Communities along the road networks	Communities along the road networks
Number of total people	
Number of native people	

Other major factors associated with development that impact subsistence harvest include higher demand due to increased community populations, their proximity and access to urban markets, higher energy prices, and applicable game management regulations. Development activities may cause increase in community populations due to in-migration, which may increase the total harvest amounts. However, higher population can result in lower per capita harvest amount. Per capita harvest declined by half from almost 1,300 pounds per capita in 1964 to almost 750 pounds per capita in 1992 in Kivalina (Magdanz et al. 2002) as the community's population increased from 142 in 1960 to 317 in 1990. Alaska Native communities traditionally relied on subsistence, and place a higher social and cultural value on subsistence activity (Tetra Tech, Inc. 2009). The impacts of increased population are higher and more pronounced in larger communities than in smaller communities.

Easy or affordable access to urban markets that offer multiple food choices tend to have a negative effect on per capita harvest amounts. Communities along the road networks harvest less than the communities that are off the road networks. Higher fuel prices have mixed impacts on subsistence harvest amounts. While the increased transport costs may decrease subsistence harvests, costs increase to import foods from otherwise accessible and affordable urban markets. Applicable game management regulations at all levels during, after, or before development have a direct impact on harvest amounts and patterns. The 1970 declaration of bowhead whale as an endangered species criminalized bowhead whale hunting. Summer caribou harvest near Nuiqsut was restricted in the late 1970s. The local government in Arctic Village restricted caribou harvest in 1981 (Pederson and Caulfield 1980). In 1970s the lack of walrus and bowhead in Wainwright caused more hunting for fish and seal, but the total amount of harvest may have stayed the same. Table E-13 shows the list of factors impacting subsistence harvest of caribou and fish.

7.4. Results for Perceived Impacts

SAP Minutes for Caribou

A textual analysis of 13 years of SAP minutes conducted in 2013-2014 revealed that for the NPR-A, caribou and fish were considered at risk from three primary sources of disturbance: air traffic, contamination, and seismic activities. More generally, areas of concern with regards to oil and gas development included erosion, contamination, oil spills, ice roads, air traffic, and seismic activities. This analysis was reassessed to identify pertinent themes. These themes were used as guidance during the literature review.

Table E-14. Results of co-occurrence analysis of “caribou” with factors perceived to be impacting subsistence harvest of caribou.

Factor	Co-occurrence count
Air Traffic	38
Contamination	3
Erosion	1
Ice Roads	4
Seismic	17
Spills	1
Subsistence	58

“Caribou” was one of the two most commonly occurring categories in the transcripts (N=223). “Caribou” co-occurred with all six of the “areas of concern” which may be easily categorized within the identified CAs for this project. “Caribou” likewise co-occurred with “air traffic” (38) and “seismic activities” (17). Unsurprisingly “caribou” co-occurred with “subsistence” (58) reflecting the strong association between these two categories (Table E-14).

The collection of SAP issues and recommendations collected over the course of the 13-year documented period show similar patterns to those identified in the SAP Minutes analysis, which also includes notations on the result/solution of the concerns cited. The document was used to identify concerns relating to caribou, and then tie them to CAs. Of the 182 issues and recommendations listed in the document, twenty-two pertain directly to caribou (Table E-15).

Table E-15. Specific threats to subsistence harvest of caribou.

Threat factor	Co-occurrence count
Energy Development	2
Natural Resource Extraction	8
Transportation and Communication Infrastructure	4
Air Traffic	4
General/unspecified Concern	8

SAP Minutes for Fish

“Fish” was the other commonly occurring category in the dataset (N=339). “Fish” co-occurred with all six of the “areas of concern”. “Fish” most frequently co-occurred with “seismic activities” (28) and “air traffic” (19). Unsurprisingly “fish” co-occurred with “subsistence” (51) reflecting the strong association between these two categories. Importantly, “lakes” (60), “rivers” (45), and “creeks” (49) were discussed with similar frequency (Table E-16), and more so than any other CEs, barring “fish” and “caribou”. This is indicative of a concern not only for the water resources but the subsistence resources living in them as well.

Table E-16. Results of co-occurrence analysis of “fish” with factors perceived to be impacting subsistence harvest of fish.

Factor	Co-occurrence counts			
	Fish: General	Creeks	Lakes	Rivers
Air Traffic	19	5	3	2
Contamination	15	0	3	3
Erosion	3	0	1	3
Ice Roads	9	0	4	1
Seismic	28	0	3	4
Spills	6	1	4	3
Subsistence	51	4	10	9

Of the 182 issues and recommendations listed in the document, twelve pertain directly to fish (Table E-17). Perceived threats to fish were spread equally amongst concerns comprised of energy development (3), natural resource extraction (3), transportation and communication infrastructure (3)

and general or unspecified (3). More specific areas of concern included: contamination (2), infrastructure (4), seismic activities (3), pipelines (1), and general/unspecified concerns (as below).

Table E-17. Specific threats to subsistence harvest of fish.

Threat Factor	Co-occurrence count
Energy Development	3
Natural Resource Extraction	3
Transportation and Communication Infrastructure	3
General/unspecified Concern	3

In addition, there were also six references to subsistence practice in general and forty-five references wherein the species of concern is not identified or pertains to an animal other than fish or caribou.

Literature Review

The literature search produced few articles pertinent to the “perceived impacts” of oil and gas activity on the subsistence harvest of caribou. Primary results included material on subsistence harvest numbers, caribou health and articles specifically addressing caribou behavior or health vis-à-vis particular oil and gas activities (such as air traffic). In addition, those reports and articles selected for further review were also identified during database searches of ADF&G, BLM, and BOEM.

Document sources utilized in the literature review generally fell into two categories: subsistence harvest reports and subsistence documentation contained within environmental impact statements (EIS), environmental assessments (EAs) and/or findings of no significant impact (FONSI). The major limitation of these types of documents is that although they identify current and past subsistence activities, numbers, and locations, they are rarely designed to take into account the perceptions of subsistence users. For example, one of the most comprehensive of these documents, “Subsistence Mapping of Nuiqsut, Kaktovik, and Barrow” (Braund and Associates 2010) states that “[r]esidents’ observations about changes in resource use, abundance, quality, distribution, and migration are a key indicator of changes related to development,” and that “[a]lthough traditional knowledge about resource change is beyond the scope of this study, the study team recommends that future studies include systematic documentation of observed resource changes” (p. 29). A secondary but equally important limitation is that although the author(s) of these documents may have synthesized documentation regarding the perceived impacts of the oil and gas industry on subsistence resources, it is not always clear whether the “perception” is that of the subsistence user or the author.

A complete list of sources used for this exercise is included in the database of literature compiled and delivered as a final product.

Physical and Perceptual Limitations to Access

Participation in subsistence is integral to the lifestyle of people who live on the North Slope, daily and seasonal activities revolve around the availability of particular resources (Brower Jr. and Hepa 1998). Subsistence activities also have a seasonal component, meaning that changes in climate, hydrology, and weather events will influence different subsistence activities more than others. Residents of the North Slope have expressed concern about access disruptions to subsistence areas and resources (Bureau of Land Management 2005).

Ability to access subsistence resources is influenced by both availability of physical access and the abundance and location of the resource. In addition to limitations caused by development, access to land mammals and their harvest are also subject to climate change. Fires, freeze-thaw events, and snow depths all influence caribou availability; with snow depths also influencing physical access by hunters. In addition, changes in the timing of freeze up and breakup have been shown to inhibit the ability of hunters to access caribou (Gustine et al. 2014, Rattenbury et al. 2009). Both coastal and inland communities are influenced by erosion, which can prevent river and sea access to areas (Brubaker et al. 2014). Changes in season also influence phenology and the timing of production which in turn affect when waterfowl arrive on the North Slope (Sweet et al. 2015).

Anthropogenic activities are likely to influence access and availability to subsistence resources (Lawhead et al. 2006). As identified and described earlier in this report from the analysis of the SAP meeting minutes and other documents, air traffic is perceived as the most severe threat to subsistence harvest. Air and road traffic can spook caribou. Whereas pipelines, if not constructed properly, can influence caribou movements (Lawhead et al. 2006). The most perceived threat related to ground traffic is from seismic exploration activities. While these activities are not actual physical barriers to accessing any part of the study area, strong perceptions of the threat make them physical barriers for subsistence hunters. Pipelines, roads and other infrastructure facilities fragment the habitat and potentially alter migration patterns, thereby creating access issues and availability of subsistence resources.

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8. Parameters for Determining Natural and Anthropogenic Change

MQ AT 1	What parameters can help measure impacts from anthropogenic activities independently of natural cycles and vice-versa?
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It is well recognized that most environmental drivers (climate, wildfire, biogeochemistry, etc.) are constantly changing, operating on various time scales, and creating multiple 'stages' of environmental setting. These natural cycles are often the cause of major environmental change operating on relatively short ("flickering switch" from Taylor et al. 1993) to very long timescales (interglacial periods). Thus, it is increasingly important to identify the role human activity has independent of larger natural phenomenon.

Disentangling the impact of anthropogenic activities from natural cycles has been a crux of conservation biology, and ecology in general. The original goal of monitoring cumulative effects came from the recognition that environmental change comes from multiple stressors acting at the same time. However, quantifying the cumulative impact has been extremely difficult for the same reason this arose as a management question: there is no clear answer.

Several studies have been conducted in the region that identify the impacts of anthropogenic activities on wildlife species and other ecological processes, including impacts on nest survival of tundra birds on the arctic coastal plain, arctic fox, and caribou. Although many models have been built to try and isolate the impact of different stressors, there is no standard set of parameters or indicators that have been developed to specifically disentangle the impact of human activity versus natural cycles.

Given the ongoing debate over the role of anthropogenic emissions and activities on climate change, we interpreted this question as only those human activities that occur in the North Slope study area. Using the landscape integrity estimates (see Section F), it is clear that the effect of anthropogenic activities on the broader North Slope ecosystems is very limited. It is safe to assume then that natural cycles can be considered the primary drivers of ecosystem change at the ecoregional-level. With this observation, we suggest that the attributes and indicators (see Section G, H, I, J) tables that have been developed for each CE will be a useful guide for establishing monitoring parameters to help disentangle the impacts from anthropogenic activities and natural cycles. In some cases, CE status includes a weighted impact of different stressors based on the best available literature. This information can help managers identify the most important parameters to measure impacts from anthropogenic versus natural cycles.

Additionally, we suggest using the Cumulative Impacts (CI) model to identify those areas that are most likely to change due to the abiotic (climate, wildfire, permafrost) vs. anthropogenic-driven (development, invasive species) CAs. Strategically designing monitoring procedures to occur in watersheds with all CAs changing, versus those with only abiotic changes, and those with only anthropogenic changes, would help identify the relative impact of the different stressors on local and regional ecosystem resources.

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9. Impacts of Oil and Gas Development on CE Habitats

MQ AT 2

What potential impacts will oil/gas exploration and development have on CE habitat?

Oil and gas development may potentially impact CE habitat through direct loss or fragmentation of habitat from the footprint of associated infrastructure development, including roads, pipelines, drilling pads, and residential facilities, or contamination of habitat through toxic spills. These effects to habitats impact wildlife CEs through direct mortality and displacement, reduced reproductive rates, and creating more suitable conditions for predators. Furthermore, significant effects to wildlife (CEs) and habitat will likely accumulate as industry expands in the future.

Resource extraction and infrastructure development have caused the fragmentation of caribou habitat throughout Alaska. Patch sizes are likely to decrease as development increases. While a previous study in Prudhoe Bay found that caribou cows and calves did not avoid drilling areas (Fancy 1983), more recent studies have found that caribou generally avoid areas of human activity (up to 50 - 95% reduced presence; Vistnes and Nellemann 2008) and can be displaced from preferred calving grounds by human disturbance (Joly and Klein 2011, Wolfe et al. 2000). When caribou cows are displaced from preferred calving areas, their calves are smaller at birth and may not grow as fast or survive as well.

The calving areas and summer habitat of the Central Arctic Herd coincide with industrial development in the North Slope study area. The construction of roads, pipelines, and facilities has changed the spatial distribution patterns of the herd by splitting aggregations to an eastern group and a western group. East-west movement across the developed corridors decreased by at least 90% compared to pre-development observations from the 1970s (Cameron et al. 2005).

While some caribou have occasionally used gravel pads and roads as insect relief areas (Fancy 1983), infrastructure can typically delay or redirect caribou moving towards coastal areas to seek mosquito relief. If displacement from foraging and relief habitats causes energetic stress, then affected cows will likely respond with lower fecundity (Murphy and Lawhead 2000, Vistnes and Nellemann 2008).

Greater white-fronted geese are loyal to breeding and molting sites, which may hinder a population's ability to relocate if breeding or molting habitats are negatively impacted or destroyed by development. All-weather roads, necessitated by a warming climate and shortened ice road season, associated with energy extraction activities could impact Greater white-fronted geese and other waterfowl, especially near important molting areas around Teshekpuk Lake (Liebezeit et al. 2009). Because geese concentrate at pre-nesting and molting sites, the effects of severe but rare local disturbance events, such as oil spills or toxic contamination, will likely have large negative impacts on populations (Schoen and Senner 2002). During years of late snow melt, geese nest on drier upland sites (Ely and Raveling 1984) that are more likely to be restricted by future development. Greater white-fronted geese and cliff nesting raptors are sensitive to machine noise (Barry and Spencer 1976 in Ely and Dzubin 1994) and aircraft disturbance (Derksen et al. 1979) which can result in habitat avoidance and nest abandonment (Ritchie et al. 1997).

These are just a few specific examples of how oil and gas activities impact wildlife habitat. For more in-depth discussion, please see Section H. Terrestrial Fine-Filter Conservation Elements.

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10. Contaminants

MQ AT 3	What additional contaminants baseline data are needed for fish, birds, marine and terrestrial species, particularly those that affect the health and safety of subsistence foods?
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We focused on synthesizing baseline information related to contaminants of concern for marine and terrestrial organisms within the North Slope study area, with emphasis on subsistence species. This information will help with current and future contaminant monitoring and management programs. For this MQ, we focused on the contaminants of greatest concern to humans through use of subsistence resources to include: heavy metals, petroleum products (PAHs), persistent organic pollutants (POPs), and radionuclides. Data on most frequently harvested species per community were obtained from Alaska Department of Fish and Game (ADF&G) household subsistence harvest surveys. For this review, we included the five most commonly harvested species per community (Table E-18). We provide a brief overview of these species, contaminants of most concern to subsistence users, and a detailed discussion on the baseline contaminants data that exists for each subsistence species.

Terrestrial and freshwater species that are frequently harvested in communities within the North Slope study area include: caribou, greater-white fronted geese, Dolly Varden, broad whitefish, chum salmon, grayling, and burbot (Table E-18). Marine mammals comprise a significant proportion of the harvest of subsistence resources for communities within the North Slope study area, especially coastal communities, and include: bowhead whale, beluga whale, pacific walrus, bearded seal, ringed seal, spotted seal, and polar bear (Table E-18).

Table E-18. Top five most harvested subsistence species (taken from Sum of Estimated Pounds Harvested not in the order of amount of harvest) in North Slope communities. Data for missing North Slope communities are not available. Data Source: Alaska Department of Fish and Game (ADF&G).

Species	Barrow	Kaktovik	Kivalina	Noatak	Nuiqsut	Point Lay	Wainwright	Anaktuvuk Pass
Terrestrial and fresh water species								
Caribou	x	x	x	x	x	x	x	x
Greater white-fronted goose	x	x	x	x	x	x	x	x
Grayling	x	x	x	x	x	x	x	x
Dolly Varden/Char		x				x		x
Broad whitefish	x				x			x
Burbot	x		x	x	x			
Chum salmon			x	x		x		
Marine mammals								
Bowhead whale	x	x			x	x	x	
Walrus	x		x	x		x	x	
Bearded seal	x	x	x	x	x	x	x	
Ringed seal	x	x	x	x	x	x	x	
Polar Bear	x	x			x		x	
Beluga			x	x	x	x		
Spotted seal		x	x	x				

10.1. Current Status of Contaminants

Studies on contaminants in the region cover spills from industrial activities, general living of the population, and presence of contaminants in natural food sources. This study was limited to identifying contaminants on the ground as part of the human footprint in the North Slope study area. The Department of Environmental Conservation of the State of Alaska tracks contaminated sites and monitors clean up activity. Figure E-27 shows contaminated sites identified in the North Slope study area.

Every community is identified as a contaminated site. This is largely owing to the presence of bulk fuel storage tanks in each community for local supply needs through the year. Several spills in the Prudhoe

Bay area are petroleum products associated with the oil and gas industry. A total of 141 contaminated sites are identified in the region.

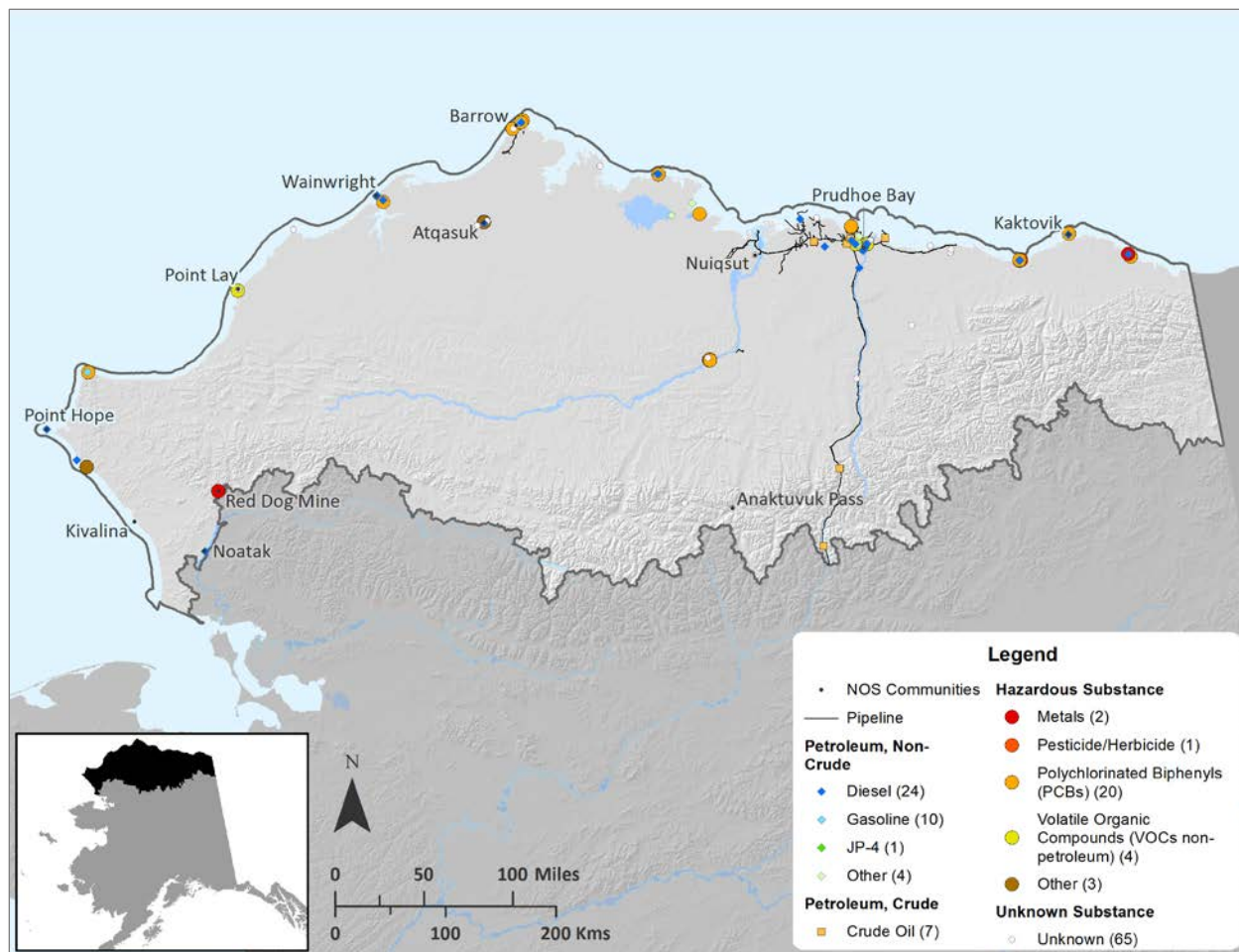


Figure E-27. Sites with known contaminants in the North Slope study area. Data Source: ADEC Contaminated Sites Program.

10.2. Overview of Contaminants of Concern

Petroleum Products with Emphasis on Polycyclic aromatic Hydrocarbons (PAHs)

PAHs are a group of organic contaminants that form from the incomplete combustion of hydrocarbons, such as coal and gasoline. PAHs are an environmental concern because they are toxic to aquatic life and because several are suspected human carcinogens. Pollution from oilfield activities is a major threat to habitats within the North Slope study area, and exposure to petroleum oil from natural sources such as seeps or coal bed areas are also a concern for fish and wildlife. Regardless of the source, establishing baseline levels in subsistence species is important.

Terrestrial wildlife may be exposed to PAHs, but the biggest concern is for aquatic fish and waterbirds. PAHs do not accumulate in tissues, thus monitoring for these contaminants must happen within a short

window of time after exposure (about 2 weeks) or when there is longer-term chronic exposure as in more highly polluted areas. PAHs are a concern for subsistence users because direct ingestion of tissues contaminated by PAHs are possible, in addition to the effects that exposure to PAHs could have to wildlife including carcinogenesis, endocrine disruption and dermal irritation (Eisler 1987).

Heavy Metals

Heavy metals, including mercury, cadmium, selenium, arsenic, copper, nickel, and lead are of greatest concern to subsistence species and can be attributed to both local natural sources and anthropogenic activities, as well as long-range transport. Some of these heavy metals provide essential micronutrients (e.g., selenium), while others have no known biological benefit and are considered toxic to biota (e.g., mercury). All metals can have serious negative health consequences at elevated levels. Additionally, heavy metals are a concern for subsistence species because they can bioaccumulate within individuals and biomagnify through food webs. Thus, humans that rely on subsistence species may be exposed to greater levels of toxic metals due to exposure through diet. Heavy metals can affect both terrestrial and aquatic wildlife and have been documented in several important subsistence species within the North Slope study area.

Radionuclides

Radioactivity is a concern for subsistence species within the North Slope study area because contamination within plants and animals can persist for long periods and can lead to high exposure rates to subsistence users (AMAP 2010). Fallout from nuclear weapons tests is the primary source of contamination to arctic regions, but nuclear fuel reprocessing plants are additional anthropogenic sources of radionuclides. The Chernobyl accident in 1986 and more recently the 2011 partial nuclear reactor failures in Fukushima are a concern as potential sources of radionuclide contamination to arctic communities. Though levels of this contaminant have been declining over the last couple of decades, potential for contamination and movement through food webs still exists and may pose a health threat to humans. Cesium-137 can accumulate in animal muscle and is the most commonly studied radionuclide. Thus, we focused our review on baseline Cesium-137 data.

Persistent Organic Pollutants (POPs)

POPs are organic compounds that are resistant to environmental degradation. For this reason, they often persist in the environment, are capable of long-range transport, bioaccumulate in human and animal tissue, and biomagnify in food chains http://en.wikipedia.org/wiki/Persistent_organic_pollutant_-_cite_note-ritter-1. Most POPs are the result of anthropogenic sources (e.g., pesticides, pharmaceuticals, and solvents), but POPs also occur naturally in very low levels from volcanic activity and fires. Some of the more common and well-known POPs include polychlorinated biphenyl (PCB), dichlorodiphenyltrichloroethane (DDT), mirex, and dioxins. Similar to heavy metals, POPs have the potential to bioaccumulate within individuals and biomagnify through food webs, thus these chemicals pose a risk to wildlife and humans that rely on wildlife for subsistence.

10.3. Subsistence Species and Baseline Contaminants

Caribou (*Rangifer tarandus*)

The summer diet of caribou consists largely of grasses, sedges, twigs, leaves, and mushrooms, which generally tend to have lower levels of contaminants. The winter diet is composed mainly of lichens, which are known to accumulate contaminants from air and precipitation, especially radionuclides (AMAP 2010).

Baseline data for most heavy metals of concern have been collected for caribou within the North Slope study area (Table E-19). Though baseline levels of cadmium in caribou tissues within the North Slope study area exist, further study of this contaminant may be warranted. Cadmium is a particular concern for subsistence users given that relatively high levels were documented in caribou from communities sampled within the North Slope study area (O'Hara et al. 2003). Studies from other regions have also documented similarly high levels (AMAP 1998, Aastrup et al. 2000, Elkin, 2001, Odsjö 2002). Although O'Hara et al. 2003 documented relatively high levels of cadmium in caribou tissues from areas within the North Slope study area, they did not find corresponding histological effects and advise caution when interpreting these data in the context of subsistence use. For these reasons, further studies on exposure rates of subsistence users to cadmium in caribou tissues and the potential impacts on human health may be warranted. Similarly, iron levels in caribou from Cape Thompson, Barrow, and Point Hope (O'Hara et al. 2003) were relatively high and may warrant further data collection.

Baseline data on radionuclides for caribou within the North Slope study area are lacking. Other arctic countries including Norway, Greenland, Iceland, and Russia have documented relatively high levels of radionuclides in caribou (AMAP 2004, Macdonald et al. 2007, AMAP 2010). Given that these other arctic countries documented relatively high levels of radionuclides, and caribou are an important subsistence species in every community included in this review (Table E-19) baseline data on caribou radionuclide data are needed.

Baseline data for POPs, particularly DDTs, and PCBs are lacking. Braune et al. (1999) found a decreasing trend in PCB levels in caribou from eastern Canada to western Canada. Although levels were found to be low in caribou from Canada, there is no baseline data for the North Slope study area. The North Slope Borough 2006 reported collection of baseline data for POPs in caribou within the North Slope study area, but these data are currently not publicly available.

Greater White-Fronted Goose (*Anser albifrons*)

The Greater white-fronted goose is primarily a grazer and feeds on terrestrial and aquatic sedges and grasses, berries (e.g., crowberry), and aquatic insects and their larvae (Ely and Dzubin 1994, Rothschild and Duffy 2005).

Baseline data for all contaminants are lacking for Greater-white fronted goose within the North Slope study area (Table E-19). Given its importance as a subsistence species in communities throughout the

North Slope study area, in addition to its aquatic foraging habits, baseline data for heavy metals and PAH's in particular are recommended.

Rothschild and Duffy (2005) reported low levels of mercury in tissues of Greater-white fronted goose from western Alaska. The diet of Greater-white fronted goose is similar between these regions, but point sources of mercury contamination may differ. Thus, baseline data should be collected to confirm that Greater white-fronted goose within the North Slope study area also have low levels of mercury. Similarly, Braune et al. (1999) found relatively low levels of cadmium, mercury, selenium, and radionuclides for other goose species in Canada.

Dolly Varden (*Salvelinus malma*)

Dolly Varden occur within the North Slope study area as lake-resident, stream resident, and anadromous populations although they are considered to be predominantly anadromous within the North Slope study area. Larger juvenile and adult fish consume salmon fry, salmon eggs, invertebrates, and small fish. Juveniles feed primarily on macroinvertebrates. Due to their largely piscivorous diet, Dolly Varden may be more susceptible to exposure to contaminants as well as biomagnification of contaminants.

Baseline data for many of the heavy metals of concern exist for this species (Table E-19). However, we are not aware of any studies that have looked at radionuclides, mercury, POPs, or PAHs within Dolly Varden sampled from the North Slope study area. Low levels of mercury have been reported in Dolly Varden from Canada (Braune et al. 1999), but baseline levels from Dolly Varden within the North Slope study area have not been reported.

Broad Whitefish (*Coregonus nasus*)

Broad whitefish are bottom feeders that primarily feed on snails, bivalves and other mollusks, as well as aquatic insect larvae. Due to their lower trophic level diet, their exposure to contaminants especially, POPs and heavy metals, is assumed to be low. Most contaminants of concern have been studied at baseline levels for broad whitefish except radionuclides (Table E-19). All contaminants studied have been reported at relatively low levels. Studies in Canada also found relatively low levels of PCBs in broad whitefish (Lockart et al. 1993).

Chum Salmon (*Oncorhynchus keta*)

Chum salmon only feed in freshwater during a short period of time as juveniles (2-3 weeks). As adults they feed at sea on copepods and mollusks and a variety of fish. Thus, their piscivorous diet at sea makes them more susceptible to exposure to contaminants as well as biomagnification of contaminants.

Most contaminants of concern have been studied at least at baseline levels for chum salmon within the North Slope study area, except radionuclides, POPs, and PAHs (Table E-19). Most contaminants studied are reported at relatively low levels. Additionally, relatively low levels of PCBs, DDTs, and heavy metals (specific metals not reported) were reported for chum salmon from the Yukon-Kuskokwim region (USFWS 2004). Levels of POPs for chum salmon within the North Slope study area may differ from chum

salmon sampled within the Kuskokwim region. Thus baseline levels of these contaminants are recommended. Similarly, baseline levels of radionuclides and PAHs in chum salmon within the North Slope study area are recommended.

Grayling (*Thymallus thymallus*)

Arctic grayling are considered generalists, but primarily consume macroinvertebrates. They will also eat salmon eggs and out-migrating salmon smolts. Most contaminants of concern have been studied at least at baseline levels for Arctic grayling, except radionuclides and mercury (Table E-19). Most contaminants studied are reported at relatively low levels and do not appear to pose a risk to subsistence users. Furthermore, extensive studies elsewhere in Alaska have documented relatively low levels of mercury (Jewett and Duffy 2007, Jewett et al. 2003, Duffy et al. 1999, Mueller and Matz 2002, Synder-Conn et al. 1992), and PCBs (Mueller and Matz 2000) in grayling tissues. Thus, it is likely that grayling within the North Slope study area also have low levels of mercury. However, to confirm this assumption, baseline mercury tissue data should be collected. We are not aware of any studies within Alaska that have looked at radionuclides in grayling tissues and baseline data are recommended.

Burbot (*Lota lota*)

Burbot are a long-lived freshwater fish found in deep lakes and rivers. Juveniles feed on insects for the first few years, and then shift to a mostly piscivorous diet as adults (Morrow 1980). Because they feed higher on the food chain, burbot are expected to have higher levels of contaminants.

Most contaminants of concern have been studied at least at baseline levels, except mercury, and radionuclides (Table E-19). PCB and DDT levels in burbot, collected near Nuquist and Umiat slough, have been documented at relatively high levels. As a consequence, recommendations on consumption levels have been suggested (Hanns 2006). In Canada, burbot PCB and DDT levels were also relatively high (Braune et al. 1999, Kidd et al. 1995). Given these high levels, further study of burbot PCBs and DDT from other areas within the North Slope study area that are regularly used by subsistence users may be warranted.

Mercury levels in burbot from elsewhere in Alaska (Jewett and Duffy 2007, Duffy et al. 1999, Hinck et al. 2006) and Canada (Braune et al. 1999) have been reported at relatively high levels. Hinck et al. (2006) found that burbot from the Yukon River in Alaska had mercury levels high enough to warrant concern for piscivorous wildlife. Because burbot feed higher on the food chain, are more susceptible to accumulating contaminants and because they represent an important subsistence resource, it should be a priority to obtain baseline levels of this contaminant within the North Slope study area.

Bowhead whale (*Balaena mysticetus*)

All contaminants of concern have been studied for bowhead whales and most contaminants have been documented at low levels (Table E-19). For an excellent review of knowledge about contaminants in bowhead whale tissues see O'Hara et al. (2004).

Beluga whale (*Delphinapterus leucas*)

Most contaminants of concern have been studied for beluga whales, except for PAHs (Table E-19). Mercury, cadmium, and selenium were reported at intermediate to relatively high levels, but are consistent with other studies in Alaska and other arctic regions and do not appear to warrant concern for subsistence users (Becker et al. 1995, Woshner et al. 2001, Wagemann et al. 1996, Koeman et al. 1973, Dietz et al. 1990). Baseline data on PAHs in beluga whale tissues are recommended.

Pacific Walrus (*Odobenus rosmarus divergens*)

Most contaminants of concern have been studied for Pacific walrus, except for PAHs (Table E-19). Robards 2009 provide a thorough review of contaminant studies in Pacific walrus. Concentrations of most contaminants studied are relatively low. However, high levels of cadmium have been reported in walrus tissues (Taylor et al. 1989, Lipscomb 1995), though no histopathological effects in Pacific walrus tissues were reported (Lipscomb 1995). Similarly, Taylor et al. (1989) reported relatively high levels of mercury and recommend further study of both cadmium and mercury to better understand the effects of these contaminants on walrus populations and subsistence users.

Bearded seal (*Erignathus barbatus*)

Most contaminants of concern have been studied for bearded seals, except PAHs (Table E-19), and most contaminants have been documented at relatively low levels. However, concentrations of cadmium and mercury from bearded seals collected near Barrow, Wainwright, and Kaktovik where relatively high (Quakenbush et al. 2011) compared to bearded seals collected near Nome (Mackey et al. 1996), but lower than another study that sampled liver of bearded seals near Barrow (Dehn et al. 2006). Bearded seals from northern Alaska have especially low levels of POPs when compared to seals from other arctic countries (Weis and Muir 1997, Nakata et al. 1998).

Ringed seal (*Pusa hispida*)

Most contaminants of concern have been studied for ringed seals, except PAHs (Table E-19), and most contaminants have been documented at relatively low levels.

Spotted seal (*Phoca largha*)

Most contaminants of concern have been studied for spotted seals, except PAHs (Table E-19), and most contaminants have been documented at relatively low levels.

Polar bear (*Ursus maritimus*)

Most contaminants of concern have been studied for polar bears, except PAHs (Table E-19), and most contaminants have been documented at relatively low levels.

Table E-19. Baseline data collection for select contaminants and subsistence species within the North Slope study area.

Species	Contaminant	Baseline Data (Y/N)	Reference
<i>Mammals</i>			
Caribou	Radionuclides	N	Robillard et al. 2002
	Cadmium	Yes	O'Hara et al. 2003
	Arsenic	Yes	O'Hara et al. 2003
	Copper	Yes	O'Hara et al. 2003
	Lead	Yes	O'Hara et al. 2003
	Mercury	Yes	Gerlach et al. 2006
	Selenium	No	
	POPs	No	
	PAHs	No	
<i>Birds</i>			
Greater White-Fronted Goose	Radionuclides	No	
	Cadmium	No	
	Arsenic	No	
	Copper	No	
	Lead	No	
	Mercury	No	
	Selenium	No	
	POPs	No	
	PAHs	No	
<i>Fish</i>			
Dolly Varden	Radionuclides	No	
	Cadmium	Yes	DEC Fish Monitoring Program 2011
	Arsenic	Yes	DEC Fish Monitoring Program 2011
	Copper	Yes	DEC Fish Monitoring Program 2011
	Lead	Yes	DEC Fish Monitoring Program 2011
	Mercury	No	
	Selenium	Yes	DEC Fish Monitoring Program 2011
	POPs	No	
	PAHs	No	
Broad Whitefish	Radionuclides	No	
	Cadmium	Yes	DEC Fish Monitoring Program 2011, Spies et al. 2003

Species	Contaminant	Baseline Data (Y/N)	Reference
	Arsenic	Yes	DEC Fish Monitoring Program 2011, Spies et al. 2003
	Copper	Yes	DEC Fish Monitoring Program 2011, Spies et al. 2003
	Lead	Yes	DEC Fish Monitoring Program 2011, Spies et al. 2003
	Mercury	Yes	Jewett and Duffy 2007, Spies et al. 2003
	Selenium	Yes	DEC Fish Monitoring Program 2011, Spies et al. 2003
	POPs	Yes	Hanns 2006, Spies et al. 2003
	PAHs	Yes	Wetzel and Mercurio 2007, Spies et al. 2003
Chum	Radionuclides	No	
	Cadmium	Yes	DEC Fish Monitoring Program 2011
	Arsenic	Yes	DEC Fish Monitoring Program 2011
	Copper	Yes	DEC Fish Monitoring Program 2011
	Lead	Yes	DEC Fish Monitoring Program 2011
	Mercury	Yes	Jewett and Duffy 2007
	Selenium	Yes	DEC Fish Monitoring Program 2011
	POPs	No	
	PAHs	No	
Arctic grayling	Radionuclides	No	
	Cadmium	Yes	DEC Fish Monitoring Program 2011
	Arsenic	Yes	DEC Fish Monitoring Program 2011, Mueller and Matz 2002
	Copper	Yes	DEC Fish Monitoring Program 2011
	Lead	Yes	DEC Fish Monitoring Program 2011
	Mercury	Yes	Jewett and Duffy 2007, AMAP 2011
	Selenium	Yes	DEC Fish Monitoring Program 2011
	POPs	Yes	Hanns 2006, Wilson et al. 1995, Verbrugge and Middaugh 2004
	PAHs	Yes	Wetzel and Mercurio 2007
Burbot	Radionuclides	No	
	Cadmium	Yes	DEC Fish Monitoring Program 2011
	Arsenic	Yes	DEC Fish Monitoring Program 2011
	Copper	Yes	DEC Fish Monitoring Program 2011
	Lead	Yes	DEC Fish Monitoring Program 2011
	Mercury	No	Jewett and Duffy 2007, AMAP 2011
	Selenium	Yes	DEC Fish Monitoring Program 2011

Species	Contaminant	Baseline Data (Y/N)	Reference
	POPs	Yes	Hanns 2006, Meuller and Matz 2000
	PAHs	Yes	Wetzel and Mercurio 2007
Marine mammals			
Beluga whale	Radionuclides	Yes	Cooper et al. 2000
	Cadmium	Yes	Dehn et al. 2006
	Arsenic	Yes	Dehn et al. 2006
	Copper	Yes	Dehn et al. 2006
	Lead	Yes	Dehn et al. 2006
	Mercury	Yes	Dehn et al. 2006, Woshner et al. 2001
	Selenium	Yes	Dehn et al. 2006
	POPs	Yes	O'Hara et al. 2004, Hoekstra et al. 2003
	PAHs	No	
Pacific walrus	Radionuclides	Yes	Hamilton et al. 2008
	Cadmium	Yes	Taylor et al. 1989, Lipscomb 1995
	Arsenic	Yes	Taylor et al. 1989
	Copper	No	
	Lead	Yes	Taylor et al. 1989
	Mercury	Yes	Taylor et al. 1989
	Selenium	Yes	Taylor et al. 1989
	POPs	Yes	Cooper et al. 2000, Taylor et al. 1989, Seagars and Garlich-Miller 2001
	PAHs	No	
Bearded seal	Radionuclides	Yes	Cooper et al. 2000, Hamilton et al. 2008
	Cadmium	Yes	Quakenbush et al. 2011, Dehn et al. 2005, Mackey et al. 1996
	Arsenic	Yes	Quakenbush et al. 2011
	Copper	Yes	Dehn et al. 2005
	Lead	Yes	Quakenbush et al. 2011
	Mercury	Yes	Quakenbush et al. 2011, Dehn et al. 2005
	Selenium	Yes	Dehn et al. 2005
	POPs	Yes	Quakenbush et al. 2011, Hoekstra et al. 2003, Krahn et al. 1997
	PAHs	No	
Ringed seal	Radionuclides	Yes	Cooper et al. 2000

Species	Contaminant	Baseline Data (Y/N)	Reference
	Cadmium	Yes	AMAP 2011, Dehn et al. 2005, Becker et al. 1995, Woshner et al. 2001
	Arsenic	Yes	Woshner et al. 2001
	Copper	Yes	Dehn et al. 2005, Woshner et al. 2001
	Lead	Yes	Woshner et al. 2001
	Mercury	Yes	Dehn et al. 2005, Woshner et al. 2001
	Selenium	Yes	Dehn et al. 2005, Woshner et al. 2001
	POPs	Yes	Kucklick et al. 2002, Krahn et al. 1997
	PAHs	No	
Spotted Seal	Radionuclides	Yes	Whoshner et al. 2001
	Cadmium	Yes	Moses et al. 2009, Dehn et al. 2005
	Arsenic	Yes	Moses et al. 2009
	Copper	Yes	Whoshner et al. 2001, Dehn et al. 2005, Moses et al. 2009
	Lead	Yes	Moses et al. 2009, Quakenbush et al. 2011
	Mercury	Yes	Moses et al. 2009, Dehn et al. 2005
	Selenium	Yes	Dehn et al. 2005
	POPs	Yes	Moses et al. 2009
	PAHs	No	
Polar Bear	Radionuclides	Yes	Cooper et al. 2000
	Cadmium	Yes	Evans 2004, Woshner et al. 2001, Kannan et al. 2007
	Arsenic	Yes	Woshner et al. 2001
	Copper	Yes	Evans 2004, Woshner et al. 2001, Kannan et al. 2007
	Lead	Yes	Evans 2004, Woshner et al. 2001, Kannan et al. 2007
	Mercury	Yes	Evans 2004, Woshner et al. 2001, Kannan et al. 2007
	Selenium	Yes	Evans 2004, Woshner et al. 2001
	POPs	Yes	Bentzen et al. 2008, Kucklick et al. 2002, Verreault et al. 2005
	PAHs	No	

10.4. Conclusion

Other potential contaminants of concern include phthalates, plutonium, polybrominated diphenyl ethers (PBDEs) and brominated compounds. In general, for species that have some baseline contaminants data, there are large spatial and temporal gaps. While studies show that many of these

contaminants are attributed to point sources (military activities, oil and gas industry, infrastructure, etc.), recent focus on long-range transport of contaminants to Arctic environments is a growing concern and should be studied to better understand sources of these contaminants. Most subsistence species covered for this review have at least some baseline contaminants data. However, we are not aware of any contaminants data related to greater-white fronted goose within the study area. In general, most species were lacking baseline data on PAHs. Baseline data for all these contaminants provides information on contaminant levels in these important subsistence species and may serve as a reference point for future changes. Although the focus of this MQ was on subsistence species and thus the potential impact on human health, the biological implications for the animals themselves is relatively unknown and should also be a point of further study.

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11. Air Quality

MQ AP 2	How are oil, gas, and mineral development on the North Slope impacting near- and far-field air quality, with particular emphasis on communities and “sensitive class 2” areas such as Arctic National Wildlife Refuge, Gates of the Arctic National Park, and Noatak National Preserve?
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The BLM modeled air quality for the 2012 Integrated Activity Plan/Environmental Impact Statement (IAP/EIS) for NPR-A based on meteorological data and emissions scenarios (BLM 2012). Input data was spatially limited and therefore the outputs had high uncertainty. However, the results indicated that oilfield development could fail to meet both Clean Air Act (CAA) ambient air standards and air quality related value standards in National Parks and National Wildlife Refuges hundreds of miles away. Further air quality modeling is needed to determine potential effects of increased oil and gas extraction on air quality in the North Slope study area and surrounding lands.

11.1. Methods

MQ AP 2 is a data gap and requires extensive modeling to be answered. **This section does not provide any further information directly related to MQ AP 2**, as it is beyond the scope of the REA. No spatial or mathematical modeling was conducted for this question nor is the question explored by literature review. At the request of BLM, the remainder of this section is a description of factors and processes affecting air quality in the North Slope study area.

A conceptual model of factors affecting air quality in the North Slope study area was developed. This conceptual model is explained by the brief, introductory literature review provided in the text below. A database of existing literature and publicly available datasets related to air quality and air quality modeling on the North Slope was provided to BLM to help land managers review available information, data, and tools for future modelling efforts aimed at exploring MQ AP 2.

11.1. Processes Affecting Air Quality on the North Slope

The conceptual model below (Figure E-28) is a general summary of processes affecting air quality in the North Slope study area. The model focuses on emissions sources, meteorological influences on transport and diffusion, chemical transformation of emissions, and contaminant fate.

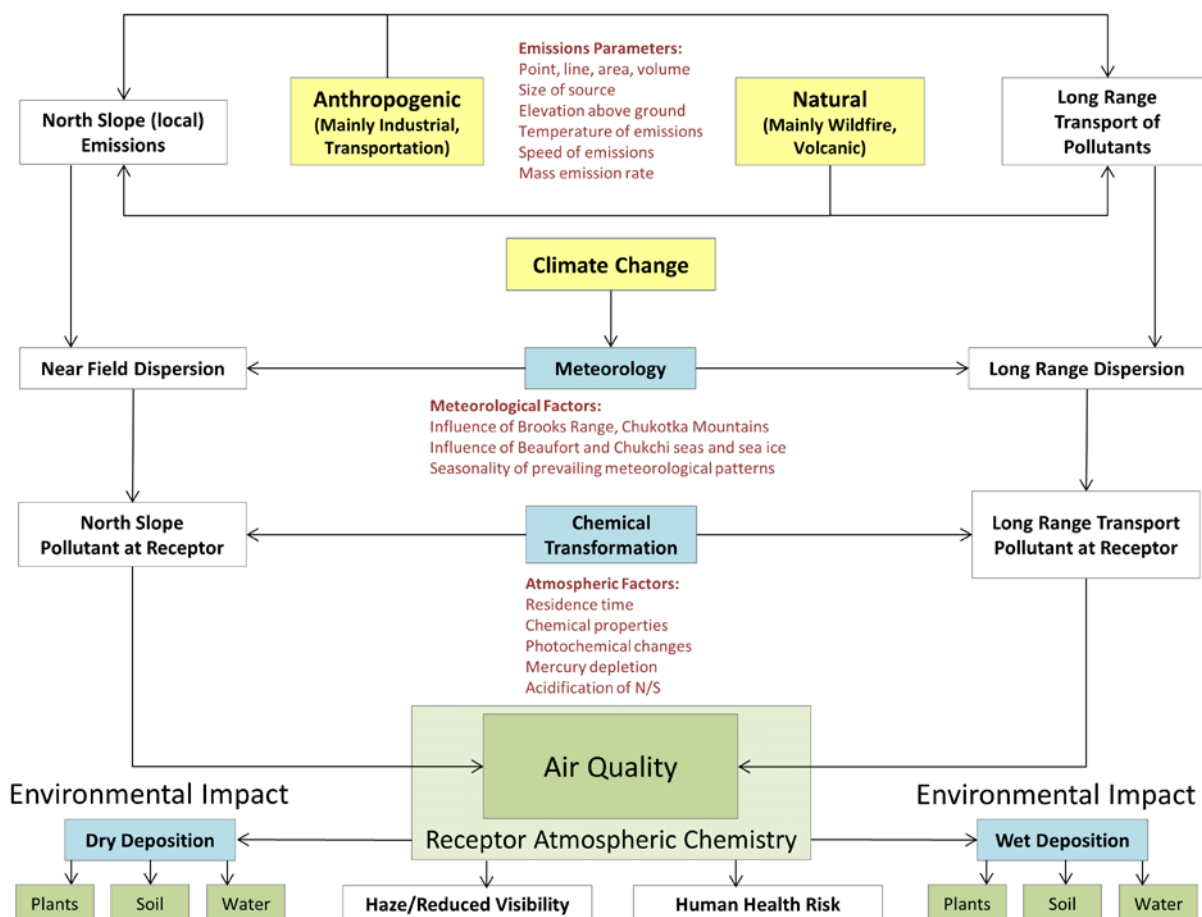


Figure E-28. Conceptual model for air quality in the North Slope study area.

Emissions Sources

Emission sources of airborne pollutants and contaminants are either anthropogenic in origin or natural in origin. Anthropogenic emissions are determined by economy, population sizes, technology, land use plans, and emissions reduction strategies. In the North Slope study area, industrial activities and transportation to these activities are the primary sources of emissions (Roe et al. 2007). Currently, the majority of industrial emissions sources are located in the Prudhoe Bay region. Additional industrial development is approved at the Greater Moose's Tooth Unit 1 of NPR-A. The medium- and high-development scenarios for landscape condition suggest that industrial activity, and therefore emissions, are likely to increase in the North Slope study area by 2040. Increase in industrial activity will likely be compounded by an associated increase in transportation. Additional, but less significant, emissions are generated by rural communities (Delaney and Dulla 2007).

Natural emissions depend on fuel loads and burn frequencies for wildfires or are stochastic for volcanic activity. Fires within and outside Alaska are significant sources of emissions in the North Slope study area (Larkin et al. 2012, Warneke et al. 2009). Fire frequency within the North Slope study area has historically been low and is projected to remain low in the near-term and long-term futures (see Section

C. Abiotic Change Agents); however, fire frequency elsewhere in Alaska is expected to increase in the next 50 years (Fresco et al. 2014). Smoke from wildfires originating in the contiguous U.S. and Canada can be transported to the North Slope study area given proper atmospheric conditions (Figure E-29). Future increases in fire frequency in Alaska south of the Brooks Range, Canada, and the contiguous U.S. will reduce air quality in the North Slope study area. Biotic emissions of Environmental Protection Agency (EPA) criteria pollutants have also been documented in the Arctic (e.g. Sharma et al. 2012).

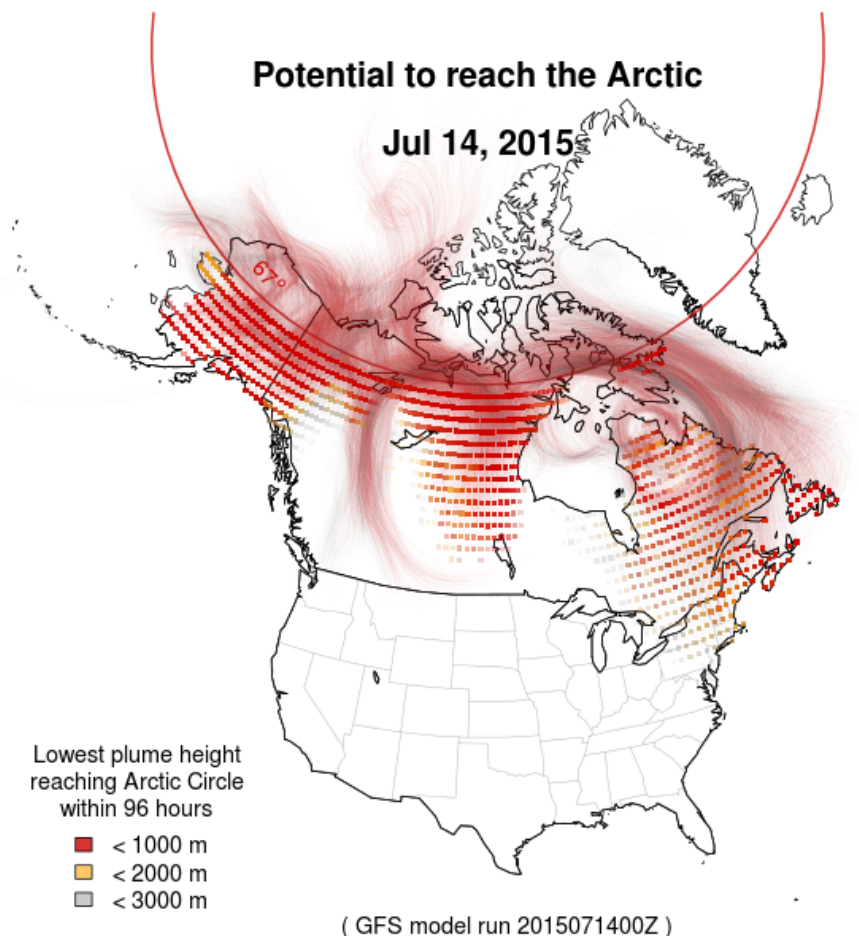


Figure E-29. Daily Arctic transport forecast showing potential for atmospheric transportation of smoke from wildfires to the Arctic (available from <http://www.airfire.org/>).

Particulate material, usually in the form of dust from roads, also affects air quality in the North Slope study area. The prevalence of dirt roads and ATVs in communities contributes to increased airborne dust locally (ADEC 2011). Traffic along the dirt portions of the Dalton Highway increases airborne dust along the highway corridor (see Section G. Terrestrial Coarse-Filter Conservation Elements for discussion of impacts on vegetation).

Both anthropogenic and natural emissions are treated by dispersion models as point, line, area, or volume sources. The source geometry is an important modeling consideration, as well as source

strength (emission rate), release height, and exit temperature and velocity (influence buoyancy). The temporal pattern of emission is another important factor considered by dispersion models.

Meteorology

The mechanics of dispersion of near-field emissions and long-range emissions that reach the study area are determined by the prevailing meteorological patterns of the region. The North Slope study area includes both the polar maritime climate subtype along the coast, which is strongly influenced by the Beaufort and Chukchi seas, and the continental maritime subtype in and towards the Brooks Range, which is strongly influenced by the large land mass of North America (Wilcox and Velkamp 2007).

In winter, prevailing winds blow onshore from the ocean. Temperatures are cold, and storms and temperature inversions are common. In summer months, the Brooks Range and Chukotka Mountains generate seaward winds. While the coastal plain is largely flat, meteorological patterns within the Brooks Range are substantially altered by the extreme topographic texture. Even within individual ecoregions, meteorological patterns vary. For example, the Brooks Range exerts a stronger influence over the nearshore weather of the northeastern Beaufort Coastal Plain than that of the northwestern Beaufort Coastal Plain because of its greater proximity on the eastern side. Onshore winds become more dominant to the west and north (Wilcox and Velkamp 2007).

During the ice-free season for the Beaufort and Chukchi seas, pollutants can concentrate at ground level from the process of coastal fumigation. The coastal thermal internal boundary layer forms during daylight hours because of the temperature difference between the water and land. Offshore pollutants in a stable air layer are transported onshore and encounter the coastal thermal internal boundary layer, which forces the pollutants to mix downwards to ground level. As a result, the surface concentrations of pollutants increase (Luhar 2002). From November to early June, the Beaufort and Chukchi seas freeze over (MACTEC 2011). The coastal fumigation process does not occur in winter while the seas are frozen; thus if the duration of the sea ice decreases (see Section C. Abiotic Change Agents) in the future then the length of time during which coastal fumigation can occur would be expected to increase.

Long-range transport potential to the North Slope is influenced by the release height of the emissions and the timing of emissions in relation to meteorological interactions at circumpolar or trans/intercontinental scales (Larkin et al. 2012). For example, wildfires in Central Asia have been documented to have air quality impacts on the Arctic in Alaska (Warneke et al. 2009). Air quality in the North Slope study area is therefore significantly influenced by emissions outside the region.

Chemical Transformation

The chemicals released at emissions sources are often volatile and react with other chemicals while in residence in the atmosphere. Gaseous forms of mercury (Hg), when transported to the Arctic, are photochemically oxidized into a form that precipitates and accumulates in the snowpack. This results in a flush of mercury when the snow melts in spring and early summer (Lindberg et al. 2002). Nitrates and sulfates are also commonly transformed while in the atmosphere. Sulfuric oxides (SO_x) eventually

convert to sulfuric acid via oxidation pathways. Nitric oxides participate in ozone formation through photochemical reactions with reactive volatile organic compounds.

Impacts

Impairment of air quality lowers visibility distance and can cause, or aggravate, adverse human health conditions. Increased oil and gas extraction activity is likely to cause episodic events of decreased air quality near oil field facilities. This may cause a subsequent decrease in air quality affecting people (e.g. at subsistence camps). A reduction in air quality in the North Slope study area could have health consequences such as a resulting increase in rates of pulmonary disease. Inupiat populations have high baseline rates of pulmonary disease (Wernham 2007), making them especially sensitive.

11.2. Limitations

Air quality monitoring data within the North Slope study area are sparse due to the high cost and difficult logistics of monitoring air quality in Arctic Alaska. A BLM-maintained air quality monitoring station was installed at Inigok in 2014 and will be the first permanent, public air quality monitoring station in the study area. Other air quality monitoring in the study area has been conducted by private industries associated with oil and gas extraction, e.g., Nuiqsut monitoring site (maintained by ConocoPhillips). Public air quality monitoring data useful for the North Slope study area currently exist only for Bettles (originally located at Ambler) just south of the study area boundary. The general lack of monitoring hinders accurate air quality modeling in the region. Additional monitoring sites, especially arranged along terrain gradients such as elevational transects, would be beneficial to a better understanding of air quality issues in the study area.

Existing meteorological data are also sparse within the North Slope study area. There is only one upper air meteorological station within the study area, at Point Barrow. Upper air stations provide the vertical profiles necessary to prepare surface meteorological data for input to air quality models. Surface meteorological stations are also limited and often do not contain full data for all years of operation. The Bureau of Ocean Energy Management (BOEM) has developed a modeled meteorological dataset, the Beaufort and Chukchi Sea Mesoscale Meteorological dataset, to serve as a meteorological input to some of the dispersion models. However, the accuracy of this modeled dataset is limited by the paucity of observational data. Additional upper air and surface meteorological stations, especially in the northern Brooks Range and eastern half of the study area, are necessary for more complete spatial coverage of meteorological conditions across the study area.

Existing air dispersion models vary in their purpose, scale, resolution, inputs, computing requirements, and cost. Not all existing meteorological and emissions datasets include the necessary parameters required for input to various existing models.

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