North Slope Rapid Ecoregional Assessment

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Edited by E.J. Trammell, M.L. Carlson, N. Fresco, T. Gotthardt, M.L. McTeague, and D. Vadapalli.

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Denver, Colorado 80225

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.

Prepared by:

Alaska Natural Heritage Program
University of Alaska Anchorage
3211 Providence Dr.
Anchorage, Alaska 99508

Institute of Social and Economic Research
University of Alaska Anchorage
3211 Providence Dr.
Anchorage, Alaska 99508

Scenarios Network for Alaska Planning
University of Alaska Fairbanks
3352 College Road
Fairbanks, Alaska 99709

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Assessment Management Team and Technical Team Contributors:

BLM

Arctic Field Office
Stacey Fritz
Cindy Hamfler
Lon Kelly (Retired)
Richard Kemnitz
Stacie McIntosh*
Debbie Nigro
Matt Whitman
Dave Yokel

Alaska State Office
Cory Black
Eric Geisler
Alan Peck
Matt Varner

Fairbanks District
Steve Hartmann (Retired)

National Operations Center
Matt Bobo
Vanessa Stepanek
Megan Walz
David Wood

Oregon
Stewart Allen

Fish and Wildlife Service

Arctic NWR
Dave Payer

Arctic LCC
Phillip Martin

USGS

Alaska Science Center
Courtney Amundson
Tony Degange (retired)

Climate Science Center
Jeremy Littell

NPS

Central Alaska Network Inventory & Monitoring Program
Robert Winfree

State of Alaska

Fish and Game
Steve Machida
Sue Rodman

Department of Commerce, Community, and Economic Development
Sally Cox
Melissa Taylor

Department of Natural Resources
Melissa Head
Chris Milles

North Star Borough

Wildlife Department
Brian Person
Qaiyaan Harcharek

North Slope Science Initiative

Jess Grunblatt
Denny Lassuy
John Payne

United States Arctic Research Commission

Cheryl Rosa

Michigan Tech

Liza Jenkins

University of Alaska Fairbanks

Chris Arp
Donie Bret-Harte

* Assessment Management Team Chair

NOS REA Team Members:

BLM

Alaska State Office
Scott Guyer

Anchorage Field Office
Aliza Segal

National Operations Center
David Wood

MJ King and Associates

Margaret King

University of Alaska
University of Alaska Anchorage

Alaska Natural Heritage Program
Megumi Aisu
Keith Boggs
Tina Boucher
Matthew Carlson
Lindsey Flagstad
Justin Fulkerson
Marcus Geist
Tracey Gotthardt*
Brian Heitz
Leah Kenney
Priscilla Lema
Monica McTeague
Dustin Merrigan
Timm Nawrocki
Jesika Reimer
Rebecca Shaftel
Jamie Trammell

Institute of Social and Economic Research
Vitor deCarli
Rosyland Fraizer
Lauren Fritz
Caitlin Kennedy
Stephanie Martin
Sohrab Pathan
Diwakar Vadapalli

University of Alaska Fairbanks

Scenarios Network for Alaska and Arctic Planning
Angelica Floyd
Nancy Fresco
Michael Lindgren
Lena Krutikov
Tom Kurkowski

Geophysical Institute Permafrost Lab
Sergey Marchenko

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* Principal Investigator

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

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

Monica L. McTeague, E. Jamie Trammell, Tracey Gotthardt, Matthew L. Carlson, Justin R. Fulkerson, Timm Nawrocki

Alaska Natural Heritage Program, University of Alaska Anchorage, 3211 Providence Dr., Anchorage, Alaska 99508

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.

Contents

Tables

Figures

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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)
Climate
precipitation
temperature
thaw date
freeze date
climate envelopes
Fire
return interval
vegetation response
Permafrost
mean annual ground temperature
active layer thickness
Invasive Species
Anthropogenic Uses
subsistence
natural resource extraction
transportation and communication infrastructure
recreation
energy development

Conservation Elements (CEs)	
Coarse-Filter CEs	**Fine-Filter CEs**
Terrestrial Coarse-Filter	**Terrestrial Fine-Filter**
coastal plain moist tundra	Nearctic brown lemming
coastal plain wetland	Arctic fox
sand sheet wetland	caribou
sand sheet moist tundra	Lapland longspur
foothills tussock tundra	willow ptarmigan
alpine dwarf shrub	greater white-fronted goose
tidal marsh	raptor concentration areas
marine beach, barrier islands, and spits	**Aquatic Fine-Filter**
Aquatic Coarse-Filter	broad whitefish
deep connected lakes	Dolly Varden
shallow connected lakes	Arctic grayling
large streams	burbot
small streams	chum salmon

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	*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?*
AB-2	*How will permafrost change spatially and temporally over the next two decades?*
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?*
TC-5	*How is climate change affecting the timing of snow melt and snow onset, spring breakup and green-up, and growing season length?*
Anthropogenic Factors (Section E)	
AP-1	*What physical and perceptual limitations to access to subsistence resources by local residents are caused by oil/gas activities?*
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 ANWR, Gates, Noatak?*
AT-1	*What parameters can help measure impacts from anthropogenic activities independently of natural cycles and vice versa?*
AT-2	*What potential impacts will oil/gas exploration and development have on CE habitat?*
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?*
AF-2	*What are the measurable and perceived impacts of development on subsistence harvest of fish?*
TF-3	*What are the measurable and perceived impacts of development on subsistence harvest of caribou?*
Aquatic Coarse Filter CEs (Section I)	
AC-1	*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?*
Aquatic Fine Filter CEs (Section J)	
AF-1	*What are baseline characteristics and trends in fish habitat (lakes and streams), fish distribution, and fish movements?*
AC-2	*How does oil and gas infrastructure (e.g., roads, pads, pipeline), both permanent and temporary, affect fish habitat, fish distribution, and fish movements?*

Terrestrial Coarse-Filter CEs (Section G)	
TC-1	*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.)*
TC-2	*What are the changes in habitat and vegetation related to changing permafrost conditions, and what will these changes mean to wildlife and habitats?*
TC-4	*What are the expected changes to habitat as a result of coastal erosion and coastal salinization?*
Terrestrial Fine-Filter CEs (Section H)	
TF-1	*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?*
TF-2	*What are caribou preferences for vegetation communities? Where do these vegetation communities exist?*
TF-4	*What are caribou seasonal distribution and movement patterns and how are they related to season and weather?*

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

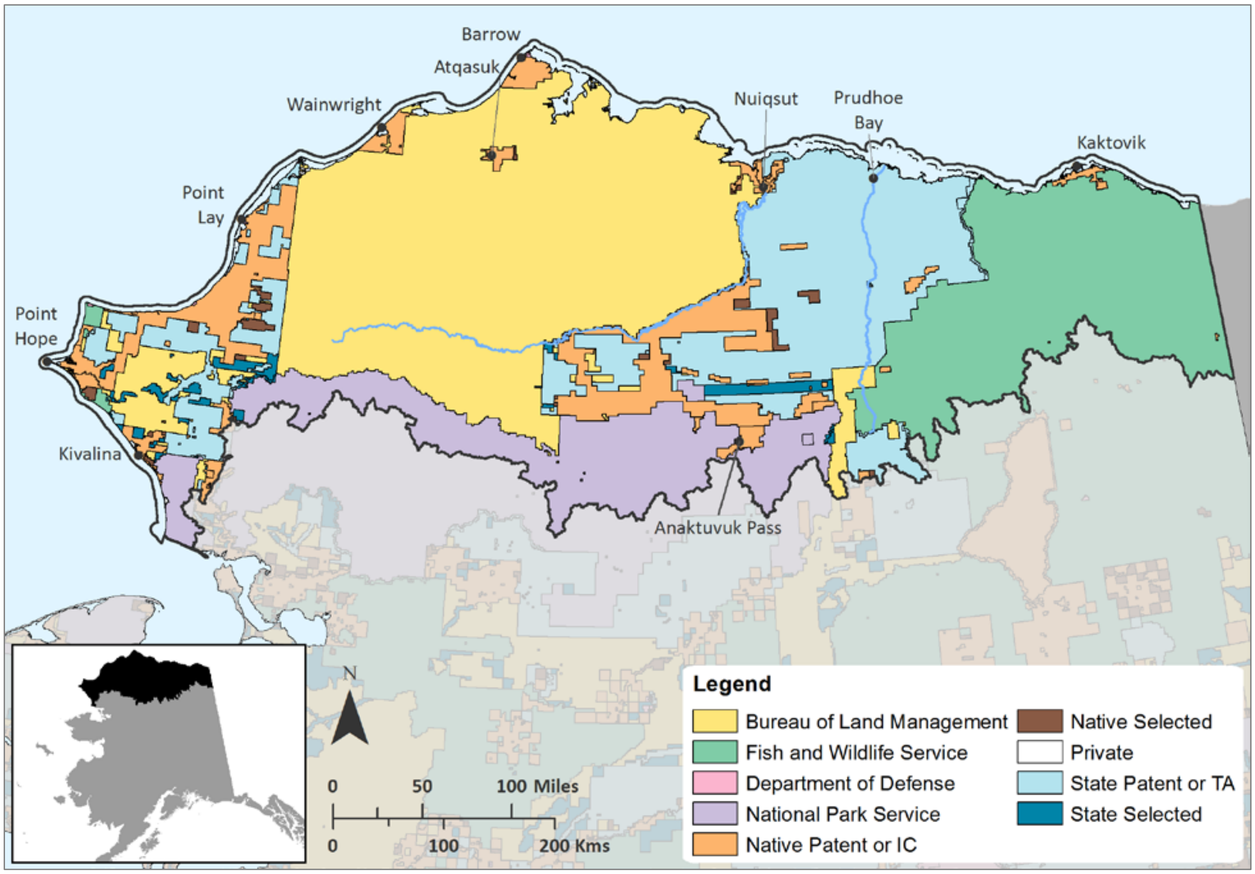

Figure B-1. Land management status in the North Slope study area in 2014.

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 (km^2)	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, Omerrnik 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.

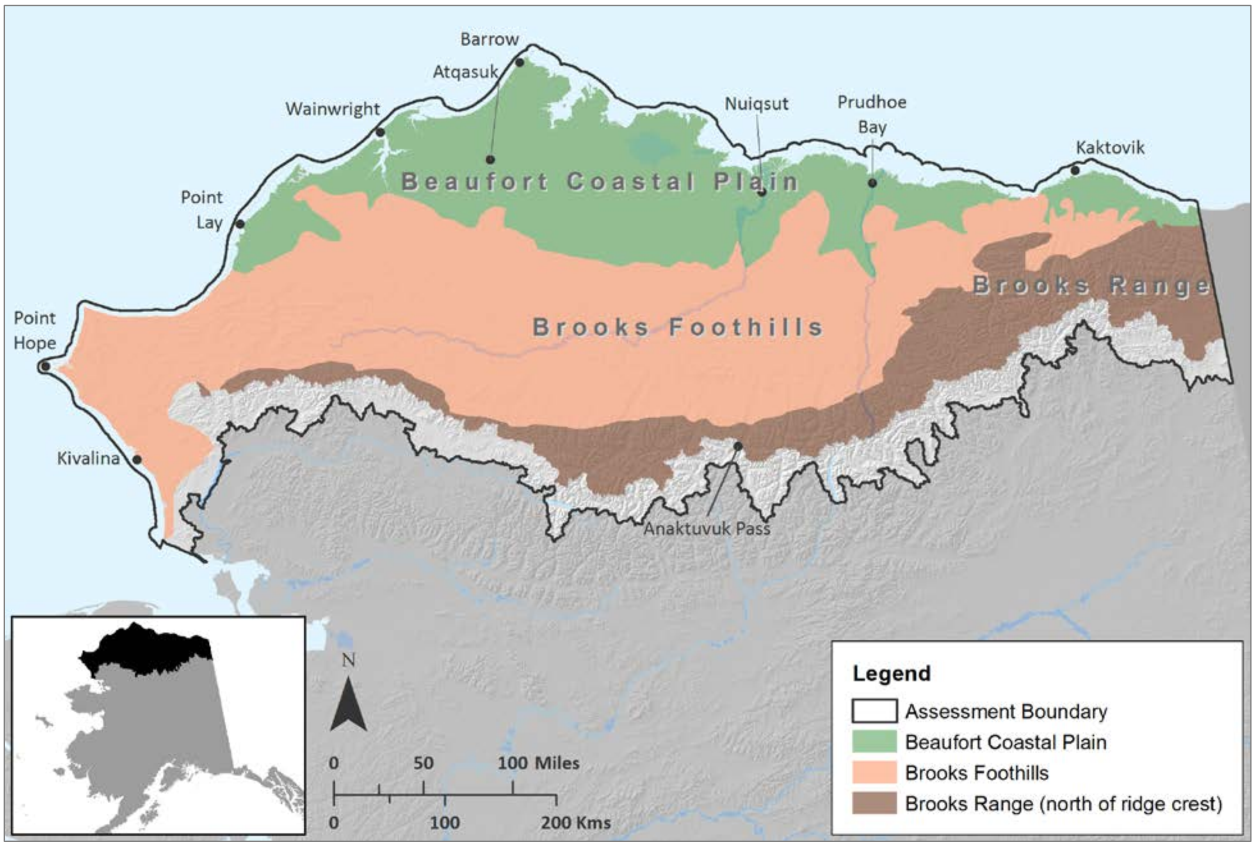

Figure B-2. Ecoregions included in the North Slope study area.

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, Atqasuk, 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.

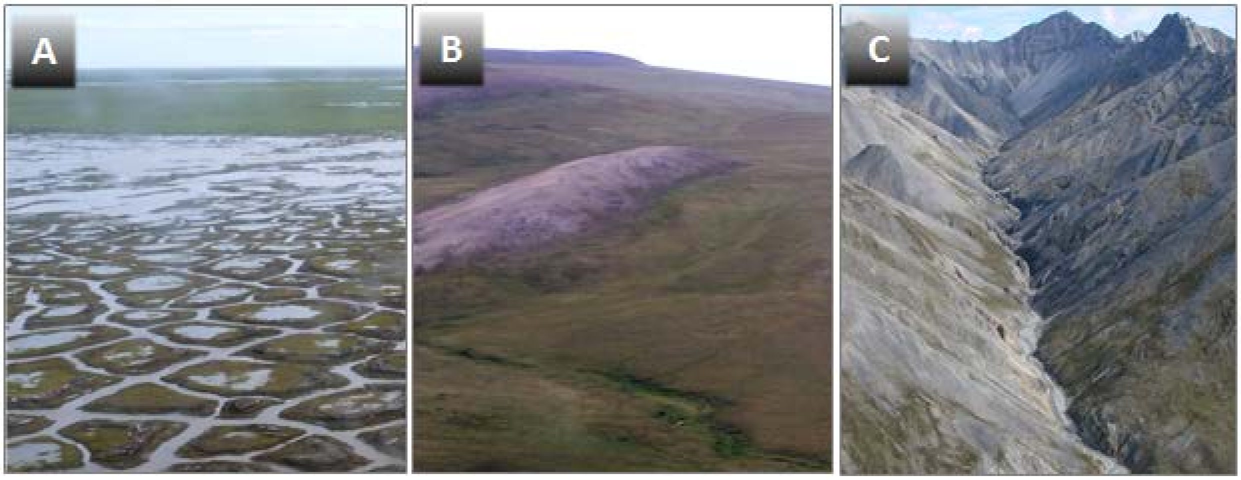

Figure B-3. Ecoregions included in the North Slope study area: Beaufort Coastal Plain (A), Brooks Foothills (B), and Brooks Range (C).

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 5^{th} 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 5^{th} 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.

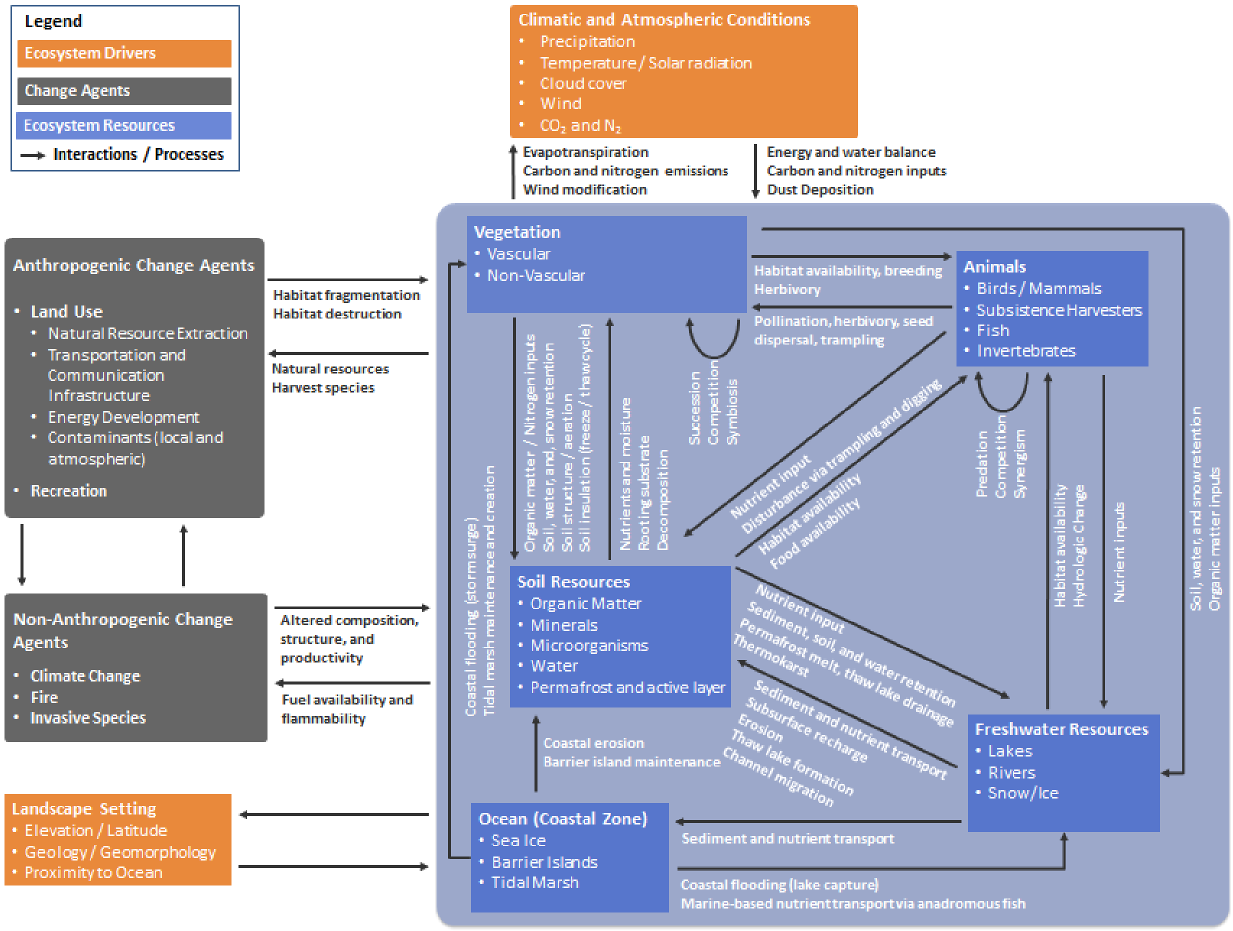

Figure B-4. Ecoregional Conceptual Model for the North Slope study area.

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.

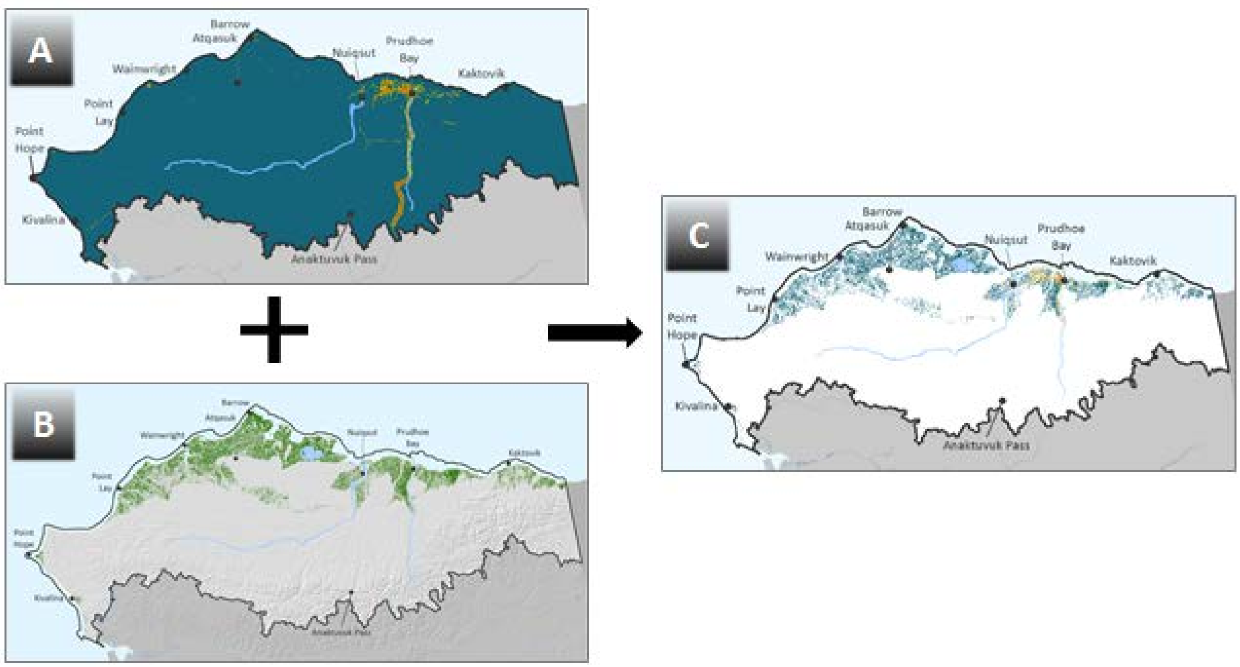

Figure B-5. Example process of assessing status of a Conservation Element (CE). Landscape condition (A) is extracted to the distribution of a CE (B) to generate the CE status (C). Warmer colors in the CE status represent areas of lower expected ecological condition.

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

Nancy Fresco[1], Angelica Floyd[1], Michael Lindgren[1], Alec Bennett[1], Lena Krutikov[1], and Sergey Marchenko[2]

[1]Scenarios Network for Alaska Planning, University of Alaska Fairbanks, 3352 College Road, Fairbanks, Alaska 99709

[2]Geophysical Institute, University of Alaska Fairbanks, 903 Koyukuk Drive, Fairbanks, Alaska 99775

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.

Contents

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Tables

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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
Atqasuk*	-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 at 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 (Fussel 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.

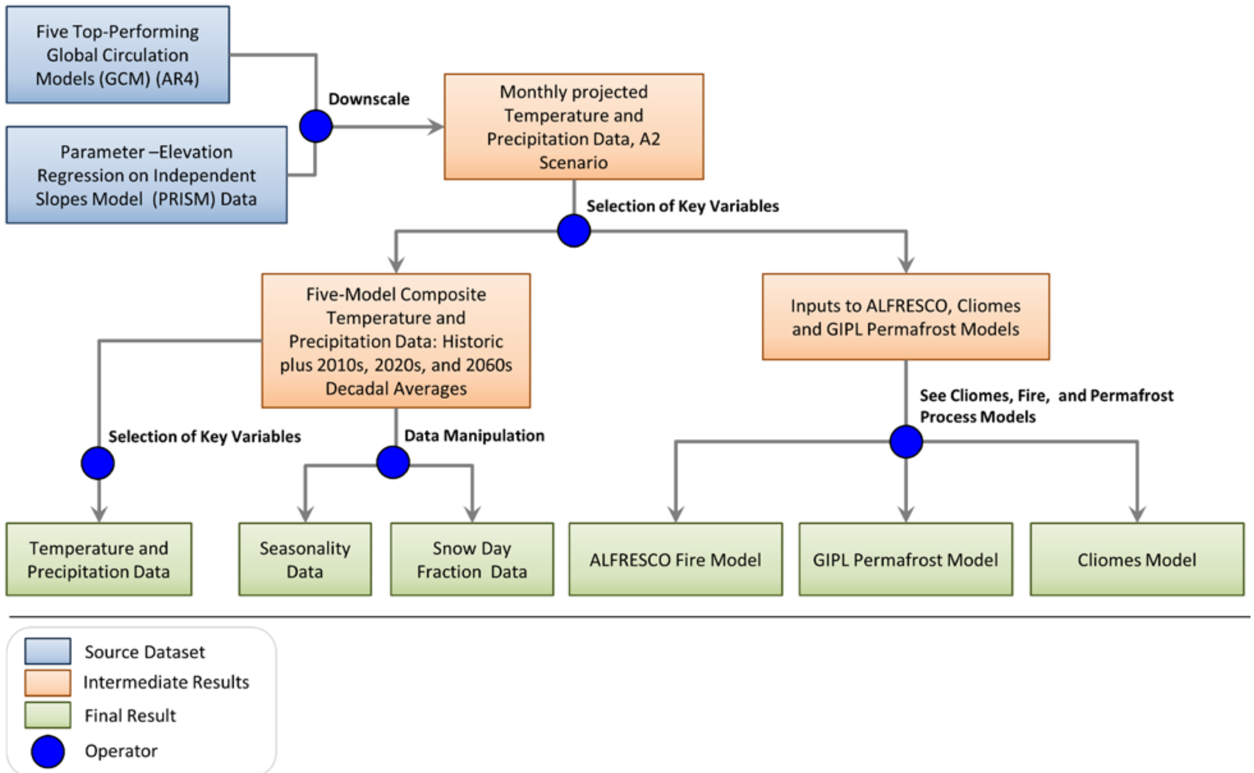

Figure C-1. Process model of downscaled climate products.

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.

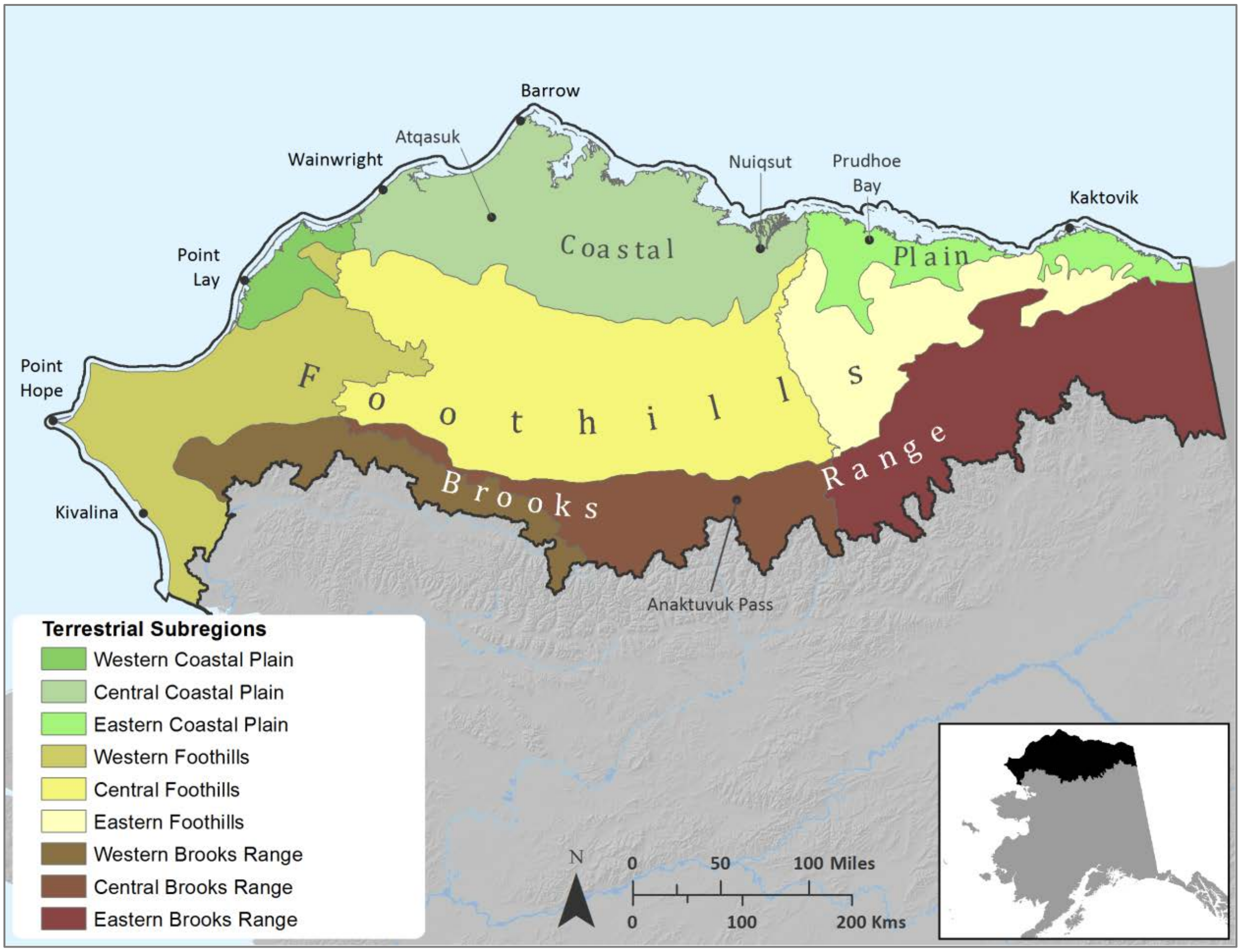

Figure C-2. Terrestrial sub-regions defined for the North Slope study area.

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

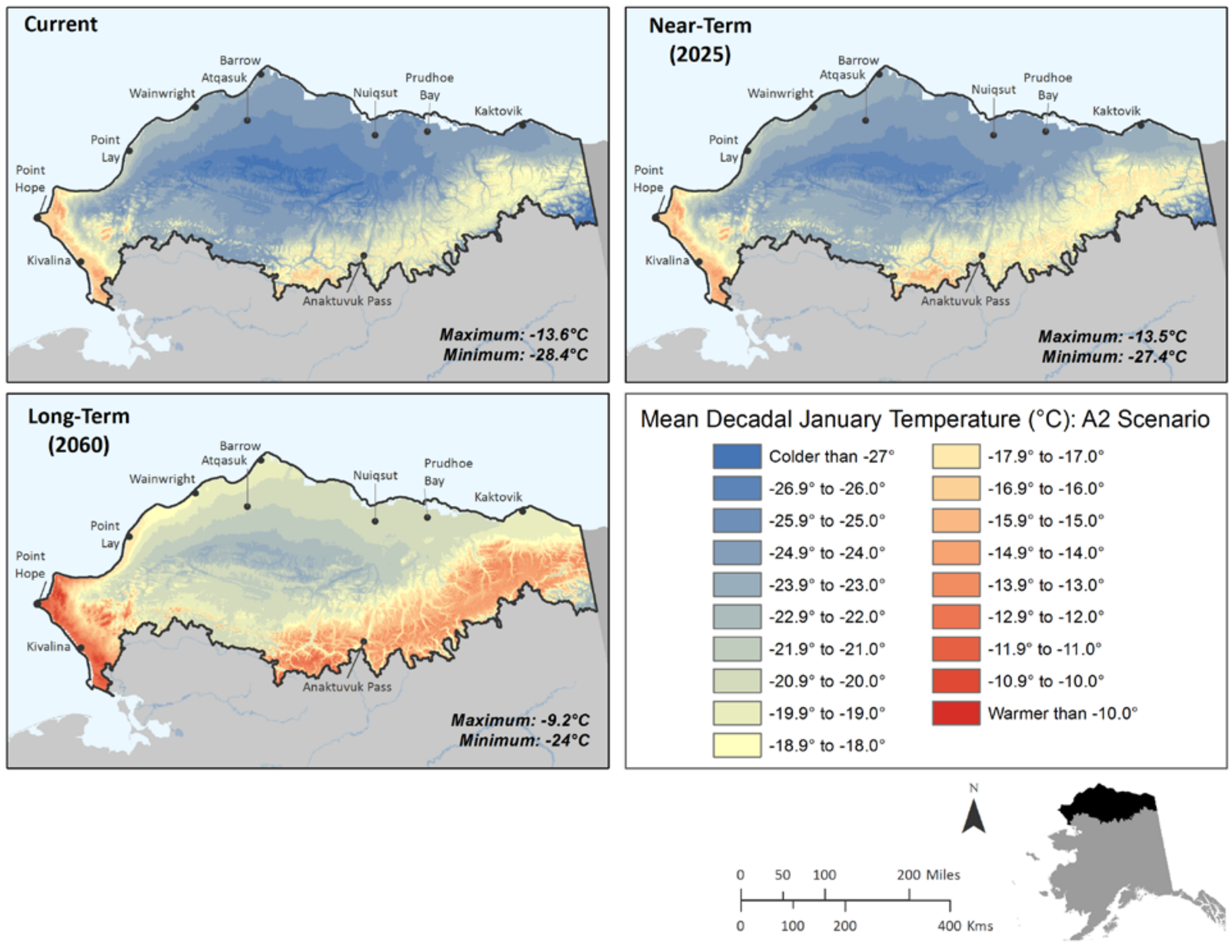

Figure C-3. Projected mean January temperatures.

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

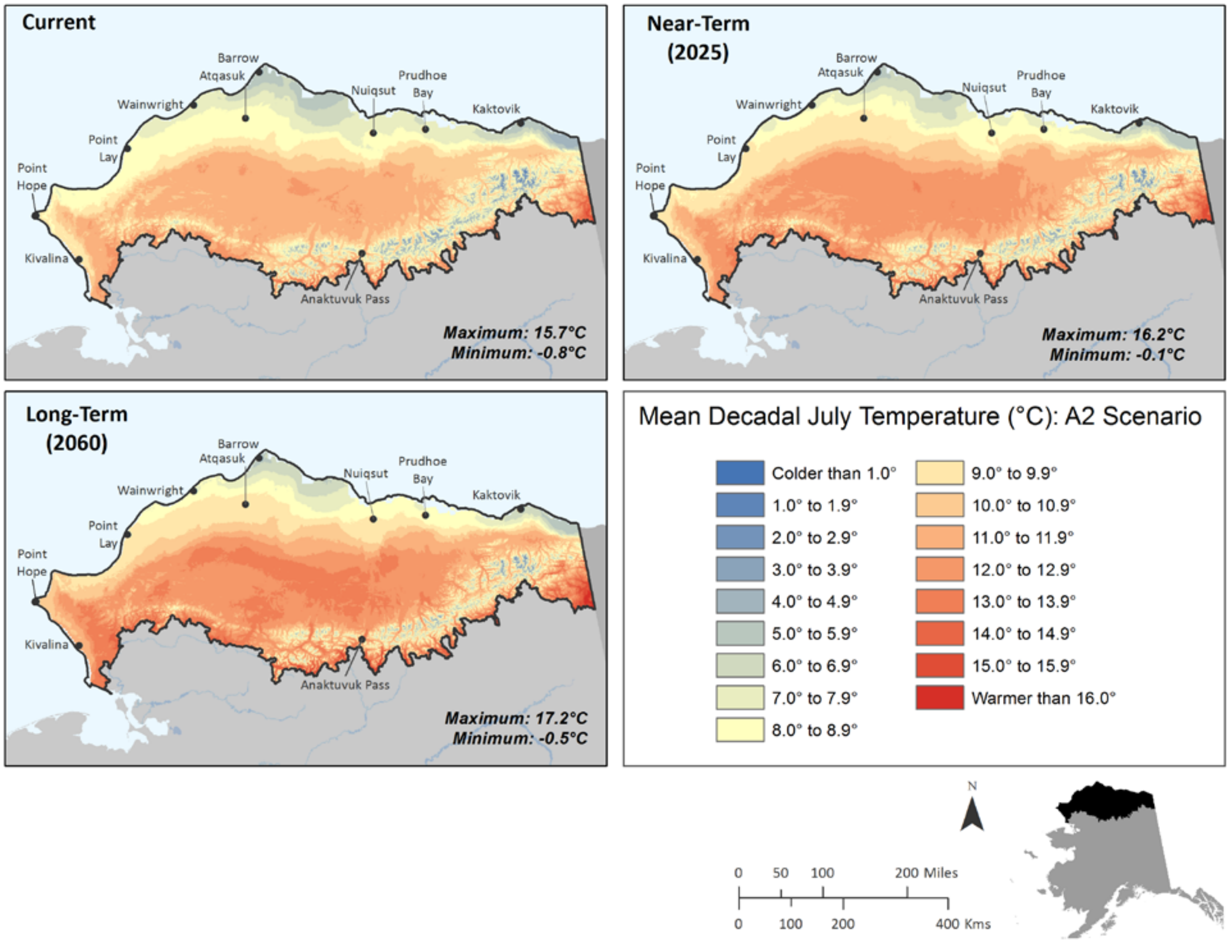

Figure C-4. Temperature projections for July (A2 Scenario).

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.

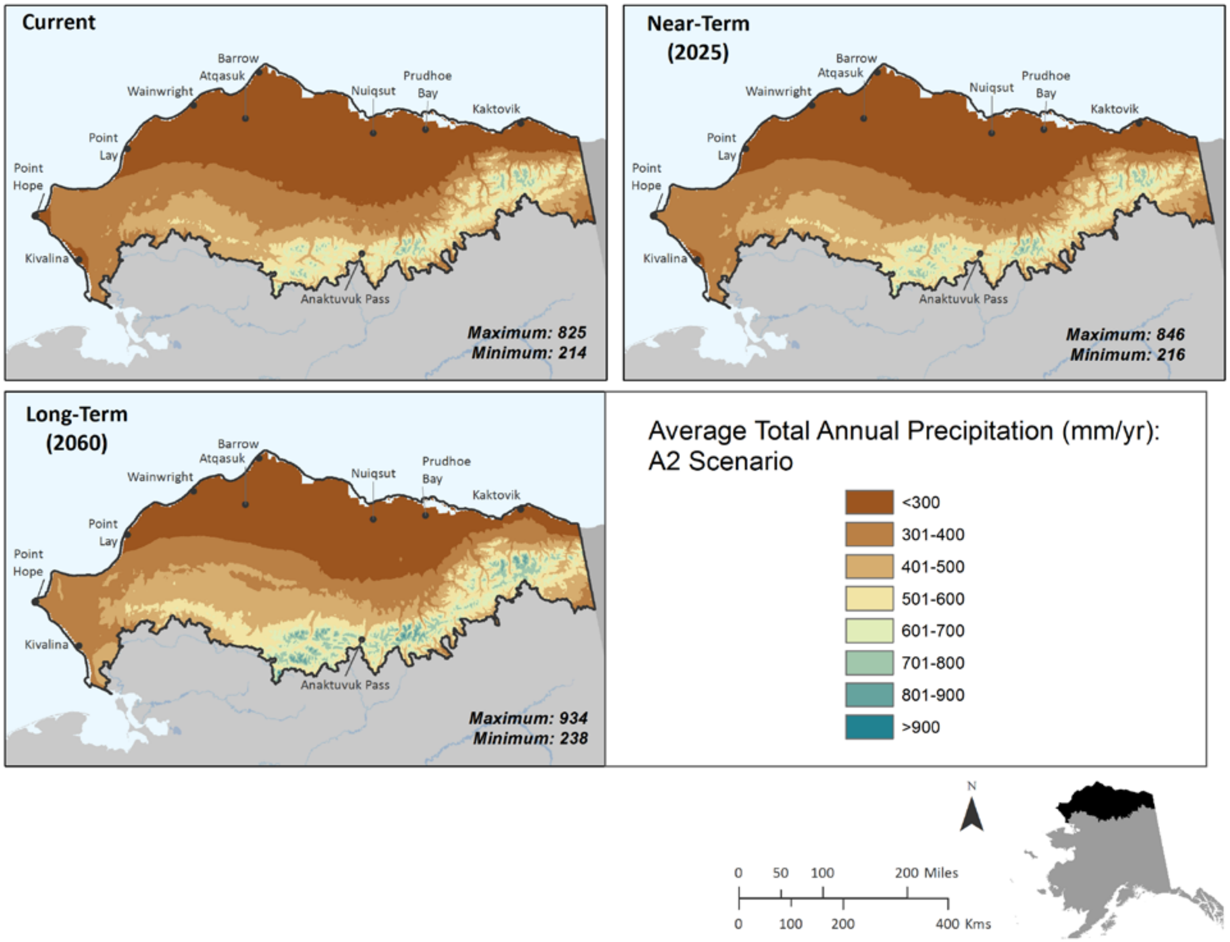

Figure C-5. Projected annual precipitation (mm, rainwater equivalent).

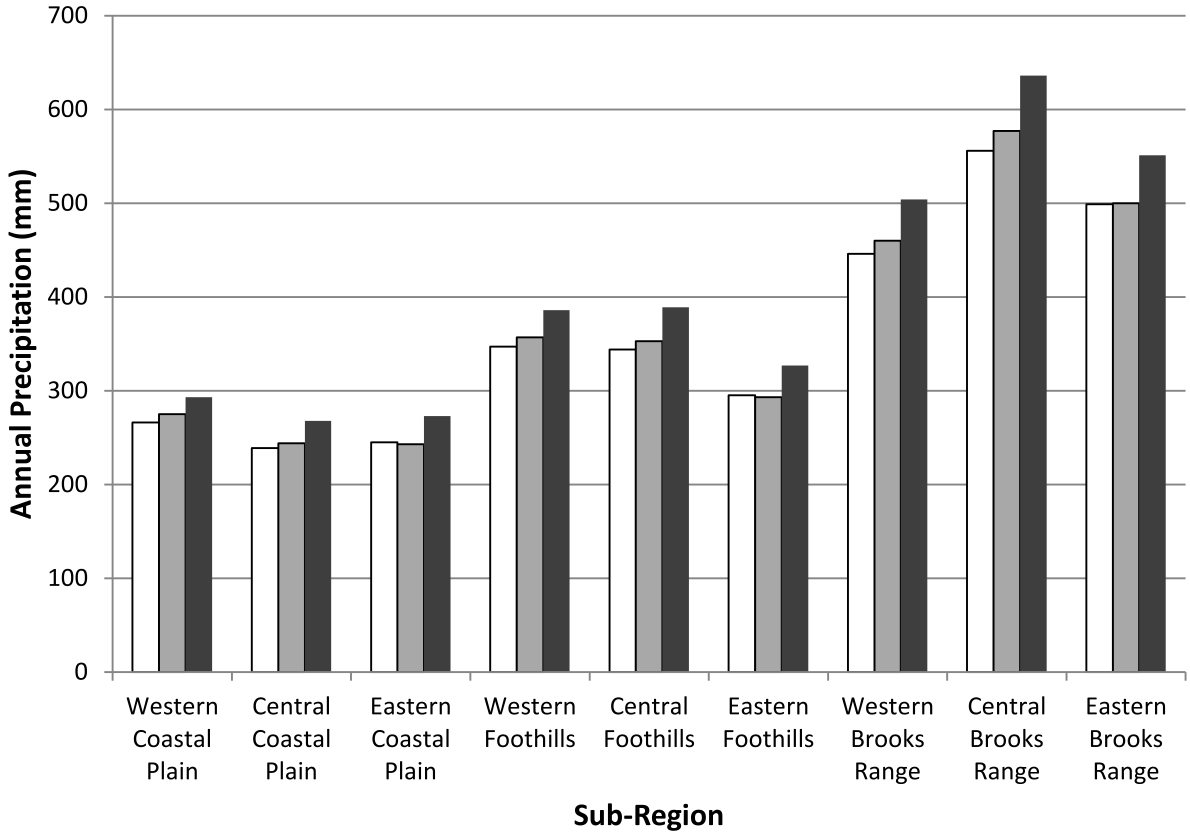

Figure C-6. Annual precipitation projections by terrestrial sub-regions (mm, rainwater equivalent). Current (white), near-term (light gray), and long-term (dark gray) time steps are shown.

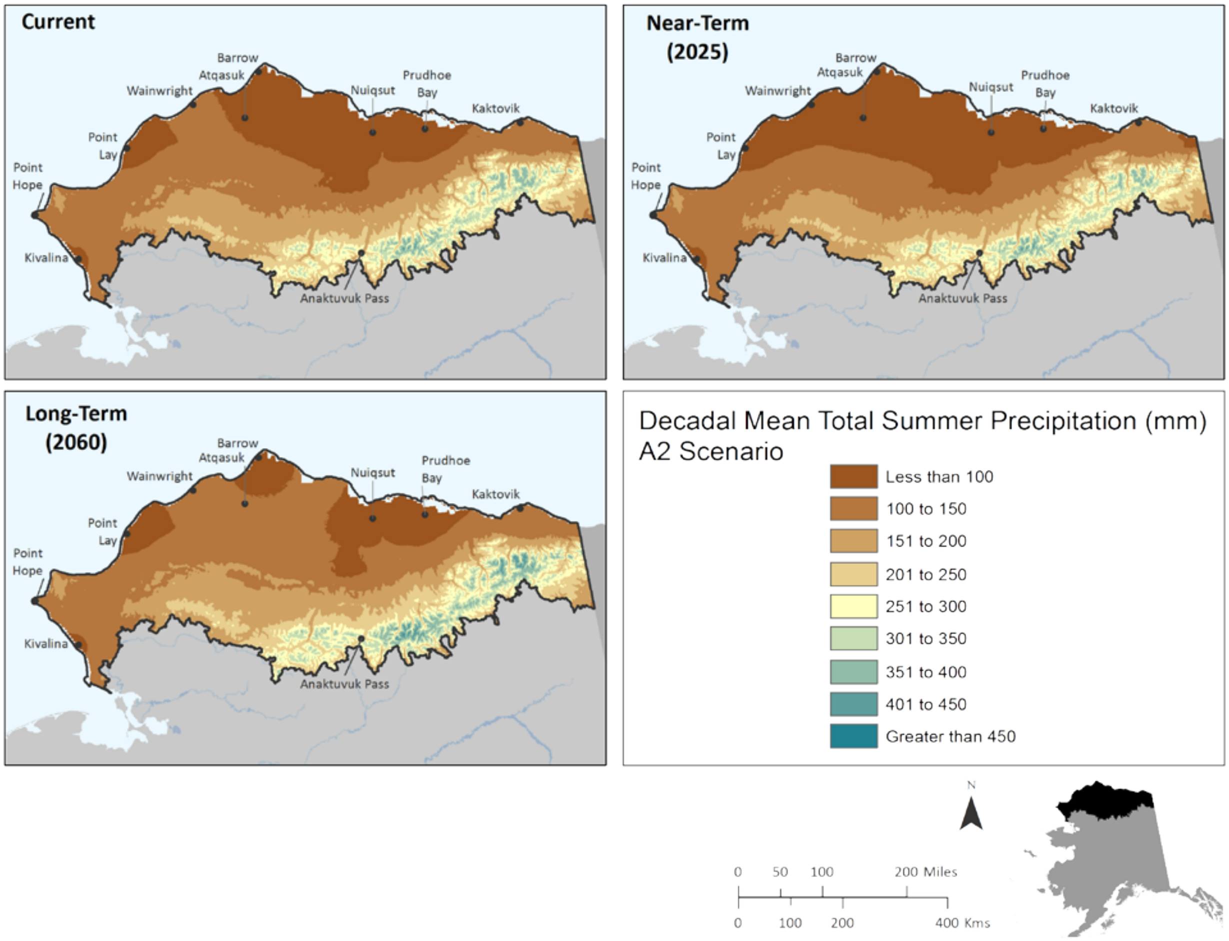

Figure C-7. Summer precipitation projections (mm, rainwater equivalent).

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.

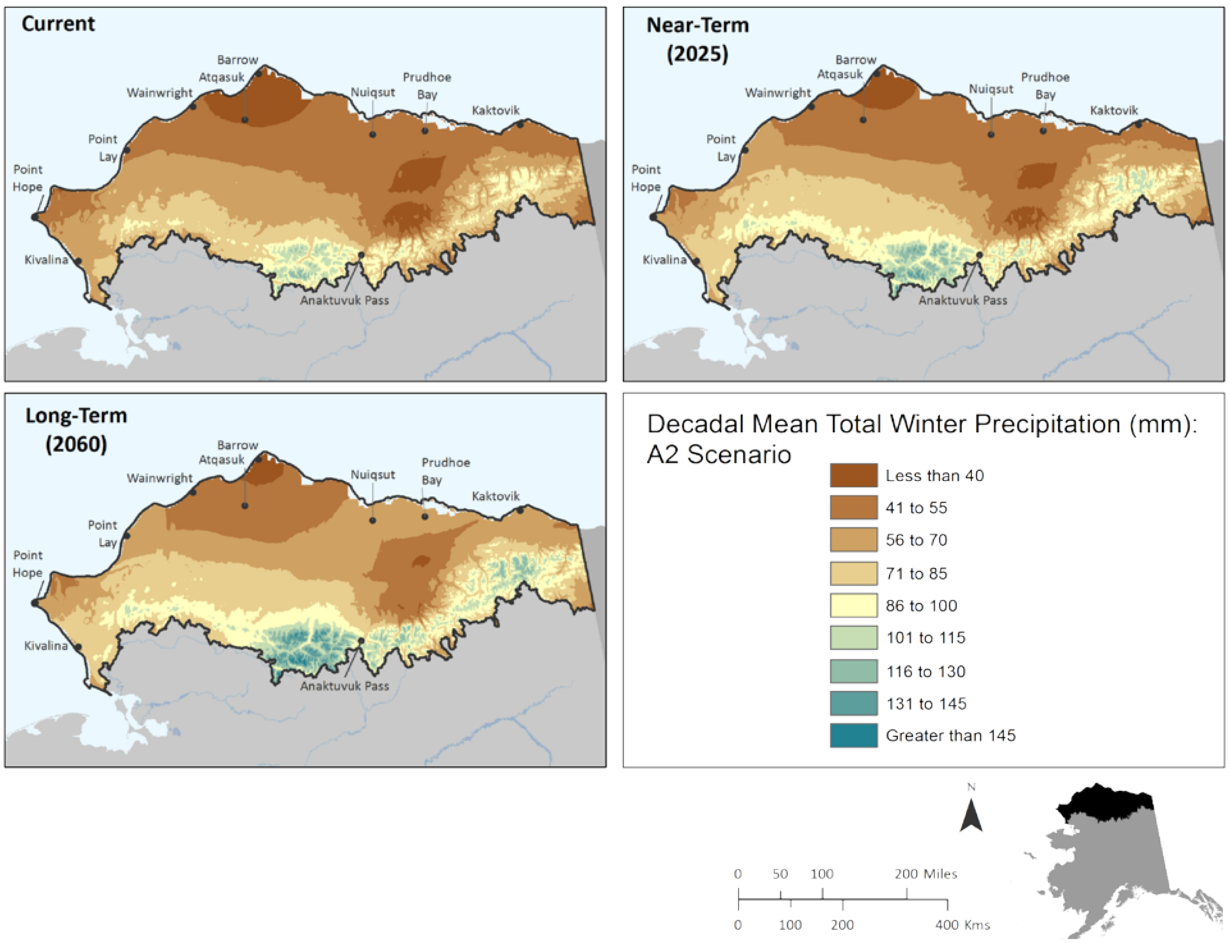

Figure C-8. Winter precipitation projections (mm, rainwater equivalent).

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.

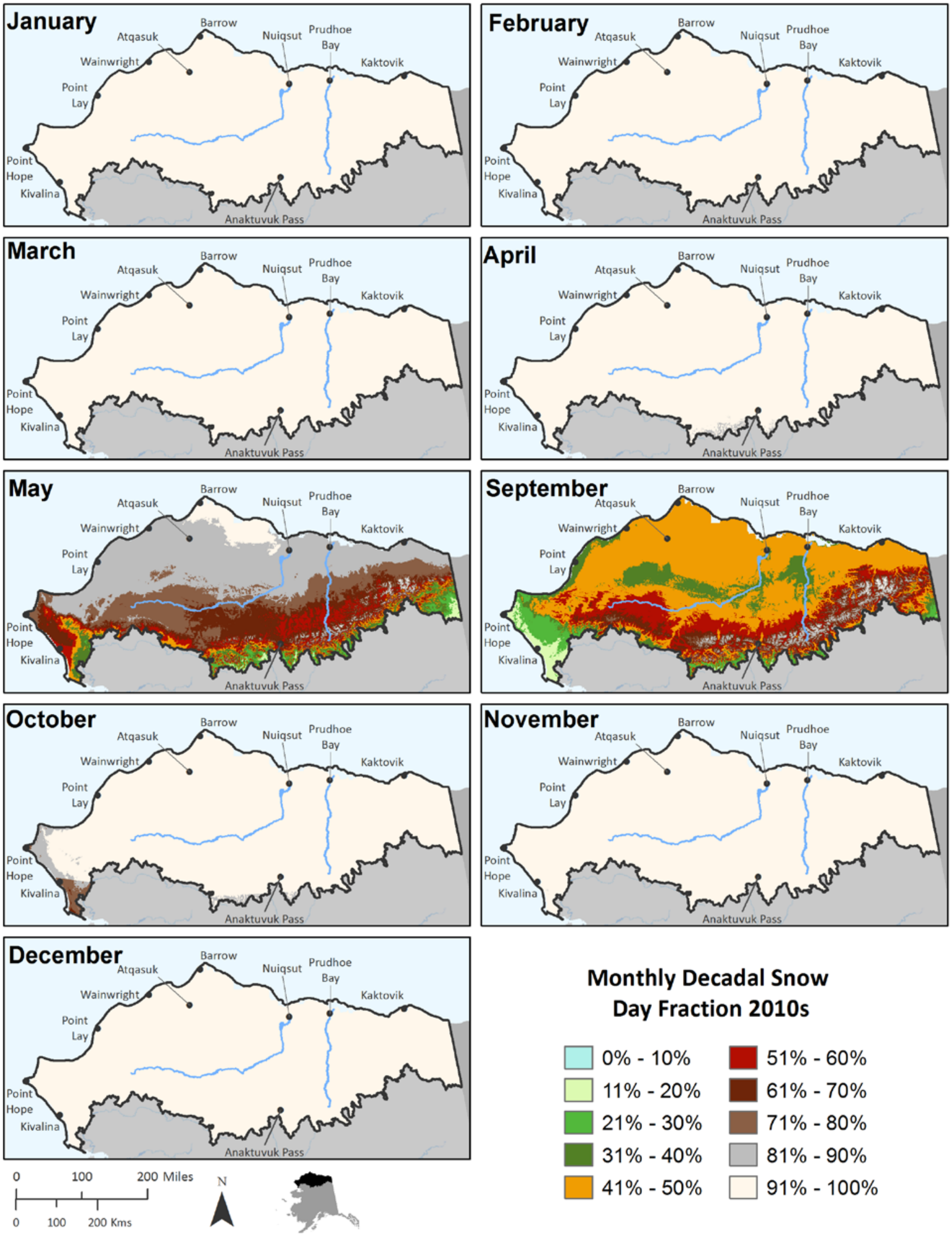

Figure C-9. Projected monthly snow-day fraction for winter and shoulder-seasons in the current decade.

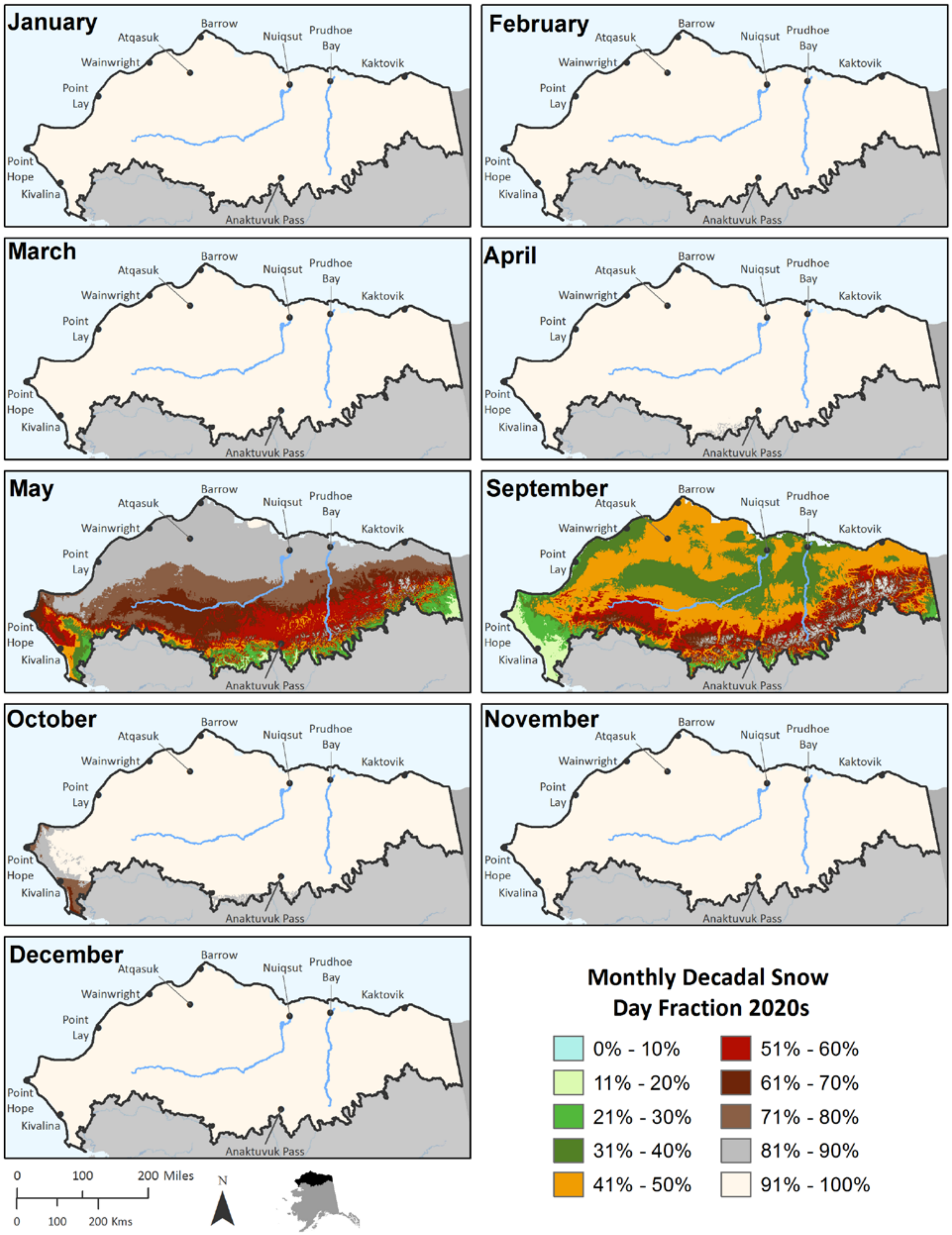

Figure C-10. Near-term projected monthly snow-day fraction winter and shoulder-seasons.

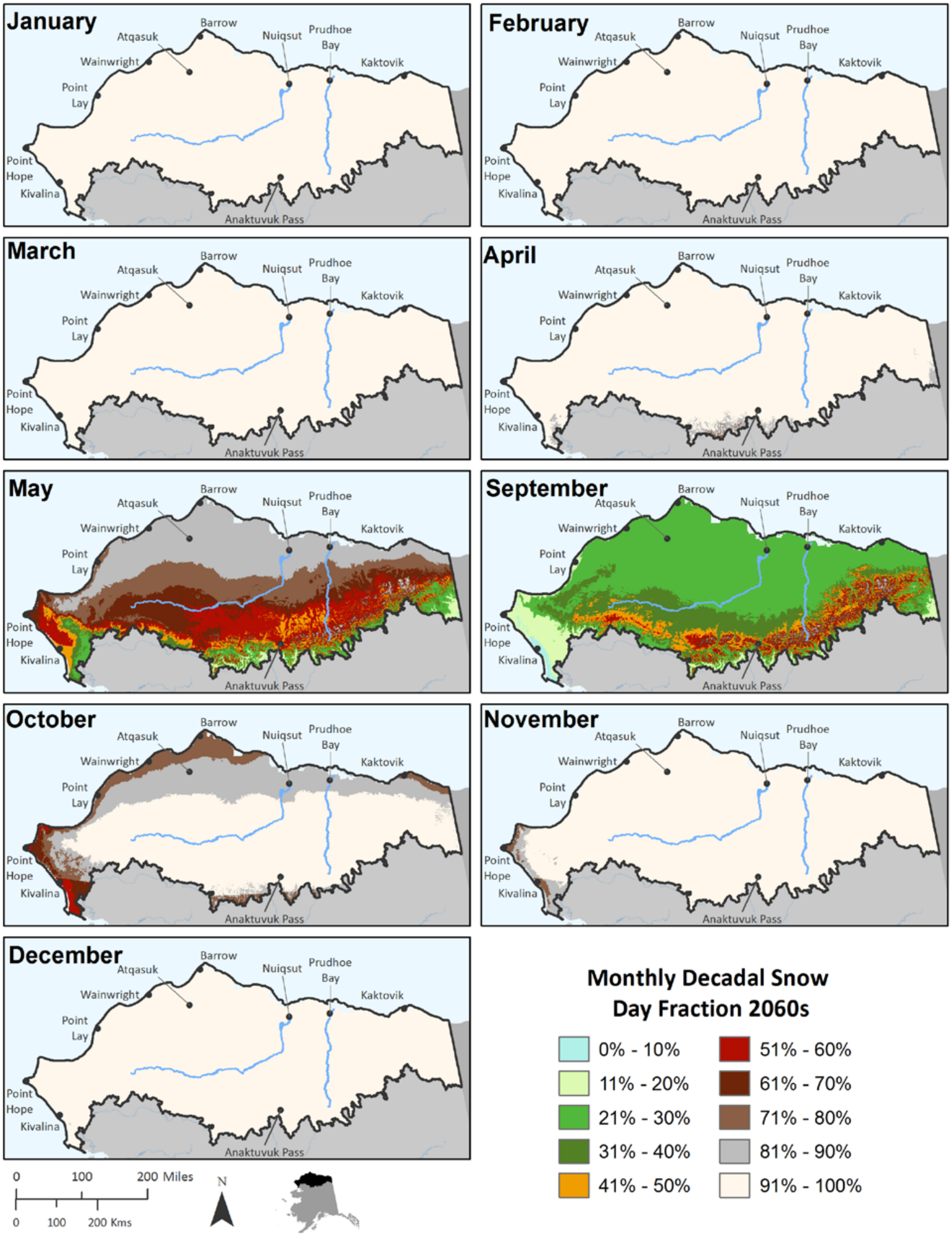

Figure C-11. Long-term projected snow-day fraction winter and shoulder-seasons.

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.

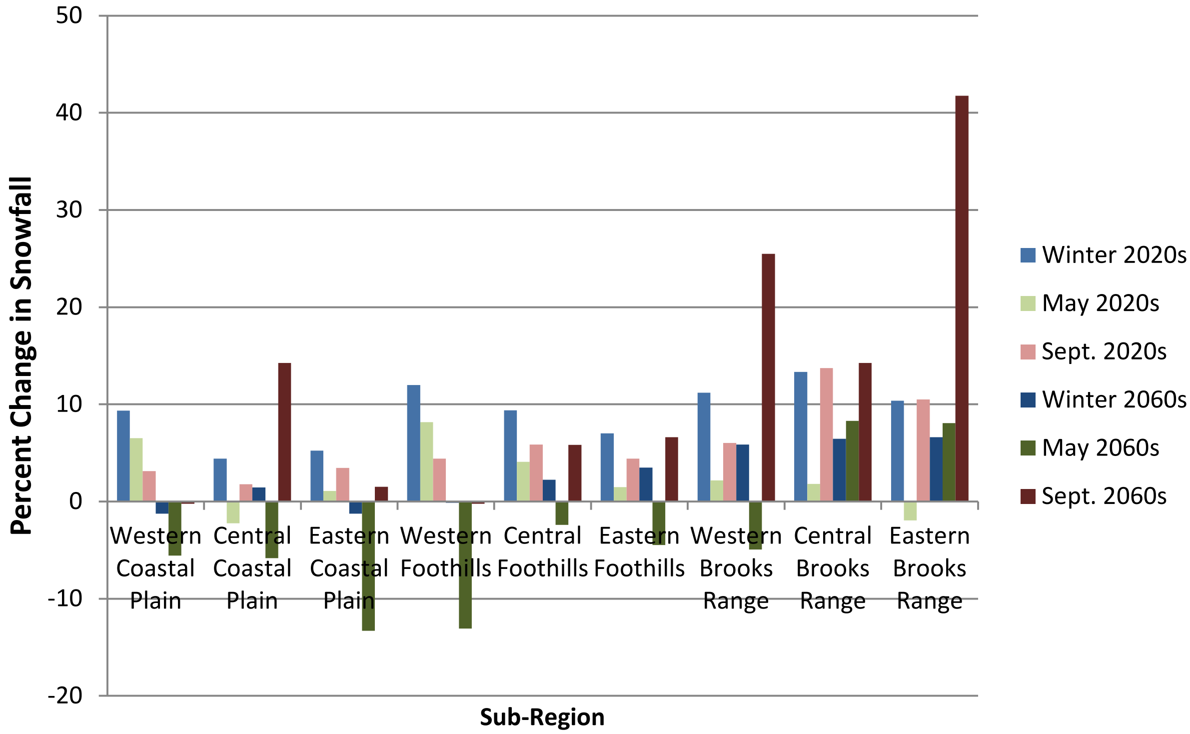

Figure C-12. Projected change in snowfall (as compared to the current decade) by sub-region. Values are based on projected precipitation and snow day fraction.

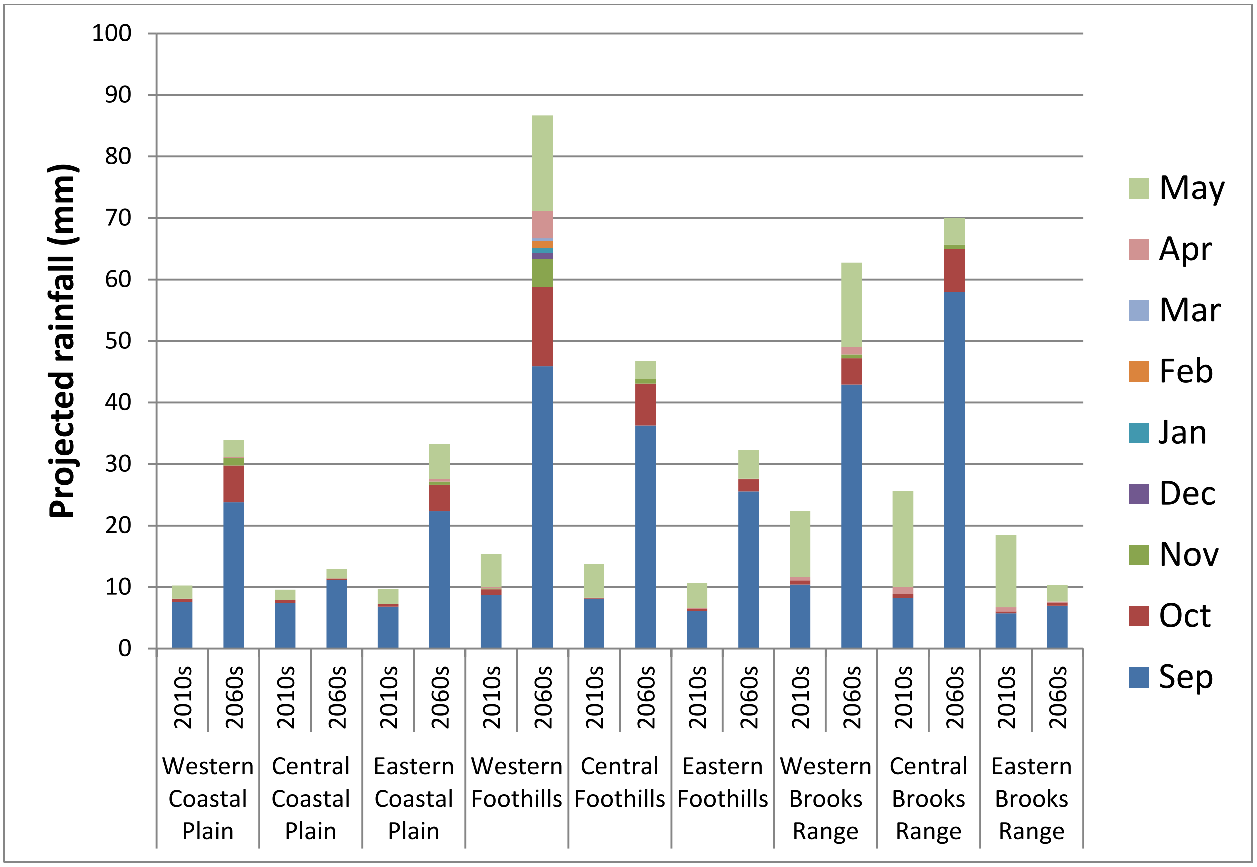

Figure C-13. Estimated current and long-term shoulder-season and winter rainfall by sub-region.

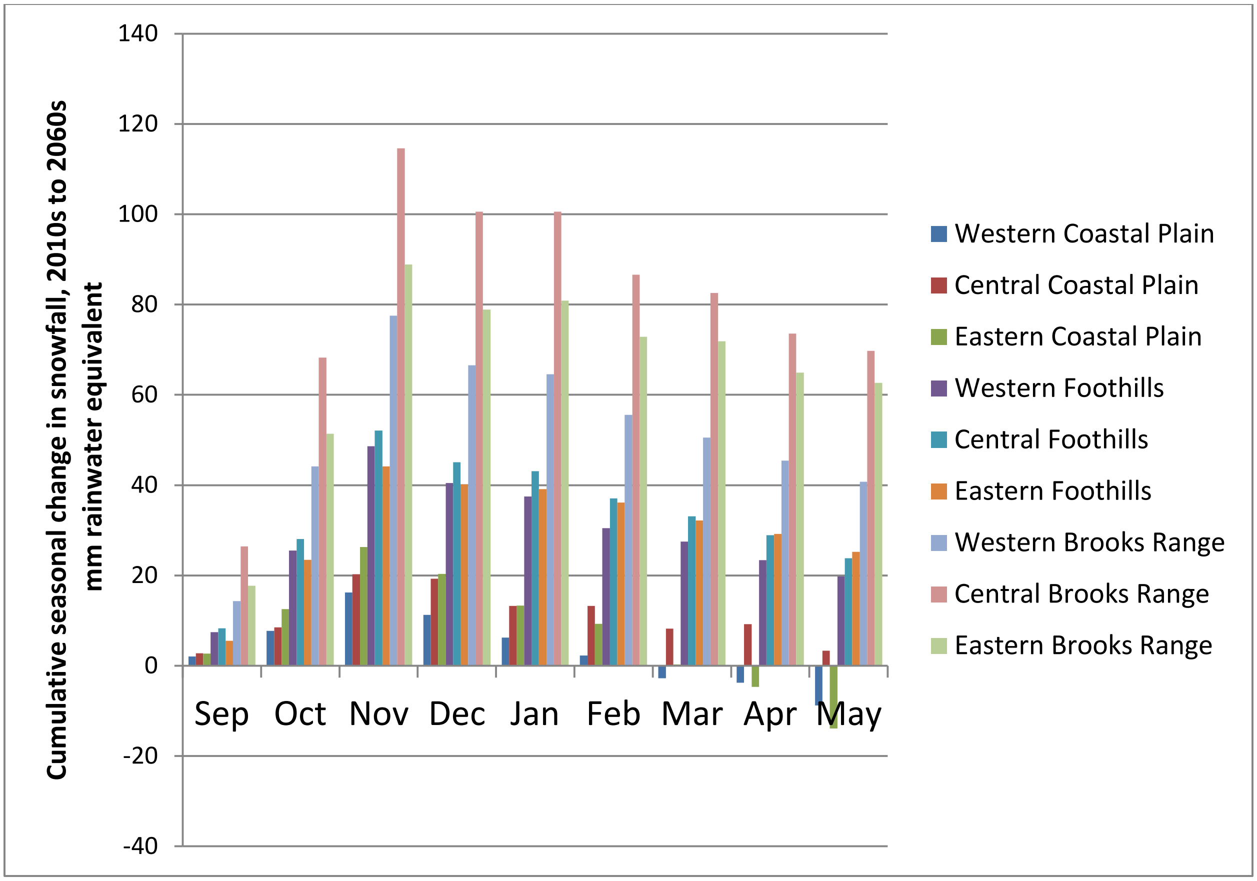

Figure C-14. Cumulative change in snowfall across the winter season for the long-term, as compared to the current decade.

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?

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.

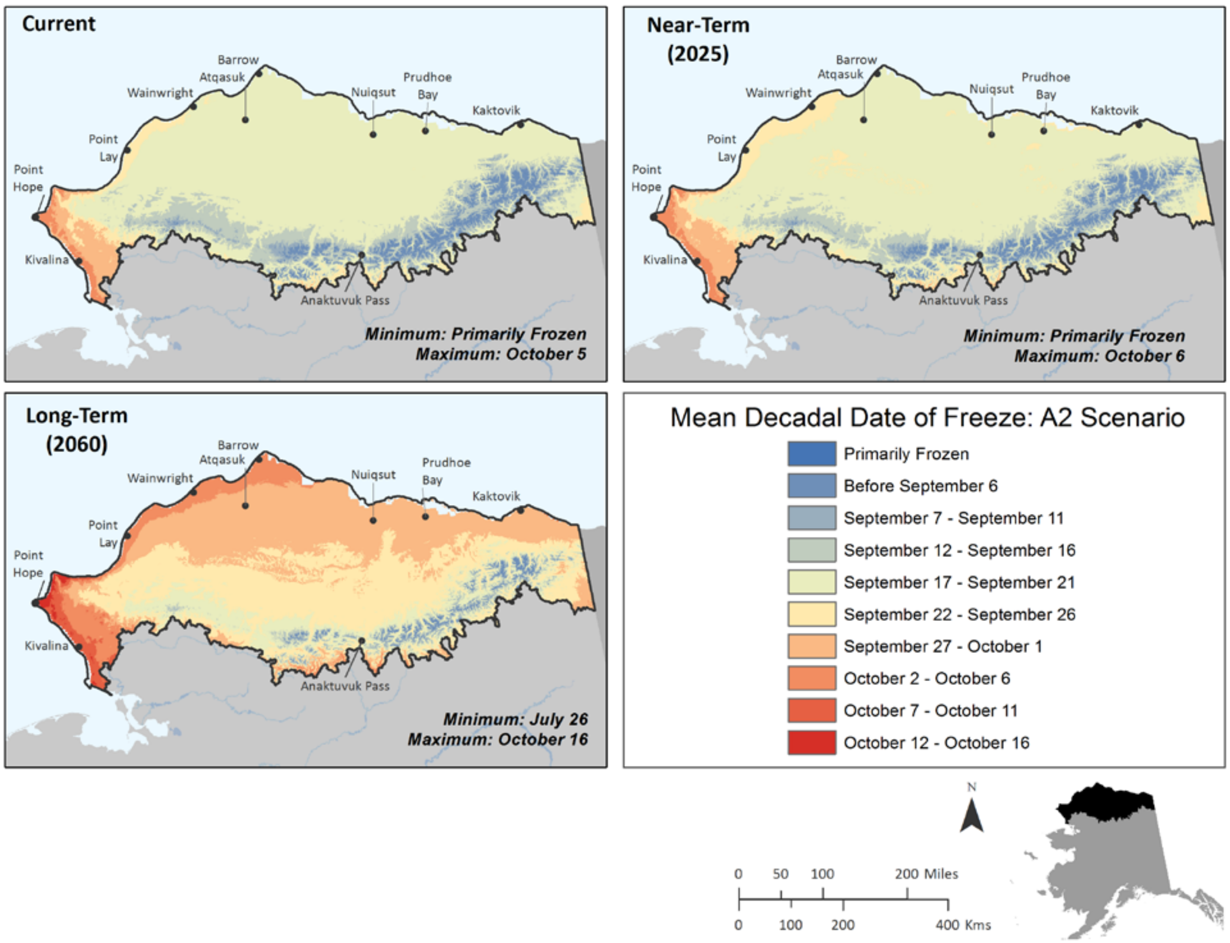

Figure C-15. Projected Date of Freeze.

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.

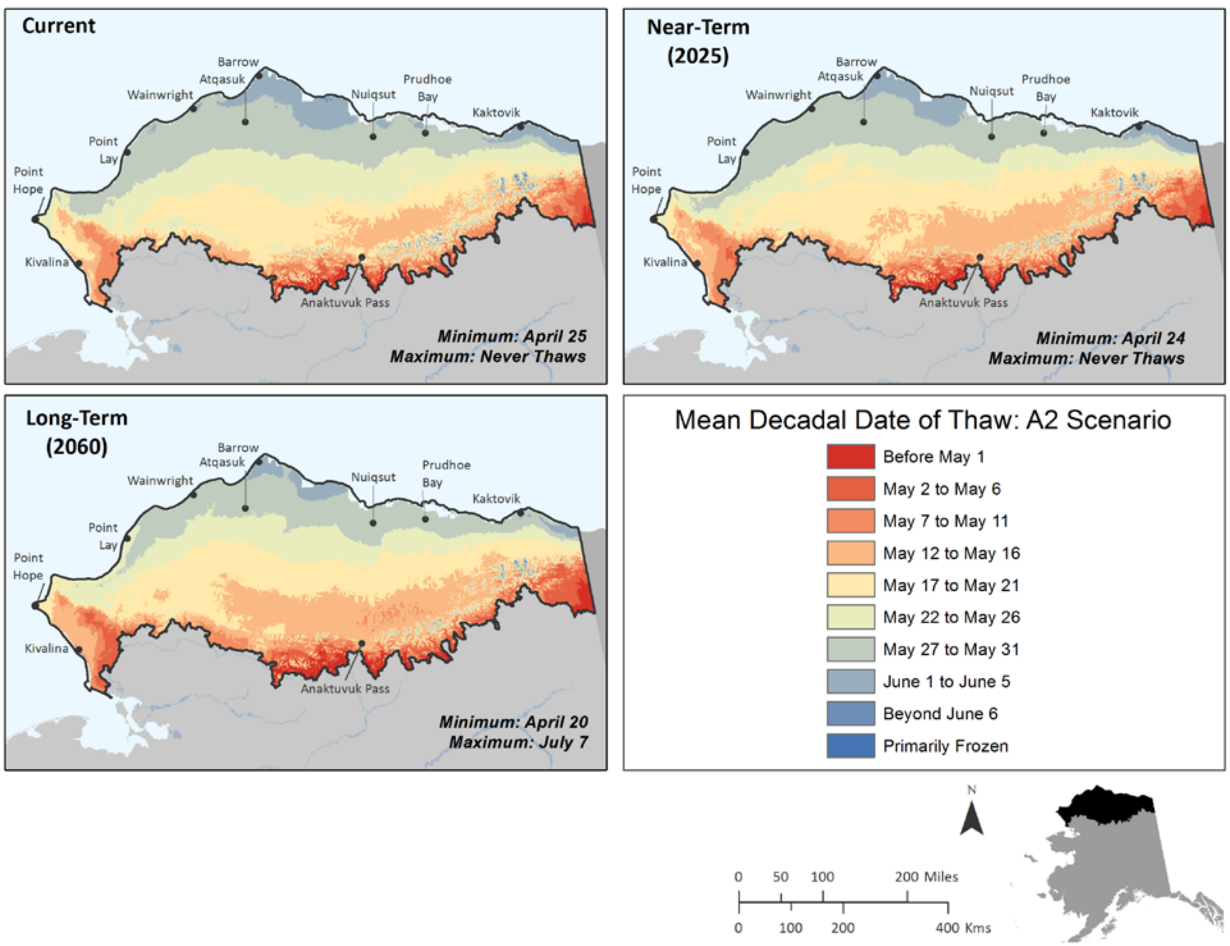

Figure C-16. Projected Day of Thaw.

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
Atqasuk	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.

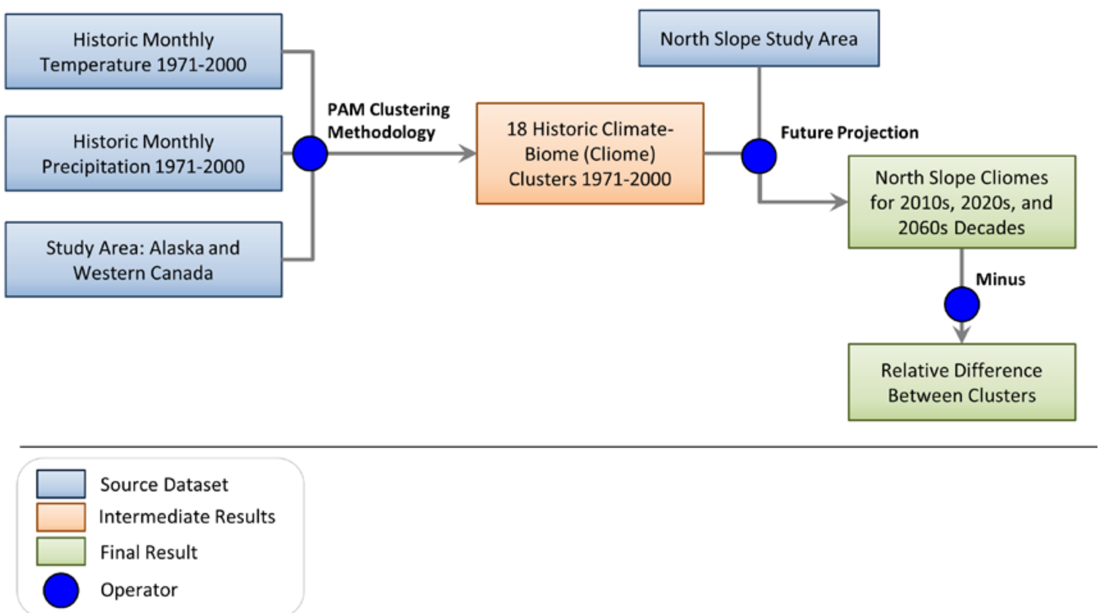

Figure C-17. Process model for cliome shift methodology.

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°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 1-4°C. This cliome experiences and 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.

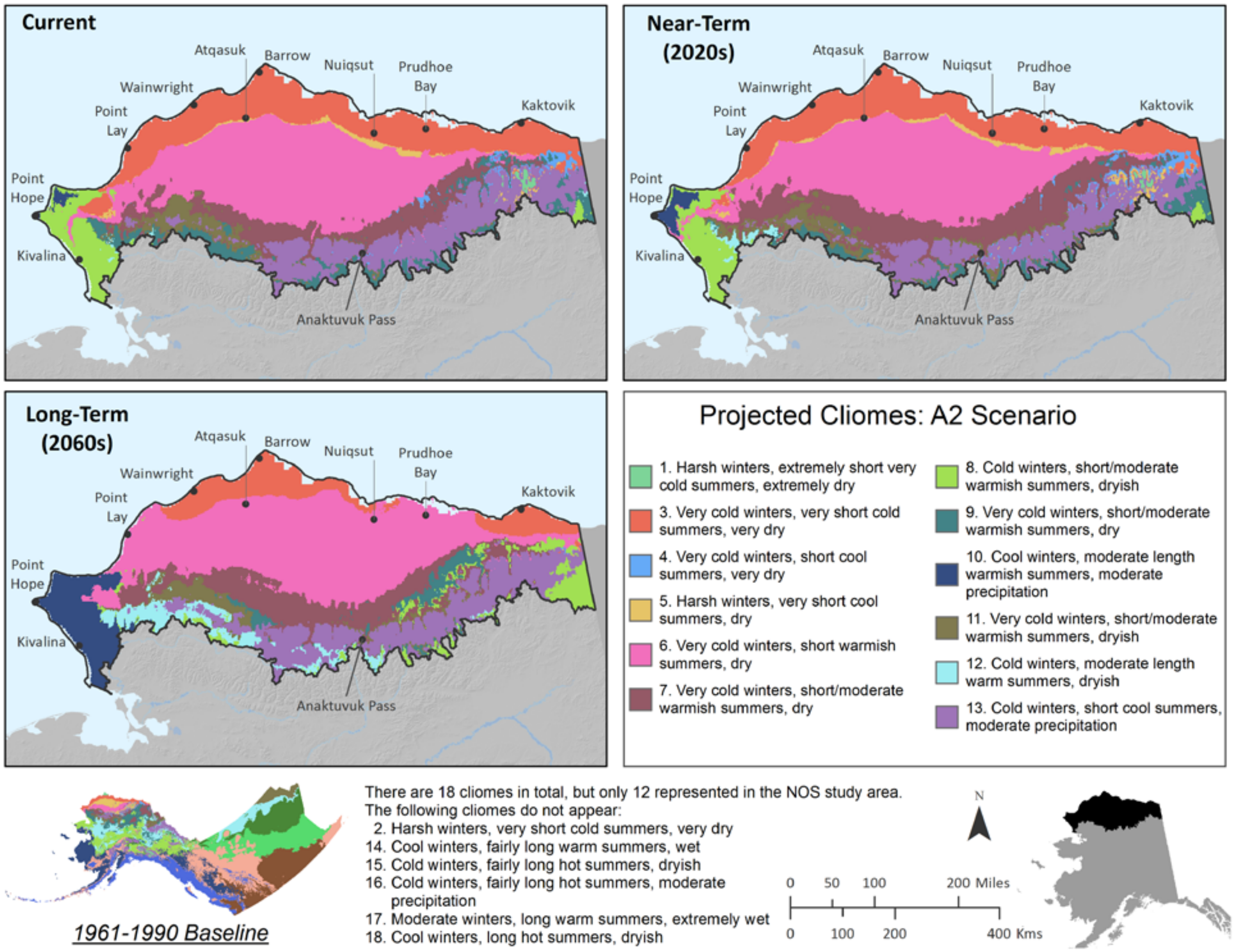

Figure C-18. Projected cliome shifts over time. Each color group represents an area of similar climate characteristic based on 12 month patterns of precipitation and temperature.

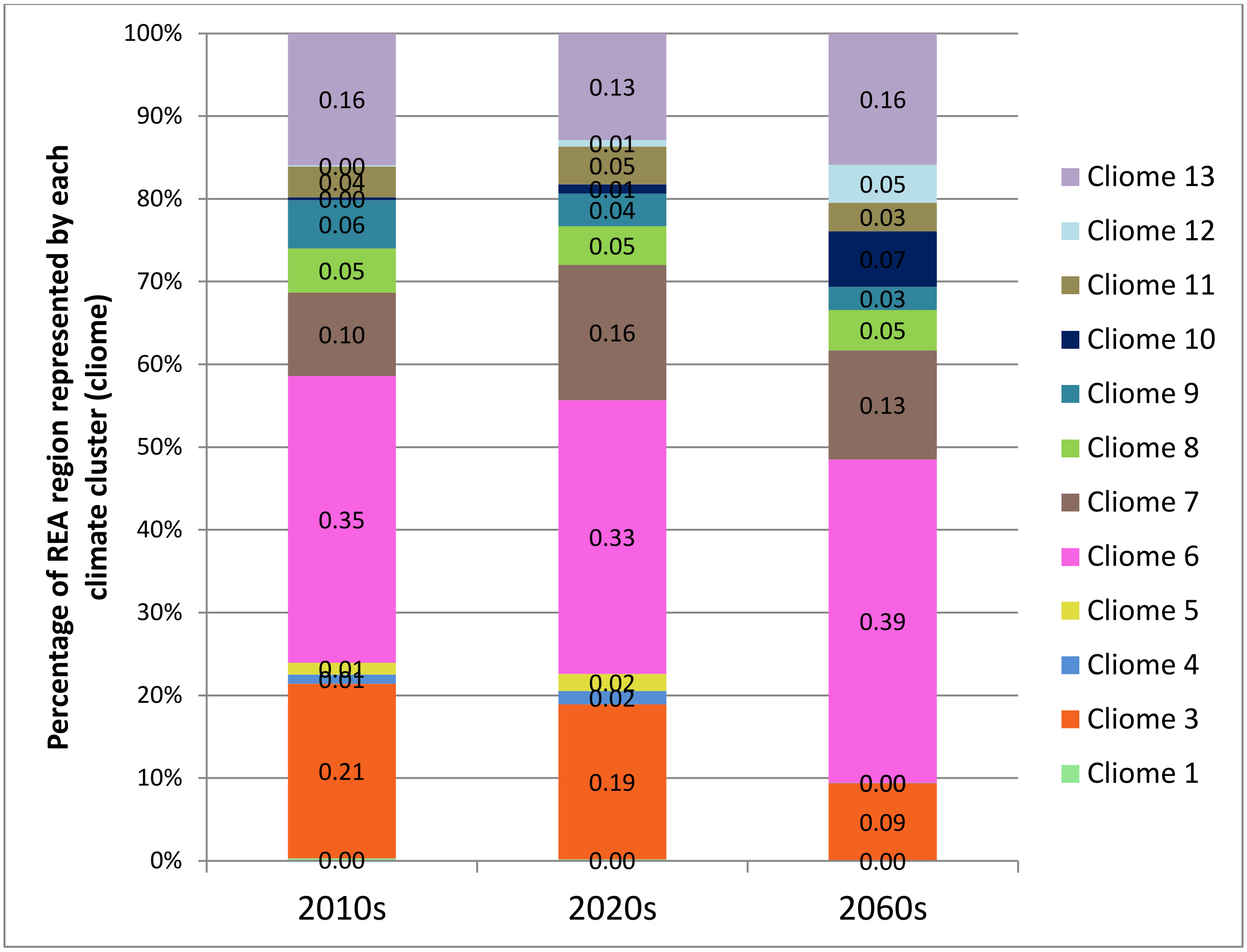

Figure C-19. Change in climate cluster (cliome) percentage over time across the REA.

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?

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.

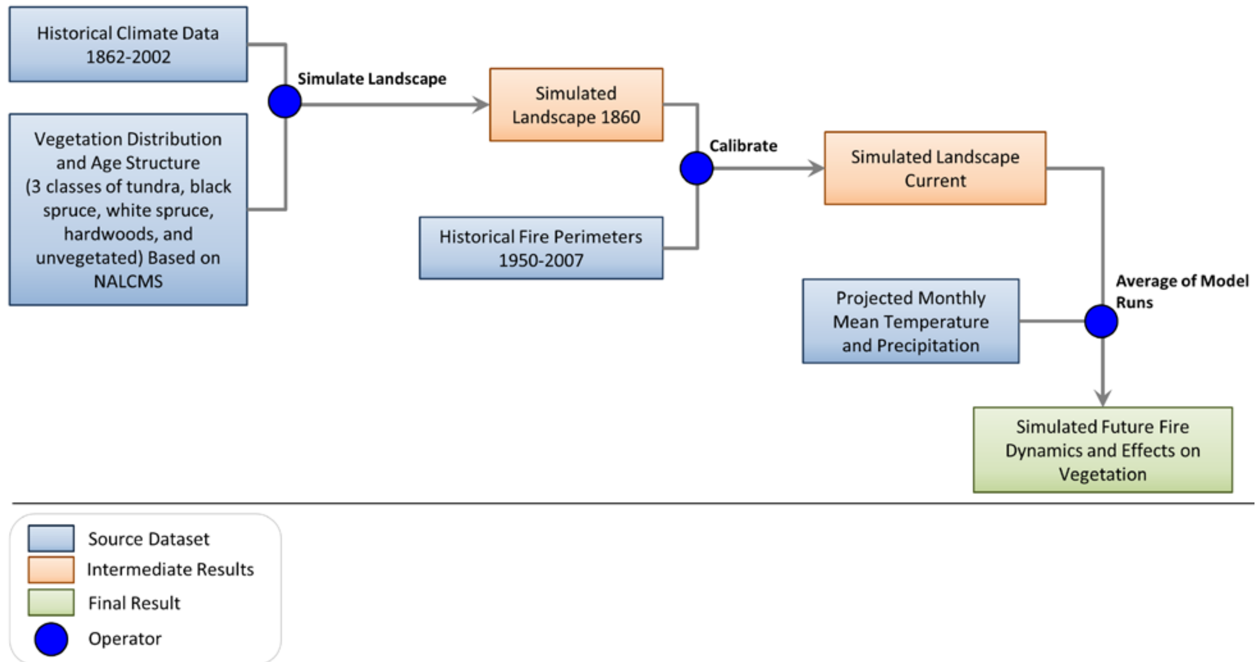


Figure C-20. Process model of ALFRESCO fire simulation methodology.

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 meangrowing 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.

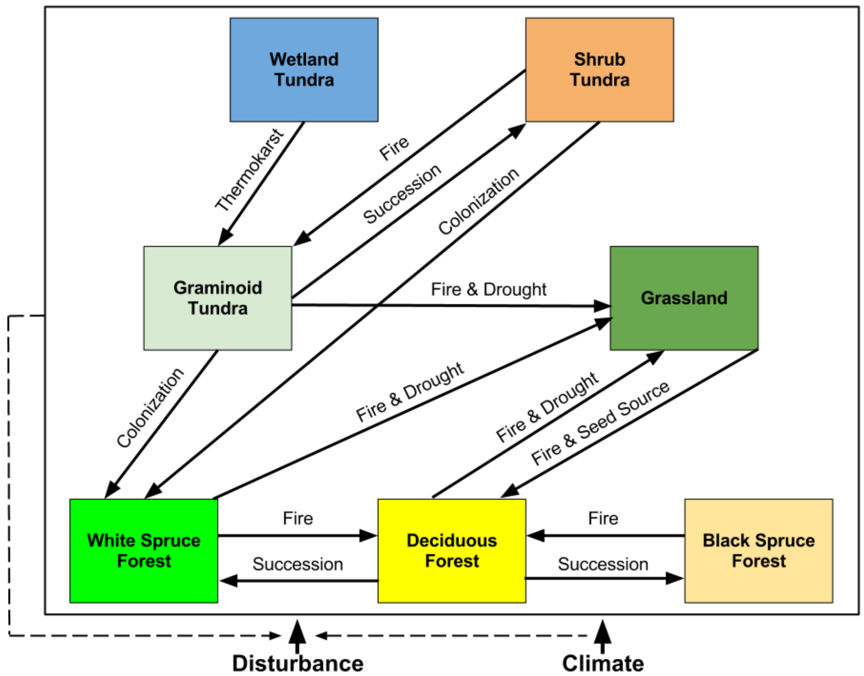


Figure C-21. Schematic of the ALFRESCO model showing potential vegetation transitions.

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 ≥ 12°C and SWI ≥ 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 m^2/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).

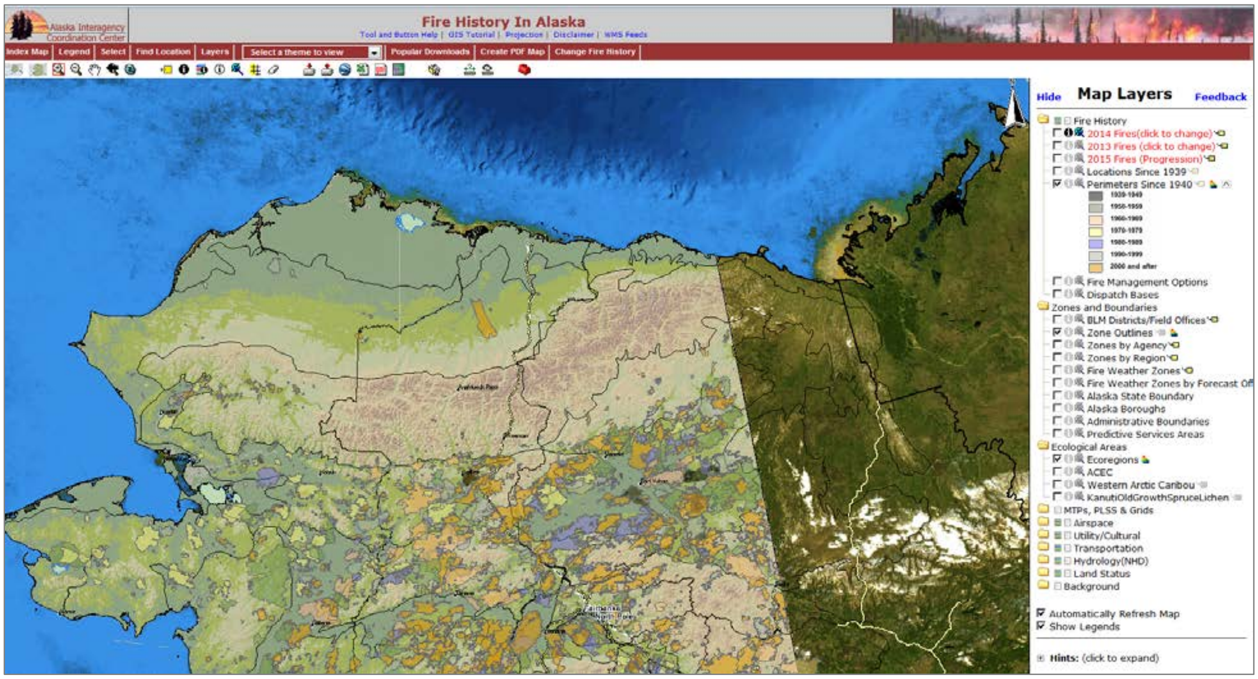


Figure C-22. Fire history, 1940 to the present, as shown via the BLM online map tool available at http://fire.ak.blm.gov/predsvcs/maps.php

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.

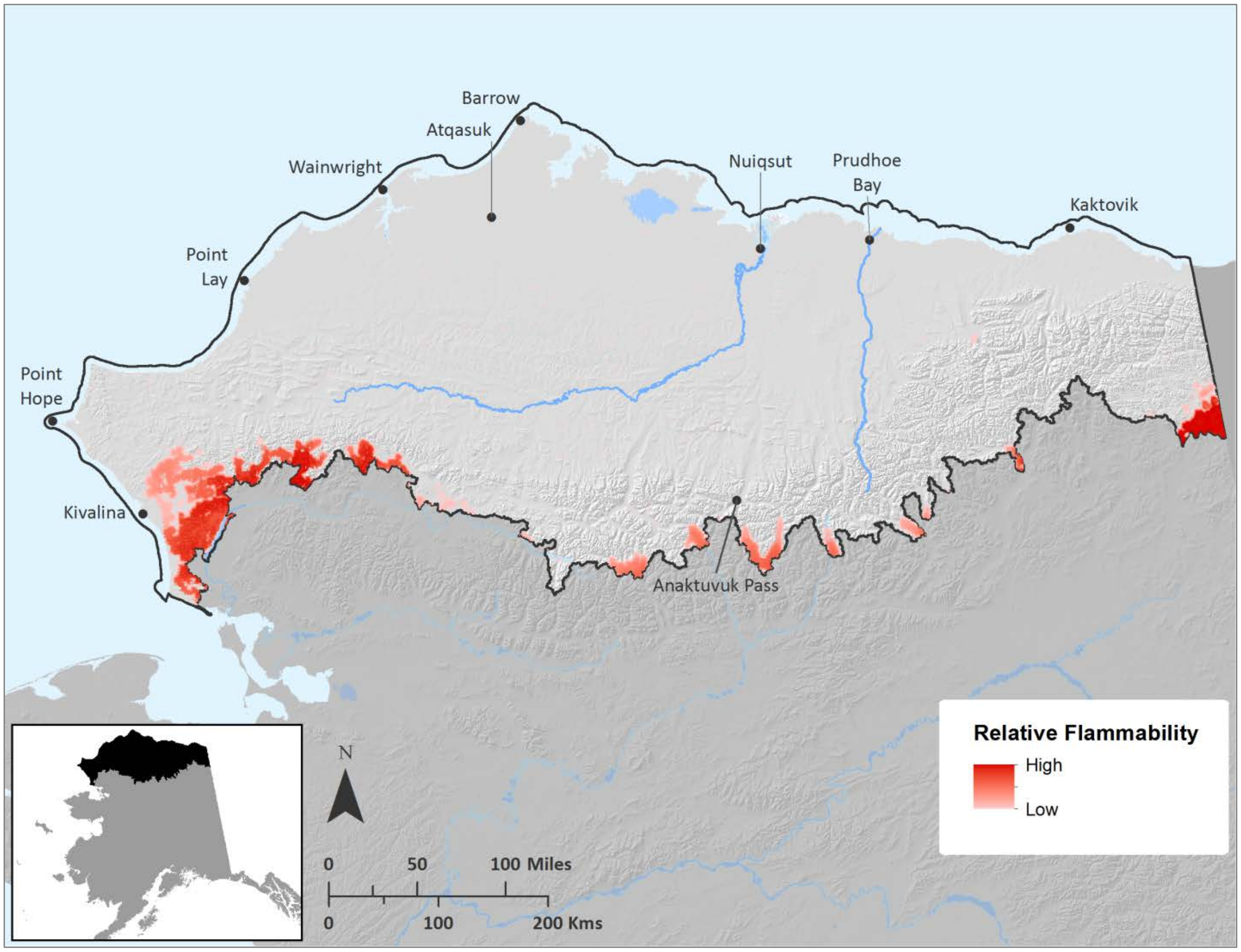


Figure C-23. Projected relative flammability across the North Slope study area.

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.

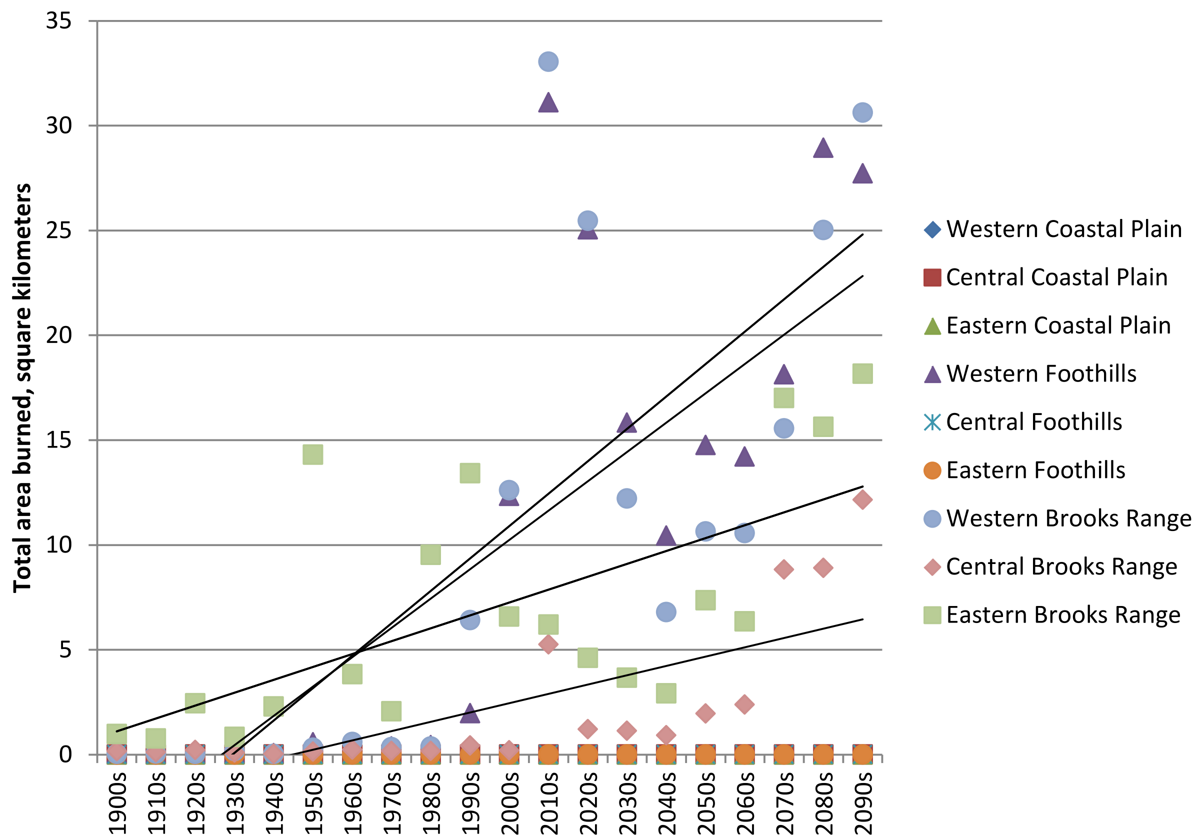


Figure C-24. Modeled mean decadal area burned (by sub-region) 1900s to 2090s.

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).

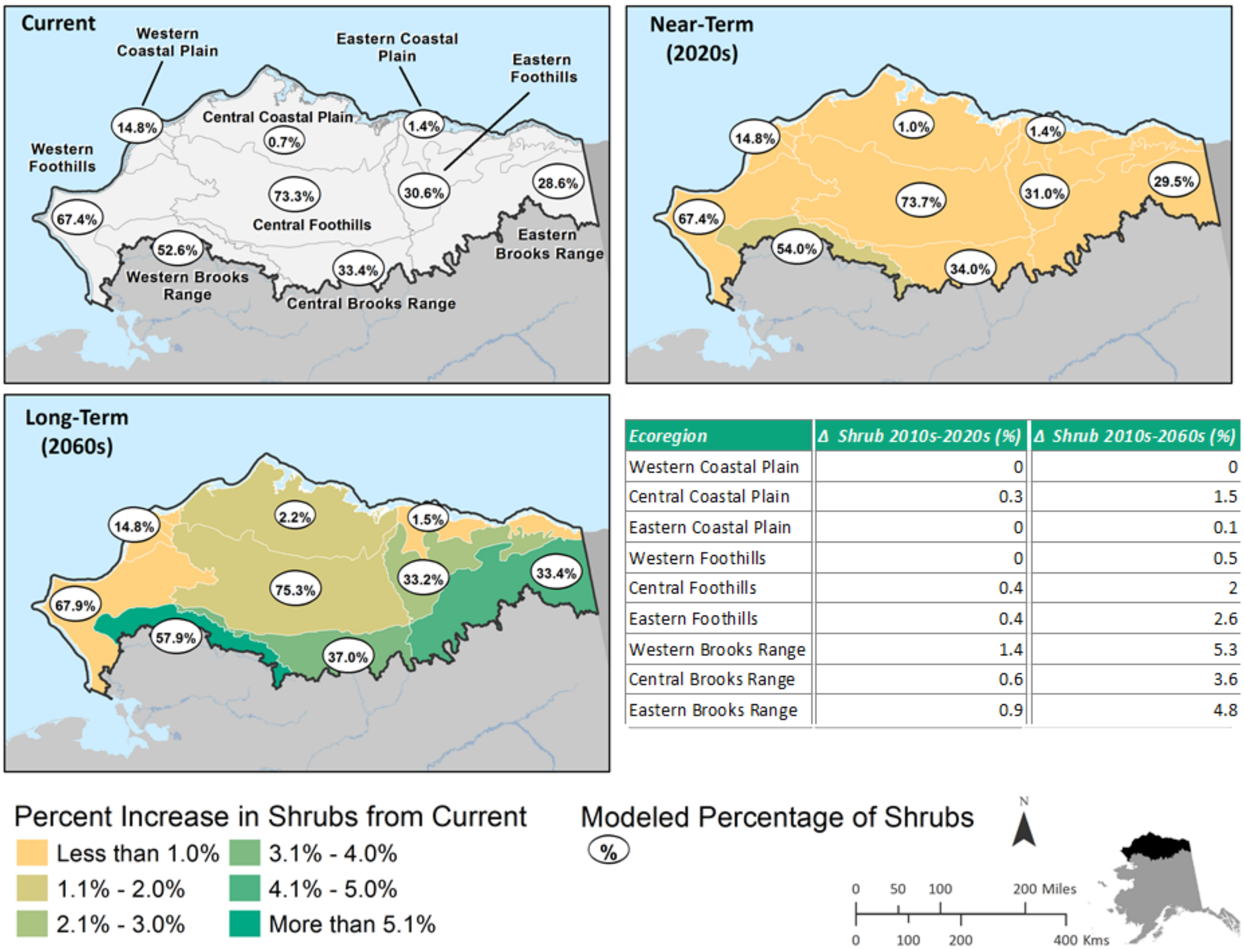
Analyses suggest that changes in fire frequency on Alaska's landscapes may be driven at least as much by climate-induced changes in vegetation as they are by climate-induced changes in fire frequency

(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.



Ecoregion	*Δ Shrub 2010s-2020s (%)*	*Δ Shrub 2010s-2060s (%)*
Western Coastal Plain	0	0
Central Coastal Plain	0.3	1.5
Eastern Coastal Plain	0	0.1
Western Foothills	0	0.5
Central Foothills	0.4	2
Eastern Foothills	0.4	2.6
Western Brooks Range	1.4	5.3
Central Brooks Range	0.6	3.6
Eastern Brooks Range	0.9	4.8

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.

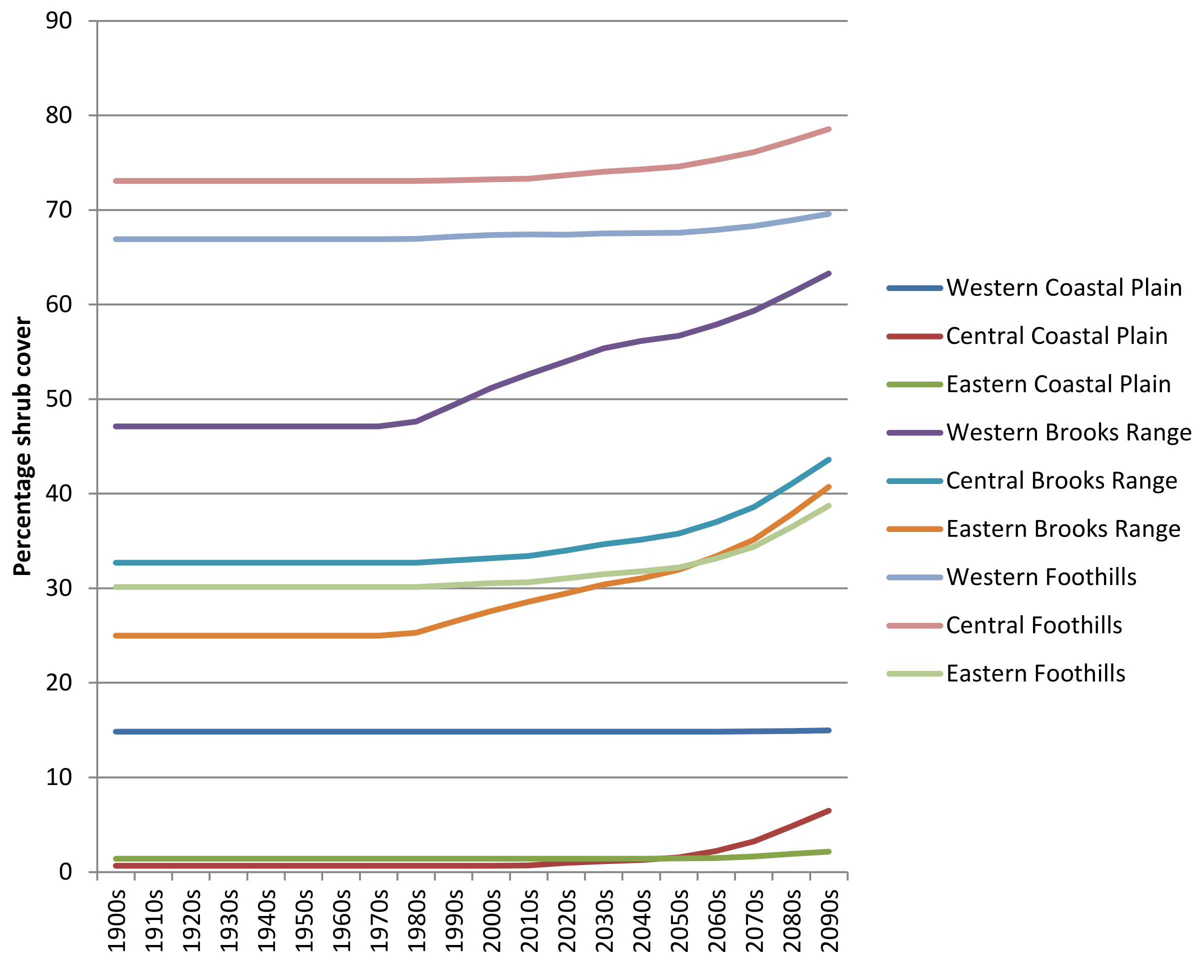


Figure C-26. Projected changes in shrub tundra by sub-region.

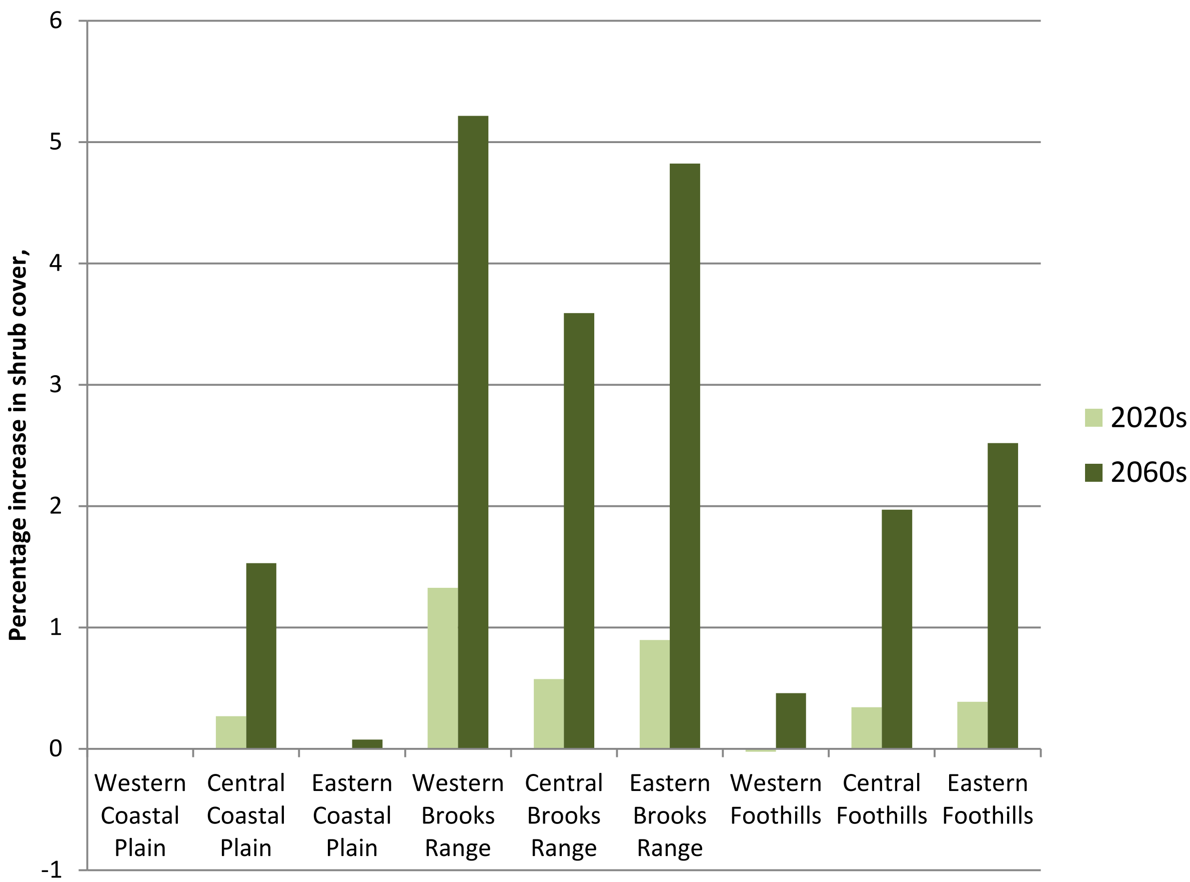


Figure C-27. Projected shrub expansion by sub-region in the near-term and long-term. (Increase, as compared to the current decade, in percentage total land cover).

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?

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.

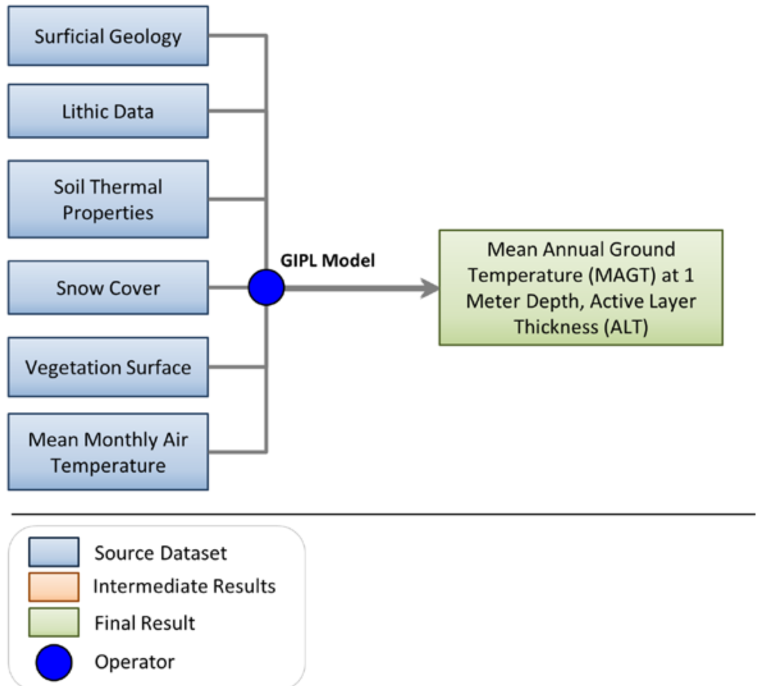

Figure C-28. Process model of permafrost modeling techniques.

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 5^{th}-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.

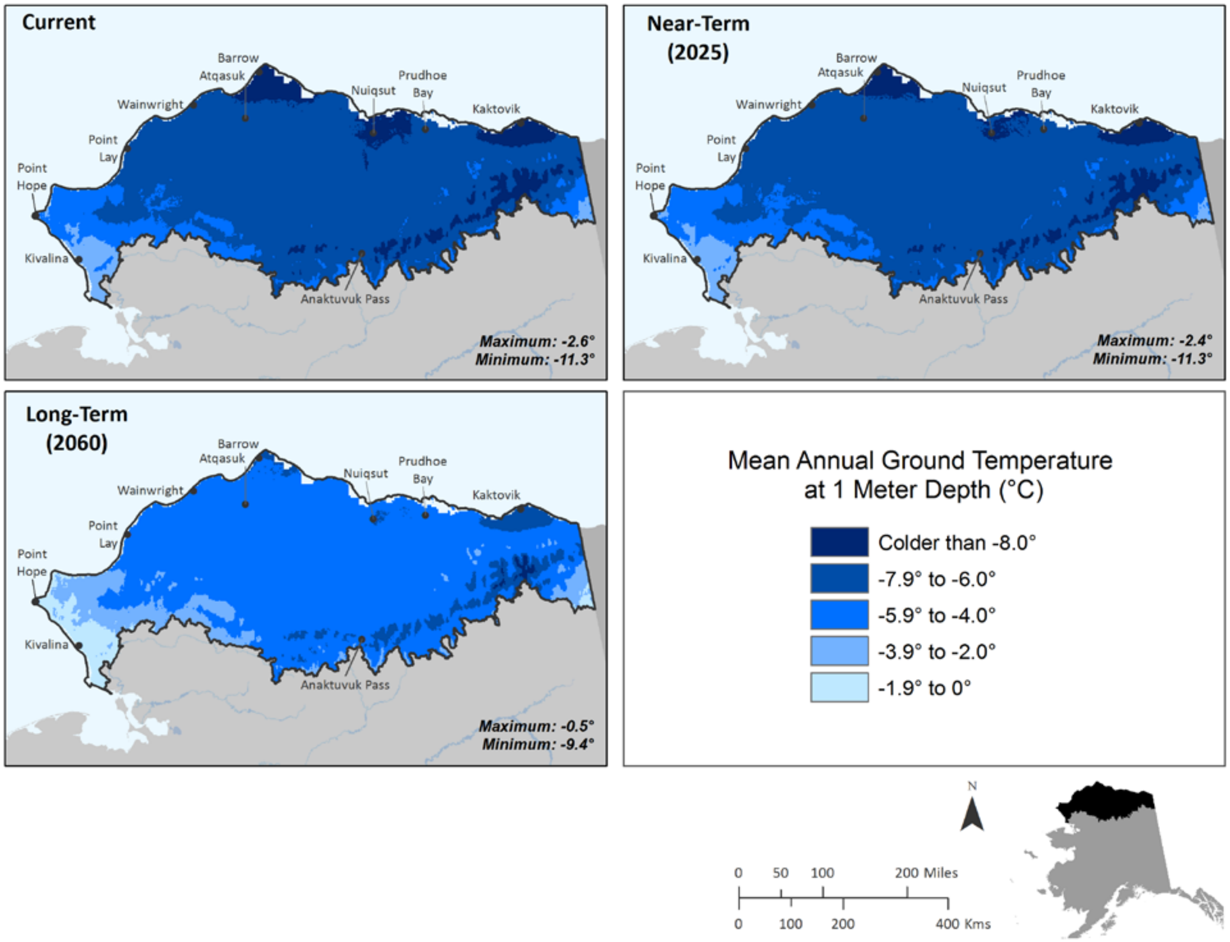

Figure C-29. Mean Annual Ground Temperature projections based on SNAP climate inputs into the GIPL permafrost model. Darker blue colors represent colder soil conditions.

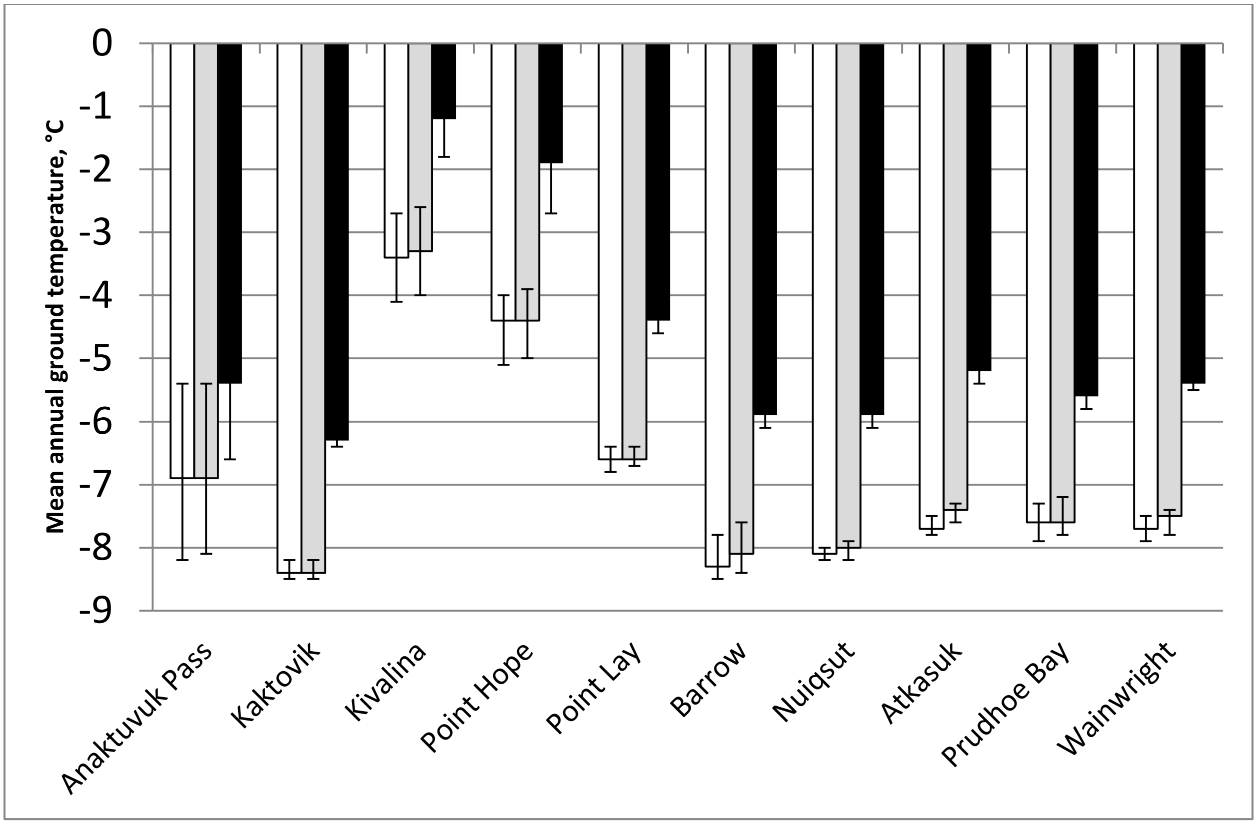

Figure C-30**.** Mean annual ground temperature (°C) at one meter depth (MAGT) for community watersheds in the North Slope study area. Current (white), near-term (light gray), and long-term (dark gray) time steps are shown.Active layer thickness is expected to increase across the North Slope study area (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).

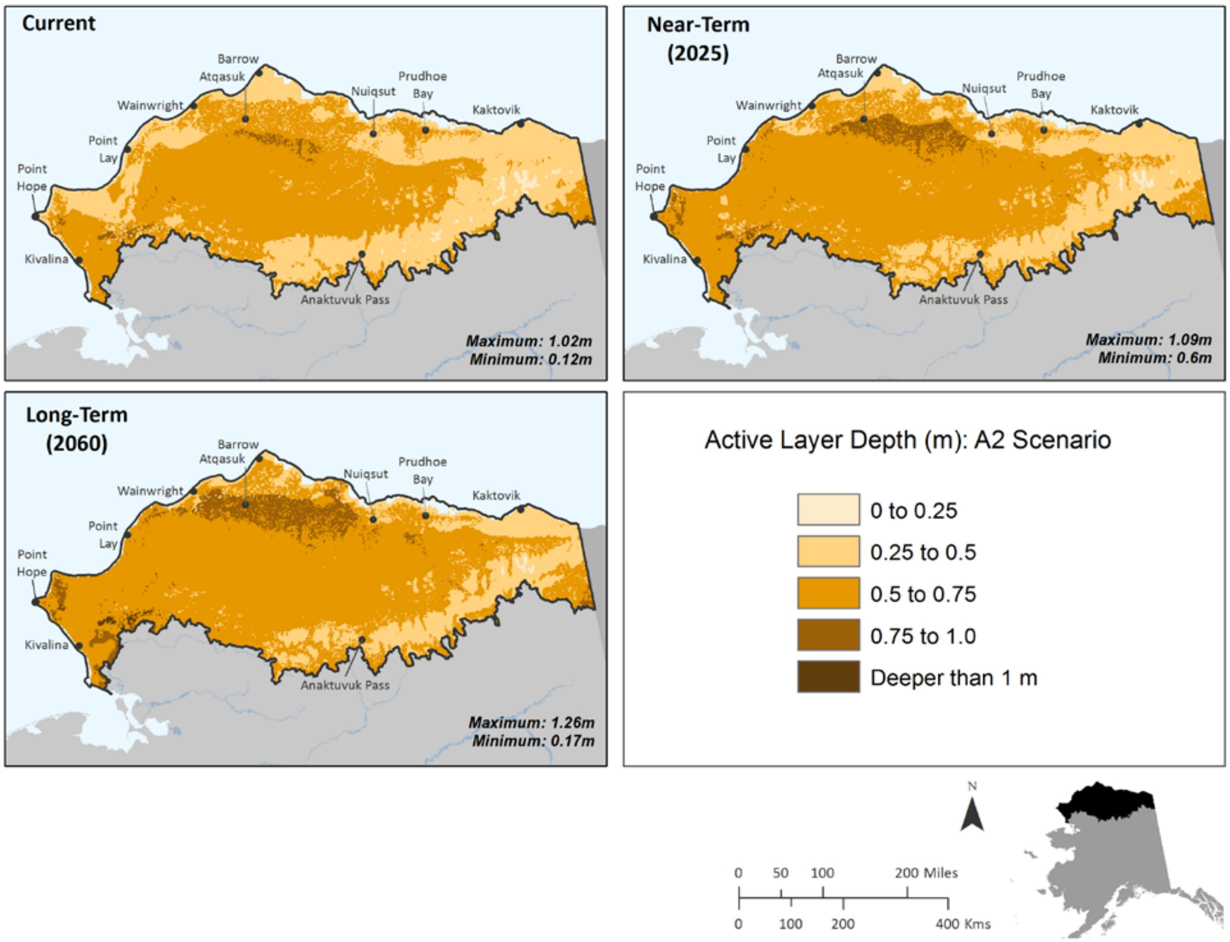

Figure C-31. Projected active layer thickness and depth of seasonal thaw. Darker brown colors indicate deeper active layer depths (m).

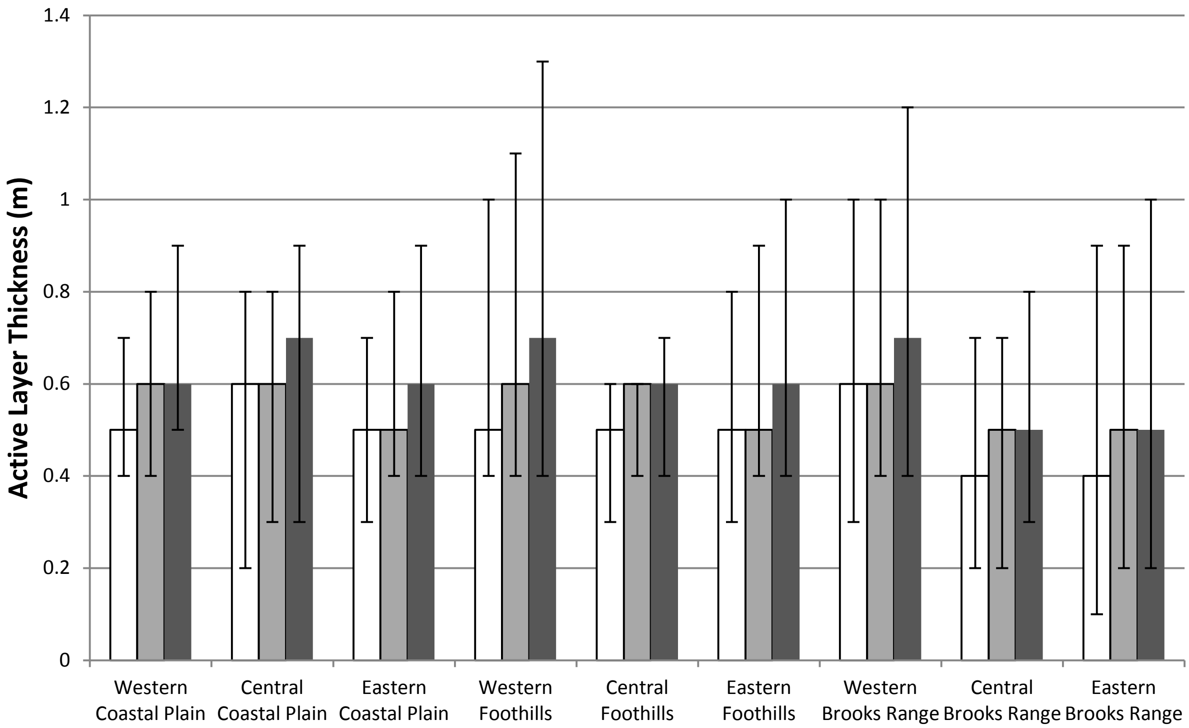

Figure C-32. Active Layer Thickness (ALT) projections by ecological sub-region. Current (white), near-term (light gray), and long-term (dark gray) time steps are shown. Error bars show minimum and maximum values for pixels in each sub-region.

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.

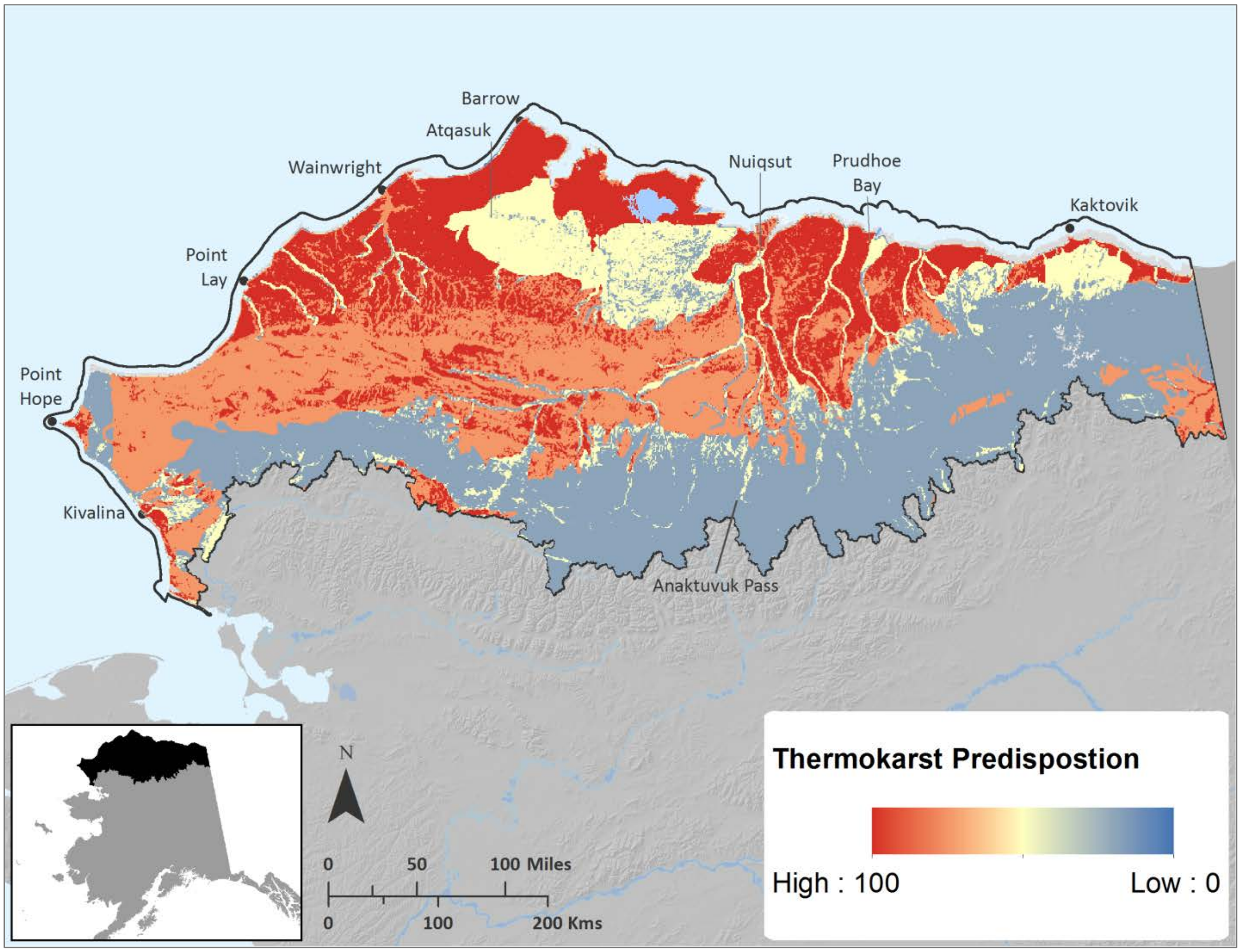

Figure C-33. Thermokarst predisposition based on topography and soil ice content. Warmer colors represent a higher thermokarst predisposition.

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 Lougheed (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

Matthew L. Carlson[1, 2], Megumi Aisu[1], E. Jamie Trammell[1,3], and Timm Nawrocki[1]

[1]Alaska Natural Heritage Program, [2]Biological Sciences Department, & [3]Geography and Environmental Sciences Department University of Alaska Anchorage, 3211 Providence Drive, Anchorage, Alaska 99508

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 place 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).

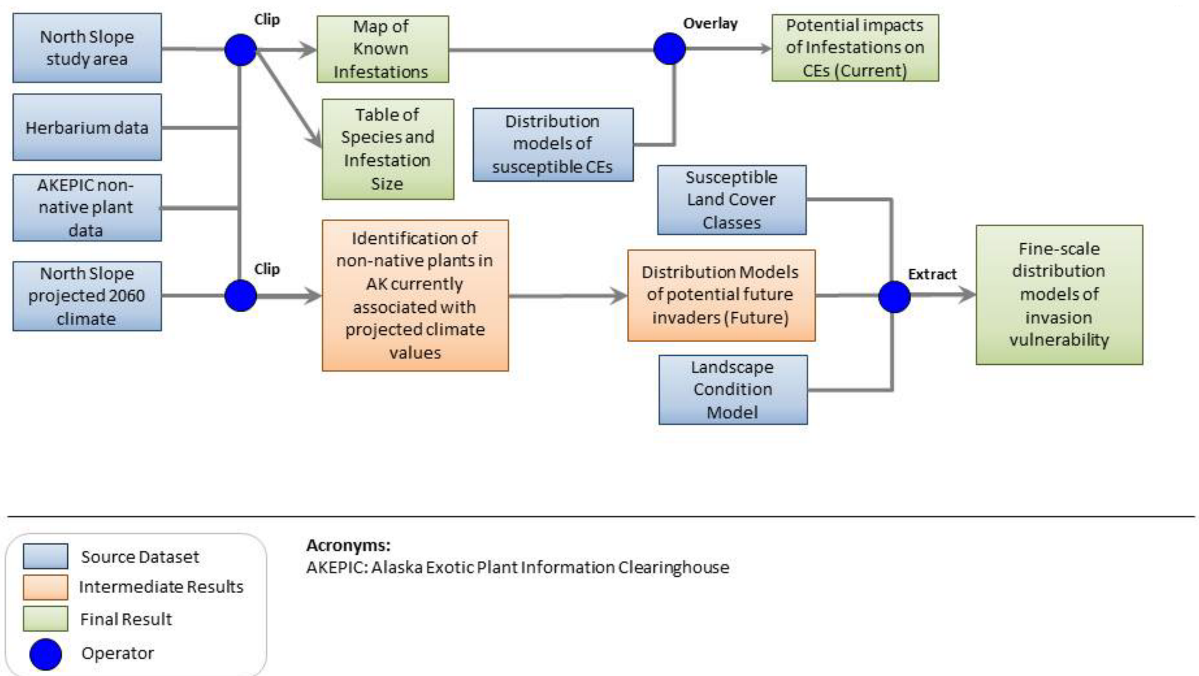

Figure D-1. Process model of invasive species current and predicted future condition methodology.

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 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.

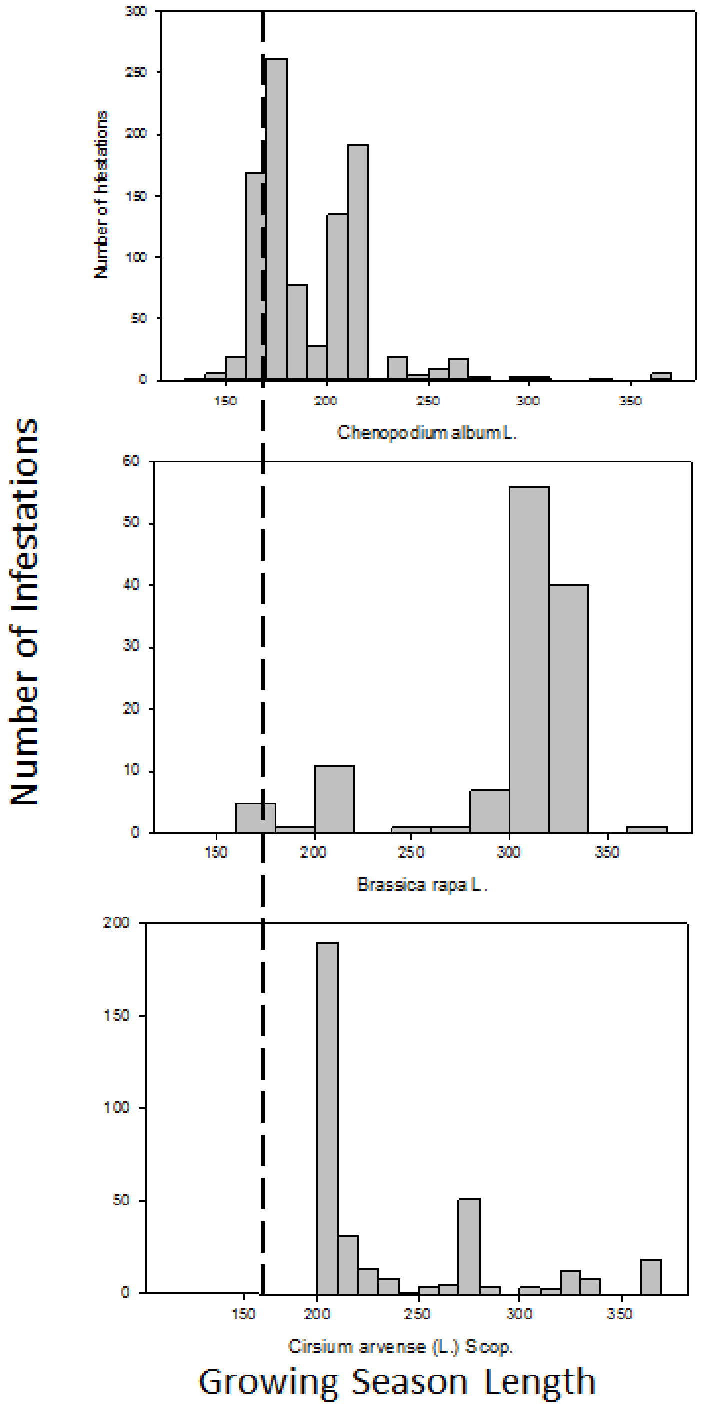

Figure D-2. Example histograms of number of infestations relative to growing season length for three non-native plant species in Alaska. The dashed line represents the maximum predicted growing season length present within the REA region by 2060. Species with recorded infestations at or below this growing 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
Brassica rapa (field mustard)	NA	1	50
Chenopodium album (lambsquarters)	0.01	1	37
*Descurainia sophia** (herb sophia)	1.0	1	41
Hordeum jubatum (foxtail barley)	16.63	21	63
Lepidium densiflorum (common pepperweed)	NA	1	25
Matricaria discoidea (disc mayweed)	1.01	2	32
Plantago major (common plantain)	1.52	4	44
Polygonum aviculare (prostrate knotweed)	1.01	3	45
Taraxacum officinale (common dandelion)	2.5	4	58

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

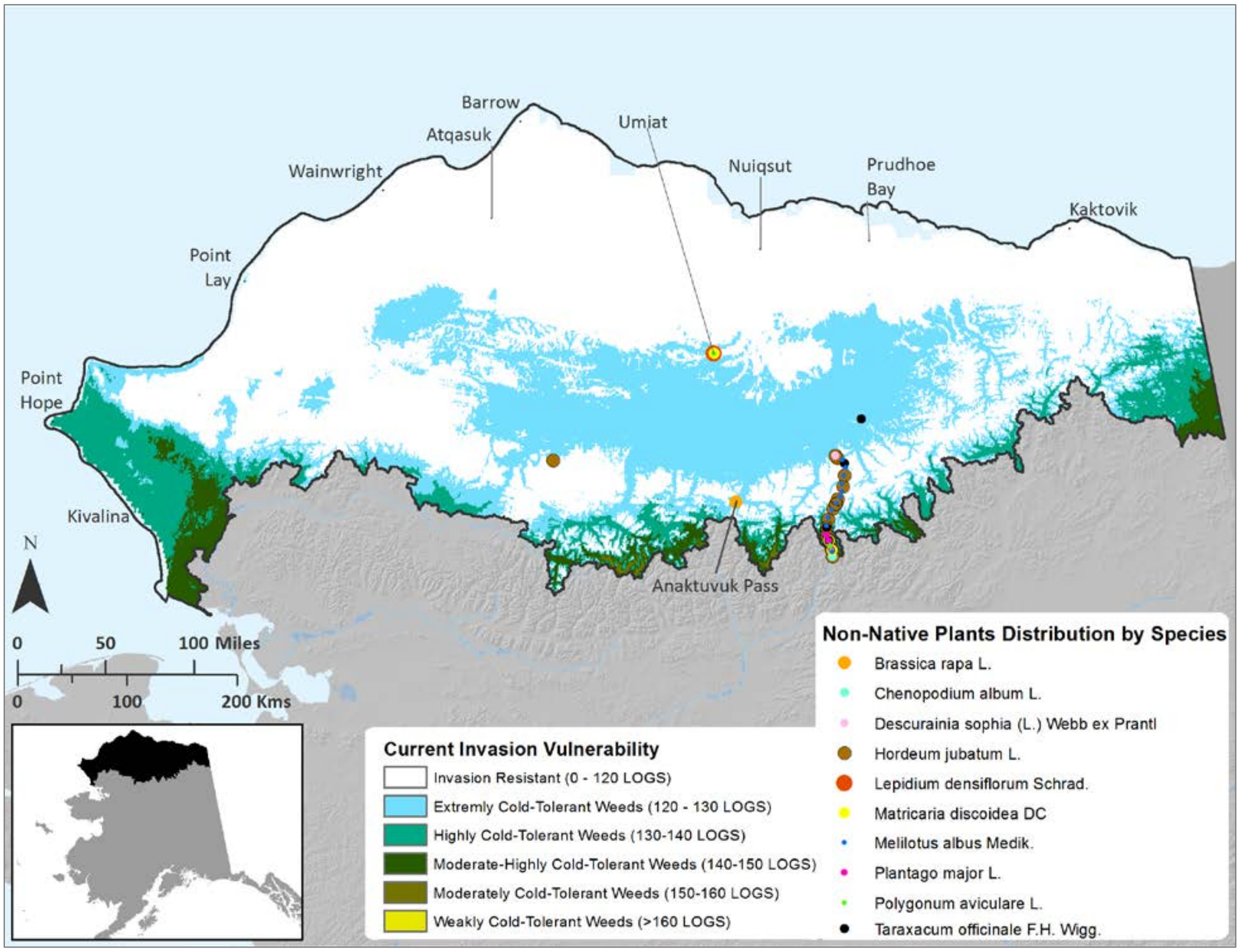

Figure D-3. Distribution of non-native plant infestations in the North Slope study area (circles). General plant invasion vulnerability is illustrated by the colored polygons. Areas with a Length of Growing Season (LOGS) of less than 120 days are predicted to be invasion resistant (white); areas in blue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

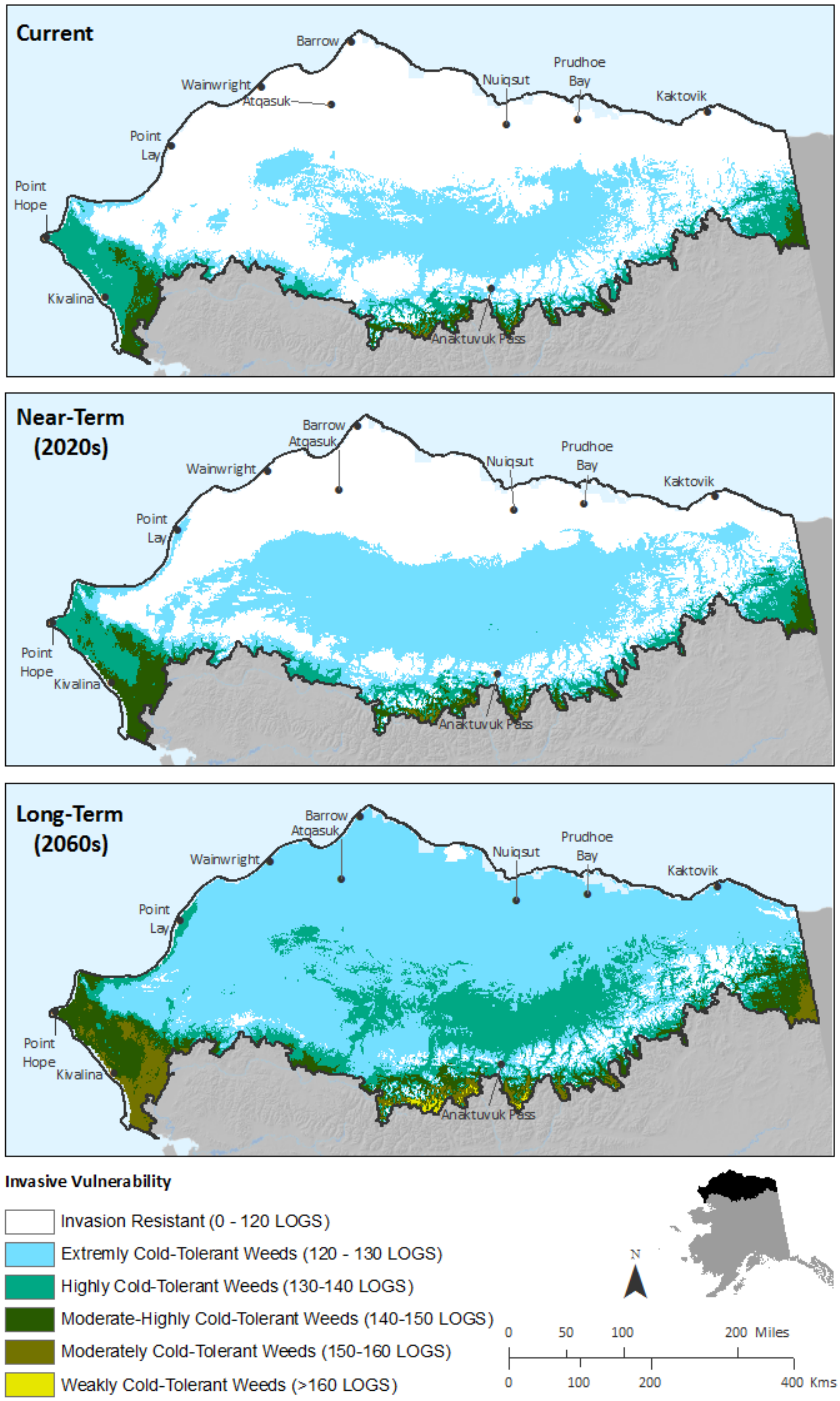

Figure D-4. General plant invasion vulnerability is illustrated by the colored polygons. Areas with a growing season of less than 120 days are predicted to be invasion resistant (white); areas in blue represent regions vulnerable to invasion by extremely cold-tolerant plants; and warmer colors represent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

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 Ikpikpuk, 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 in 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.

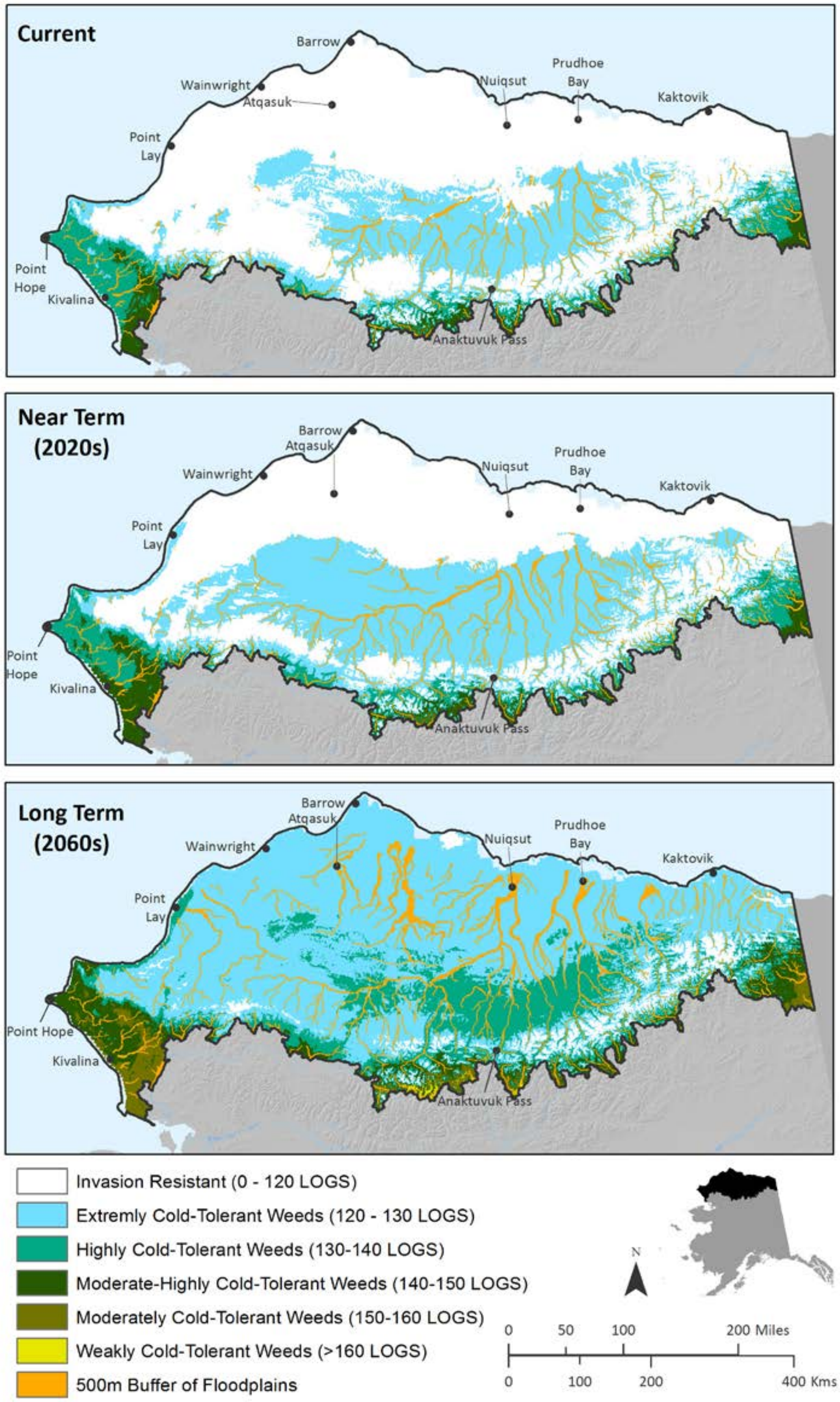

Figure D-5. General plant invasion vulnerability is illustrated by the colored polygons overlaid with the most susceptible habitats in floodplains (orange). Areas with a growing season of less than 120 days are predicted to be invasion resistant (white); areas in blue represent regions vulnerable to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

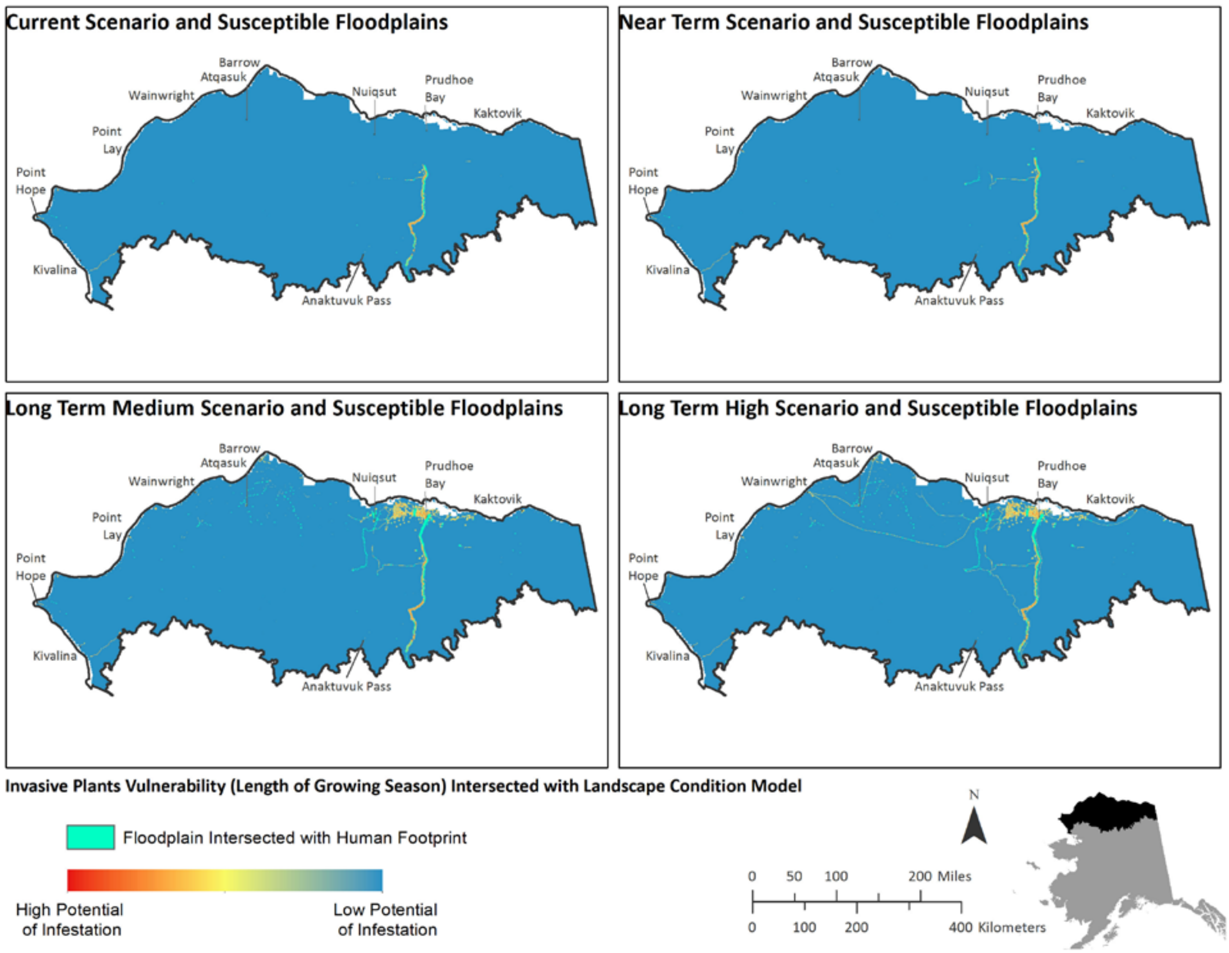

Figure D-6. Modeled infestation vulnerability in the North Slope for clockwise from upper right: current (a), near-term (b), long-term medium development Landscape Condition Model (LCM) scenario (c), and long-term high development LCM scenario (d). Areas predicted to have higher probabilities of invasion 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 turquois.

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

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

Diwakar Vadapalli, Stephanie Martin, Sohrab Pathan, Caitlin Kennedy, Lauren Fritz, Vitor deCarli, Rosyland Frazier

Institute of Social and Economic Research, University of Alaska Anchorage, 3211 Providence Drive, Alaska 99508

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 km^2, 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 km^2 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.

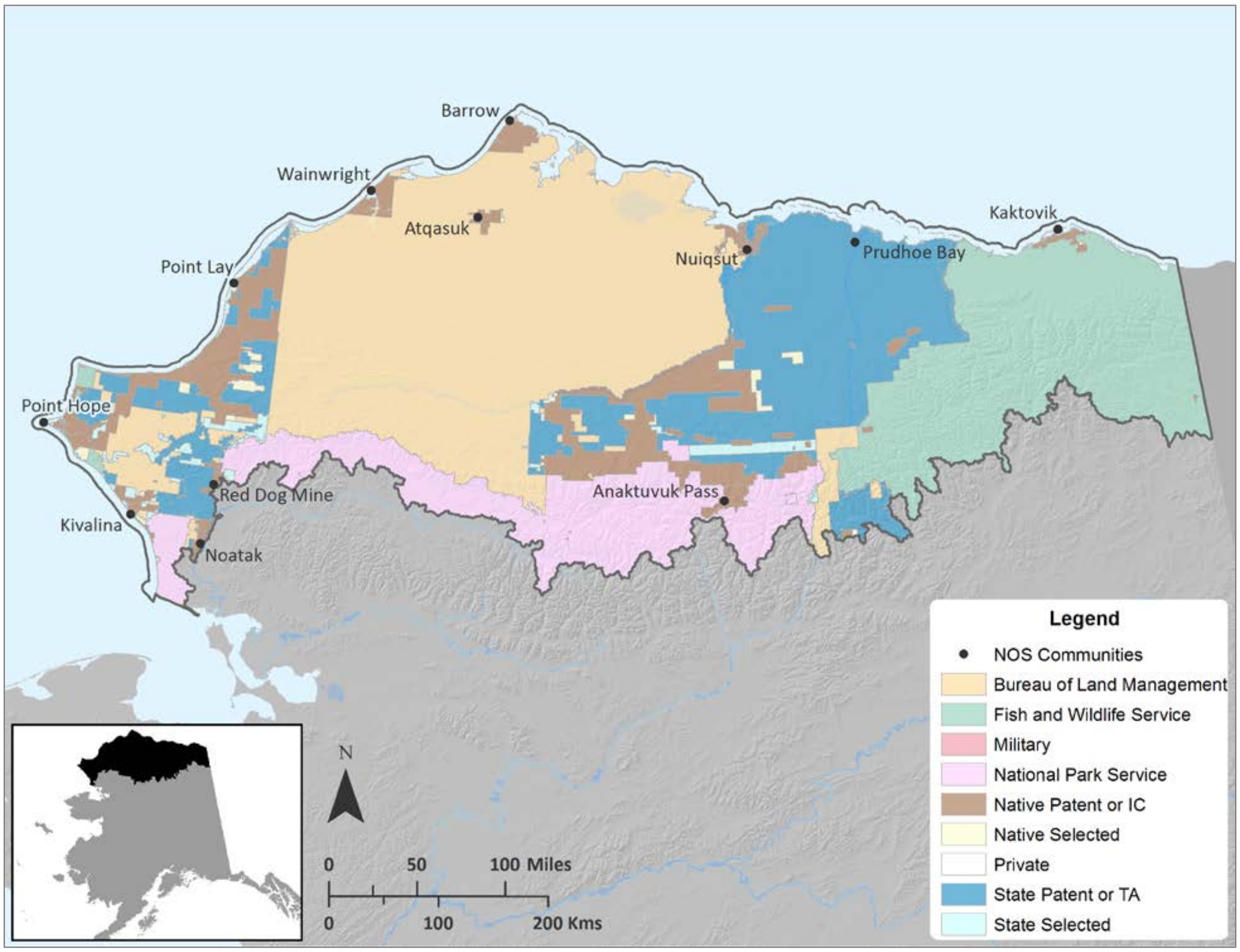


Figure E-1. Land status in the North Slope study area. Data Source: Bureau of Land Management.

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. km^2 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.

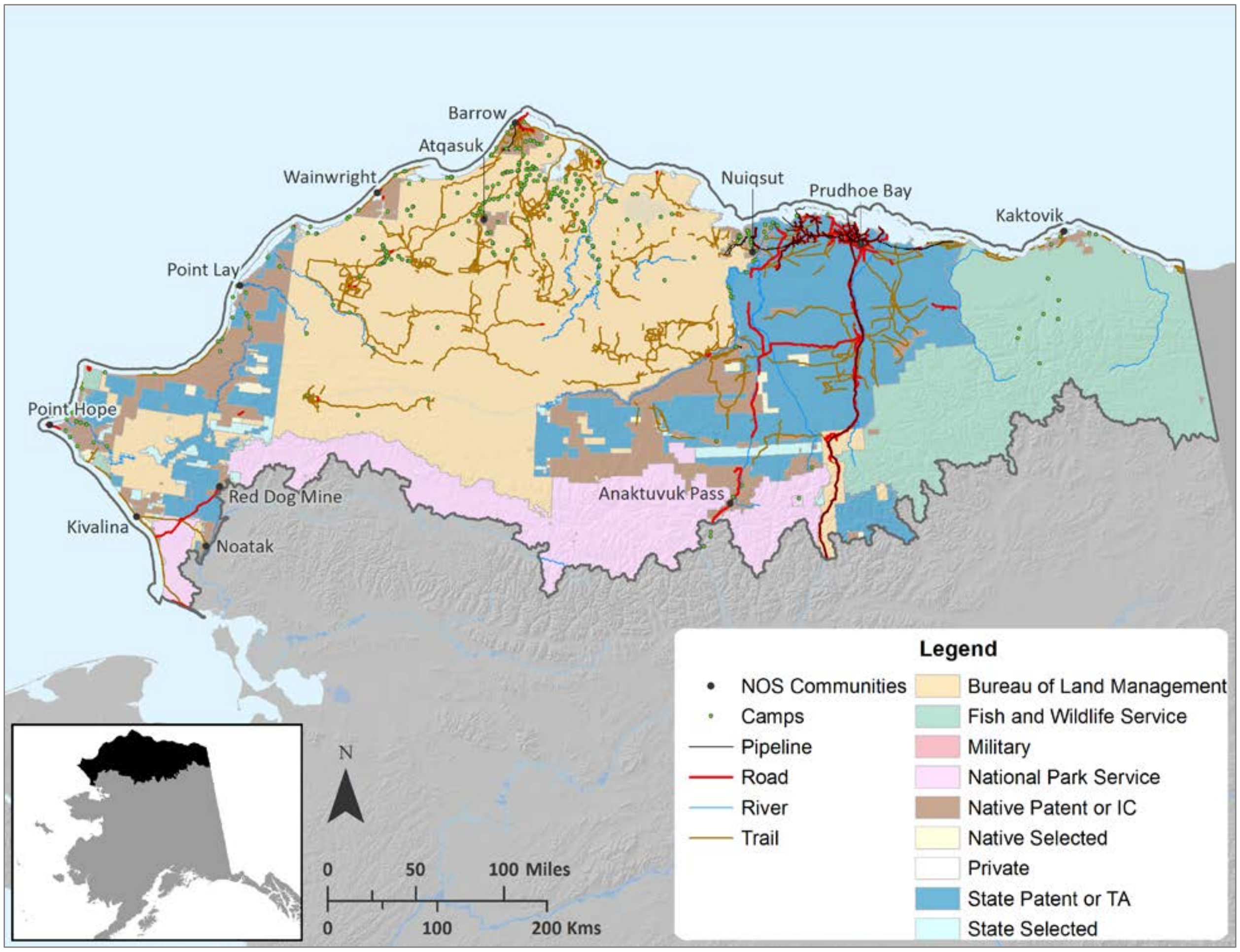


Figure E-2. Locations of camps and cabins in the North Slope study area. Data Sources: Bureau of Land Management; North Slope Borough; USGS; ADNR; ADFG; Mapmakers Alaska; UAA-ISER; UAA-AKHNP.

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

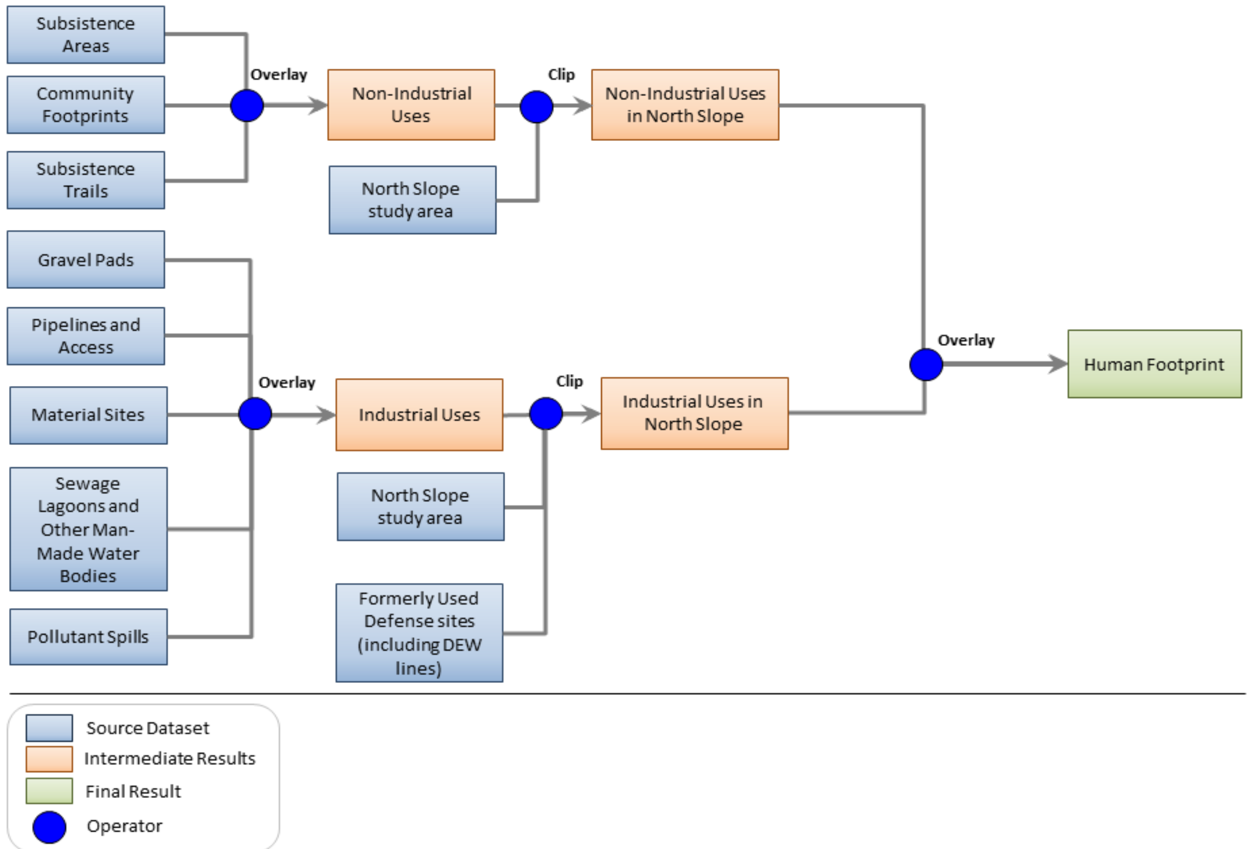


Figure E-3. Process Model for computing human footprint in the North Slope study area.

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 Atqasuk 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

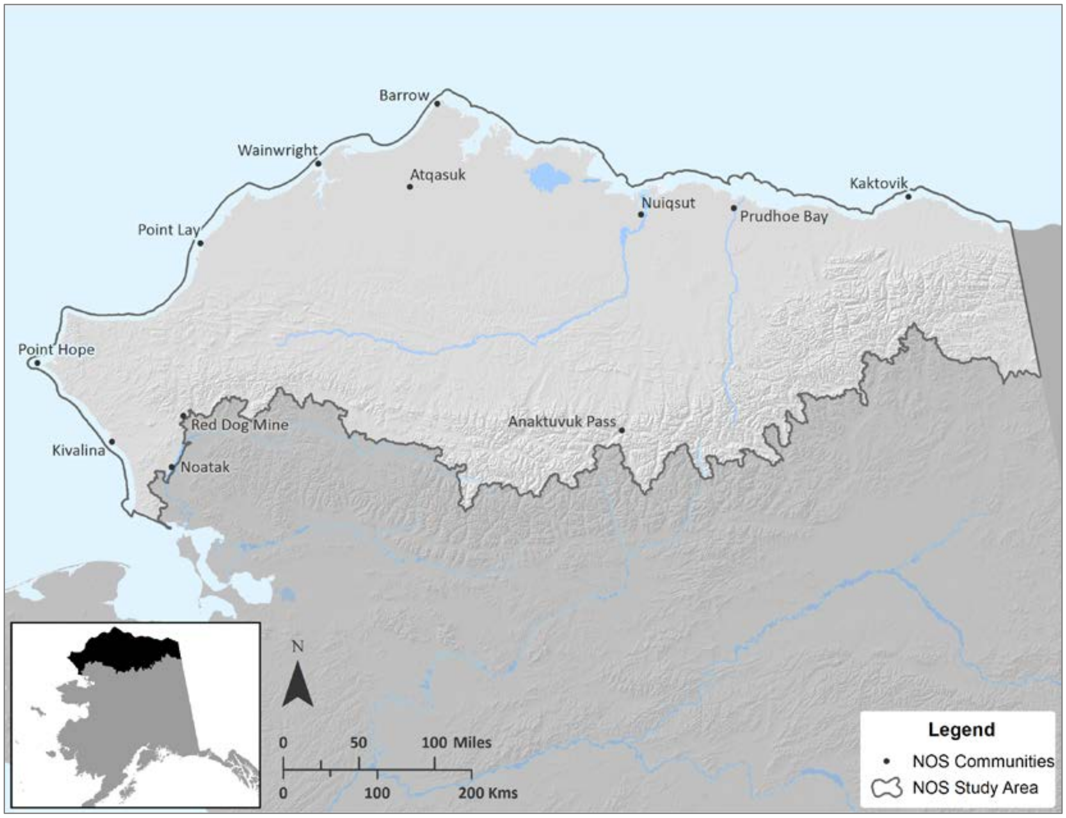


Figure E-4. Footprints of communities and populated places in the North Slope study area. Prudhoe Bay and Red Dog are not treated as communities, and their footprint is discussed in a separate section. Data Source: U.S. Census; UAA-ISER.

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
Atqasuk	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.

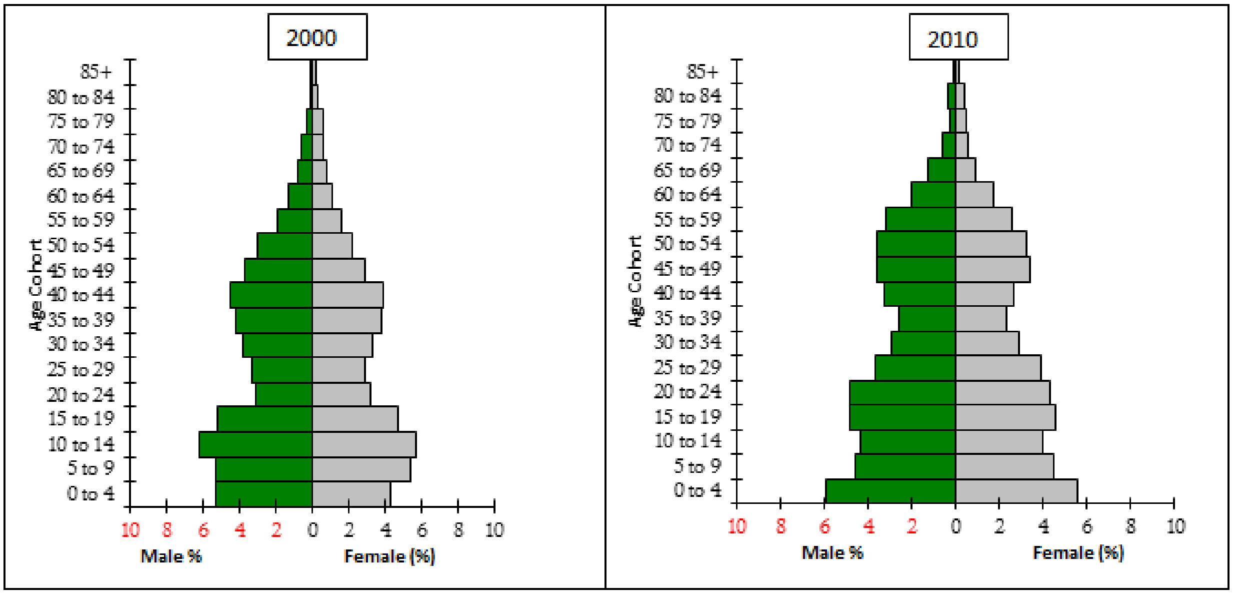


Figure E-5. Population structure of the North Slope study area (excluding group quarters; 2000 and 2010). Data Source: U.S. Census.

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 Atqasuk, 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.

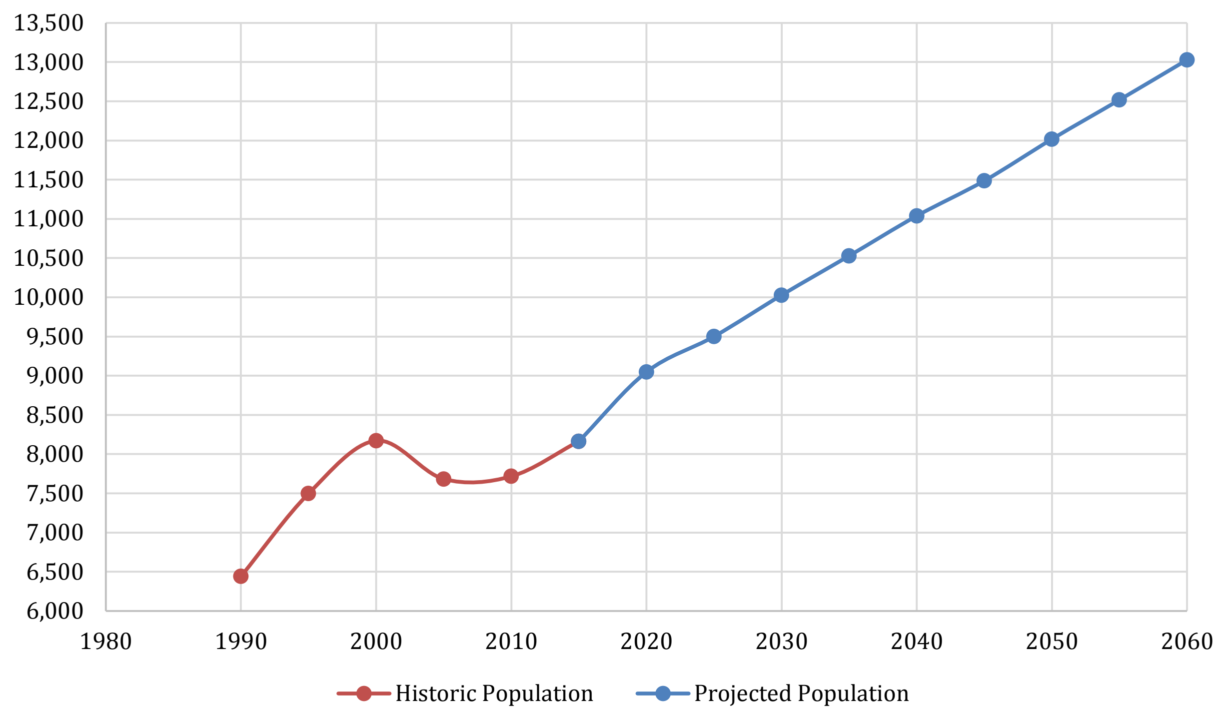


Figure E-6. Population projection of the North Slope study area (excluding Prudhoe Bay and Red Dog Mine). Data Source: Estimated by ISER

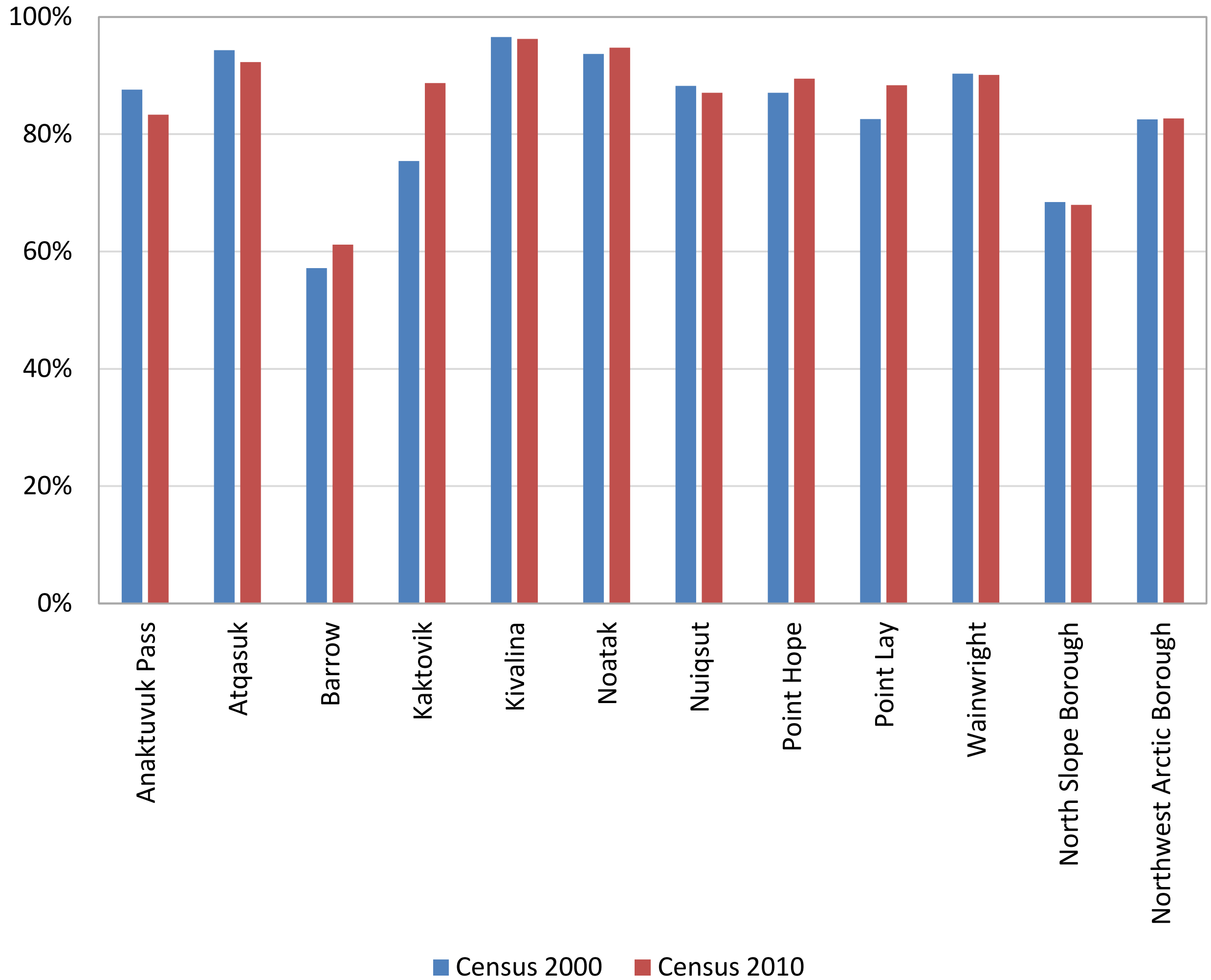


Figure E-7. Percentage of population reported as Alaska Native in each community in the North Slope study area. Data Source: Estimated by ISER.

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

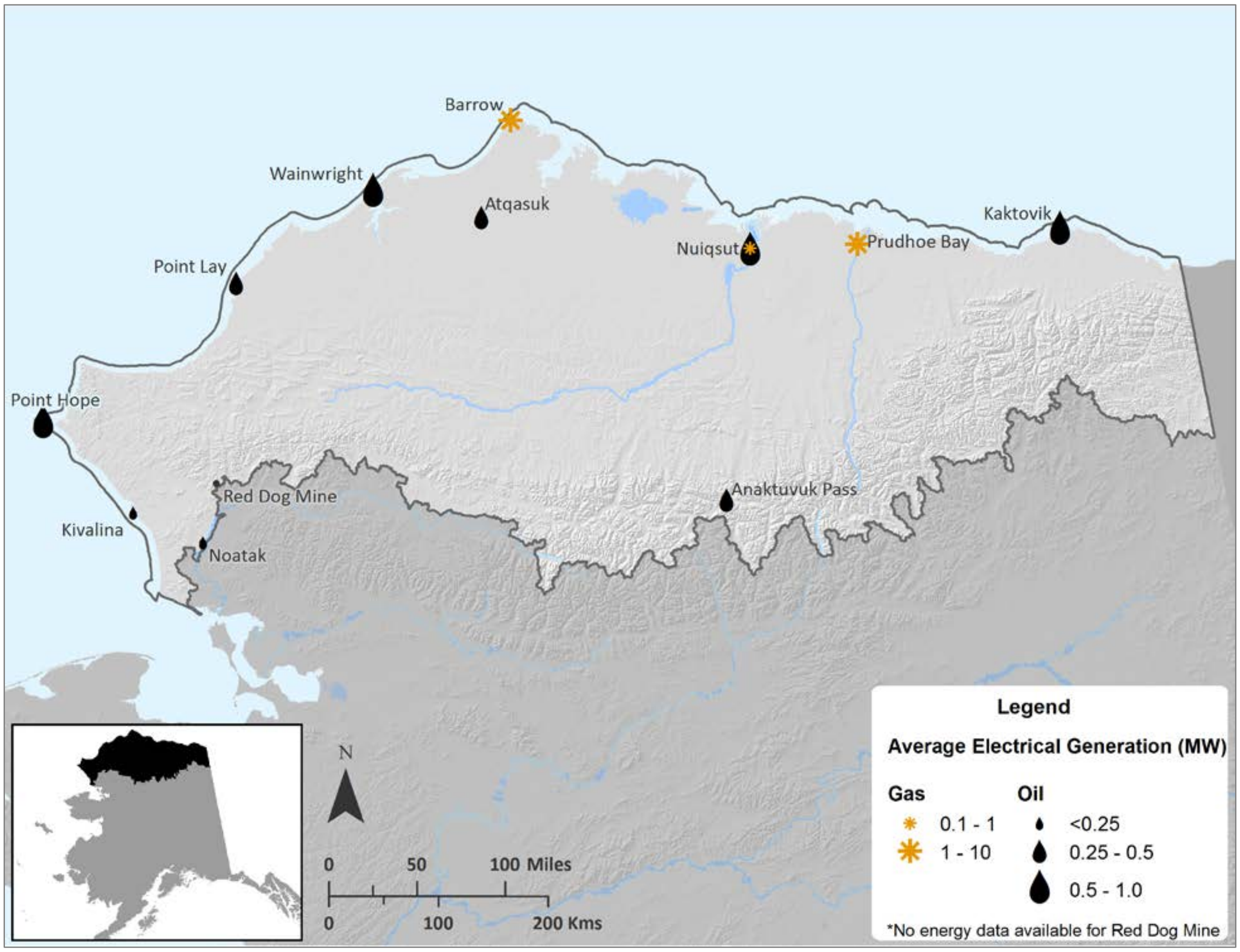


Figure E-8. Electricity generation capacity and source for each community in the North Slope study area. Data Source: Alaska Energy Authority (AEA).

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.

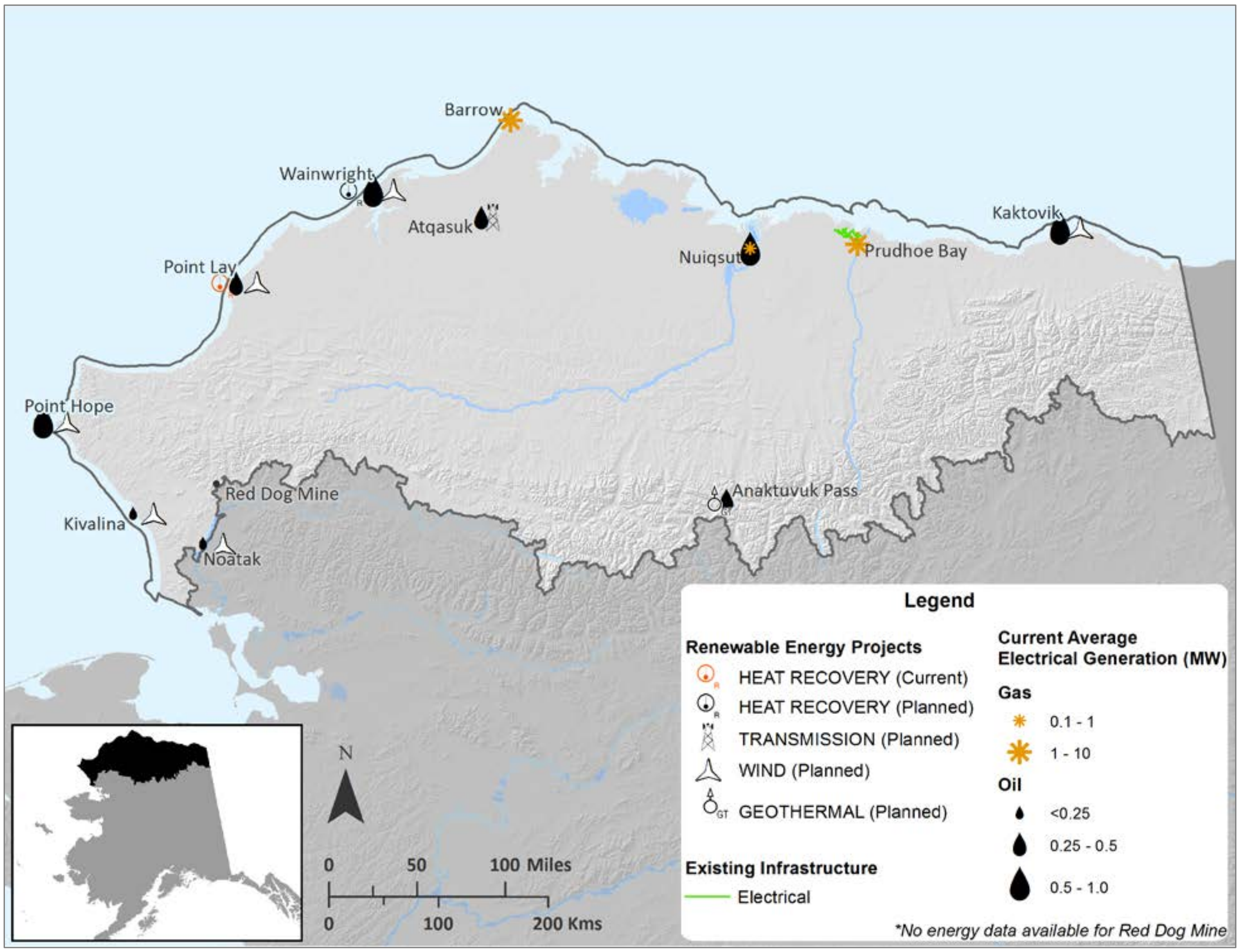


Figure E-9. Planned renewable energy projects in the North Slope study area. Data Source: Alaska Energy Authority (AEA).

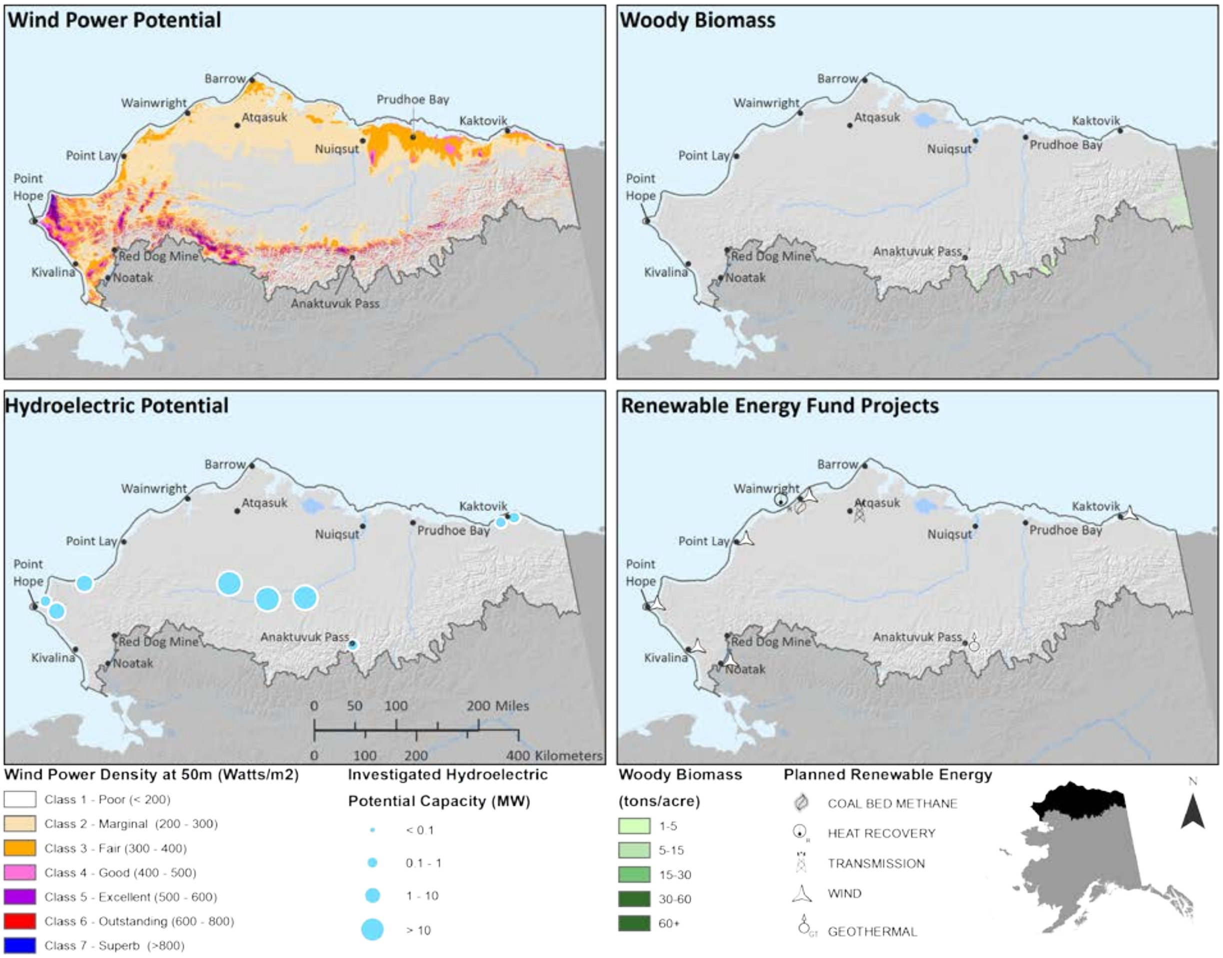


Figure E-10. Renewable energy potential in the North Slope study area. Data Source: Alaska Energy Authority (AEA).

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.

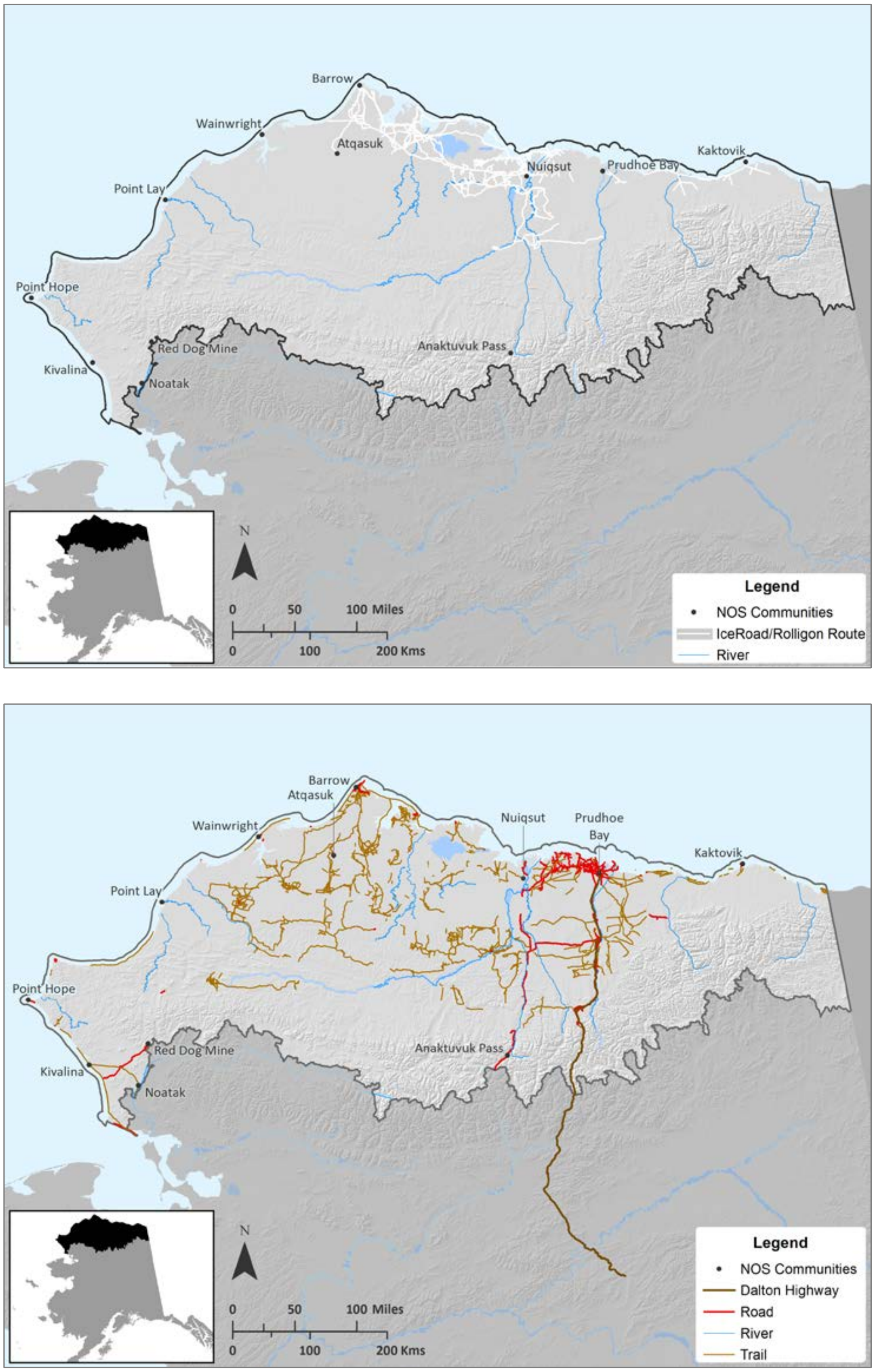


Figure E-11. Transportation infrastructure in the North Slope study area. Data Source: BLM; North Slope Borough; USGS; ADNR; ADFG; ADOT; Mapmakers Alaska; UAA-ISER; UAA-AKHNP.

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 Atqasuk 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 Atqasuk 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.

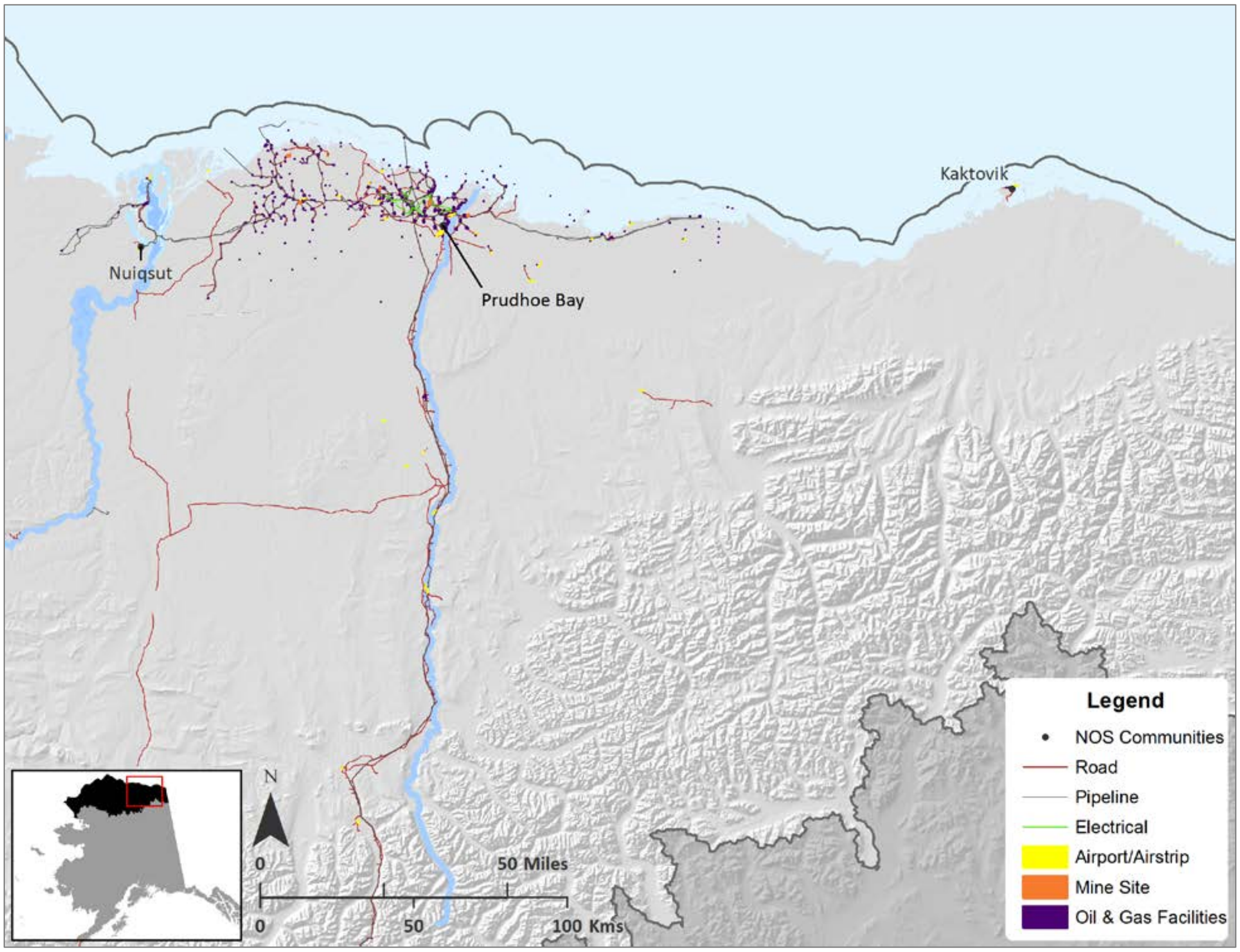


Figure E-12. Oil and gas infrastructure in the North Slope study area. Data Source: Mapmakers Alaska.

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.

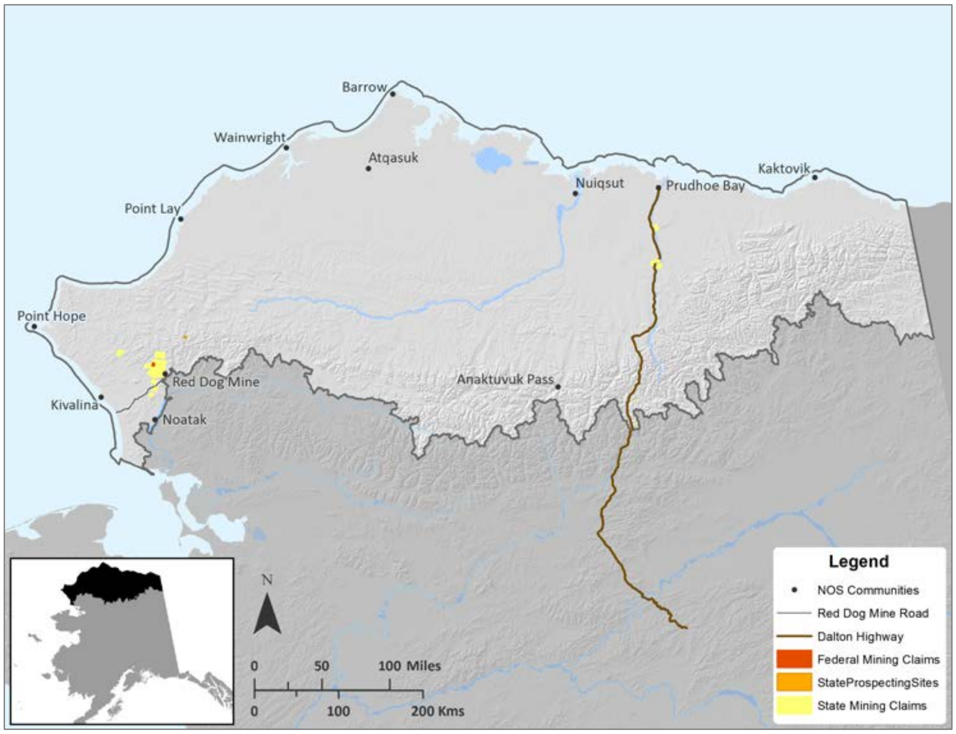


Figure E-13. Mining claims in the North Slope study area. Data Source: BLM; ADNR.

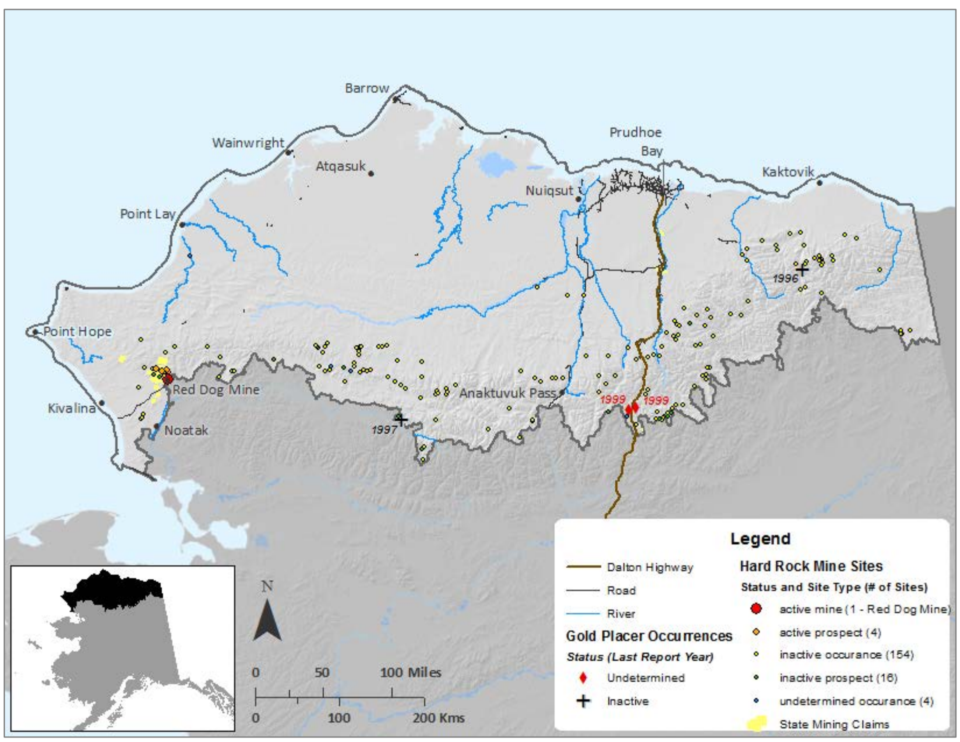


Figure E-14. Placer and hard rock mine sites from the Alaska Resource Data File (ARDF). Data Source: Alaska Resource Data File (ARDF).

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

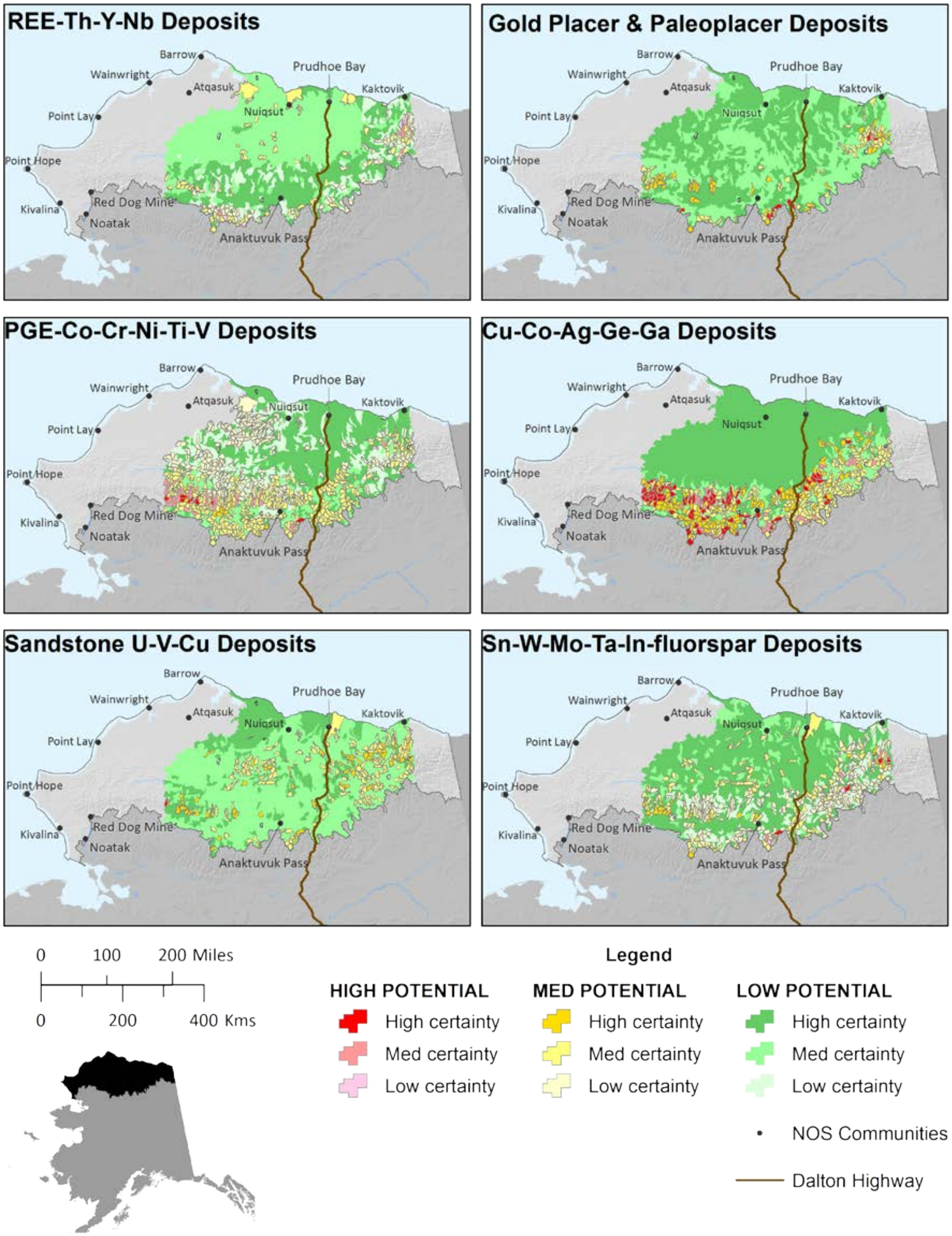


Figure E-15. Mineral potential for six deposit groups in the eastern part of the North Slope study area. Data Source: USGS.

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*Ga/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.

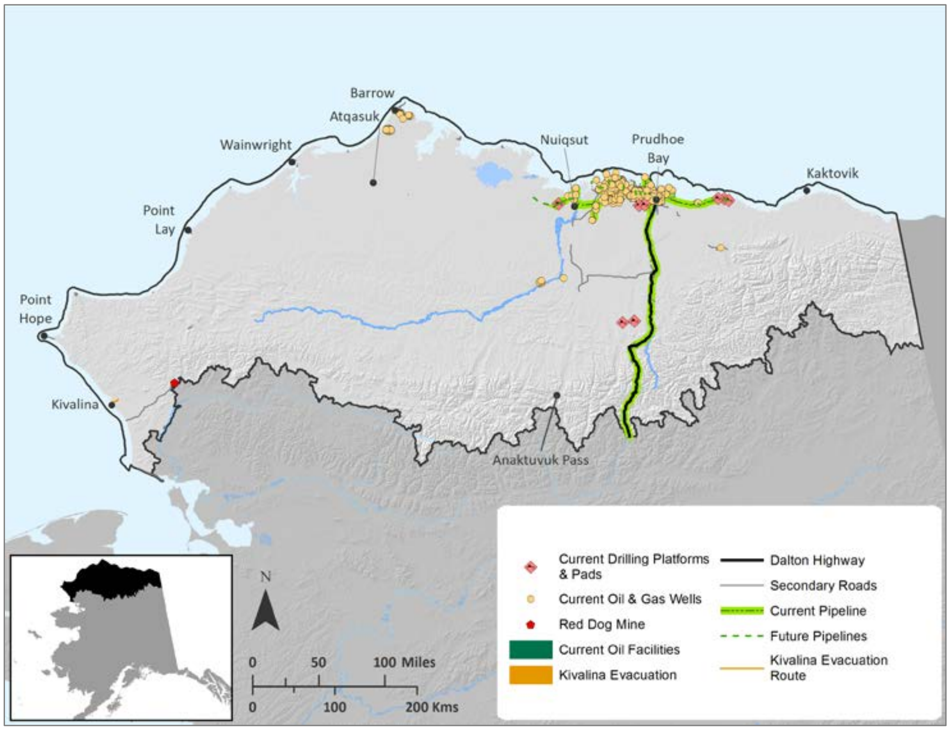


Figure E-16. Medium development scenario (2040) showing changes in oil and gas activity in the North Slope study area. Data Source: North Slope Science Initiative Scenarios Project.

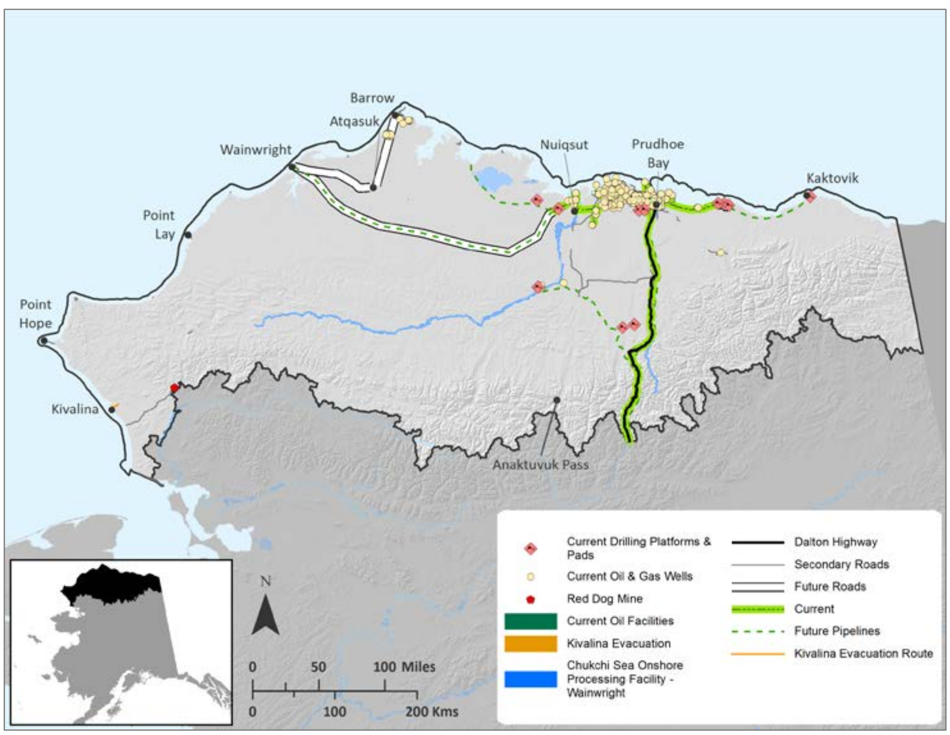


Figure E-17. High development scenario (2040) showing changes in oil and gas activity in the North Slope study area. Data source: North Slope Science Initiative Scenarios Project.

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, education, cultural wellbeing, closeness to nature, 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.

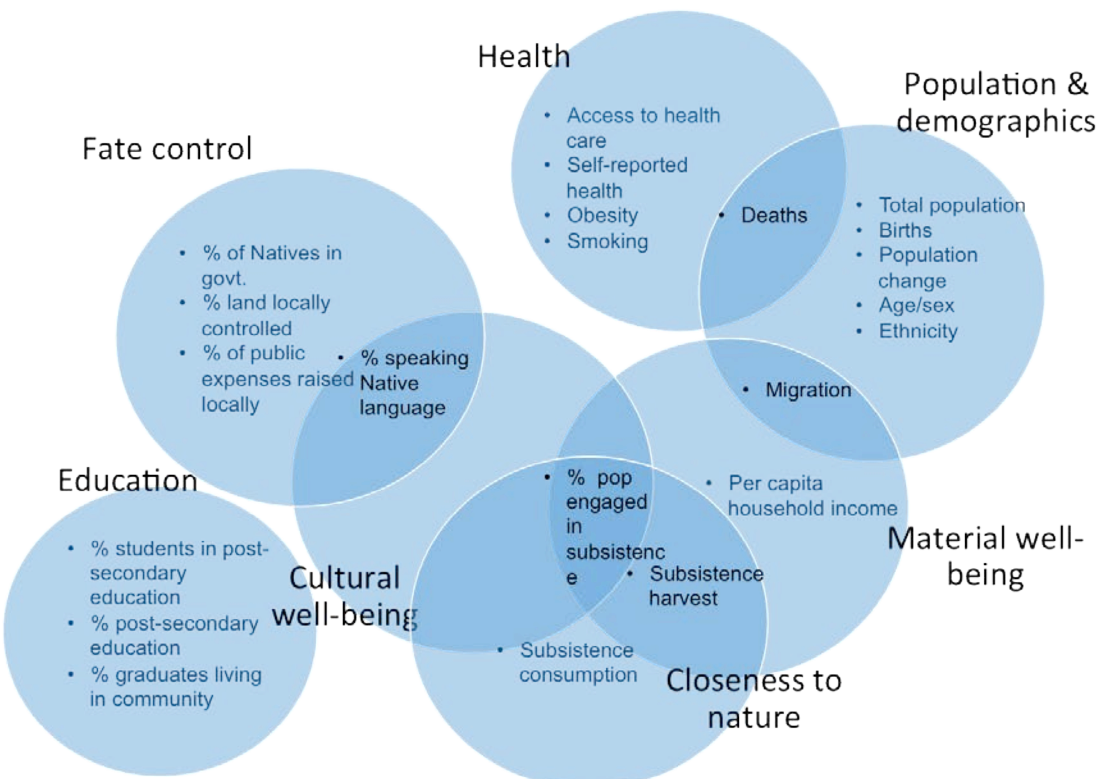


Figure E-18. Arctic Social Indicators (ASI) organized into seven domains. Data Source: Arctic Social Indicators (ASI) Report.

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-censual 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 NANA[1] 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.

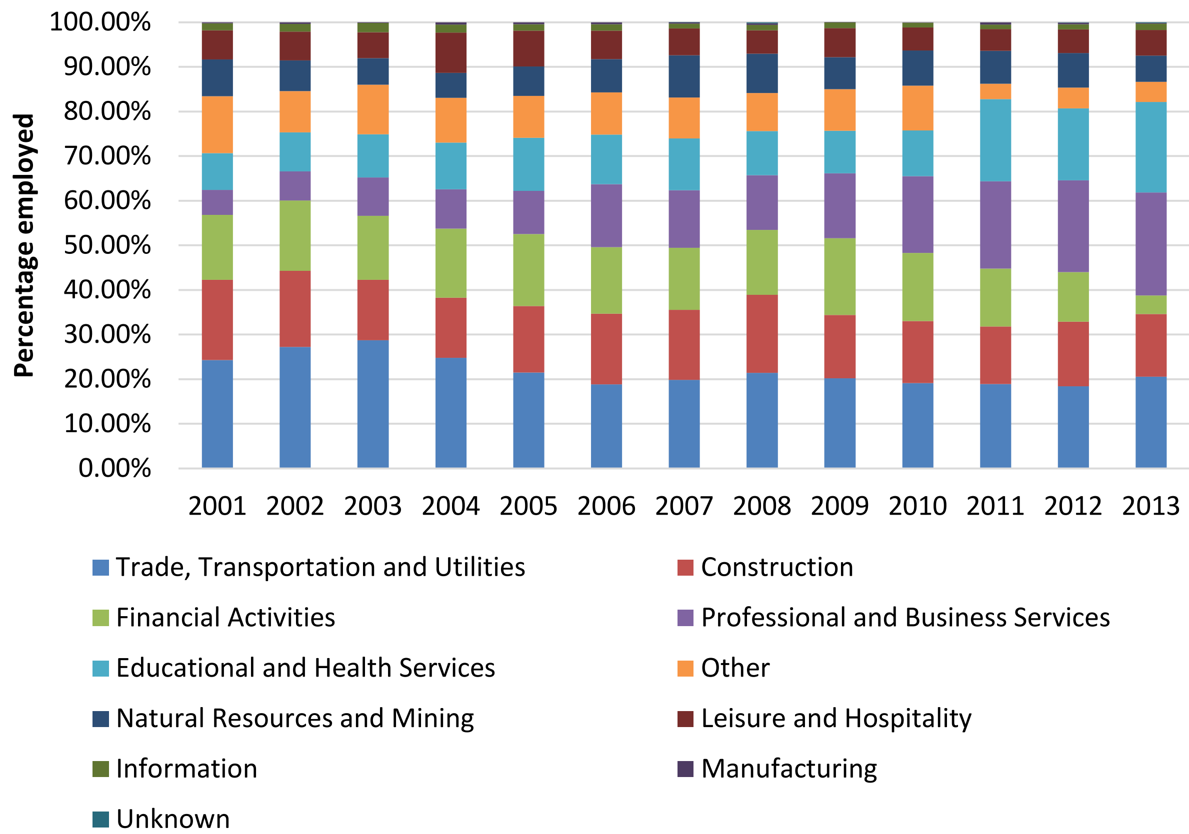


Figure E-19. Employment by industry in the private sector – North Slope study area including the oil industry and Red Dog Mine (2001-2013). Data Source: Alaska Department of Labor and Workforce Development (AK-DOLWD).

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
Atqasuk 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.

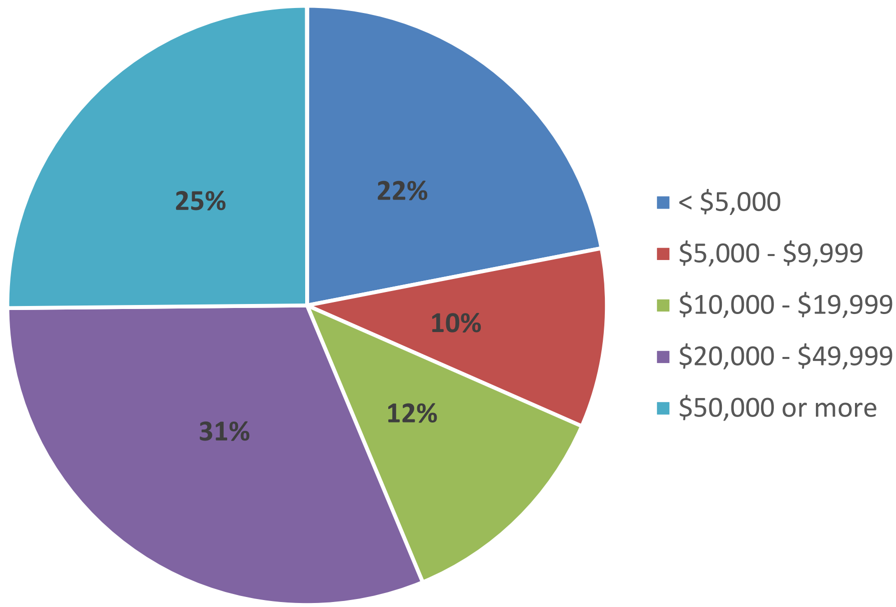


Figure E-20. Percentage of workers by annual per capita wage income (2001-2010 average) in the North Slope study area. Data Source: Alaska Department of Labor and Workforce Development (AK-DOLWD).

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
Atqasuk	Atqasuk 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 Atqasuk, 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 Atqasuk 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.

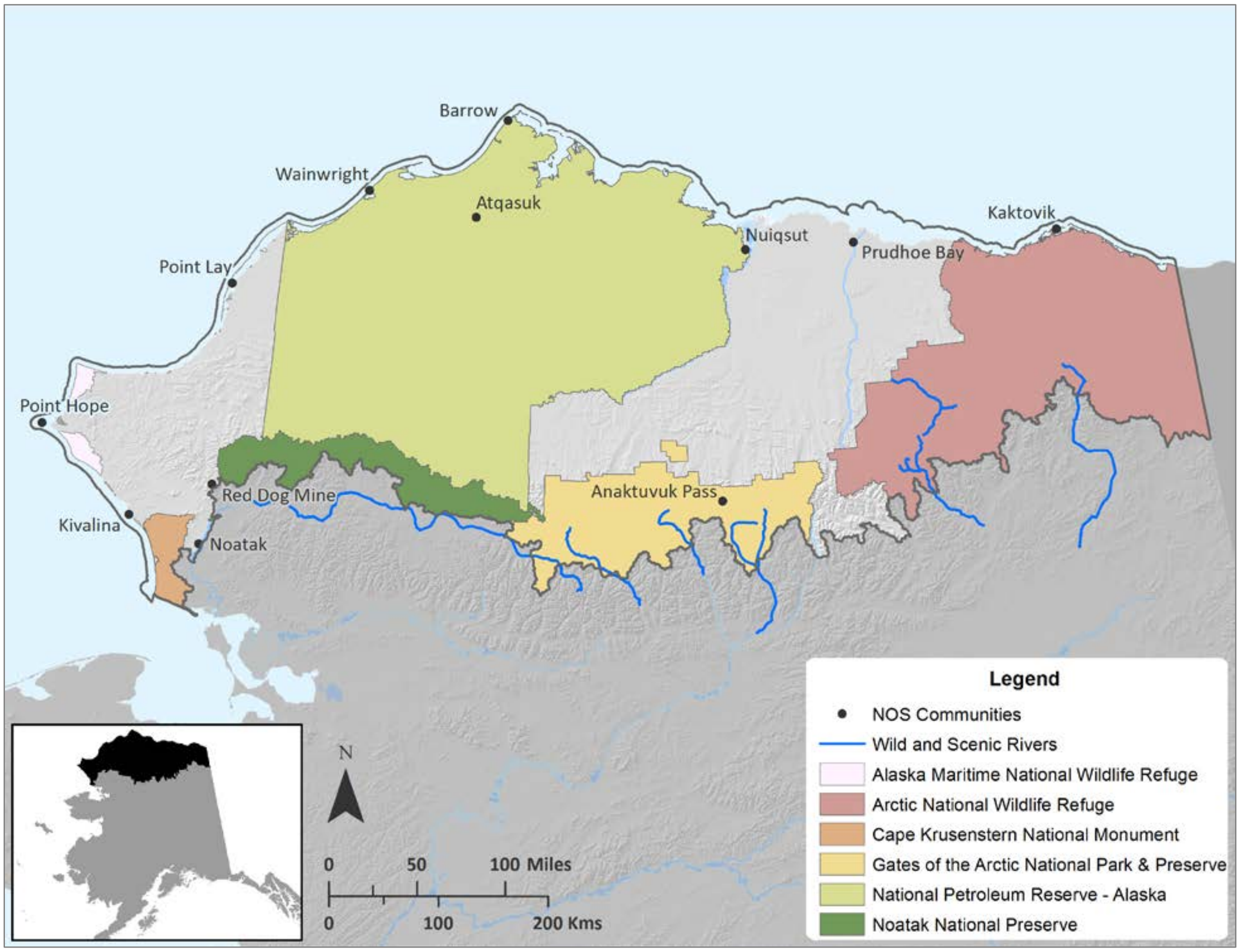
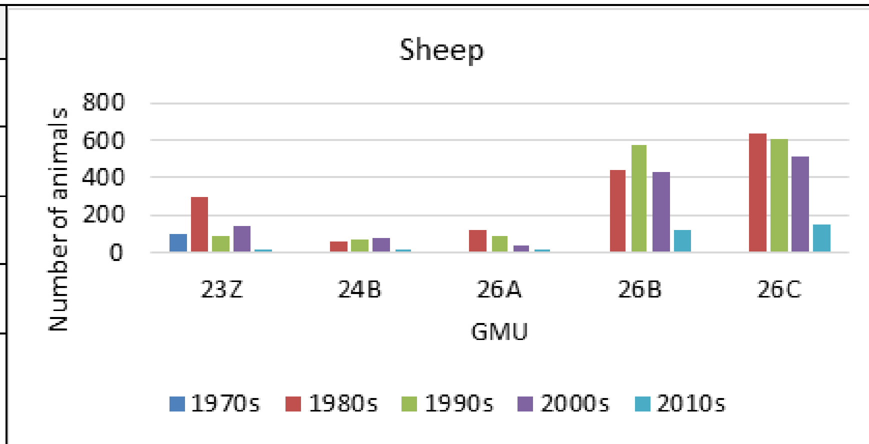


Figure E-21. Federal protected areas in the North Slope study area. Data Source: BLM; ADNR; U.S. Dept. of the Interior.

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.

NS Community	GMU
Anaktuvuk Pass	24B
Atqasuk	26A
Barrow	26A
Kaktovik	26C
Kivalina	23Z
Noatak	23Z
Nuiqsut	26A
Point Hope	23Z
Point Lay	26A
Prudhoe Bay	26B
Red Dog	23Z
Wainwright	26A



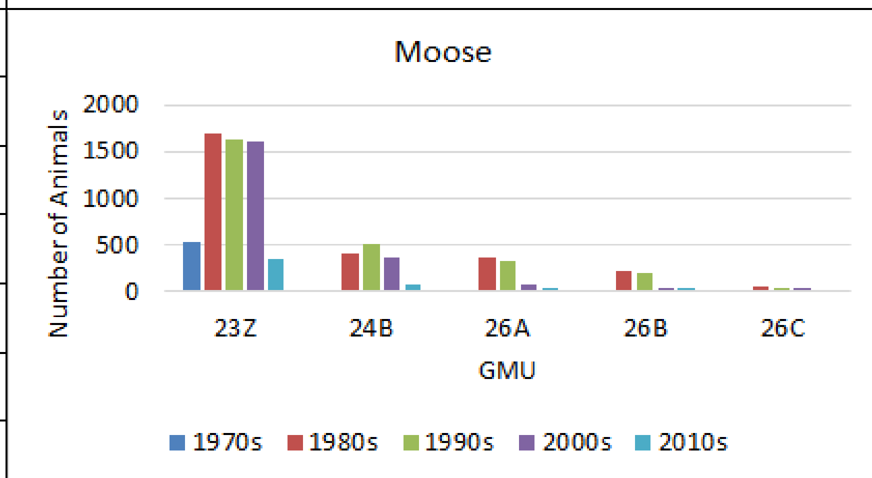


Figure E-22. Sport harvest of sheep and moose in the North Slope study area (1970s – 2010s). Data Source: Alaska Department of Fish and Game (ADF&G).

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.

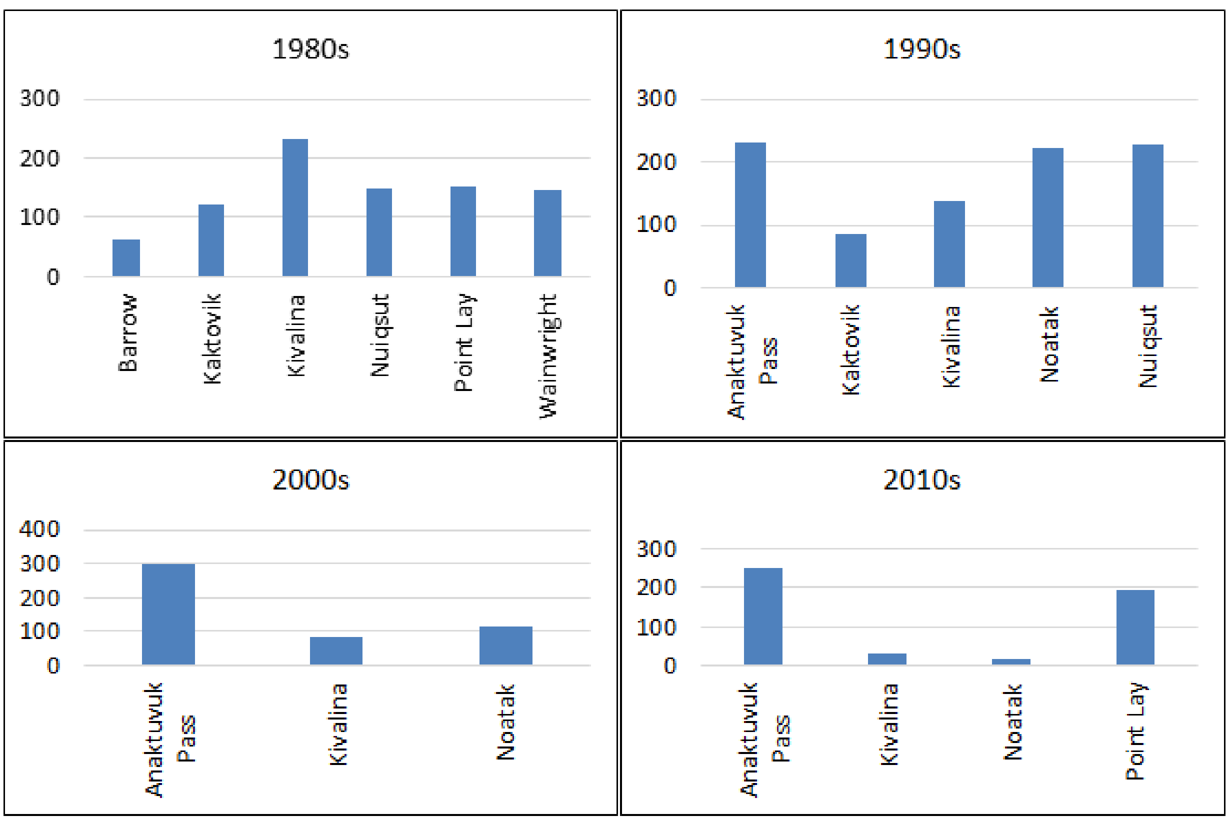


Figure E-23. Average per capita subsistence harvest of caribou (in pounds) for communities surveyed (1982 – 2013). Data Source: Alaska Department of Fish and Game (ADF&G).

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.

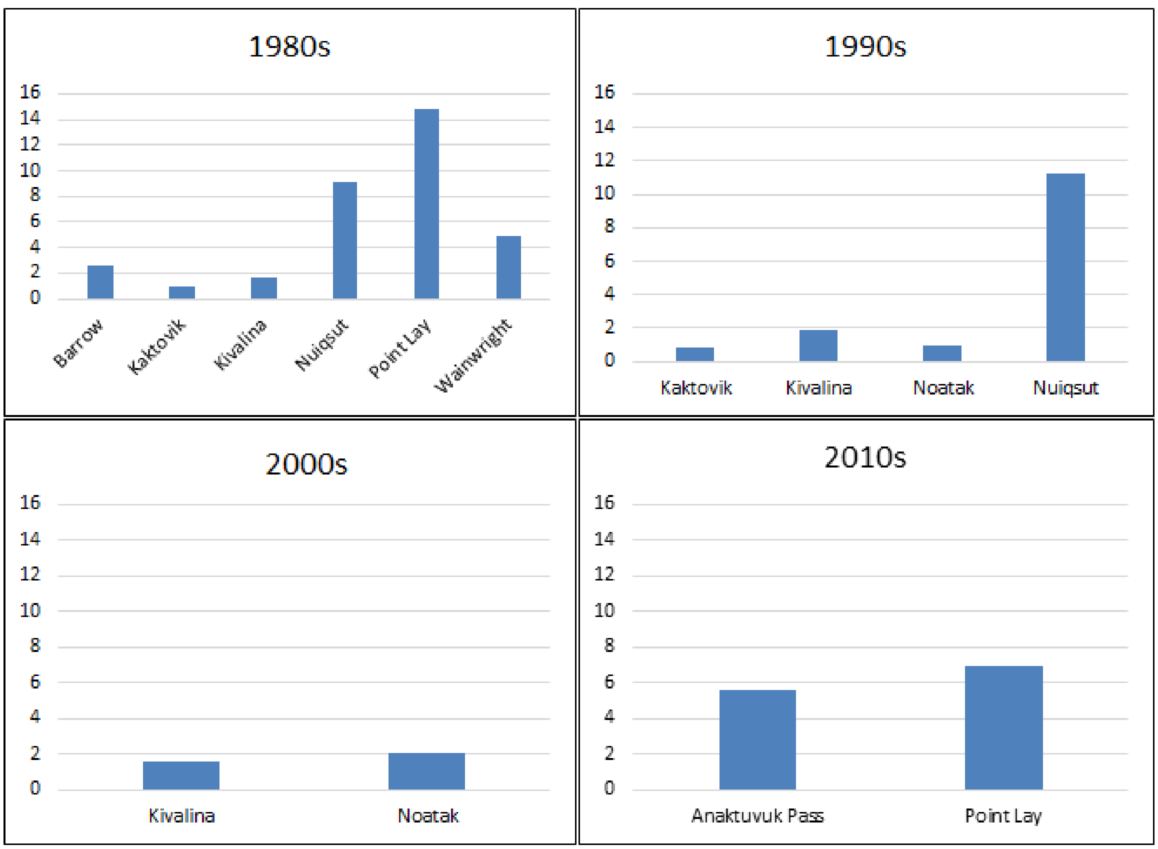


Figure E-24. Average per capita subsistence harvest of grayling (in pounds) for communities surveyed (1982 – 2013). Data Source: Alaska Department of Fish and Game (ADF&G).

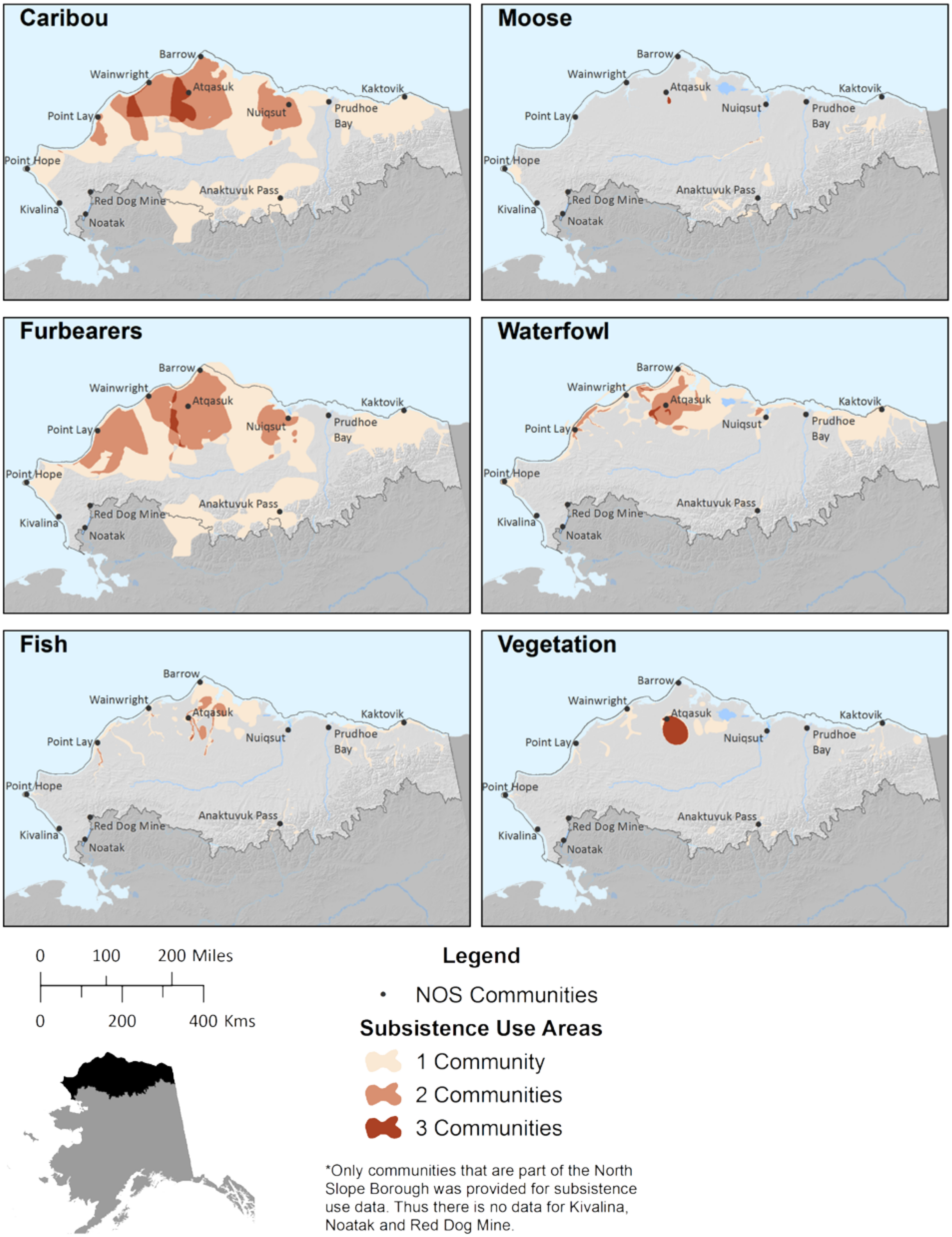


Figure E-25. Subsistence use areas within the North Slope study area. Data Source: North Slope Borough.

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, Atqasuk, 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.

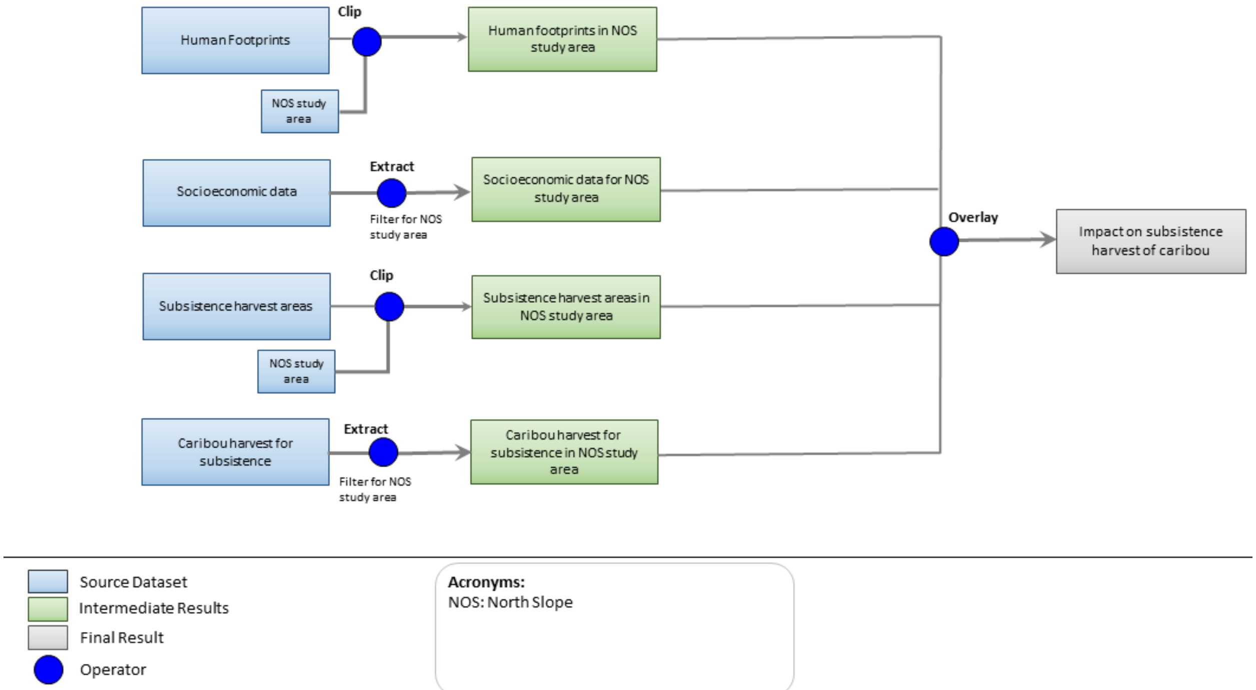

Figure E-26. Process model identifying measurable impacts of development on subsistence harvest.

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 (ft^2 or m^2) 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 Atqasuk 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?

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?

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.

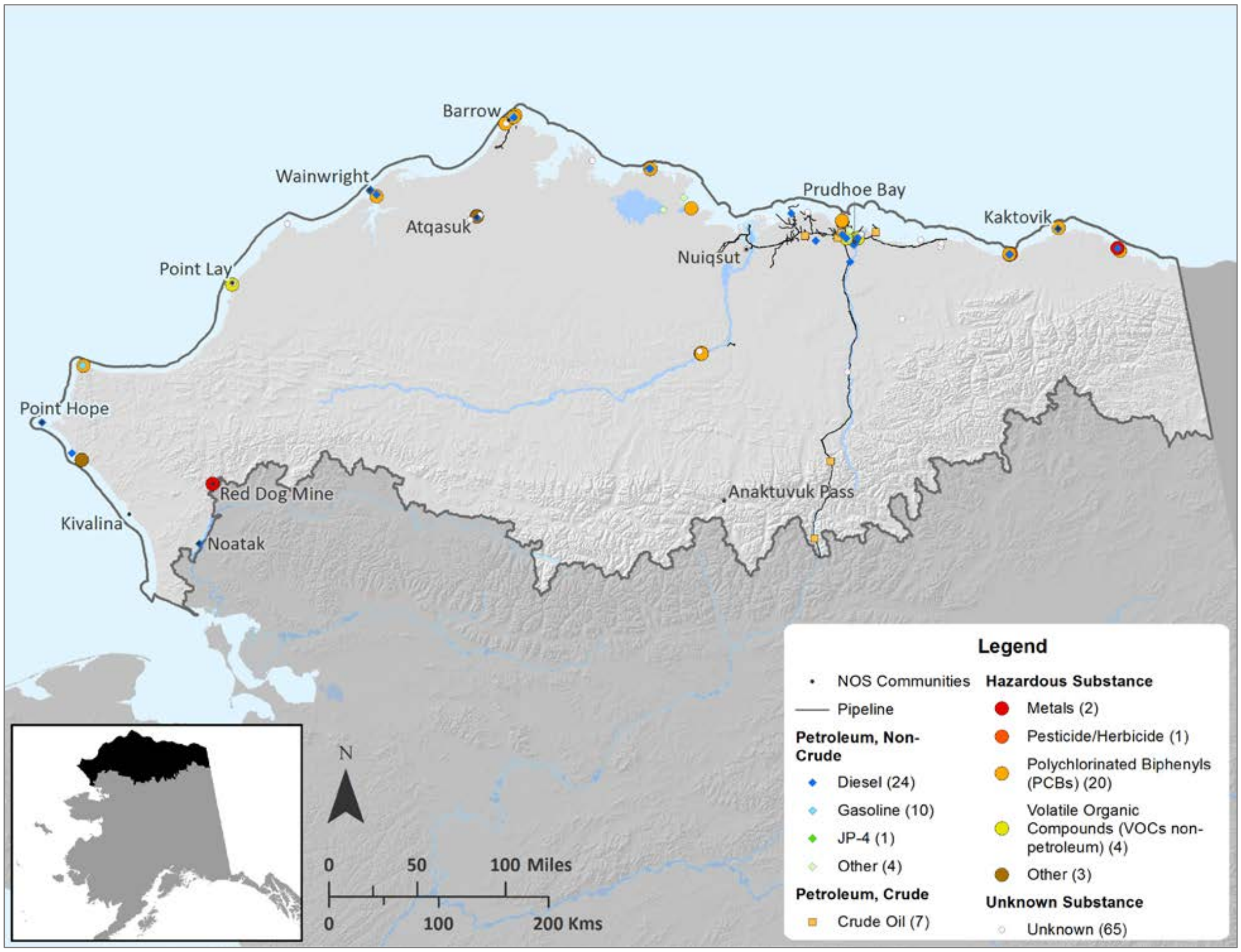

Figure E-27. Sites with known contaminants in the North Slope study area. Data Source: ADEC Contaminated Sites Program.

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 contaminates. 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 contaminates 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 contaminates 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
		Mammals	
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	
		Birds	
Greater White-Fronted Goose	Radionuclides	No	
	Cadmium	No	
	Arsenic	No	
	Copper	No	
	Lead	No	
	Mercury	No	
	Selenium	No	
	POPs	No	
	PAHs	No	
		Fish	
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?

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.

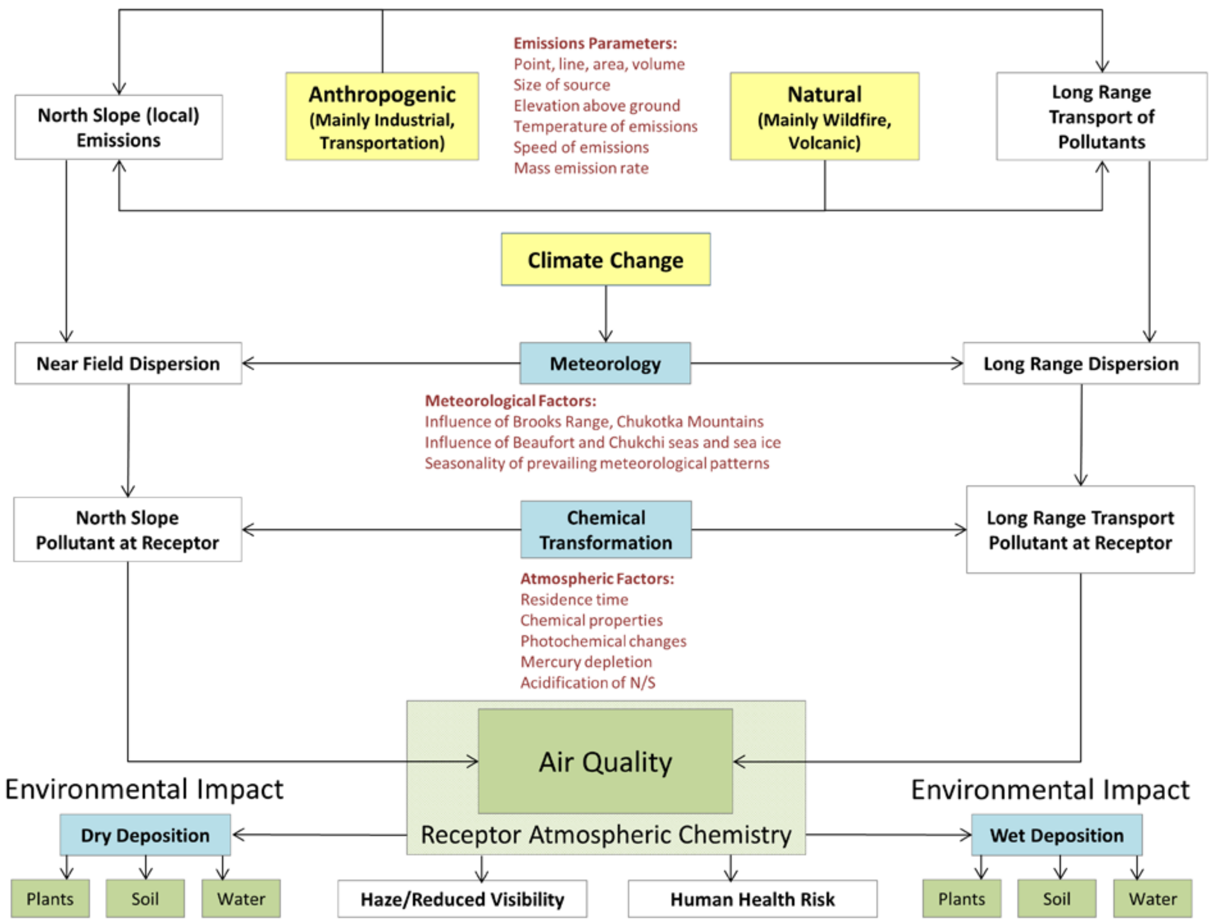

Figure E-28. Conceptual model for air quality in the North Slope study area.

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 in 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).

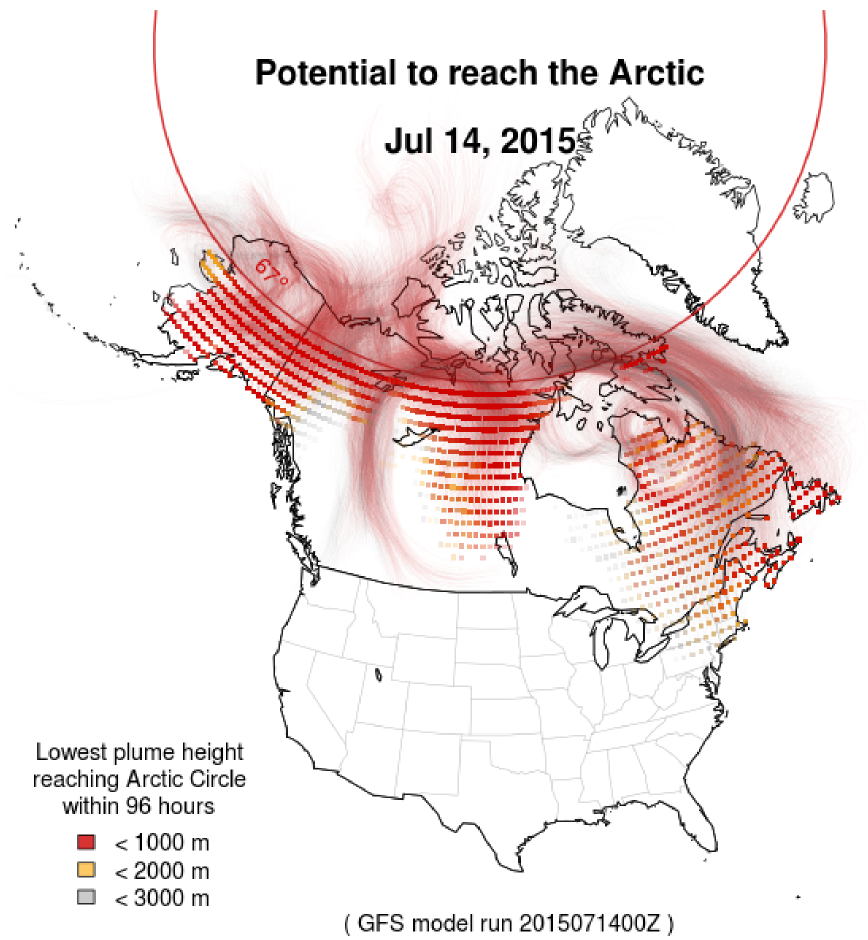

Figure E-29. Daily Arctic transport forecast showing potential for atmospheric transportation of smoke from wildfires to the Arctic (available from http://www.airfire.org/).

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 circumarctic 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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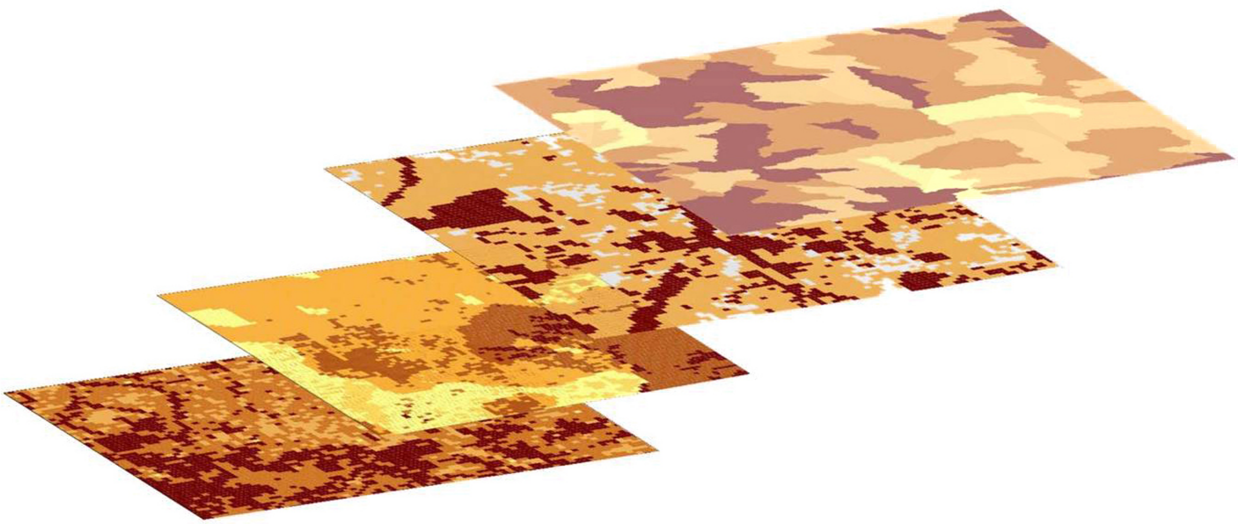
F. Landscape and Ecological Integrity

E. Jamie Trammell

Alaska Natural Heritage Program & Geography and Environmental Studies Department, University of Alaska Anchorage, 3211 Providence Drive, Anchorage, Alaska 99508



Summary

Section F. *Landscape and Ecological Integrity* provides the detailed descriptions, methods, datasets, results, and limitations for the assessments of Landscape Condition, Landscape Intactness, and Cumulative Impacts of Change Agents.

Contents

Tables

Figures

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1. Introduction

There is little debate that humans have dramatically impacted the landscape, particularly in the last 200 years. How we measure the impact, however, has been widely debated and discussed (Baldwin et al. 2009, Steinitz 1990, Anderson 1991, Danz et al. 2007, Girvetz et al. 2008, Alberti 2010). Many attempts at mapping and quantifying the "human footprint" exist (Forman and Alexander 1998, Trombulak and Frissell 2000, Theobald 2001, Sanderson et al. 2002, Theobald 2004, Theobald 2005, Theobald 2010). Additionally, it is largely recognized that merely the presence or absence of humans does not mean that the ecosystem is or is not operating in its peak condition. The presence or absence of human modification is only one of three criteria thought to define ecological integrity (Noss 2004). *Ecological resistance* (the ability to resist changes and stay intact regardless of the modification) and *resilience* (the ability to recover quickly, and without loss of function, following a disturbance) are equally important in quantifying the integrity of an ecosystem. Unfortunately, appropriate measures of resistance and resilience are difficult to identify, and often require intensive surveying and research effort. Human footprint on the other hand, is easily measurable. Further, the human footprint is the one factor that land managers have the most control over.

The BLM originally proposed an ecological integrity assessment as one of the integrated datasets created for the Rapid Ecoregional Assessments (REAs). However, due to the reasons stated above, most REAs have assessed what they call *ecological intactness*. After multiple discussions with the AMT and representatives at the BLM National Operations Center (NOC), we were approved to assess *Landscape Integrity* (LI) instead of ecological intactness or ecological integrity. Given that Alaskan landscapes are largely intact, landscape integrity better captures the impacts of human modification on the landscape without assuming that ecological integrity is compromised.

We define Landscape Integrity to include three different descriptions of the landscape: landscape condition, landscape intactness, and potential cumulative impacts (Figure F-1). It should also be noted that landscape condition is used in other sections to provide a measure of status for each CE. More information and interpretation of CE status can be found in Section H. Details and methods for each of these are described in more detail below.

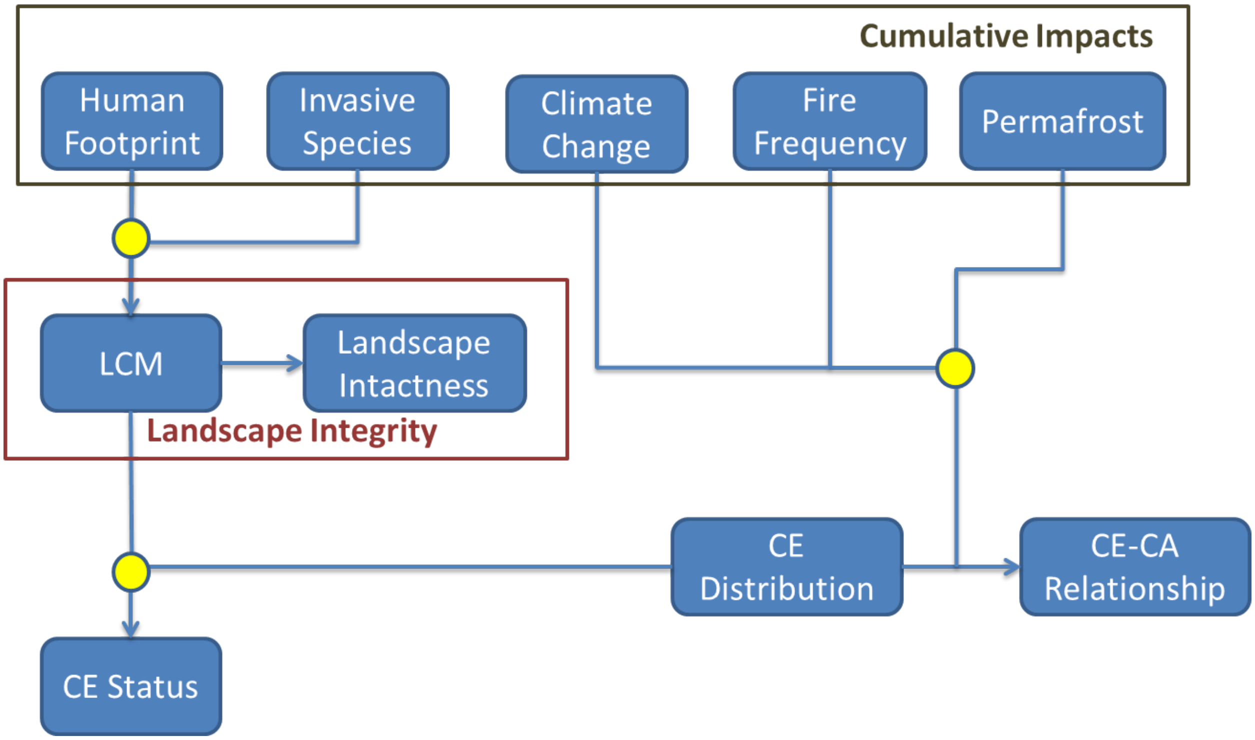

Figure F-1. Process model describing the various integrated products developed in this REA to explore the integrity of this region.

2. Landscape Condition

The Landscape Condition Model (LCM) is a simple yet robust way to measure the impact of the human footprint on a landscape (Comer and Hak 2009). The LCM weights the relative influence of different types of human footprints based on factors such as permanence and the nature of the activity. Permanent human modification is weighted the highest, while temporary use, like snow roads and snowmachine trails, receives less weight. Intensive land uses like mining is also weighted higher than less intensive land uses like hunting or trapping cabins. These weights are summed across the landscape and coalesced into a single surface identifying how impacted a given area is due to human modification. The LCM was specifically requested by AMT members for this REA to compliment the LCM developed for the Seward Peninsula and Yukon Kuskokwim REAs. The LCM, unlike the other models in this section, is provided at both its native resolution (60 m) and as a 5^{th}-level HUC summary.

2.1. Methods

Human Land Use Data

The LCM was originally developed to understand landscape condition across the contiguous United States, and therefore includes many datasets that either do not exist in Alaska or are not common modifications to Alaska landscapes (see Comer and Hak 2012 for a complete table of required datasets for LCM). Thus, we modified the data inputs to fit data availability and utility. Additionally, there are some forms of transportation that are unique to Alaska (at least in scale; e.g., using frozen rivers as snow machine trails) and therefore needed to be included in the LCM. Table F-1 is a list of the datasets used for the LCM, while Table F-2 details how the specific datasets were modeled in the LCM. In addition to the source datasets listed below, current human development footprints were also developed for the region (see Section E).

Table F-1. Source datasets for analysis of Landscape Condition.

Dataset Name	Data source
Transportation routes; including local roads, industrial roads, and the Dalton highway.	AK Department of Transportation
Industrial lines; including power lines, phone lines and transmission lines	AK Department of Natural Resources
Oil and gas wells	Audubon Alaska
Current mines (Red Dog mine)	USGS-AK Resource Data File
Introduced plant species	AKEPIC

Model Parameters

There are two key parameters in the LCM that determine how a defined human modification of the landscape impacts the condition of that landscape. The first is the site impact score that indicates how intense a human modification is to the landscape. The impacts are normalized to be on a score of 0 (for biggest impact, or lowest condition score) to 1 (least impact, or highest condition score). The second is the decay distance that indicates the distance at which the impact to the landscape is no longer experienced. Both of these parameters are defined in the original LCM through an exhaustive literature and expert review. The limitation is that these impacts are generically implemented across the contiguous U.S. and Alaska through previous REAs, and therefore do not include the potentially unique impact that land uses have on systems in Alaska. However, when available, we updated both the site impact score and decay distance values based on literature of impacts to systems in Alaska. Specifically, the decay distance associated with major roads is thought to be much larger due to the extensive use of ATVs and snowmachines by Alaskans (Strittholt et al. 2006). We extend this increase to some of the other road types as well as the urban land uses, as snowmachine and ATV use is not excluded to major roads.

Table F-2. List of datasets and parameters assigned to different human land uses for use in the Landscape Condition Model.

Theme	Data Source	Description	Site Impact Score	Est. Relative Stress	Decay Distance (m)
Transportation					
Alternative Transportation Routes	Digitized using aerial imagery (BDL-GINA)	Lower Coleville River	0.7	Low	500
Local Roads	AK DOT, refined using aerial imagery (BDL-GINA)	Local roads within villages	0.2	High	500
Haul Road	AK DOT	Dalton Highway	0.05	Very High	5000
Urban and Industrial Development					
High Density Development	Digitized using aerial imagery (BDL-GINA)	Oil facilities	0.05	High	2000
Medium Density Development	Digitized using aerial imagery (BDL-GINA)	Village footprints	0.5	Medium	1000
Medium Density Development	North Slope Borough	Hunting/fishing camps	0.5	Medium	1000
Powerline/Transmission lines	AK DNR	Current industrial lines	0.5	Medium	500
Oil /gas Wells	Audubon Alaska	Current, non-exploratory oil and gas wells	0.5	Medium	500
Current Mines	USGS-ARDF	Red Dog mine	0.05	Very High	1500

Theme	Data Source	Description	Site Impact Score	Est. Relative Stress	Decay Distance (m)
Managed and Modified Land Cover					
Introduced Plant Species	AKEPIC	Same dataset used in Invasive Species CA analysis	0.5	Medium	200

Surface Creation

Once site impact scores and decay distances are defined, a series of GIS-based models generate multiple layers of landscape condition. To create a continuous surface representing the combined landscape condition, we mosaicked the various raster datasets using the “minimum” function. This allowed multiple land uses to be considered for any given cell, but assigned the lowest condition score (highest impact) to the cell. This created a continuous surface of human modification for the region. To aid in our core analysis, the LCM was then summarized at 5th-level HUCs and bracketed into equal interval quantiles (for ease in interpretation) representing categories of condition. Condition classes are defined in Table F-3.

Table F-3. Classification of Landscape Condition Model.

LCM Score	Condition Class
0.0 – 0.2	Very Low
0.2 – 0.4	Low
0.4 – 0.6	Moderate
0.6 – 0.8	High
0.8 – 1.0	Very High

Future Landscape Condition

Different from other REAs in Alaska, we worked closely with the North Slope Science Initiative Scenarios project to incorporate future human footprint estimates from their scenario exercises (see Section E). Instead of near and long-term futures, we use the interim “Medium” and “High” development oil and gas scenarios generated as part of that effort. The NSSI scenarios project is currently ongoing and the development scenarios provided should be considered interim products that may be change. It is also important to note that the NSSI scenarios show different plausible futures through the year 2040, which is different than our near and long-term time steps of 2025 and 2060, respectively. Due to the scope of the NSSI scenarios project that focused on energy development and supporting activities on the North Slope, and the anticipated lack of population change in the villages, our future human footprint is largely driven by changes in oil and gas infrastructure. Future oil and gas infrastructure associated with the Medium Scenario develops part of the Greater Mooses Tooth region of NPR-A, and further expands the development currently at Point Thompson. The Liberty drilling pads are expanded, and there is a new pipeline built connecting offshore activities to the Point Thompson region in the Medium Scenario as well. Additionally, we included the road and relocation of Kivalina in the Medium Scenario. The High Scenario included all the same development of the Medium Scenario, but expanded the Greater Mooses Tooth development to include a pipeline connecting to development on Smith Bay, develops a pipeline and road from the potential Chukchi Sea facilities, and develops a pipeline connecting Umiat to other oil and gas infrastructure. Although offshore activities are included in the NSSI scenarios, we did not include those developments given our terrestrial focus. 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 Scenario, the results should be considered representative of potential changes to overall landscape condition.

2.2. Results

Current and Future Human Footprint

As expected, the landscape condition for the region is very high, and is expected to remain high. Human modification is highly localized and although the activity is sometimes intense, the overall landscape condition is very high (Figure F-2). Although the range of scores is similar to other applications of the LCM, the majority of the REA has scores that are well above most of the contiguous U.S. Average score in the North Slope is 0.987 for the current landscape. In the Medium Scenario, the average LCM score for the region is unchanged. In the High Scenario, the average landscape condition score for the North Slope study area is anticipated to be 0.986.

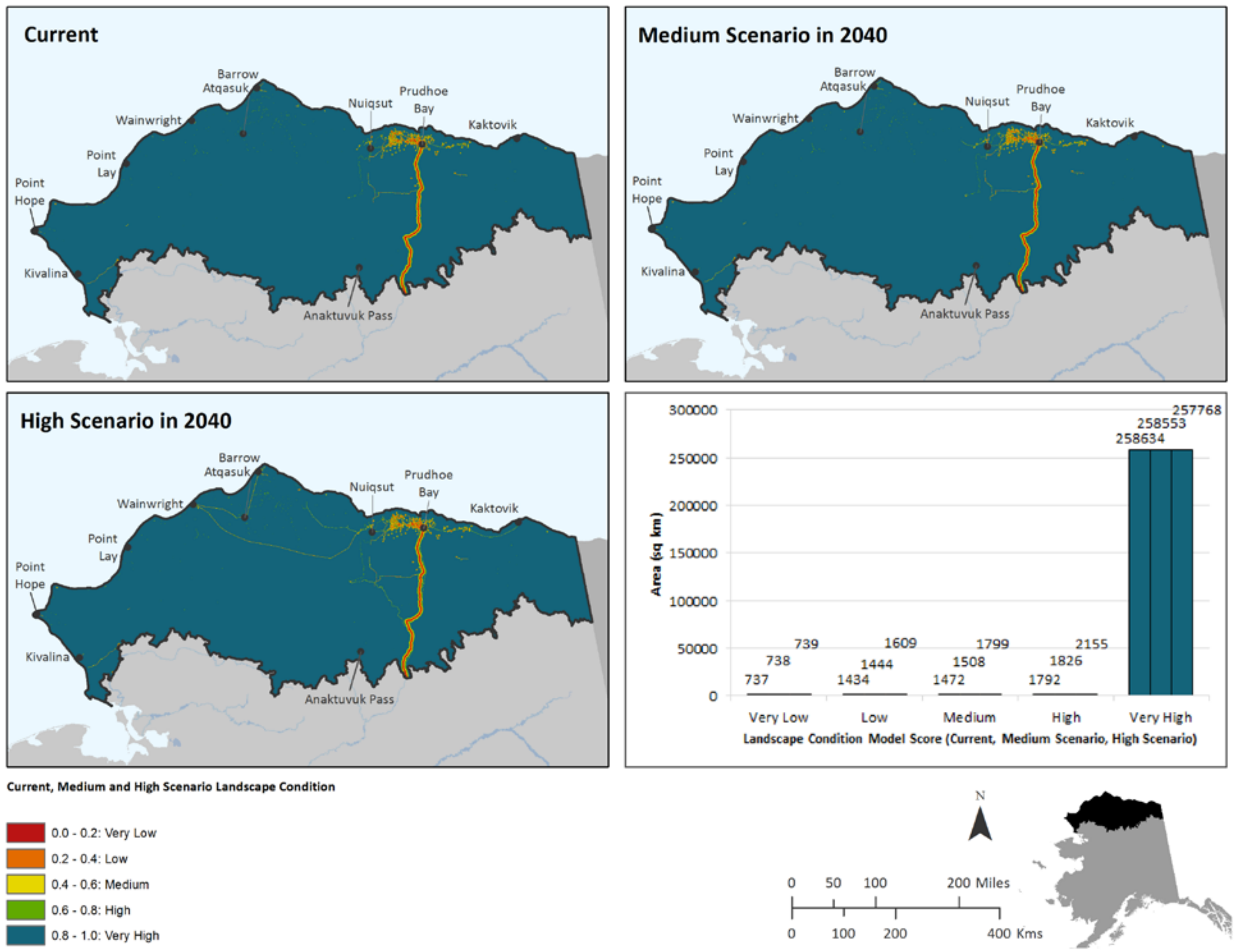

Figure F-2. Current (2015), Medium (2040), and High Scenario (2040) landscape condition.

Summarized LCM

When summarized at the 5th-level HUCs for the region, patterns in the landscape condition become very apparent. Most of the current reduction in landscape condition can be traced back to the Dalton Highway and oil infrastructure around Prudhoe Bay (Figure F-3). Overall, condition scores are still quite high, and the lowest LCM score for any HUC in the North Slope is 0.61 for current and future time periods. Small changes in summarized landscape condition are due to the new pipelines from Wainwright to Greater Mooses Tooth and Umiat to TAPS.

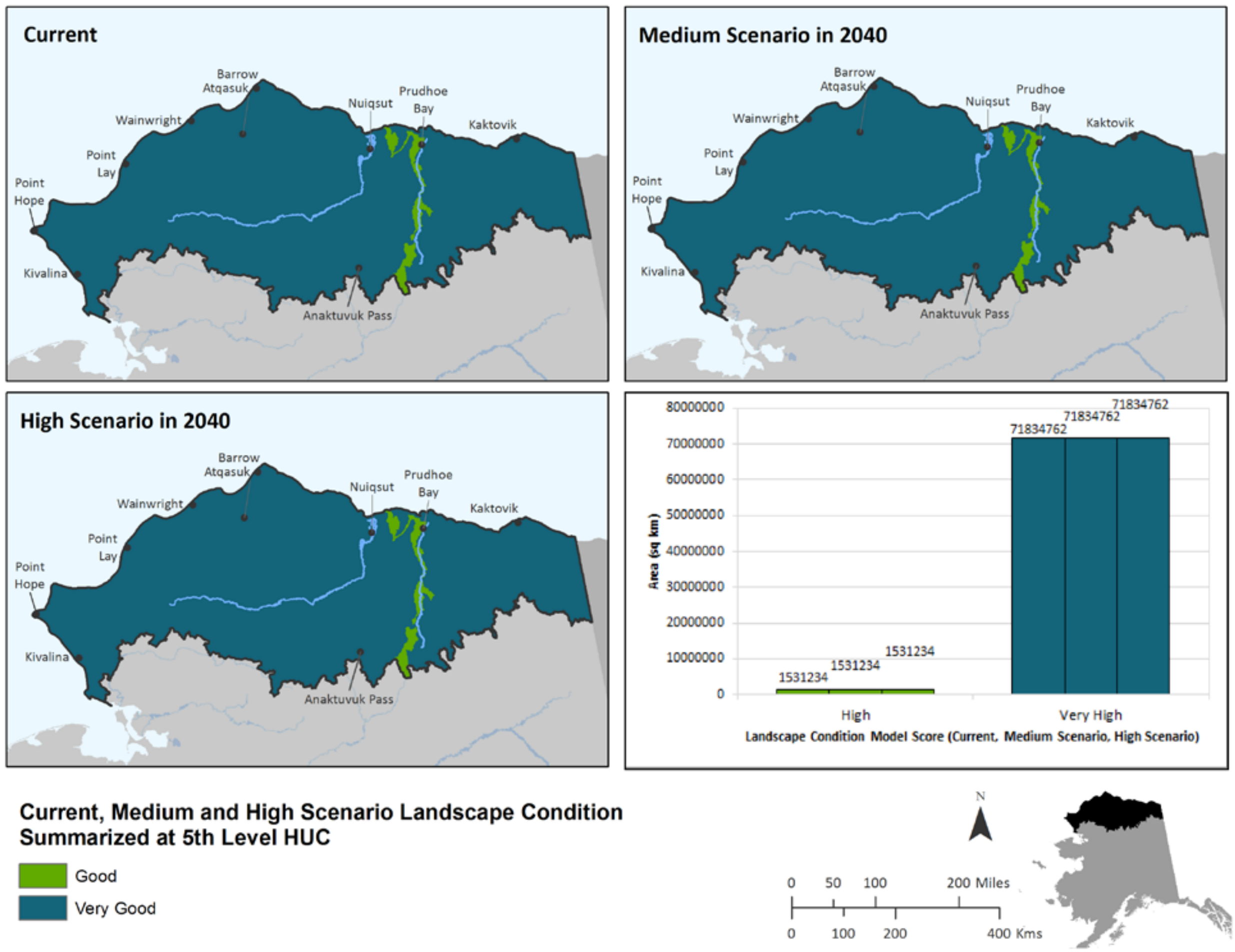

Figure F-3. Current (2015), Medium (2040), and High Scenario (2040) landscape condition at 5th-level HUC resolution.

2.3. Applications

Given the highly pristine condition of the North Slope, management needs in this REA are quite different than those in the contiguous U.S. Instead of monitoring and managing for increasing ecological condition, managers in Alaska have to be aware of how their land use plans impact the current condition. This creates some novel opportunities for monitoring the impacts of various land uses (since the baseline condition can also be considered the reference condition, a luxury that most landscapes in the U.S. do not have). Furthermore, it provides an opportunity to identify ways in which land use plans can still move forward without compromising the overall landscape condition. The LCM provides a robust way to quickly weight the potential impacts of a new project on the overall condition of a landscape, thus providing a useful land use planning tool.

As seen in Table F-4, landscape condition varies by land status classification. Although most of the lands managed by the State of Alaska have very high condition, it is apparent that the State manages the majority of the lower condition lands. BLM also manages a large portion of the lower condition areas;

however, it represents a very small portion of the land they manage. Proportionately, military lands represent the most degraded landscapes on the North Slope, but they also manage very little of the landscape. Overall, landscape condition by land status mirrors the regional patterns.

Table F-4. Current landscape condition relative to land management status (areas in km^2).

Land Management Status	Very Low Condition	Low Condition	Moderate Condition	High Condition	Very High Condition
Bureau of Land Management	246	306	284	426	96,108
Fish and Wildlife Service	1	6	11	18	45,796
Military	6	21	13	10	30
National Park Service	0	21	31	46	29,045
Native Patent or IC	5	57	66	152	22,855
Native Selected	-	-	0	1	1,673
Private	-	-	0	-	-
State Patent or TA	516	1,009	1,008	1,026	45,925
State Selected	0	1	1	1	3,006

2.4. Limitations and Data Gaps

Although the LCM utilizes our best available knowledge related to impacts of human land use on a landscape, there are some necessary generalizations made. Not all landscapes respond the same way to specific land uses (i.e. roads likely have a larger impact on wetlands than uplands), and thus the LCM serves as a *relative* measure of impact. Along these lines, little empirical data exist for the impacts of specific land uses on ecosystem components that exist in Alaska. Additionally, the nature of human land use on the North Slope is quite different than in other regions, especially given the extensive network of seasonal transportation routes. We did not include snow and ice roads in the LCM for two important reasons. First, there have been only a couple studies examining the impact of ice roads on environmental resources, and the results show from those select studies have shown little to no detectible impact to the environment (Adam and Hernandez 1977; Brown and Berg 1980; Johnson and Collins 1980). The impact of snow roads on ecosystem resources has yet to be studied. Second, there is no known method for modeling future snow and ice road development. Although we anticipate future snow and ice roads to be built and utilized as oil and gas infrastructure increases, we have no way of forecasting the location for use in the LCM.

Additionally, some attempt has been made to map local community roads, as many are missing from the Alaska Department of Transportation dataset, and could not be extracted from other datasets. Thus, accurately mapped local road data are identified as a data gap. Additionally, we excluded trail data from this analysis do to the poor quality and unreliability of the data. Accurately mapped and attribute trail information is an important data gap identified in this analysis, and would allow for a more accurate estimate of landscape condition.

Finally, although this data is provided at a 60 m resolution, results and analysis should be interpreted at a broader scale. The LCM, like other datasets from this REA, is best considered in the context of the entire assessment area, or summarized at the 5th-level HUCs.

3. Landscape Intactness

Merely considering the condition without considering the landscape context may misrepresent the actual impact of different human activities on the overall Landscape Integrity. Most importantly, landscape condition should not be assessed at a particular location without some explicit consideration of the surrounding environment (Scott et al. 2004). Landscape intactness provides a quantifiable and readily assessable measure of naturalness. More simply, landscape intactness is a measure of how fragmented an intact landscape might be. Modeling landscape intactness provides a way to assess the relative landscape condition across a region to identify if the areas with degraded conditions are isolated or connected, which could then be used to assess how resilient an area might be to future changes.

3.1. Methods

There is no universal definition of an intact (versus non-intact) landscape. Thus, we chose to define intactness based on the *a priori* assumption that most of the North Slope study area is unmodified by humans. Previous efforts have identified intact landscapes as those with a landscape condition similar to what you find in nearby national parks or wilderness areas (Scott et al. 2004). Given the exceptionally high condition found in national parks within the North Slope, we defined intact landscapes as those with the top quantile condition score. We extracted areas from the LCM with a score of 0.8 or higher as our “intact” landscapes. This calculation is performed on the raw LCM output (60 m cell resolution) so that smaller and localized fragmentation would be captured. Areas that meet the condition criteria were then lumped together and total area of contiguous high condition landscape was calculated.

Large Intact Blocks

The high condition blocks were labeled as large intact blocks (LIBs) and assigned values based on previous studies in Alaska that have defined intact landscapes (Strittholt et al. 2006, Geck 2007). LIBs that are greater than or equal to 50,000 acres are to coincide with the Global Forest Watch program from the World Resources Institute and their Intact Forest Landscapes (Strittholt et al. 2006). We consider these LIBs as having the highest landscape condition and intactness, and thus are labeled as the highest landscape integrity. Blocks that are less than 50,000 acres but greater than or equal to 10,000 acres correspond to previous wilderness area designations studies (Geck 2007), and are considered to have high landscape integrity. Third, we identified all the blocks that are less than 10,000 acres as potentially vulnerable to disturbances.

3.2. Results

Results from the landscape intactness models largely mirror the results from the LCM. However, a substantial amount of small, fragmented areas were indeed identified throughout the region (Table F-5). Most of these fragmented habitats are located around communities and oil and gas developments.

Table F-5. Current and future landscape integrity categories for the North Slope study area.

Designation	Size Threshold	Current (km^2)	Medium Scenario (km^2)	High Scenario (km^2)
Highest Landscape Integrity	≥ 50,000 acres	258,321	258,220	257,258
High Landscape Integrity	< 50,000 acres, ≥ 10,000 acres	69	69	225
Vulnerable to change	< 10,000 acres	92	112	138

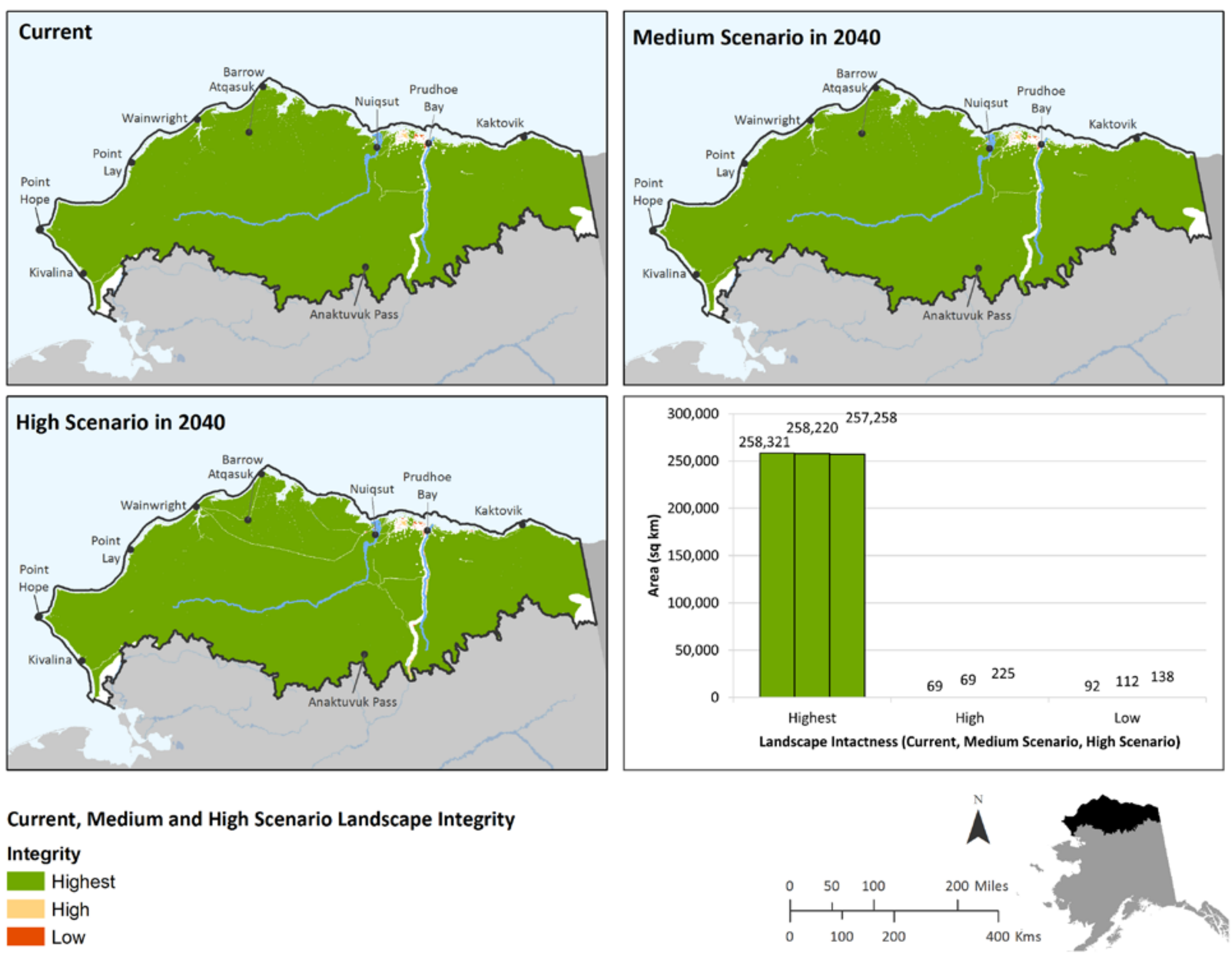

Figure F-4. Current (2015), Medium (2040) and High Scenario (2040) landscape intactness for the North Slope study area.

3.3. Applications

Landscape integrity mirrors the landscape condition for this region, but also highlights the potential to fragment even the largest regional resources. Most areas in the North Slope have both high condition and high intactness, leading us to conclude that the landscape integrity is currently quite high. However, our future forecasts do identify the potential for increased fragmentation and degraded integrity. There is a steady decrease in the highest integrity class, and a 50% increase in the low landscape integrity category over time. Thus, while the overall landscape integrity is still quite high, in smaller more localized areas, there is certainly potential for increased fragmentation of potentially important regional resources. At minimum, the increase in low integrity areas can be used to help identify new monitoring locations in order to understand the role of fragmentation in the larger landscape, especially given the potential for other stressors to act upon those regions.

3.4. Limitations and Data Gaps

While considered a robust way to measure naturalness, there are some key assumptions made in the conceptualization of landscape intactness. Landscape intactness assumes that systems that are not physically impacted by humans are indeed intact. While there are philosophical reasons to question this, there is also increasing evidence that the multitude of indirect impacts humans can have on an environment is substantially higher than previously thought. Impacts from climate change that have already occurred, as well as impacts from global systems (atmospheric nitrogen deposition, particulate matter deposition, etc.) all could be modifying systems in ways that are not captured by the human footprint. Additionally, while obvious at a local scale, human footprints are not always well mapped or captured in a geospatial framework. This is especially true for historical human use (i.e., aboriginal use, or even modern historical use prior to the establishment of environmental monitoring programs). Thus, our landscape intactness model assumes that 1) the current and historical human footprint is accurately modeled for the region and 2) areas not impacted by the human footprint are indeed intact. This is especially relevant as one of the key outputs from an REA is a better understanding of the indirect impacts of human activity on ecosystems.

4. Cumulative Impacts

To provide a more comprehensive measure of potential impacts to the ecoregions, we summarize all the potential impacts to CEs (generalized to the 5th-level HUC) under what we call the Cumulative Impacts (CI) assessment. The measurement of cumulative impacts has become increasingly emphasized both in the academic literature (Walker 1987, Theobald et al. 1997, Nellemann and Cameron 1998, Belisle and St. Clair 2001) as well as regulatory requirements (NEPA, WGA, etc). Essentially, the CI presents a rolled-up dataset of all potential threats to the landscape to identify the locations within the REA that are likely to experience the most amount of change. This does not assess the likely collinearity of the change agents, but rather considers each change agent as a separate stressor that will differentially impact CEs and other resources in the study area. The inverse of this dataset could be seen as a landscape vulnerability index (LVI) that could be used to assist in future resource planning efforts.

4.1. Methods

The CI analysis included what we consider the primary CAs that are likely to have the largest and most direct impact on the overall ecoregion (Figure F-4). However, in order to "sum" the impacts we had to define meaningful changes in the CAs. Given that the CI analysis is not targeted on any one CE, we defined a "change" in the CA based on model variability (see Section C) and the potential to impact management decisions:

- Mean January Temperature
    - Variation in January temperature was substantially higher between the models, so the threshold for meaningful change was set at 2.4°C.
- Mean July Temperature
    - Variation in July temperature was much lower between models, so meaningful July temperature change was estimated at > 0.9° C.
- Annual Precipitation
    - Variation in precipitation estimates between the models was relatively minor as well, so meaningful change in precipitation set at > 10mm change in annual precipitation.
- Change in Permafrost
    - Change in permafrost was calculated based on the change in mean annual ground temperature (see Section C). Specifically, 5th-level HUCs where more than 10 cells (20 km^2) where forecasted to increase above -1°C (i.e., the change from continuous to discontinuous permafrost) were identified as regions of permafrost change.
- Change in Active Layer
    - Change in the thickness of active layer was calculated based on the mean active layer thickness dataset (see Section C). Specifically, 5th-level HUCs where the active layer was expected to increase by 10cm or more were identified as regions of active layer change.
- Change in Relative Flammability

- o The ALFRESCO model indicates that relative flammability will be higher in the Brooks Range, so any region with greater than 0 relative flammability was identified as significant change.
- Landscape Condition
  - o Any changes in landscape condition at the 5th-level HUC were considered a significant change. For the CI model, the Medium Scenario was used in the near-term, while the High Scenario was used to forecast development in the long-term.
- Invasive Species Vulnerability
  - o Any changes in invasive species vulnerability at the 5th-level HUC were considered a significant change.

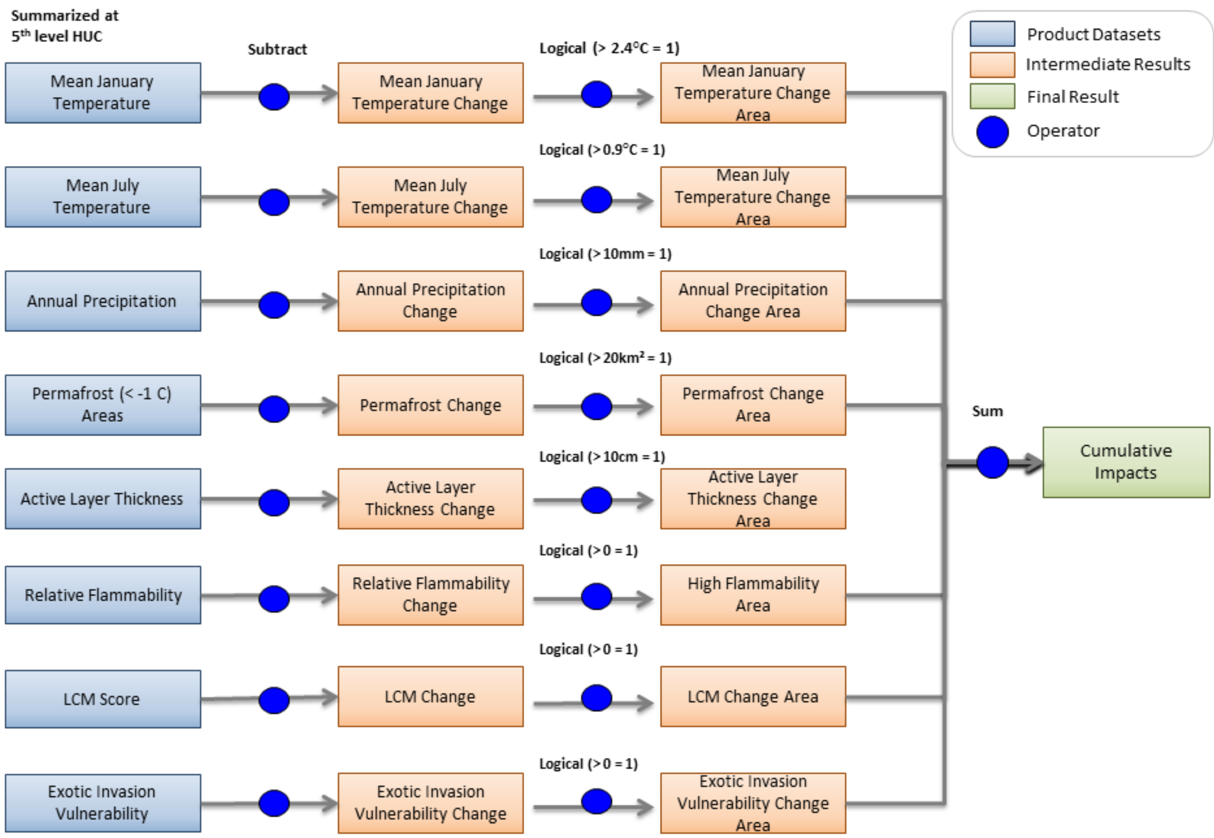

Figure F-5. Process model for Cumulative Impacts (CI) assessment in the North Slope REA. Each product dataset was first summarized at the 5th-level HUC for the current, near-term and long-term to calculate areas of change.

4.2. Results

When taken together, the CI of the various CAs identify some key areas where change to the landscape is likely to be the greatest. In the near-term there are only a few watersheds where three to four CAs are likely to cumulatively impact the environment, and they are located near Kivalina (associated with the relocation effort) and watersheds in the mountain to foothill transition (Figure F-5). The majority of the study area is expected to see no or very limited change in the near-term (Table F-6). However, in the long-term, far more impacts are expected (Figure F-6). Most of the long-term change is expected to occur in the coastal plains and in the southwest portion of the study area. Relocation of Kivalina combines with anticipated changes in permafrost, active depth layer, relative flammability, and other CAs. Equally important is the observation that no region is forecasted to have less than three CAs change in the long-term, suggesting that the entirety of the North Slope is expected to experience some landscape-level stressors.

Table F-6. Cumulative Impact scores (summarized at watersheds) within the North Slope study area.

CI Score	Near-Term Area (km²)	Near-Term (%)	Long-Term Area (km²)	Long-Term (%)
0	133,284	50%	-	0%
1	109,850	42%	-	0%
2	17,508	7%	-	0%
3	3,455	1%	65,090	25%
4	-	0%	81,496	31%
5	-	0%	68,232	26%
6	-	0%	45,824	17%
7	-	0%	3,455	1%
8		0%	0	0%

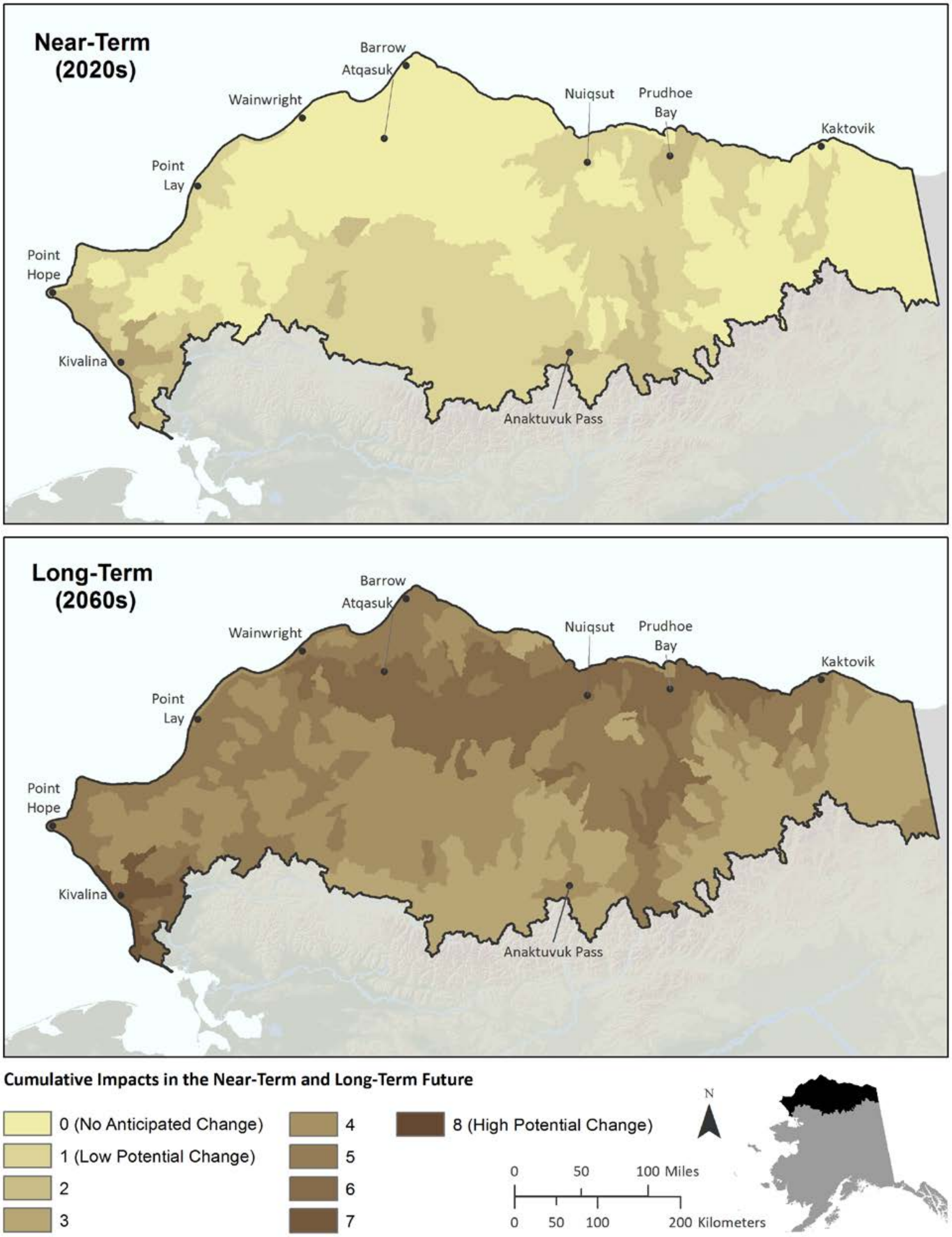

Figure F-6. Cumulative impact assessment for the North Slope study area summarized at the 5th-level HUC (moderate-sized watershed).

4.3. Applications

As mentioned above, the CI analysis is a broad-scale assessment of the potential overlap of key change agent thresholds. This is meant to merely highlight the areas of the REA that are likely to change the most. The CI analysis can be seen as landscape vulnerability index to help guide monitoring efforts. Watersheds with the highest CI score are prime candidates for monitoring efforts, especially efforts that target overall ecological function and health.

As shown in Table F-7, all land management agencies in the North Slope study area will likely have to address the cumulative impact of the CAs in the future. The Bureau of Land Management, being the largest land manager in the region, is likely to be faced with the largest amount of land that is vulnerable to multiple CAs, followed by the State of Alaska, the U.S. Fish and Wildlife Service, and Native lands. Of particular note is that proportionately, Native lands are likely to see 4 or 5 CAs influencing over 80% of their lands (Table F-7).

Table F-7. Areas (in km^2) of the region expected to undergo cumulative impacts, organized by land management agency. A score of 3 means only three change agent are anticipated to change significantly by 2060. Therefore, areas with a lower score can be interpreted as having less landscape stressors than other areas with higher scores. Note: because the assessment boundary includes a buffer out to the barrier islands, the total area here is less than the total study area.

Land Management Status	CI = 3	CI = 4	CI = 5	CI = 6	CI = 7
Bureau of Land Management	1,112	44,655	23,852	27,051	695
Fish and Wildlife Service	30,476	8,376	6,216	766	< 1
Military	-	-	66	14	< 1
National Park Service	18,139	5,378	3,843	1,477	327
Native Patent or IC	4,663	7,727	7,767	2,556	419
Native Selected	16	676	828	75	79
Private	-	-	< 1	-	-
State Patent or TA	9,278	9,932	18,859	10,730	695
State Selected	706	1,422	691	29	161

4.4. Limitations and Data Gaps

The collinearity between the different change agents means that this analysis could overestimate impacts to the landscape (i.e. active layer thickness is certainly correlated to mean July temperature, but are included as two distinct stressors in this analysis). However, impacts to any given CE from changes in mean July temperature is certainly different than impacts to the same CE than changes in active layer thickness. Thus, while the two are correlated, the impact to regional resources can in fact be different. Additionally, some CAs are spatially restricted (i.e. fire is only on the south side of the Brooks Range) and is therefore not correlated with climatic variables across the entire region. Therefore, although the CI ignores the collinearity between CAs, it does provide a cumulative assessment of potential landscape stressors that would require different resource management strategies.

Additionally, while some of the thresholds for meaningful change are derived from a statistical analysis, similar robust estimates of actual change were not available for all CAs. For example, the impact of fire on the North Slope assumes that any area with high flammability is likely to generate a management response. Thus, this analysis should be used primarily as a landscape planning tool, and not an impact model that would guide specific management actions.

Finally, given the cross-disciplinary nature of the REA analyses, there exists a high potential for error. Modeled outputs are placed into other models, each with different assumptions, potentially propagating errors throughout. However, using GIS as a common platform assists in identifying errors early in the modeling process, and (by creating intermediate data products) provides a transparent process in which critical review of our assumptions can be made. Thus, while many of these models were never designed to interact, we feel confident that all our modeling efforts represent the best available knowledge about the system and potential impacts.

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G. Terrestrial Coarse-Filter Conservation Elements

Tina Boucher[1], *Lindsey Flagstad*[1], *Nancy Fresco*[2], *Keith Boggs*[1], and *Brian Heitz*[1]

[1]Alaska Natural Heritage Program, University of Alaska Anchorage, 707 A Street, Anchorage, Alaska 99501 [2]Scenarios

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Summary

Section G. *Terrestrial Coarse-Filter Conservation Elements* provides detailed descriptions, methods, datasets, results, and limitations for the assessments of the potential impacts of CAs on selected habitats (CEs) considered to be of high ecological importance in the region.

Contents

Management Questions

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1. Summary of Terrestrial Coarse-Filter Conservation Elements

Arctic ecosystems are undergoing major shifts related to climate change. Because the Arctic is warming at nearly twice the global rate, the impacts are expected to disproportionately affect arctic ecosystems (Winton 2006). Understanding the drivers of this change and the consequences across diverse landscapes is critical to anticipating the range of ecological responses that can be expected. The goal of the Terrestrial Coarse-Filter assessment is to identify key ecosystems and drivers and provide baseline data that will help predict anticipated effects of climate change across a wide range of arctic habitats. Expansion in shrub height and cover, changes in the rate of thermokarst and permafrost subsidence, and migration of treeline are examples of some of the important habitat changes that are expected to affect the Arctic.

Terrestrial Coarse-Filter CEs are regionally important habitat types that share similar vegetation and biophysical site characteristics including permafrost characteristics, surficial deposit, disturbance and succession. Together, the Terrestrial Coarse-Filter CEs address the habitat requirements of most native species and the majority of key ecosystem functions and services within the North Slope study area (see Section A-2). After several iterations of review by the AMT and Tech Team, nine Terrestrial Coarse-Filter CEs were selected for analysis. Together, these CEs represent the majority of the terrestrial landscape covering 68.5% of the entire study area (Table G-1).

The CEs selected for the North Slope REA are consistent with the biophysical landscape stratification system developed by BLM's Assessment Inventory and Monitoring (AIM) team as the foundation of the long-term monitoring program in the National Petroleum Reserve – Alaska (NPR-A). The goal of the AIM stratification was to reduce sampling of landscape heterogeneity and create sampling strata that would respond in a similar direction to climate change or other disturbance (MacKinnon et al. 2011, Toevs et al. 2011, Taylor et al. 2014). Fourteen biophysical settings were identified as AIM sampling strata, and, of these, nine were selected as CEs for the North Slope REA. Adopting this approach for the North Slope REA allows us to more effectively evaluate the impacts of the selected CAs on vegetation pattern and composition. Biophysical settings that were delineated for AIM monitoring but not selected as CEs include: Foothills Low Shrubland, Foothills Wetland, Floodplain Wetlands, Inland Dunes (here added to Sand Sheet Moist Tundra), and Alpine Barrens.

Table G-1. Terrestrial Coarse-Filter CEs, area, and percent of study area occupied.

Conservation Element	Area (km^2)	% of Study Area
Tidal Marsh	350	0.1
Marine Beach, Barrier Island, and Spit	141	0.1
Coastal Plain Wetland	17,216	6.9
Coastal Plain Moist Tundra	18,834	7.5
Sand Sheet Wetland	3,829	1.5
Sand Sheet Moist Tundra	6,670	2.7
Foothills Tussock Tundra	83,114	33.3
Alpine Dwarf Shrub	35,967	14.4
Floodplain Shrubland	4,878	2.0

1.1. Methods

For each Terrestrial Coarse-Filter CE, we evaluated the potential for change for each pertinent CA variable by comparing the CE distribution to the current, near-term future, and long-term future status of the CAs. The current distribution of the individual CEs and the intersection of those distributions with the status of the CAs is considered the core analysis of the REA. In this section we present the methods and results for the core analysis for all Terrestrial Coarse-Filter CEs collectively, followed by individual accounts for each CE where we present more detailed explanations of specific findings. This section also presents the answers to three MQs: TC 1 (what are the impacts of oil and gas development on vegetation and hydrology?), TC 2 (what are the changes in habitat and vegetation related to changing permafrost conditions?) and TC 4 (what are the expected changes to habitat as a result of coastal erosion and salinization?). Impacts of coastal erosion to tidal marsh and barrier islands, beaches, and spits are contained within MQ TC 4. MQ TC 2 is part of the core analysis and is included in the core results. MQ TC 1 summarizes impacts across CEs and is presented at the end of the Terrestrial Coarse-Filter CE section.

For each Terrestrial Coarse-Filter CE we:

1. Mapped the **current distribution** of each CE.
2. Created **a conceptual model** based on the relationship of the CE to CAs and drivers.
3. **Intersected the mapped/modeled distribution of each CE with those CAs** identified as potentially significant through the CE-specific conceptual model.
4. Assessed the current, near-term future, and long-term future **status** of each CE by intersecting the distribution of each CE with the Landscape Condition Model (LCM).
5. Assessed the **relative distribution of each CE on public lands** by intersecting the distribution of each CE with a managed areas map.

Distribution Modeling

Four geospatial datasets were integrated to create the biophysical settings for Terrestrial Coarse-Filter CEs (Table G-2).

Table G-2. Datasets used in the analysis of Terrestrial Coarse-Filter CEs.

Dataset Name	Data Source
NSSI Landcover	Ducks Unlimited 2013
USDI National Wetlands Inventory	USFWS 2013
Vegetation Map of Northern, Western, and Interior Alaska	Boggs et al. 2012
Northern Alaska Subsections	Jorgenson and Grunblatt 2013

The North Slope study area extended slightly beyond the extent of the NSSI Landcover map (Ducks Unlimited 2013) along the southern boundary of the study area. We mosaicked the Vegetation Map of Northern, Western, and Interior Alaska (Boggs et al. 2012) into the NSSI Landcover map to create a complete coverage of the study area (Figure G-1). The combined landcover map provided the existing vegetation component for most of the CEs. Coastal zone mapping of tidal marsh and marine beaches, barrier islands, and spits was modified from the National Wetlands Inventory (USFWS 2013).

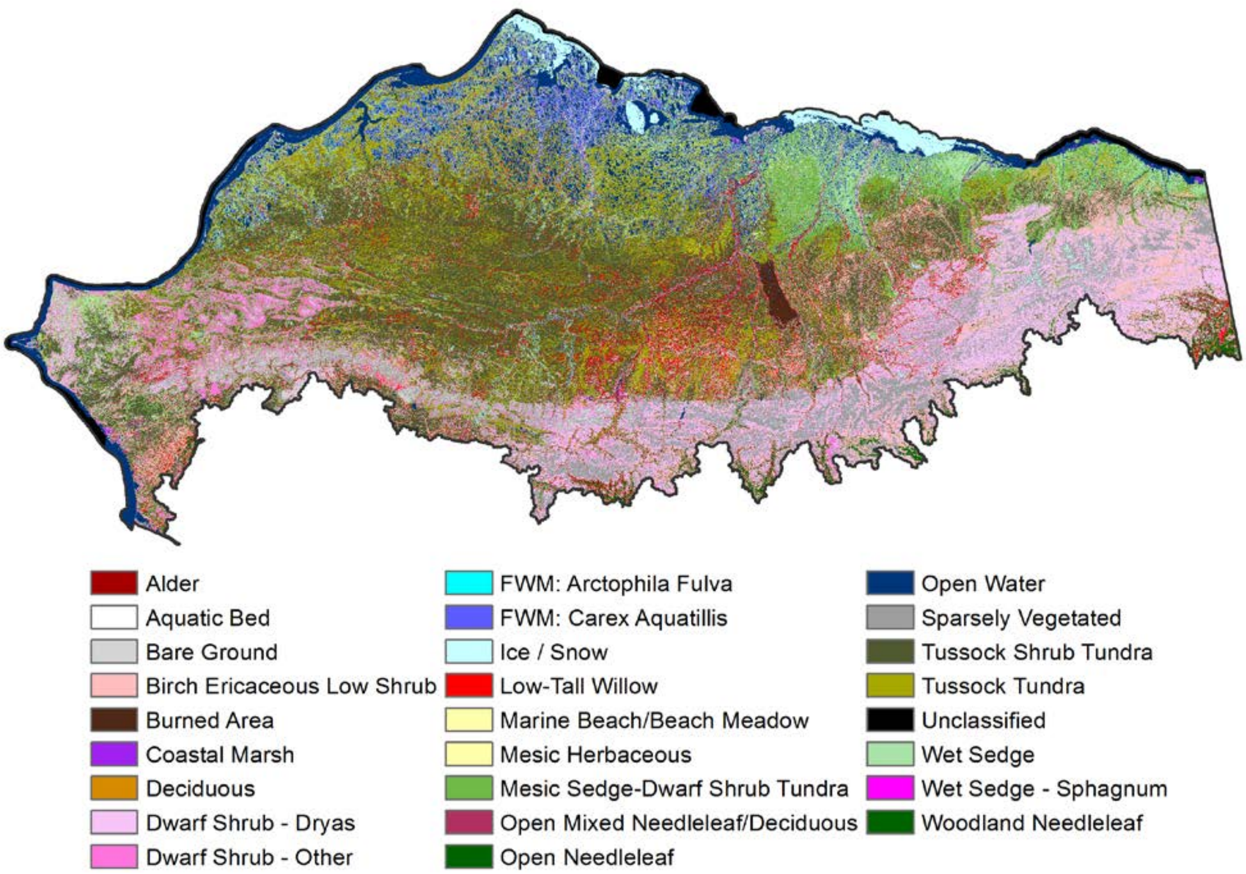


Figure G-1. Complete existing vegetation coverage of North Slope study area provided by combination of NSSI Landcover Map and Vegetation Map of Northern, Western, and Interior Alaska.

To develop the final distribution maps, we grouped vegetation landcover classes into similar units linked through succession or similar habitat types within four major physiographic regions: coastal plain, foothills, alpine, and floodplains. Floodplains and coastal plain were defined by physiographic classes in the Northern Alaska Subsections Map (Jorgenson and Grunblatt 2013). We used the arctic sandy lowland ecological landscape (Jorgenson and Grunblatt 2013) to split the sand sheet from the coastal plain physiographic unit because the ice-poor permafrost of the sand sheet contrasts with that of the rest of the coastal plain, which generally has ice-rich deposits. We used vegetation classes to capture the split between alpine dwarf shrub and foothills tussock tundra CEs. Table G-3 provides a synopsis of the vegetation classes and physiographic divisions that were selected to delineate each CE.

Table G-3. Physiographic divisions and landcover classes used in developing the Terrestrial Coarse-Filter CE distribution maps. Vegetation classes are from the combined NSSI Landcover and Vegetation Map of Northern, Western, and Interior Alaska unless otherwise noted. NWI = National Wetlands Inventory.

Physiographic Division		Conservation Element	Landcover classes
Coastal Zone		Tidal Marsh	Tidal marsh (NWI) Tide flat (NWI)
		Marine Beach, Barrier Island, and Spit	NWI sand, gravel shoreline classes NWI non-wetland classes
Coastal Plain	Arctic Silty & Arctic Peaty Lowland	Coastal Plain Wetland	*Within the coastal plain polygon:* NSSI Freshwater Marsh: Arctophila fulva NSSI Freshwater Marsh: Carex aquatilis NSSI Wet sedge NSSI Wet Sedge–Sphagnum
		Coastal Plain Moist tundra	*Within the coastal plain polygon:* NSSI Tussock tundra Tussock Shrub Tundra Mesic Sedge-Dwarf Shrub Tundra Mesic herbaceous Birch Ericaceous Low Shrub Dwarf Shrub–Dryas NSSI Dwarf Shrub–Other NSSI Sparsely Vegetated
	Arctic Sandy Lowland	Sand Sheet Wetland	*Within the sand sheet polygon:* NSSI Freshwater Marsh: Arctophila fulva NSSI Freshwater Marsh: Carex aquatilis NSSI Wet sedge NSSI Wet Sedge–Sphagnum
		Sand Sheet Moist Tundra	*Within the sand sheet polygon:* NSSI Tussock tundra NSSI Tussock Shrub Tundra NSSI Mesic Sedge-Dwarf Shrub Tundra NSSI Mesic herbaceous NSSI Birch Ericaceous Low Shrub NSSI Dwarf Shrub–Dryas NSSI Dwarf Shrub–Other NSSI Sparsely Vegetated NSSI Barren (dunes and drained lakes)
Foothills*		Foothills Tussock Tundra	*Within the foothills/alpine polygon:* NSSI Tussock tundra NSSI Tussock Shrub Tundra NSSI Mesic Sedge-Dwarf Shrub Tundra NSSI Mesic herbaceous

Physiographic Division	Conservation Element	Landcover classes
Alpine*	Alpine Dwarf Shrub	*Within the foothills/alpine polygon:* NSSI Dwarf Shrub–Dryas NSSI Dwarf Shrub–Other
Floodplains	Floodplain Shrubland	*Within the floodplain polygon:* NSSI Dwarf Shrub – Dryas NSSI Dwarf Shrub – Other NSSI Low-Tall Willow NSSI Alder NSSI Sparsely Vegetated NSSI Barren *Floodplain Wetland is excluded.*

*Vegetation classes were used to make the distinction between alpine and foothills CEs.

Conceptual Models

Conceptual models were developed for each Terrestrial Coarse-Filter CE depicting the effects that various CAs and natural drivers are expected to impose on key ecological components and processes. These models provided the scientific basis for identifying important drivers, and they guided the selection of CA variables with high ecological and management relevance for the core analysis. The CE-specific conceptual models represent the state of knowledge between the CE, CAs, and other resources. Conceptual models are based on extensive literature review. Not all relationships identified lend themselves well to measurement or monitoring, but they are important to include because they add to our overall understanding of complex interactions (Bryce et al. 2012). Each conceptual model is presented within the individual CE biophysical setting accounts. The boxes in each diagram indicate CEs, CAs, and drivers. Arrows indicate regionally important interactions known to occur in the North Slope study area. Text in dark red is positioned next to arrows to indicate the most likely relationships between constituents.

CE x CA Intersections

The purpose of the core analysis was to describe the current distribution of each CE at the ecoregional scale and to investigate how its status may change in the future as a result of CAs. For each Terrestrial Coarse-Filter CE, the current, near-term future, and long-term future impacts of the individual CA variables were evaluated. In many cases spatial overlays of the CAs on CEs did not appear to provide additional information beyond that already specified in the conceptual models (i.e., in terms of informing management or research efforts for specific CEs). Thus, for this report, our discussion of the impacts of CAs on the individual CEs includes a combination of quantitative (spatial analysis) and qualitative (conceptual model) results.

The key CA variables evaluated in this analysis include: **temperature**, **precipitation**, **change in length of growing season**, **permafrost** (active layer thickness and thermokarst potential), **fire** (ALFRESCO and vegetation change), and **invasive plants**. Modeled climate, permafrost, and fire data were developed by the Scenarios Network for Alaska and Arctic Planning (SNAP) at the International Arctic Research Center at the University of Alaska Fairbanks. Detailed information about these models can be found in Section C. Abiotic Change Agents.

Summary results for intersections between CAs and all CEs are presented in the introduction either spatially or in tabular format; additional intersections are presented between CEs and CAs in the individual coarse-filter CE sections. Terrestrial sub-regions (Figure G-2, TNC 2005) were used to summarize results where the trend by CE was not evident or the CA results were not presented as a spatial product (as in the ALFRESCO output). The nine sub-regions are nested within the three main arctic ecoregions (Nowacki et al. 2001) and facilitate data summarization that illustrates both north to south and west to east gradients within the North Slope study area.

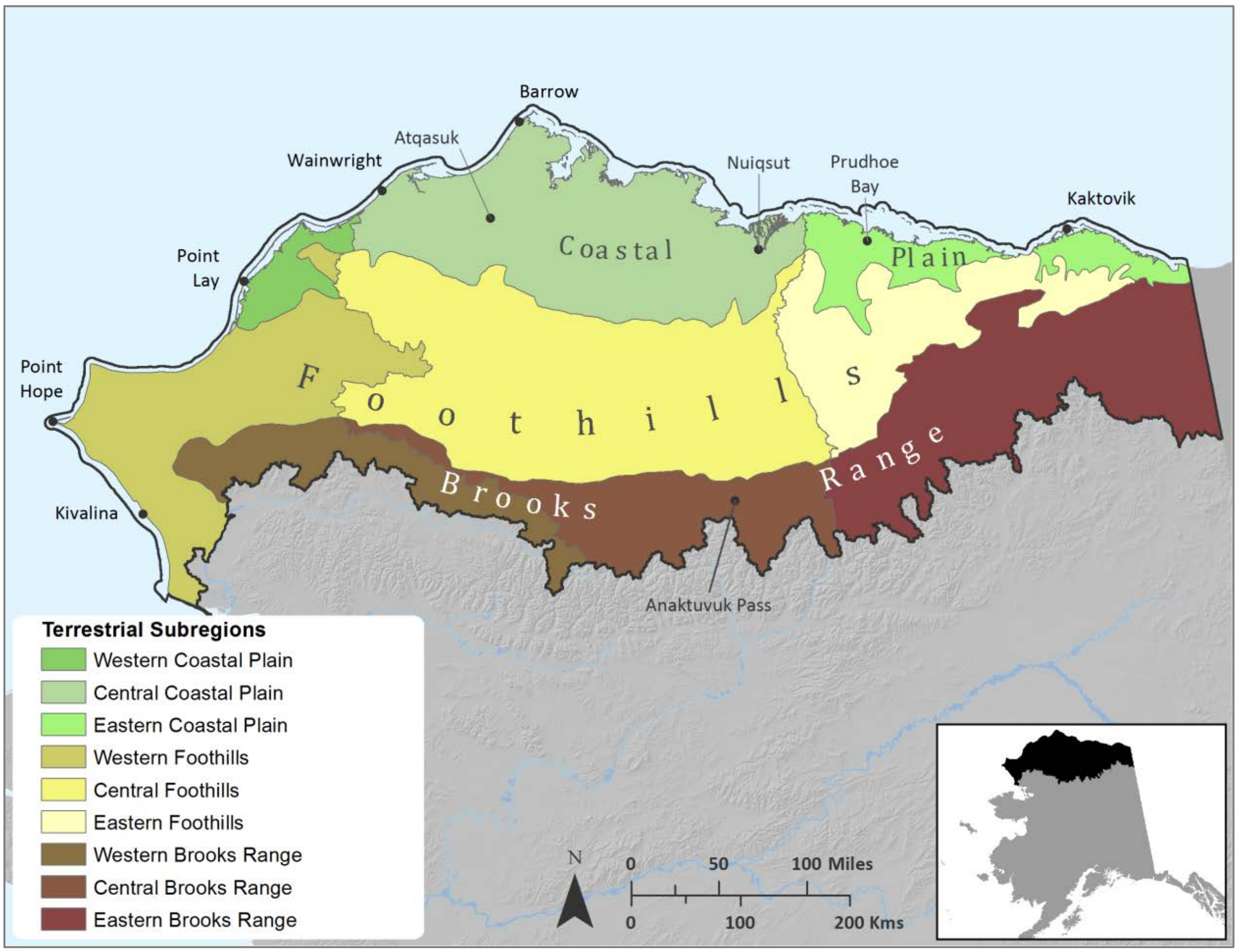


Figure G-2. Terrestrial sub-regions provide potential for both North to South and East to West comparison of spatial patterns within the North Slope study area.

Status Assessment

The overall status of each CE was assessed by intersecting the Landscape Condition Model (LCM) with the CE-specific distribution model for the current LCM and two potential human footprint scenarios: medium and high development. The future scenarios were supplied by the NSSI Scenarios project and reflect changes driven largely by increases to the oil and gas infrastructure. The LCM is a way to measure the impact of the human footprint on a landscape. See Section F. Landscape and Ecological Integrity for a detailed description of methods.

Relative Management Responsibility

The relative management responsibility on public lands for each CE was assessed by intersecting a managed areas data layer with the CE distribution models in order to provide an estimate of the proportional ownership for each CE. This type of information may be useful to managers to promote better collaboration across agencies and increase effectiveness of public lands managed for habitats that span political boundaries.

1.2. Results

Distribution Models

Figure G-3 shows the distribution of Terrestrial Coarse-Filter CEs across the North Slope study area. The CEs represent an elevational gradient from sea level to alpine that corresponds to both ecoregions (Nowacki et al. 2001) and the three arctic bioclimatic subzones that occur in Alaska (CAVM 2003, Raynolds et al. 2006). The arctic subzones portray a latitudinal gradient in vegetation height and productivity from south to north. The southernmost subzone (E) encompasses the Brooks Range Mountains and foothills ecoregions and contains the alpine dwarf shrub tundra and foothills tussock tundra CEs. Subzones D and C correspond to the Beaufort Coastal Plain ecoregion and contain the coastal plain and sand sheet CEs. Detailed descriptions of each CE are included in the individual Terrestrial Coarse-Filter sections.

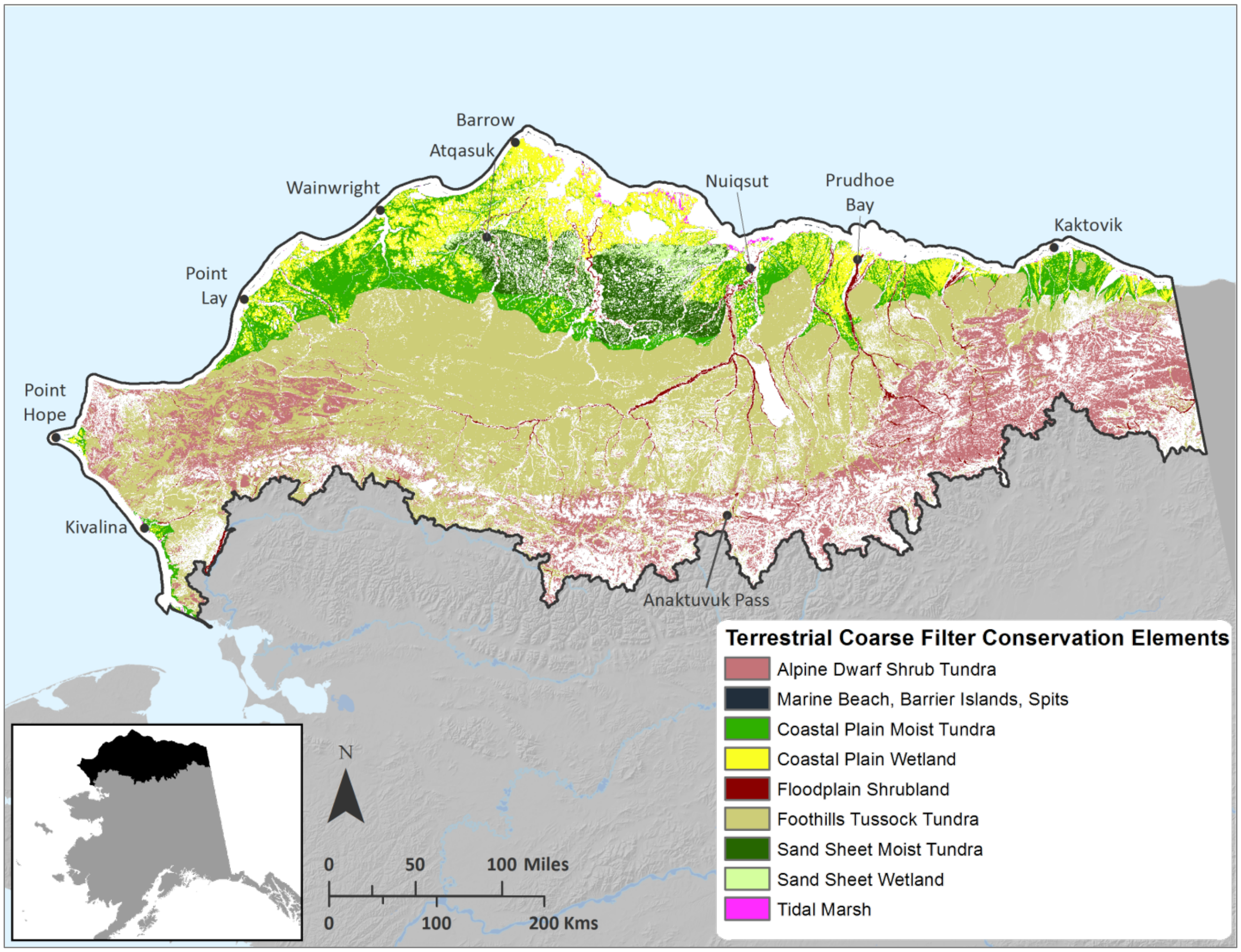


Figure G-3. Map of Terrestrial Coarse-Filter CE distributions within the North Slope study area.

Climate Variables

In the next decade, little measurable change is expected in the Terrestrial Coarse-Filter CEs, based solely on climate variables; however larger responses are predicted by the 2060s (see C-1). A summary of predicted effects of climate CAs on the Terrestrial Coarse-Filter CEs are summarized below, and are expanded on in the individual CE sections.

We focused the climate analysis on a subset of the data that is most relevant to vegetation: temperature (January, July), precipitation, and length of growing season. Seasonal and annual temperatures and precipitation are expected to increase across the North Slope REA in the near and long term, with higher uncertainty associated with the precipitation model. Temperature increase is expected to be negligible in the near term, however, in the long term, climate warming trends are clear and significant. Although precipitation increases are projected on the North Slope study area, the effect of this increase on vegetation is difficult to generalize across the landscape, particularly considering potential increases in evapotranspiration and evaporation associated with elevated temperatures. Impacts to vegetation associated with warmer temperatures and longer growing season are expected to be more important than those associated with increased precipitation. Results for changes in temperature, length of growing season, and precipitation across all CEs are presented in the following sections.

Temperature

July temperature projections based on climate models developed by SNAP are shown in Figure G-4. Models project warming across the North Slope study area during the warmest month of the year, however, this warming trend is less pronounced than winter warming, and is not significant in the near term (see Climate Change chapter for more detail). No significant warming or cooling can be expected in the near term during July, but significant warming is expected by the 2060s. Summer warming is expected to follow slightly different geographic patterns than winter warming, with greater change in the inland portion of the study area and less change along the coast, where temperatures are moderated by ocean water in the summer months.

Model outputs for January temperature (Figure G-5) show that warming is predicted throughout the North Slope study area in the coldest month of the year. The far western region of the North Slope REA and the southern margin of the Brooks Range currently have the warmest January temperatures, and this trend will continue through the 2060s. January temperatures are expected to warm more in the eastern parts of the North Slope study area, with increases of about 4.5 °C by the 2060s. In the western areas, increases of about 4.0 °C are expected (see Section C. Abiotic Change Agents for more details).

In order to evaluate the effect of climate warming on each CE, we calculated the area of each CE expected to undergo a significant increase in temperature in the near term and long term. A temperature sensitivity analysis was performed to determine significance (see Section C-1.3). The averaged inter-model standard deviation for the A2 emission scenario across the study area is 1.3. Projected shifts of > 1.3 °C can be considered significant, and changes of lower magnitude are considered non-significant. Table G-4 shows the percent area of each CE expected to undergo an increase in temperature of at least 1.3 °C in the near term and long term. We considered this threshold of 1.3 °C ecologically significant because a small change in temperature such as this can lead to changes in growing season length and active layer thickness, which in turn can lead to changes in plant growth and productivity. In the near term, July warming across 100% of all CE habitat is projected to be between 0 and 1.3 °C. However, in the long term, increases of greater than 1.3 °C are projected across a portion of each CE distribution, with the greatest amount of impacted habitat predicted in the Foothills Tussock Tundra (72%) and Alpine Dwarf Shrub Tundra (86%) CEs. Near term temperature increases for January are not significant, however, in the long term, January temperatures will increase by at least 1.3 °C across 100% of all CE distributions.

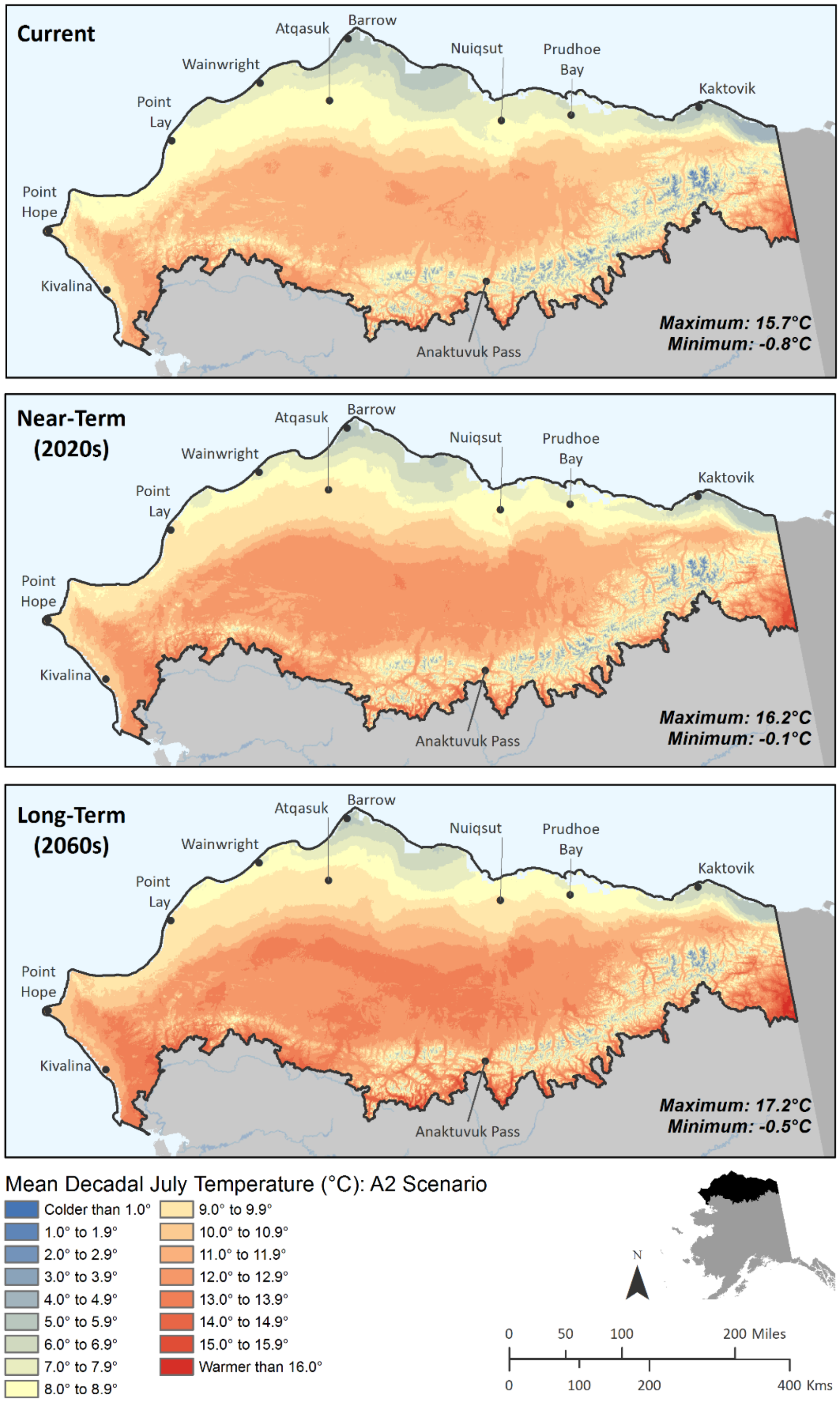


Figure G-4. Current, near-term and long-term temperature projections for July.

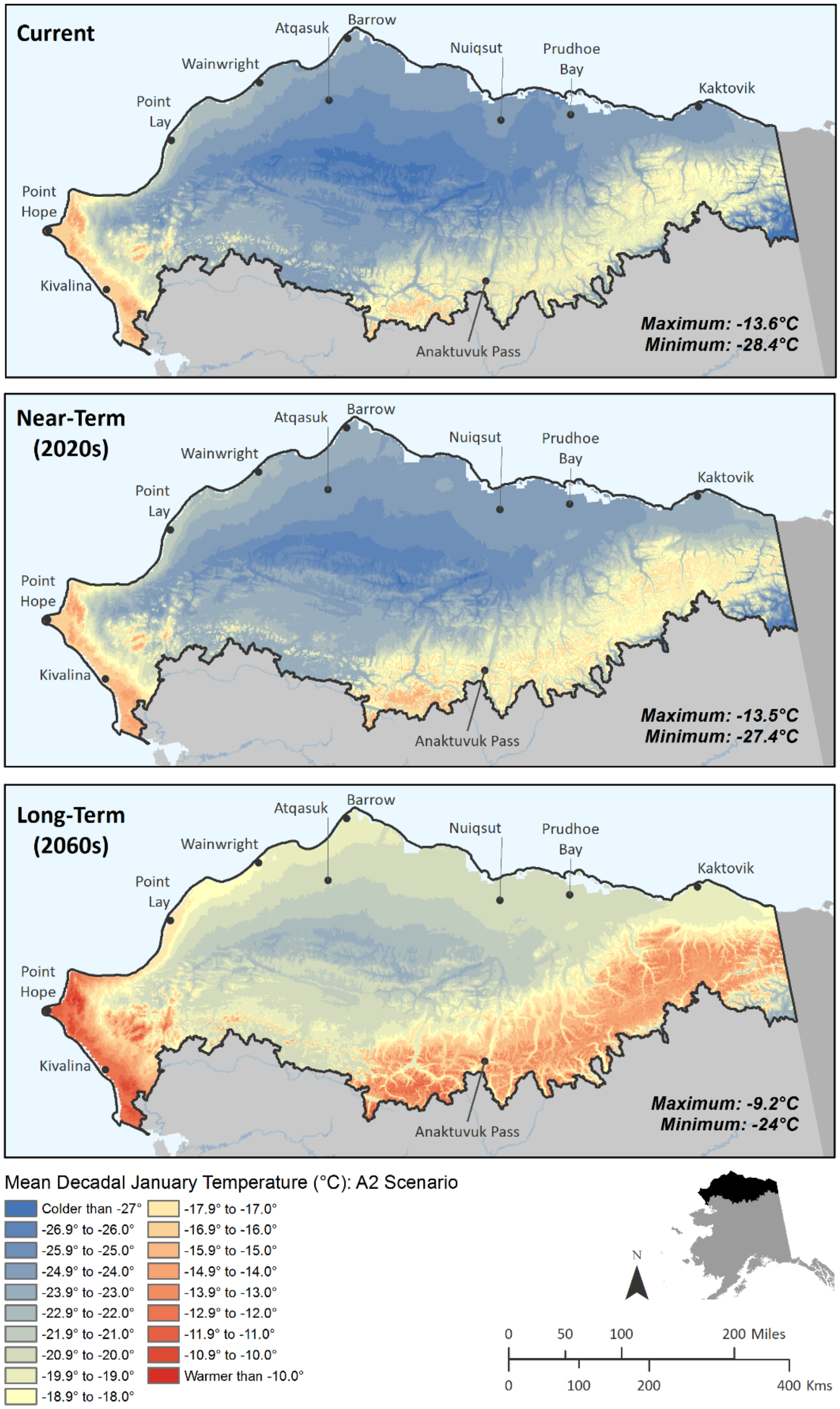


Figure G-5. Current, near-term and long-term projected mean January temperatures.

Table G-4. Percent area of each CE that will increase 0 - 1.3 °C and > 1.3 °C in temperature in the near term (2020s) and long term (2060s).

Terrestrial Coarse-Filter CE		Δ July Temp		Δ January Temp		Δ Annual Temp	
		0 - 1.3 °C	> 1.3 °C	0 - 1.3 °C	> 1.3 °C	0 - 1.3 °C	> 1.3° C
Tidal Marsh	Near	100.0%		100.0%		100.0%	
	Long	94.4%	5.6%		100.0%		100.0%
Barrier Islands Beaches Spits	Near	100.0%		100.0%		100.0%	
	Long	73.0%	27.0%		100.0%		100.0%
Floodplain Shrubland	Near	100.0%		100.0%		100.0%	
	Long	42.6%	57.4%		100.0%		100.0%
Coastal Plain Moist Tundra	Near	100.0%		100.0%		100.0%	
	Long	93.7%	6.3%		100.0%		100.0%
Coastal Plain Wetland	Near	100.0%		100.0%		100.0%	
	Long	97.9%	2.1%		100.0%		100.0%
Sand Sheet Moist Tundra	Near	100.0%		100.0%		100.0%	
	Long	91.9%	8.1%		100.0%		100.0%
Sand Sheet Wetland	Near	100.0%		100.0%		100.0%	
	Long	95.8%	4.2%		100.0%		100.0%
Foothills Tussock Tundra	Near	100.0%		100.0%		100.0%	
	Long	28.4%	71.6%		100.0%		100.0%
Alpine Dwarf Shrub Tundra	Near	100.0%		100.0%		100.0%	
	Long	13.9%	86.1%		100.0%		100.0%

Table G-5. Mean temperature values by CE for current (2010s), near term (2020s), and long term (2060s). Change in annual temperature between current and long-term future.

Terrestrial Coarse-Filter CE	Mean Annual Temp			Δ Annual Temp	Mean July Temp			Δ July Temp	Mean January Temp			Δ January Temp
	Current	Near	Long		Current	Near	Long		Current	Near	Long	
Alpine Dwarf Shrub Tundra	-7.7	-7.5	-5.4	+2.3	9.6	10.3	11.0	+1.4	-20.5	-19.7	-16.2	+4.2
Foothills Tussock Tundra	-9.0	-8.8	-6.7	+2.3	11.0	11.8	12.4	+1.4	-23.9	-23.2	-19.8	+4.1
Floodplain Shrubland	-9.3	-9.1	-6.9	+2.3	10.4	11.2	11.7	+1.3	-24.3	-23.6	-20.0	+4.2
Coastal Plain Moist Tundra	-10.2	-9.9	-7.7	+2.4	8.4	9.2	9.5	+1.1	-24.4	-23.9	-20.2	+4.2
Coastal Plain Wetland	-10.4	-10.1	-7.9	+2.5	7.7	8.4	8.7	+1.0	-24.3	-23.8	-20.1	+4.3
Sand Sheet Moist Tundra	-10.7	-10.4	-8.3	+2.4	9.1	9.9	10.2	+1.1	-25.7	-25.1	-21.5	+4.2
Sand Sheet Wetland	-10.7	-10.5	-8.3	+2.5	8.6	9.3	9.6	+1.1	-25.5	-24.9	-21.2	+4.3
Tidal Marsh	-10.4	-10.2	-7.9	+2.5	6.7	7.3	7.6	+0.9	-24.0	-23.5	-19.6	+4.4
Barrier Islands Beaches Spits	-8.7	-8.5	-6.1	+2.5	7.7	8.4	8.8	+1.1	-21.5	-21.1	-17.1	+4.3

Growing Season Length

Length of growing season (LOGS) refers to the projected number of days between the monthly interpolated dates on which the temperature crossed the freezing point (0 °C) in the spring and in the fall. It does not correspond exactly to the growing season for any particular species assemblage, but can be expected to correlate with summer season length or ice-free season length, based on historical evidence of correlation between air temperature and ice conditions (Hueffer et al. 2013, Bieniek et al. 2011). The most important climate variable responsible for breakup is April-May surface air temperatures; and earlier breakup occurs when these spring air temperatures and river flow are above normal (Bieniek et al. 2011).

Length of growing season is projected to increase across the region, with subtle short-term shifts and marked long-term shifts (Figure G-6 and Figure G-7). In this region, which offers only a very short summer season, small changes can trigger large changes in vegetation. The long-term scenario projects an average increase in length of growing season of 10.3 days for all Terrestrial Coarse-Filter CEs across the North Slope study area (Table G-6).

Vegetation change can also be triggered by an increase in Summer Warmth Index (the annual sum of the monthly mean temperatures that are above freezing) or Growing Degree Days (a similar index calculated on a daily rather than monthly basis). While LOGS and SWI are different metrics, and vary from one another on a regional basis, climate change is driving increases in both.

We developed spatial representations of growing season projections intersected with individual CEs for those CEs that have broad distributions and a spatial scale that allows comparison with the SNAP models. Spatial models were developed for foothills tussock tundra, alpine dwarf shrub tundra, coastal plain moist tundra and wetlands (combined), and sand sheet moist tundra and wetlands (combined). For this analysis, we combined moist tundra and wetland CEs because the vegetation types were intermixed at a resolution that did not allow for comparison with SNAP models.

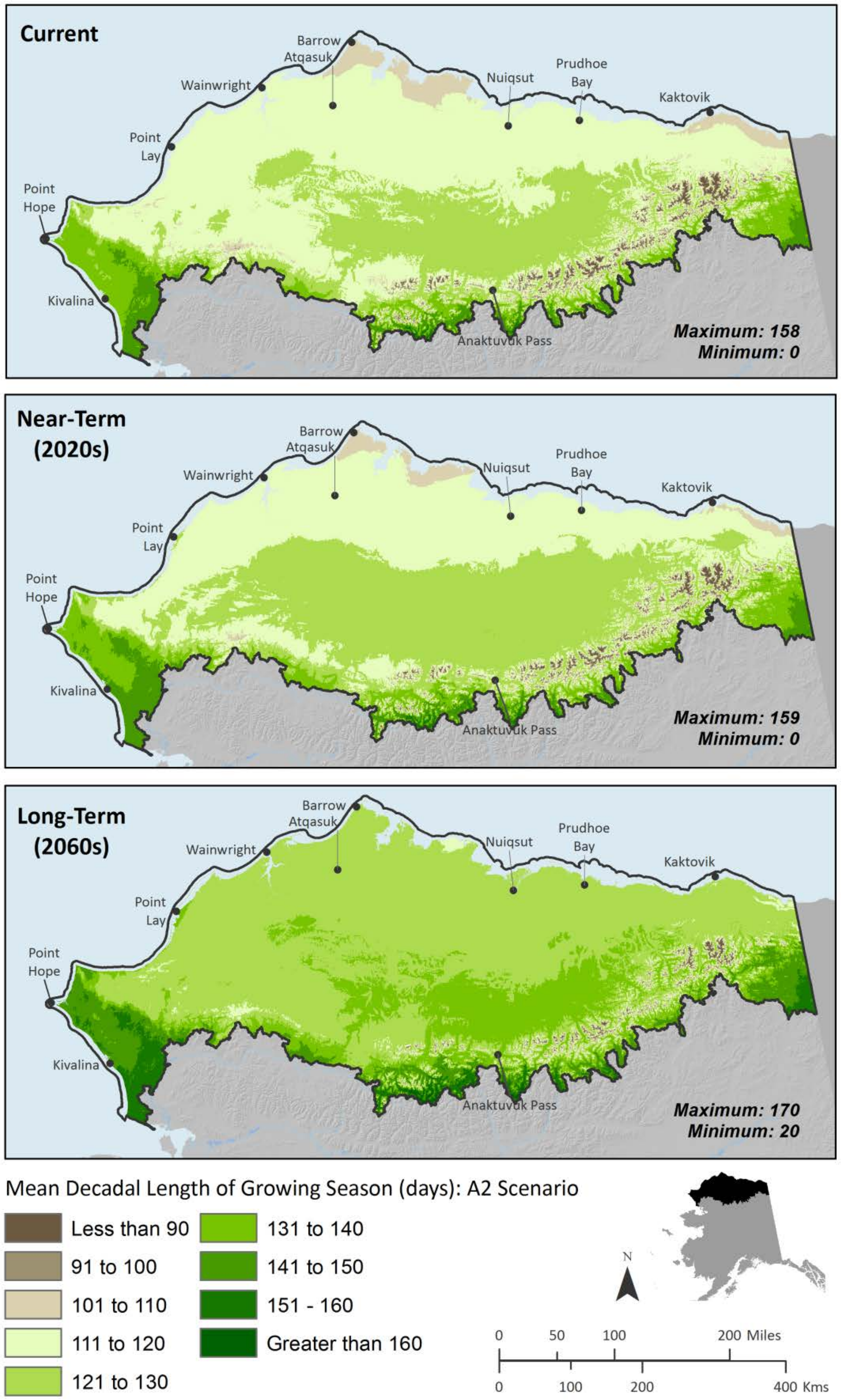


Figure G-6. Current, near-term future, and long-term future length of growing season in the North Slope study area.

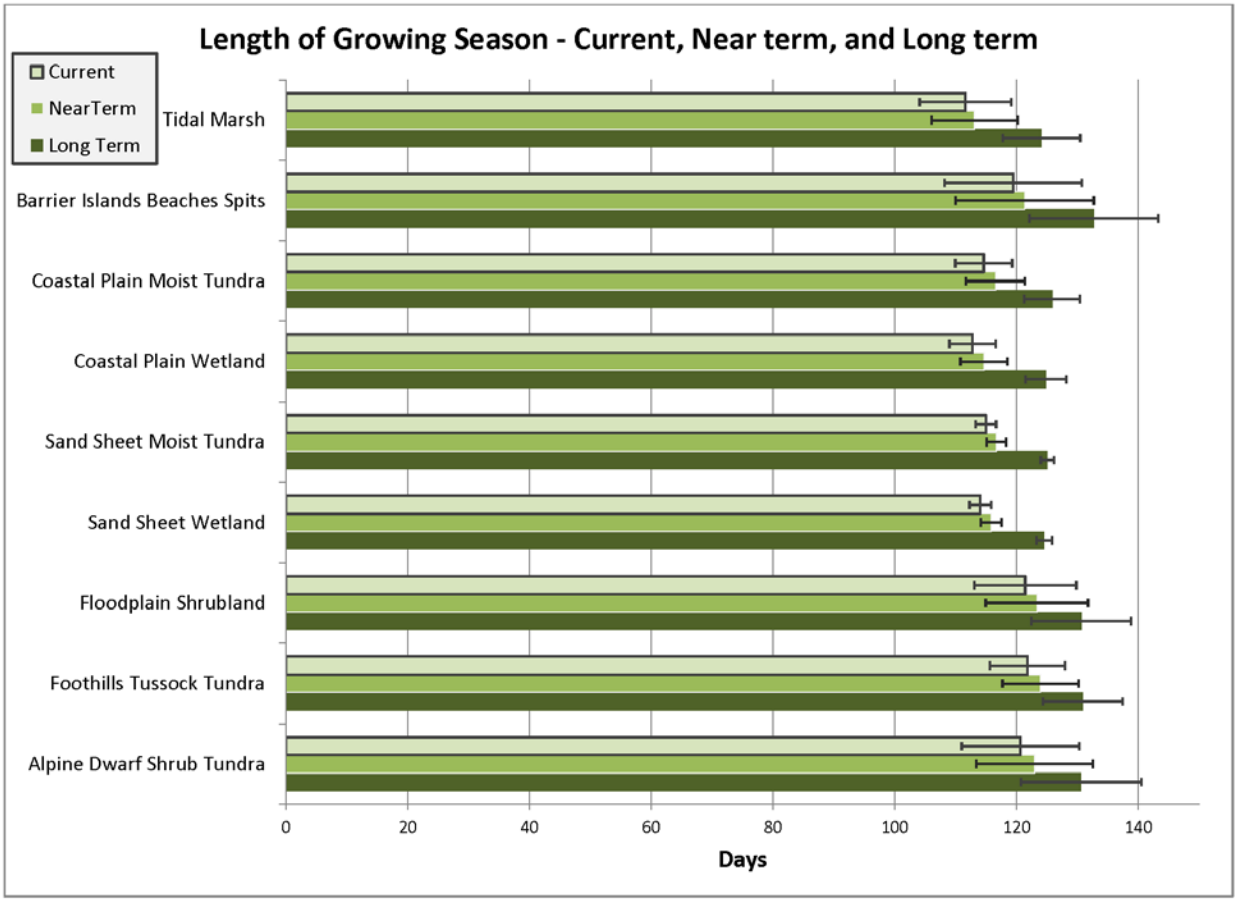


Figure G-7. Current, near-term future, and long-term future length of growing season by Terrestrial Coarse-Filter CE. Error bars represent one standard deviation in length of growing season.

Increases in temperature and length of growing season are expected to have a greater overall impact on vegetation habitat than increases in precipitation. Warmer summer temperatures and longer growing season will allow for increased vegetative growth and greater reproductive success for plants that tend to produce seeds late in the growing season (Molau 1993, Molau et al. 2005).

Table G-6. Current, near-term future, and long-term future mean length of growing season in days (LOGS).

Terrestrial Coarse-Filter CE	Current LOGS	Near-Term LOGS	Long-Term LOGS	Increase (from 2010s to 2060s)
Alpine Dwarf Shrub Tundra	120.7	123.0	130.6	+10.0
Foothills Tussock Tundra	121.8	124.0	130.9	+9.1
Floodplain Shrubland	121.4	123.4	130.6	+9.2
Sand Sheet Wetland	114.1	115.9	124.6	+10.5
Sand Sheet Moist Tundra	115.0	116.7	125.1	+10.1
Coastal Plain Wetland	112.8	114.7	124.9	+12.1
Coastal Plain Moist Tundra	114.6	116.6	125.9	+11.2
Barrier Islands Beaches Spits	119.4	121.3	132.7	+13.3
Tidal Marsh	111.6	113.1	124.1	+12.5
Average across all CEs	119.3	121.6	129.7	+10.3

Precipitation

General geographic patterns of precipitation are likely to remain unchanged across the REA, even as total precipitation increases slightly. The Brooks Range Mountains in the southern part of the REA currently experience more precipitation than the Foothills or Coastal Plain, and this trend is projected to continue in the near and long term (see Section C. Abiotic Change Agents for precipitation maps and additional discussion).

Slight to moderate increases in summer (June, July, and August) precipitation are projected for the Foothills and Brooks Range sub-regions within the REA (Table G-7), with non-significant increases in precipitation in the near term, but a significant trend appearing by 2060. The pattern of change for summer months shows greater increases in the central and eastern portions of the Brooks Range, with little change in the west, particularly on the coast.

Table G-7. Mean summer (June, July, August) and winter (December, January, February) precipitation in mm for current (2010s), near (2020s), and long term (2060s). Change by sub-region is the difference between long term and current.

Sub-region	Summer Precipitation (mm)			Summer Change (mm)	Winter Precipitation (mm)			Winter Change (mm)
	Current	Near	Long		Current	Near	Long	
W Coastal Plain	95	90	95	**0**	53	60	61	**+8**
C Coastal Plain	96	90	101	**+5**	44	48	51	**+7**
E Coastal Plain	97	89	102	**+5**	48	52	57	**+9**
W Foothills	131	127	134	**+3**	63	72	73	**+10**
C Foothills	143	139	152	**+9**	61	68	73	**+12**
E Foothills	140	132	148	**+8**	45	49	55	**+10**
W Brooks Range	178	175	187	**+9**	79	90	92	**+13**
C Brooks Range	251	253	271	**+20**	91	100	111	**+20**
E Brooks Range	256	248	272	**+16**	70	77	86	**+16**

Table G-8. Mean annual precipitation by CE for current (2010s), near term (2020s), and long term (2060s). Change in annual precipitation is the difference between current and long term.

Terrestrial Coarse-Filter CE	Mean Annual Precipitation (mm)			Δ Annual Precipitation (2010s to 2060s)
	Current	Near Term	Long Term	
Alpine Dwarf Shrub Tundra	479.0	486.4	534.9	+55.9
Foothills Tussock Tundra	348.4	356.2	391.9	+43.5
Floodplain Shrubland	310.9	315.8	348.6	+37.7
Coastal Plain Moist Tundra	254.9	259.0	283.2	+28.3
Coastal Plain Wetland	241.8	245.3	269.0	+27.1
Sand Sheet Moist Tundra	244.9	250.2	275.6	+30.7
Sand Sheet Wetland	242.3	247.2	272.4	+30.1
Tidal Marsh	237.4	239.3	265.5	+28.1
Barrier Islands Beaches Spits	263.7	269.2	293.3	+29.6

Unlike summer precipitation, winter precipitation (December, January, and February) is projected to increase across all sub-regions. The greatest amount of change is projected in the Brooks Range. The changes in precipitation across both the near term and long term are only of moderate significance. The inter-model mean standard deviation across the study area is 4.6 mm, therefore, variation in monthly, seasonal, or annual precipitation of less than 4.6 mm is considered 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 (See C-1.3 for more information).

It is difficult to predict the impact that these projected increases in precipitation will have on vegetation. While summer precipitation is predicted to increase, evapotranspiration and evaporation associated with increased temperatures will also increase, tempering the overall impact. Analysis of snow day fraction (see Section C-1.3) suggests changes to the timing of the formation of the snow pack and potentially a deeper snowpack in the Brooks Range, which could result in a shift in the timing of water availability from runoff. A deeper snowpack could also provide thermal insulation to vegetation and protect shrubs from desiccating winter winds and blowing ice-abrasion. Precipitation and snowpack projections should be interpreted cautiously because modeled 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 across the North Slope study area, because associated warming may mean that a greater percentage of this precipitation falls as rain. The ability of the landscape to store or shed water will likely have more impact on moisture status than changes to precipitation. If greater winter precipitation occurs as snow, we might anticipate increases in shrub growth in Tussock Tundra, Floodplain Shrublands, and Alpine Dwarf Shrub CEs in particular.

Fire and Vegetation Change

Tundra fires are uncommon in the Arctic (Racine et al. 2004), however recent large fires indicate arctic tundra is vulnerable to rapid changes in vegetation (Jones et al. 2009; Mack et al. 2011). Data on vegetation succession after tundra fires are particularly scarce, given the relative rarity of such fires (Barrett et al. 2012), and fire history in tundra ecosystems is poorly documented and may be under-recorded (Jones et al. 2013). Much of the information about vegetation response to fire comes from the Seward Peninsula where fires occur more frequently (Racine et al. 1987; Racine et al. 2004; Jandt et al. 2008).

Overall, ALFRESCO predicts increased fire frequency in the foothills and Brooks Range sub-regions within the North Slope study area. Fire is likely to remain absent – or almost absent – from the coastal plain sub-regions. Even with increased fire frequency, the area burned is expected to remain low.

ALFRESCO also 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. Transitions from one vegetation class to another within ALFRESCO can occur post-fire, but can also be driven by climate variables in the absence of fire (see Section C-2 for more detail about ALFRESCO). Potential transitions, and the climate factors or other events that drive these transitions are illustrated in the ALFRESCO transition model (Figure G-8).

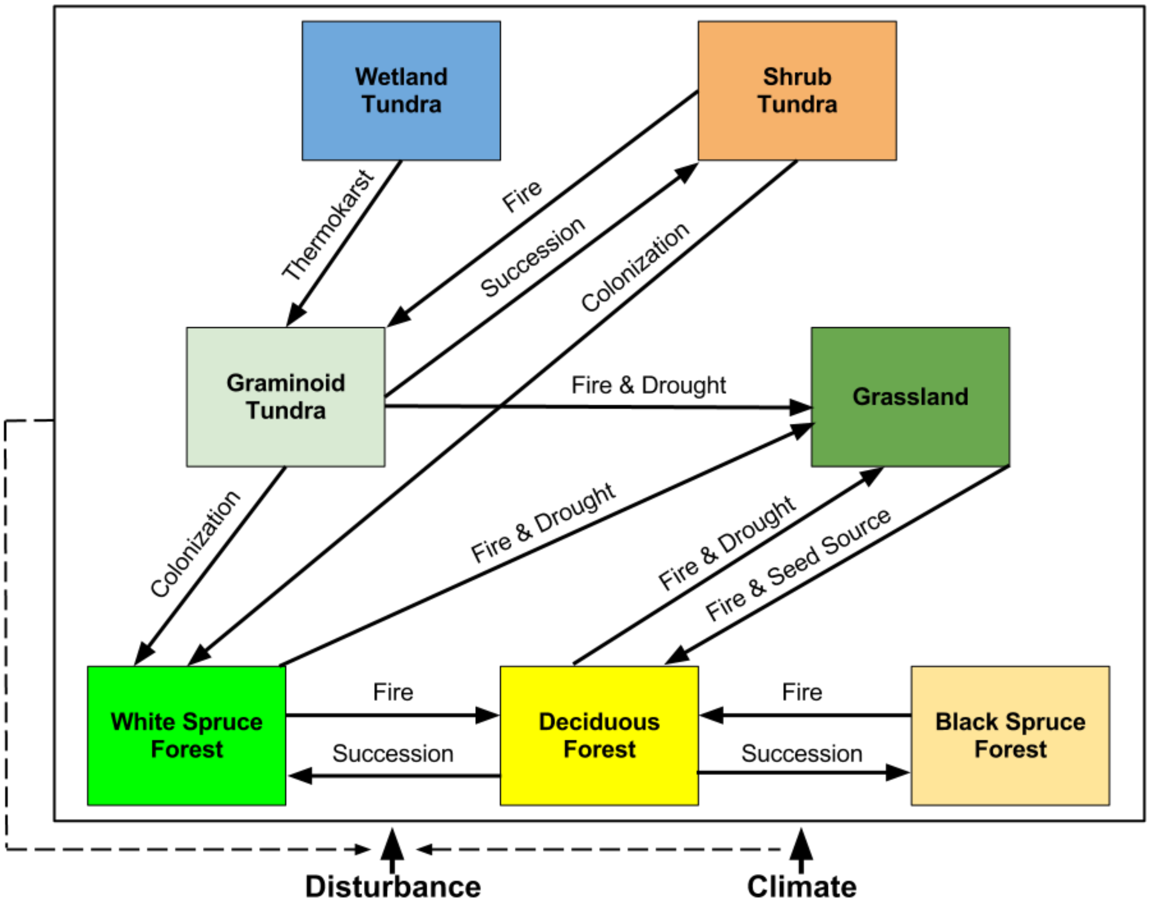


Figure G-8. Schematic of the ALFRESCO model showing potential vegetation transitions.

For the North Slope study area, the transitions modeled by ALFRESCO include shifts between graminoid and shrub tundra, and forest encroachment into tundra. Transitions involving thermokarst (the Alaska Thermokarst Model) have not yet been linked to the ALFRESCO model.

Transitions from graminoid to shrub tundra are governed by multiple factors, including time since fire and summer temperatures. Although tundra fire can promote shrub expansion (Racine et al. 2010, Breen and Gray 2015), shrubification can also occur without fire. ALFRESCO is calibrated such that immediately post-fire, shrub tundra transitions to graminoid tundra. Approximately 30 years post-fire, graminoid tundra may transition to shrub tundra. There is a greater chance of transition to shrub if a fire occurred than in the absence of fire (5% and 1% respectively). 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, and summer temperatures. For more information about the ALFRESCO transitions, refer to the Section C. Abiotic Change Agents.

While ALFRESCO is a spatially explicit model, the output for this analysis was not designed to be presented as a spatial product. Instead, ALFRESCO vegetation transitions were summarized by sub-region for near (2020s) and long term (2060s) (Figure G-2). This allowed us to make generalizations about trends across the North Slope study area, but prevented direct spatial analysis of impact on each

CE. In order to illustrate north to south trends in vegetation change, we summarized average vegetation cover by ecoregion for the three time steps (Figure G-9).

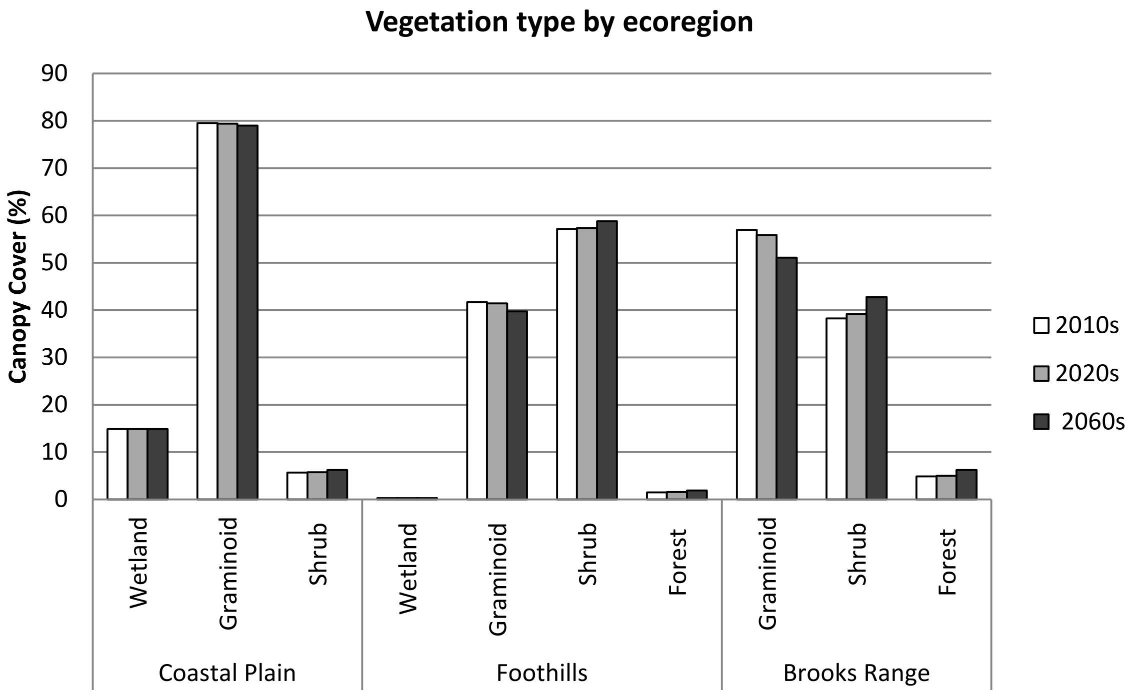


Figure G-9. Current, near-term future, and long-term future ALFRESCO projections for vegetation canopy cover summarized by ecoregion.

The ALFRESCO model predicts an increase in shrub cover in eight out of nine sub-regions across the North Slope study area (Figure G-10). The greatest increase in shrub cover is projected to occur in the Brooks Range sub-regions (Figure G-11). The increase occurs concurrently with a decrease in graminoid vegetation types indicating shrubification of graminoid tundra either through shrub migration or *in situ* height growth of shrubs. Given the relative infrequency of fire and low area burned, these transitions can be attributed mostly to climate-driven shrubification (Raynolds et al. 2013, Beck and Goetz 2011).

Change in shrub area in the foothills ecoregion may be underrepresented by the ALFRESCO model. According to the NSSI vegetation map (Ducks Unlimited 2013), tussock-shrub tundra is the dominant vegetation type in the foothills ecoregion. The North American Landcover Map, on which the ALFRESCO vegetation map is based, recognizes this class as "shrub," and therefore, the model does not account for increases in shrub canopy cover that may occur within the tussock-shrub vegetation type. Likewise, increases in shrub fraction that occur with the shrub class are not accounted for in the projections. For this reason, the increases projected in the ALFRESCO model for the foothills ecoregion should be considered very conservative, and most likely only represent shrub expansion at the margins of the ALFRESCO shrub class. These caveats do not apply to the coastal plain or Brooks Range ecoregions.

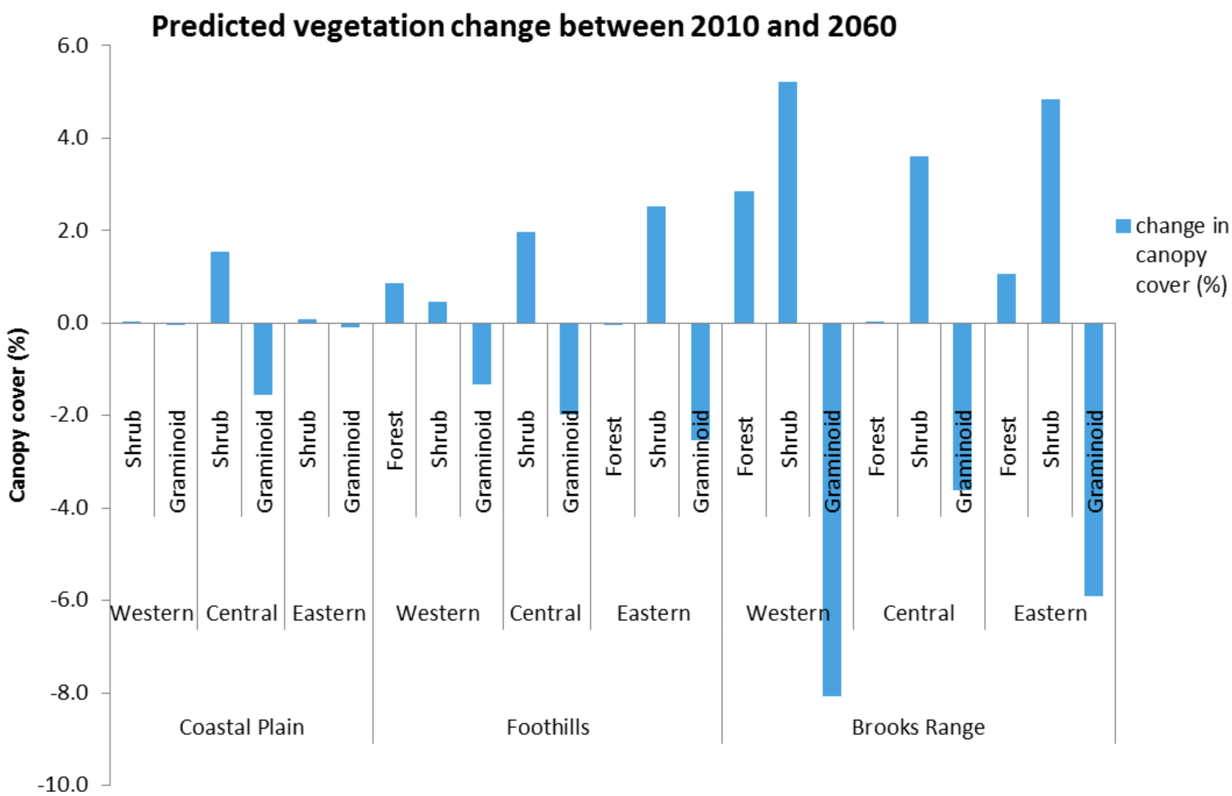
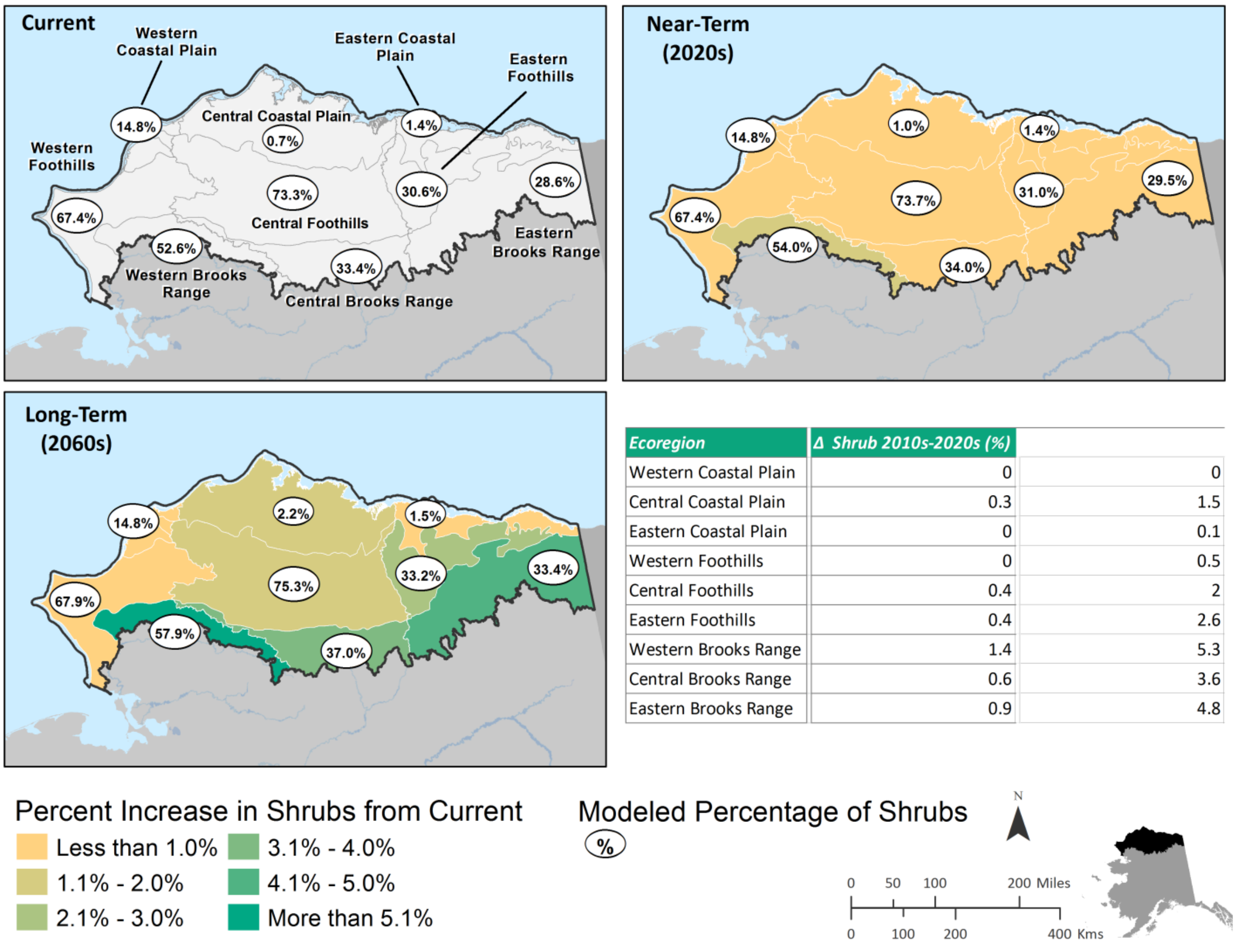


Figure G-10. ALFRESCO projections for change in vegetation canopy cover by sub-region between current and long-term conditions.



Ecoregion	Δ Shrub 2010s-2020s (%)	
Western Coastal Plain	0	0
Central Coastal Plain	0.3	1.5
Eastern Coastal Plain	0	0.1
Western Foothills	0	0.5
Central Foothills	0.4	2
Eastern Foothills	0.4	2.6
Western Brooks Range	1.4	5.3
Central Brooks Range	0.6	3.6
Eastern Brooks Range	0.9	4.8

Figure G-11. Projected long-term changes in shrub tundra modeled in ALFRESCO summarized by ecological sub-region.

Forested area is projected to increase slightly along the southern boundary of the project area where it is expected that treeline will migrate northward. The greatest change is expected in the Western Brooks Range sub-region where forest cover is projected to expand from 4.2 to 7.1% (Figure G-9). Slight increases area also projected in the Western Foothills and Eastern Brooks Range. This transition is facilitated by increased fire frequency, warmer summer temperatures, and increased growing season. Wetland transition drivers have not yet been incorporated into the ALFRESCO model, but potential transitions related to thermokarst are discussed below.

Permafrost Conditions and Vegetation

MQ TC 2	What are the changes in habitat and vegetation related to changing permafrost conditions, and what will these changes mean to wildlife and habitats?

The North Slope study area is largely underlain by continuous permafrost. Discontinuous permafrost occurs in limited areas around water bodies and coastal zones. 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).

Widespread degradation of permafrost features, particularly ice-wedge polygons, has been reported in recent decades in arctic lowlands (Jorgenson et al. 2006), and regional thermokarst activity has been reported in the Brooks Range (Gooseff et al. 2009).

Warming can affect vegetation communities directly through temperature effects on plant growth and indirectly through alteration of soil nutrient availability, changes to the underlying permafrost, and other processes. Thermokarst and increase in active layer thickness can alter hydrologic patterns and productivity.

Active layer thickness (ALT) varies on both a micro and macro level across the landscape. 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. Active layer thickness is controlled by climate variables, soil type, and the insulating properties of the vegetation, and as such, it is closely linked to vegetation composition and height. Average late summer thaw depths from representative sites across the arctic subzones in the North Slope study vary within a relatively narrow depth range, and each subzone is characterized by vegetation types with distinct structure and composition. Average values are 0.44 m in subzone C, 0.55 m in subzone D, and 0.47 m in subzone E (Walker et al. 2003). Because subtle differences in active layer thickness can yield large differences in land cover and vegetation (McMichael et al. 1997, Walker et al. 2003) we chose to categorize ALT in increments of 0.1 m for values between 0.3 m and 0.6 m instead of 0.25 m used in the Permafrost CA section (Figure G-12). Active layer thickness is expected to increase across the North Slope study area, though the amount of increase differs by CE (Figure G-13).

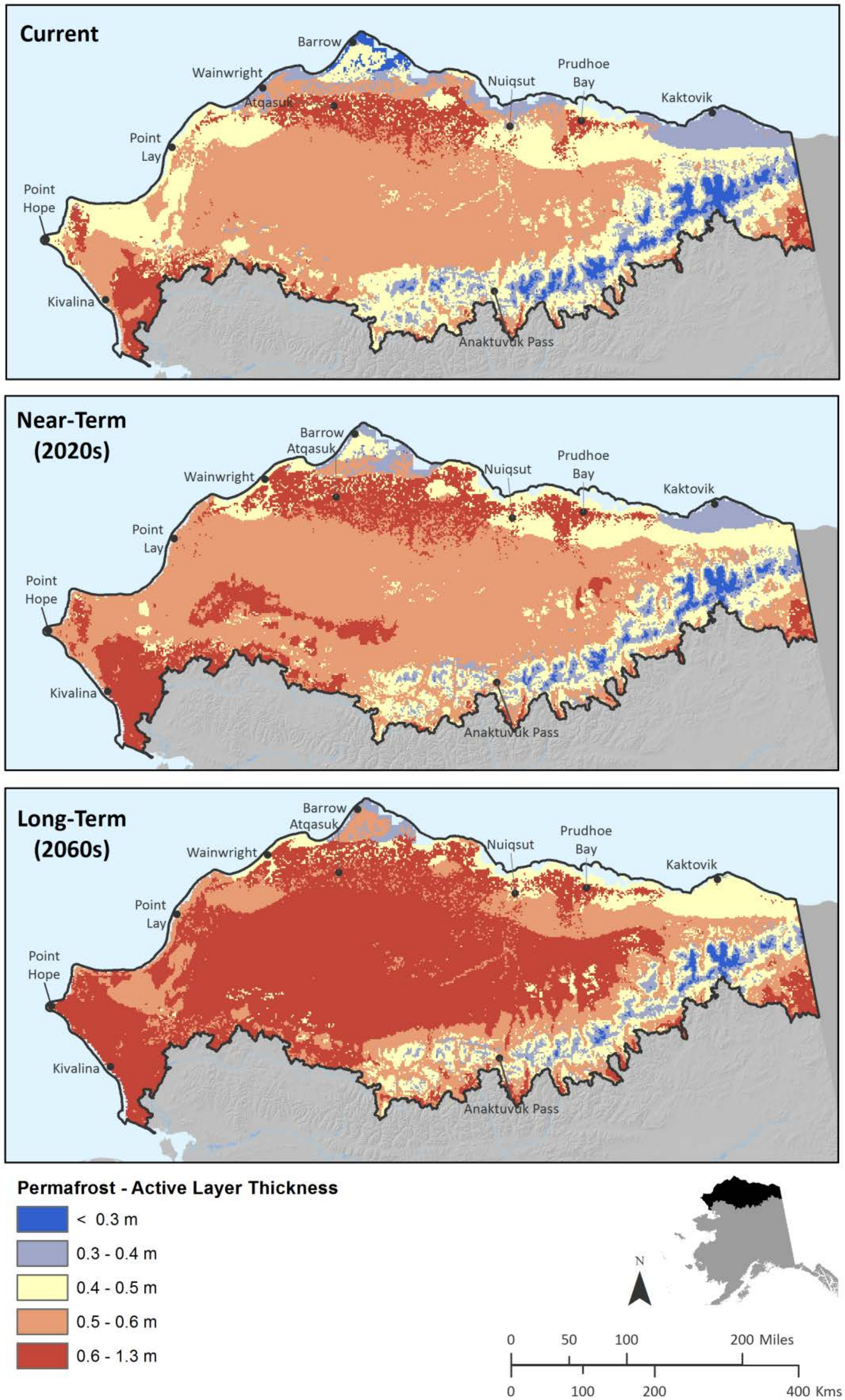


Figure G-12. Active layer thickness for current, near term, and long term.

The deepest active layers currently occur on the sand sheet, and these CEs are also projected to experience the greatest increase in ALT between current and long term. The least amount of increase is projected to occur in the alpine dwarf shrub tundra CE (Figure G-13). The resolution of the ALT model (1 km) is too coarse to compare changes in active layer to CEs that occur at a fine landscape resolution, such as floodplain shrublands, tidal marshes, and beaches, barrier islands, and spits. We removed these CEs from the analysis in order to avoid presenting misleading results.

Longer growing season combined with increased ALT will allow species with deeper rooting requirements to occupy previously unfavorable sites. Several common shrub species in the North Slope study area (such as *Salix pulchra* and *Betula nana*) exhibit great phenotypic plasticity; growing as prostrate or erect shrubs > 1 m tall depending on site conditions. These species can rapidly capitalize on changing environmental conditions by height expansion *in situ*. Subtle increases in canopy height in tundra vegetation can lead to widespread shifts in life form dominance from graminoid to shrub tundra.

Table G-9. Mean Active Layer Thickness (m) by CE for current, near, and long term.

Conservation Element	Mean ALT (m)			Increase (2010s to 2060s)
	2010s	2020s	2060s	
Alpine dwarf shrub tundra	0.46	0.50	0.54	+0.08
Foothills tussock tundra	0.52	0.57	0.61	+0.10
Sand sheet wetland	0.63	0.69	0.77	+0.14
Sand sheet moist tundra	0.61	0.67	0.74	+0.13
Coastal plain wetland	0.50	0.56	0.63	+0.12
Coastal plain moist tundra	0.49	0.54	0.60	+0.11

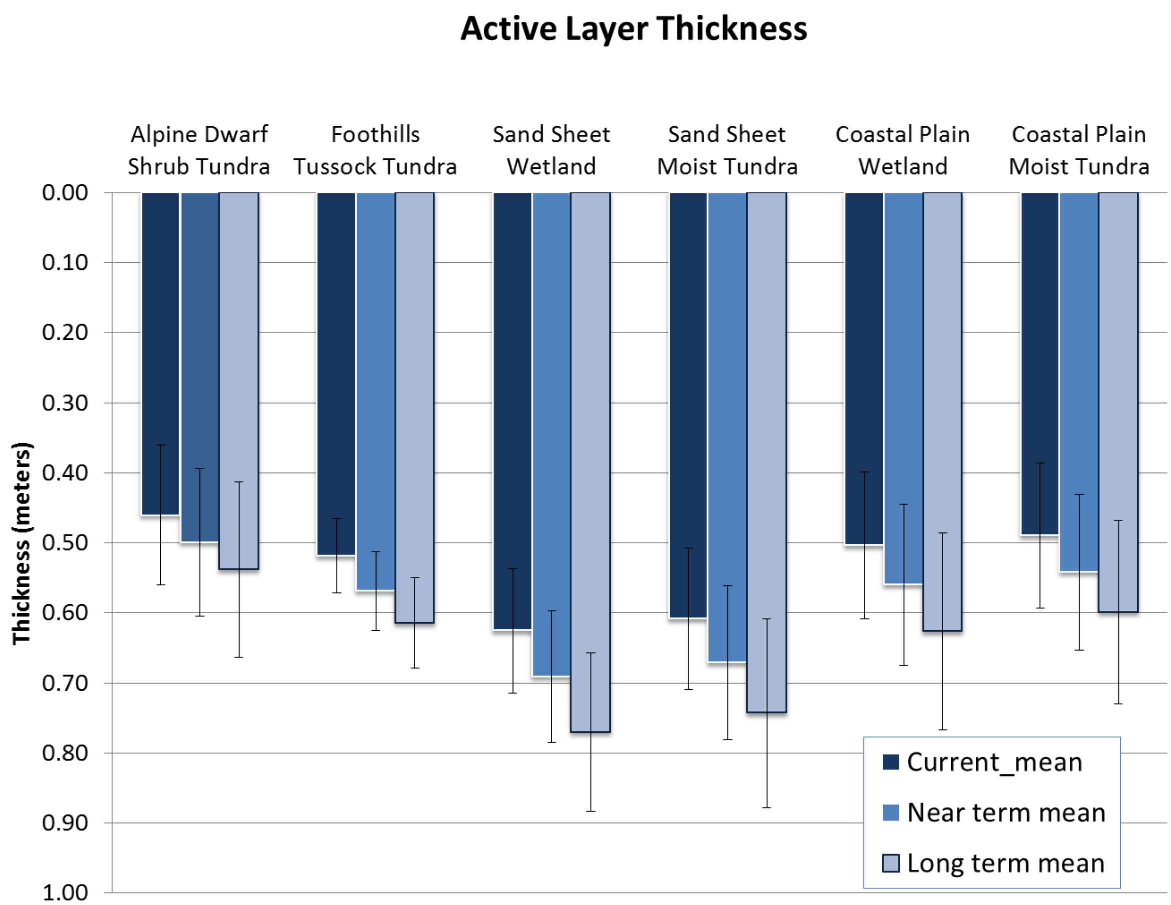


Figure G-13. Current, near-term future, and long-term future active layer thickness by CE. Error bars show standard deviation across entire CE distribution.

The ice content of the soil is a determining factor in assessing the likelihood of thermokarst and permafrost subsidence. Ice-rich permafrost has an ice volume that exceeds the total pore space of the soil and segregated ice or ice wedges can account for 10 - 45% of the soil volume in these sites (Walker et al. 1987, Williams and Smith 1989, Davis 2001). Thawing of excess ice leads to subsidence of the soil surface (Jorgenson et al. 2010). High ice-content soils are generally composed of fine-textured deposits (loess or glaciomarine deposits), while porous, well-drained sands and gravels tend to have low ice content (Jorgenson et al. 2008, Jorgenson and Grunblatt 2013). Soils with ice-rich permafrost are susceptible to greater thaw settlement than soils that have lower ice content.

The Thermokarst Predisposition Model represents the proportion of the landscape where thermokarst could initiate and expand under warming climate at a 1 km resolution (Figure G-14). The general hypothesis underlying the development of this model is that thermokarst occurs in lowland peaty soils with ice-rich permafrost (histels). The distribution of histels was assessed from the northern circumpolar soil carbon database (Hugelius et al. 2013) and permafrost distribution and ice content were assessed from the Alaska permafrost map (Jorgenson et al. 2008) and the circum-arctic map of permafrost and ground ice conditions (Brown et al. 1998).

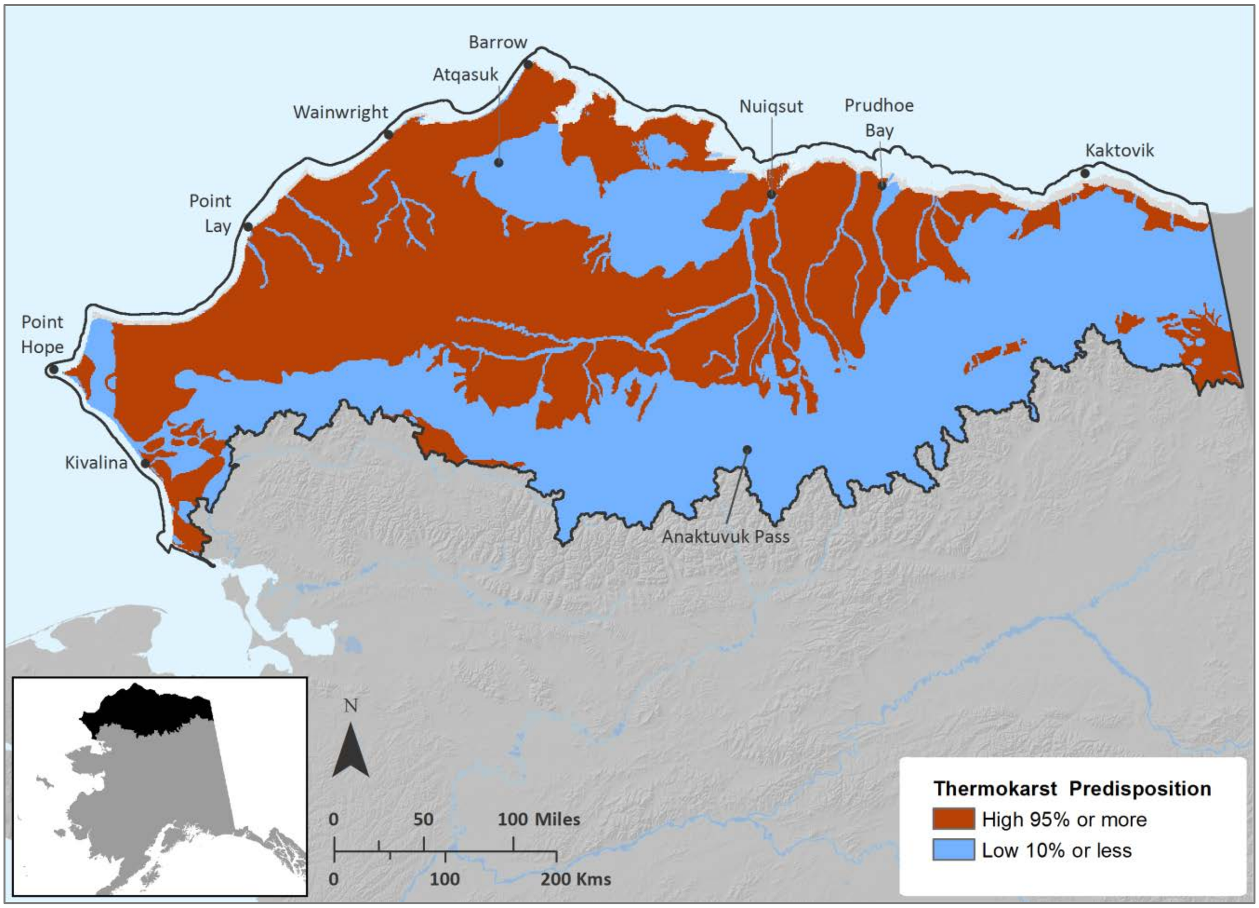


Figure G-14. Thermokarst predisposition in the North Slope study area.

Terrestrial CEs can be characterized according to ice content and permafrost features, allowing for assumptions to be made about the potential risk of thermokarst (Figure G-15 and Table G-10). High risk CEs include: coastal plain moist tundra, coastal plain wetland, and the lower portion of foothills tussock tundra (adjacent to the coastal plain), which is underlain by deep loess deposits and massive ice. Low risk CEs include: sand sheet moist tundra, floodplain shrublands, and alpine dwarf shrub tundra. Because of the difference in resolution between the thermokarst model (1 km) and the CE distribution map (30 km), we grouped CEs that were closely intermixed and occurred on similar substrates. Results of the floodplain shrubland intersection with the thermokarst model are somewhat misleading owing to the mismatch in spatial resolution between the thermokarst model and the physiography layer used to define floodplains (Jorgenson and Grunblatt 2013). The CE distribution captured more floodplain area than did the thermokarst model, and therefore the intersection yielded a higher risk than would be reflected had the models used the same floodplain distribution.

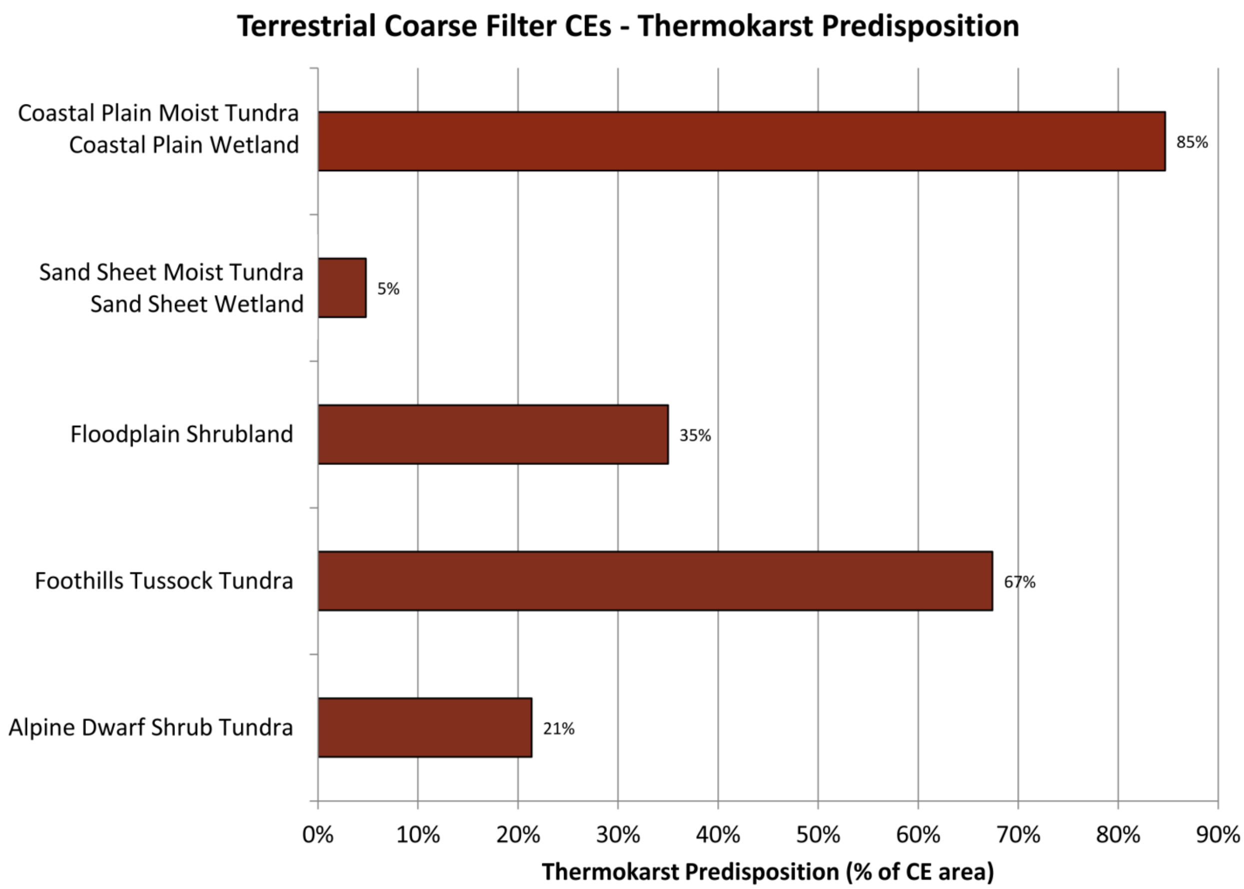


Figure G-15. Percent area of each CE with a high thermokarst predisposition.

Predicted shifts in vegetation modeled in ALFRESCO do not yet incorporate the effects of thermokarst and increasing active layer thickness on vegetation. Therefore, the effects of thermokarst could only be considered qualitatively, not quantitatively. Permafrost degradation and associated thermokarst have been reported in regions of ice-rich permafrost on the coastal plain (Jorgenson et al. 2006), so it follows that increasing temperatures and active layer thickness will trigger more thermokarst in sensitive terrain. After thermokarst initiation, transitions are determined by the ice content of the soil (potential for subsidence) and the ability of the landscape to shed or store water (drainage efficiency). Thermokarst resulting in drainage can lead to drier conditions and increased shrub cover, while areas that do not shed water can transition to open water or wetlands.

The coastal plain (exclusive of the sand sheet) is underlain by ice-rich permafrost and is prone to thermokarst subsidence. It is possible that regions of the coastal plain with low drainage efficiency could become wetter after initiation of thermokarst. The sand sheet, however, is not considered susceptible to thermokarst, and although the active layer is projected to increase in this region, this is not likely to result in widespread thermokarst subsidence.

Much of the lower portion of the foothills ecoregion (and the foothills tussock tundra CE) is underlain by deep loess deposits which support extremely ice-rich permafrost (Carter 1988, Kanevskiy et al. 2011).

The Thermokarst Predisposition Model ranks this portion of the foothills as "highly predisposed" to thermokarst based on high ice and organic content of the soil. Thermokarst failures have been reported from the Noatak Basin and near Toolik Lake (Bowden et al. 2008, Gooseff et al. 2009). The activity and number of thermokarst failures are expected to increase, especially in areas of the lower foothills where the landscape is characterized by soils with high interstitial and massive ice content. Areas of the foothills not underlain will be less likely to see thermokarst action; but changes linked to temperature, active layer and shrub increase are likely.

Alpine environments, including the alpine dwarf shrub CE, are often underlain by rocky residual soils, and are generally thaw stable. Changes in the alpine will most likely be linked to snowpack and shrub migration.

Table G-10. Ground ice content and permafrost features of CEs as derived from Alaska Permafrost Map (Jorgenson 2008).

<table>
<tr><th colspan="2">Conservation Element</th><th>Ground Ice Content</th><th>Permafrost Features and Thermokarst</th></tr>
<tr><td colspan="2">Coastal Plain Wetland</td><td>High</td><td>Low-centered polygonal tundra; thaw lake basins</td></tr>
<tr><td colspan="2">Coastal Plain Moist Tundra</td><td>High</td><td>High-centered and flat-topped polygonal tundra; pits and troughs</td></tr>
<tr><td colspan="2">Sand Sheet Wetland</td><td>May be high where fine sediments have accumulated in basins</td><td>Low-centered polygonal tundra, non-patterned</td></tr>
<tr><td colspan="2">Sand Sheet Moist Tundra</td><td>Low</td><td>Non-pattered or polygonal tundra; pits and troughs</td></tr>
<tr><td rowspan="2">Foothills Tussock Tundra</td><td>lower foothills</td><td>High (deep loess deposits)</td><td>Deep thaw lakes, thaw slumps</td></tr>
<tr><td>mid-upper foothills</td><td>Moderate</td><td>Non-pattered or polygonal tundra; Thaw slumps, gullies, water tracks</td></tr>
<tr><td colspan="2">Floodplain Shrubland</td><td>Low</td><td>Permafrost generally deeper than 120 cm. soils are porous sands and gravels</td></tr>
<tr><td colspan="2">Alpine Dwarf Shrub Tundra</td><td>Low to variable</td><td>Bedrock near surface</td></tr>
<tr><td colspan="2">Tidal Marsh</td><td>High on coastal plain tidal marshes; low in estuarine river deltas</td><td>Subsiding polygonal tundra common in Coastal Plain tidal marshes. Estuarine marshes have variable permafrost.</td></tr>
<tr><td colspan="2">Barrier islands Beaches and Spits</td><td>Barrier islands that are remnants of the old coastline may have high to moderate ice content. Spits and beaches composed of sand and gravel have low ice content</td><td>Polygonal features on remnant coastline islands</td></tr>
</table>

Invasive Species

Currently, invasive species have a very limited distribution in the study area, but have the capacity to be an increasing concern with increasing temperatures and development (see Section D. Biotic Change Agents). Resource development and travel corridors such as roads and trails, and oil and gas infrastructure provide pathways for weed dispersal and establishment (see Carlson et al. 2014). Frequently disturbed natural habitats such as floodplains and gravelly beaches are natural habitats that are frequently colonized elsewhere in the state (AKEPIC 2014). We explored the relationship of growing season to invasive plants in order to create a model for potential invasion. See Section D. Biotic Change Agents for discussion of potential effects of invasive species on floodplain shrublands and barrier islands, beaches, and spits.

Landscape Condition

We worked closely with the NSSI Scenarios project to incorporate future human footprint estimates from their scenario exercises (see Section B-5). Instead of near- and long-term futures, we use the "Medium" and "High" oil and gas scenarios generated as part of that effort. Due to the limited scope of the scenarios project, and the anticipated lack of population change in the villages, our future human footprint is largely driven by changes in oil and gas infrastructure. We did not include the footprint for ice roads and winter trails in the models of landscape condition because we lacked information on the future footprint for this type of land use. Ice roads and winter trails are included in the current footprint for oil and gas and in the models produced for the impact of oil and gas on CE habitat (MQ TC 1). Future oil and gas infrastructure associated with the Medium Scenario develops part of the Greater Mooses Tooth region of NPR-A, and further expands the development currently at Point Thompson. The Liberty drilling pads are expanded, and there is a new pipeline built connecting offshore activities to the Point Thompson region in the Medium Scenario as well. Additionally, we included the road and relocation of Kivalina in the Medium Scenario. The High Scenario included all the same development of the Medium Scenario, but expanded the Greater Mooses Tooth development to include a pipeline connecting to development on Smith Bay, develops a pipeline and road from the potential Chukchi Sea facilities, and develops a pipeline connecting Umiat to other oil and gas infrastructure. Although offshore activities are included in the NSSI scenarios, we did not include those developments given our terrestrial focus. 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 Scenario, the results should be considered representative of potential changes to overall landscape condition.

Table G-11 displays the current condition and shows the relative impact that the medium and high scenarios will have on each CE. A spatial model of landscape condition and each development scenario is provided in the individual CE descriptions. MQ TC 1 provides a spatial model of current oil and gas development for each CE and discussion about the specific impacts to CE habitat.

Most of the North Slope study area is considered relatively pristine (very high condition), with intense localized impacts (see Section F. Landscape and Ecological Integrity). When the current distribution of the Terrestrial Coarse-Filter CEs was compared to the LCM at current, medium, and high scenarios, over

92% of CE area was considered in very high condition, with the exception of Barrier Islands, beaches, and spits which as 83% very high condition.

Table G-11. Landscape condition by percent of CE for current condition and two future development scenarios: medium and high.

Conservation Element	Development Scenario	Landscape Condition (% of CE Area)				
		Very Low	Low	Medium	High	Very High
Tidal Marsh	Current	0.4	1.4	1.8	2.6	93.7
	Medium	0.4	1.5	1.9	2.8	93.4
	High	0.4	1.5	2.0	2.8	93.3
Barrier Islands, Beaches, and Spits	Current	1.2	7.9	3.7	4.5	82.7
	Medium	1.2	8.1	3.7	4.5	82.6
	High	1.2	8.1	3.7	4.5	82.6
Coastal Plain Moist Tundra	Current	0.4	1.2	1.2	1.4	95.8
	Medium	0.4	1.2	1.3	1.5	95.7
	High	0.4	1.4	1.5	1.7	95.0
Coastal Plain Wetland	Current	0.5	1.6	1.7	2.0	94.1
	Medium	0.5	1.6	1.8	2.0	94.0
	High	0.6	1.9	2.1	2.4	93.0
Sand Sheet Moist Tundra	Current	NA	0.0	0.0	0.1	99.8
	Medium	NA	0.0	0.0	0.2	99.8
	High	NA	0.5	0.5	0.6	98.4
Sand Sheet Wetland	Current	NA	0.0	0.0	0.1	99.8
	Medium	NA	0.0	0.1	0.2	99.7
	High	NA	0.3	0.5	0.8	98.4
Foothills Tussock Tundra	Current	0.1	0.3	0.3	0.3	98.9
	Medium	0.1	0.3	0.3	0.3	98.9
	High	0.1	0.3	0.4	0.4	98.8
Floodplain Shrubland	Current	1.5	2.3	1.7	1.8	92.7
	Medium	1.5	2.3	1.7	1.8	92.7
	High	1.5	2.3	1.8	1.9	92.4
Alpine Dwarf Shrub Tundra	Current	0.1	0.2	0.2	0.3	99.1
	Medium	0.1	0.2	0.2	0.3	99.1
	High	0.1	0.2	0.3	0.3	99.1

Relative Management Responsibility

Federal and state agencies are faced with the challenge of balancing needs for resource extraction, energy development, recreation, and other uses with the growing urgency to conserve wildlife and habitat. Better collaboration among agencies can increase the effectiveness of public lands management for species that migrate across political boundaries. We used the relative proportion of a CE distribution falling within agency boundaries as a proxy for relative amount of management responsibility.

Distributions of CEs in relation to areas managed both publicly and privately within the North Slope Study Area reflect the overall ratio of land ownership in the REA, with the highest percentages occurring on BLM land (Table G-12). While the BLM has largest area of land management responsibility, several important habitats are managed across several ownerships. The management of barrier islands, beaches, and spits is divided across all ownerships, with the largest percentage under Native Patent ownership. Floodplain shrublands are also split across all ownerships, with the largest percentage under state ownership. The sand sheet CEs are almost entirely under BLM management, while alpine dwarf shrub is predominantly managed by NPS and USFWS. This complex mosaic highlights the need for management strategies that transcend ownership boundaries to meet the challenge of balancing needs for resource use with conservation.

Table G-12. Land ownership status of each Terrestrial Coarse-Filter CE.

Terrestrial Coarse-Filter CE	BLM	USFWS	State	NPS	Native	DOD
Tidal Marsh	53%	5%	23%	2%	16%	1%
Barrier Islands, Beaches, and Spits	13%	15%	23%	11%	35%	3%
Coastal Plain Moist Tundra	55%	11%	21%	1%	11%	-
Coastal Plain Wetland	58%	7%	24%	-	12%	-
Sand Sheet Moist Tundra	98%	-	-	-	2%	-
Sand Sheet Wetland	98%	-	-	-	2%	-
Foothills Tussock Tundra	46%	8%	26%	8%	12%	-
Floodplain Shrubland	23%	18%	34%	7%	18%	-
Alpine Dwarf Shrub Tundra	15%	44%	12%	22%	7%	-

1.3. Applications

The approach and information outlined in this section is intended to synthesize existing data and to offer a foundation for managers and researchers to develop more specific predictions. We see a value in here to assist in focusing monitoring efforts to more appropriate locations, scales, and phenomena of resources that are of high ecological value and projected to face greater challenges in the future. Additionally, the outputs from this section may be useful in identifying relative management responsibilities for particular ecological resources among agencies.

1.4. Limitations

A large portion of the results presented in this section are derived in part by climate models developed by SNAP. The limitations and data gaps associated with climate predictions are covered in detail in Section C-1.

The accuracy of NSSI landcover classes used to generate the CE distributions is not known. While this generates uncertainty in the identity of individual pixels, we believe the larger patterns and the overlay with CAs is robust. Additionally, the distribution data of barrier islands and tidal marsh landcover classes was incomplete and we therefore used NWI polygons. Differences in scale between SNAP products and 30 m resolution of CE distributions, particularly of CEs with narrow and linear distributions can be misleading. The ALFRESCO vegetation map does not crosswalk directly with landcover classes used to generate the CEs, leading to overgeneralization of some of the key ecosystem resources. Lastly, spatial data on gravel mines was not available for incorporation with the Landscape Condition Model and is therefore not included in the overlay of the Terrestrial Coarse-Filter CEs.

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2. Coastal Plain Moist Tundra

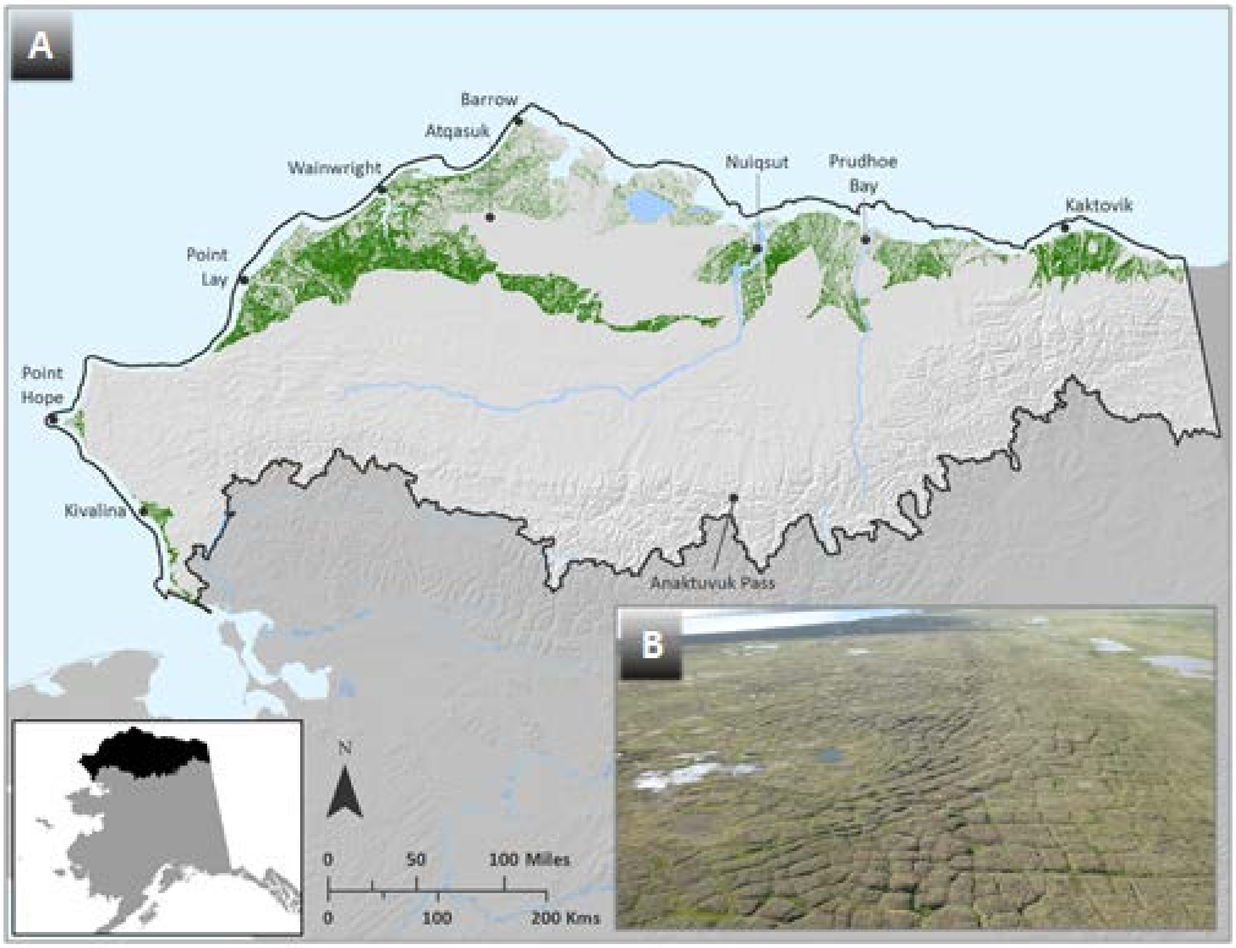

Figure G-16. Current distribution of the coastal plain moist tundra CE in the North Slope study area (A) and coastal plain moist tundra with high-centered polygons (B).

2.1. Introduction

The Coastal Plain Moist Tundra CE is composed of high-centered and flat-topped polygonal terrain with little topographic relief. This CE forms the matrix between basin wetlands and thermokarst lakes on the coastal plain. Soils are poorly drained and formed on silty deposits of marine, glacial or alluvial origin. Ice-rich permafrost occurs within 1 m of the surface (Jorgenson and Grunblatt 2013). The distribution of this CE is limited to arctic peaty lowlands and arctic silty lowlands of the coastal plain (Jorgenson and Grunblatt 2013); sandy deposits are excluded because the impact of climate warming on active layer, ice wedge stability, and surface water may differ on sandy, ice-poor substrates. The thermokarst lake cycle is the dominant landscape process controlling the distribution of vegetation communities within this CE (see the coastal plain wetland CE for a brief description of the thermokarst lake cycle).

Moist tundra occupies the raised portions of polygons and wetland vegetation occurs in the troughs.

Tussock-forming sedges *Eriophorum vaginatum* and *Carex lugens* are typically the dominant species on the raised portion of the polygons and usually have a combined cover of at least 40%. Shrubs generally have a prostrate growth form (average height is 10.3 cm, NPRA AIM plots) and cover is variable but generally exceeds 25%. *Salix pulchra, Rhododendron tomentosum, Cassiope tetragona, Betula nana,* and *Vaccinium vitis-idaea* are the most common shrubs. Common mosses include *Hylocomium splendens, Aulacomnium* spp., *Tomentypnum nitens, Dicranum* spp., and *Sphagnum* spp. Lichens are consistently present with low canopy cover; common species include *Peltigera* spp., *Flavocetraria* spp., *Cladina* spp., and *Thamnolia vermicularis.* Wetland vegetation in troughs is primarily composed of *Carex aquatilis*, *Eriophorum angustifolium*, and *Sphagnum* spp.

2.2. Conceptual Model

The conceptual model below (Figure G-17) is based on literature review and describes the relationship between the various change agents and natural drivers for coastal plain moist tundra. Bold arrows indicate interactions with high ecological relevance and potential management implications, and for which spatial datasets can be intersected with the CE distribution. The primary change agents selected for this CE include: climate change, permafrost, and land use change (i.e. human development).

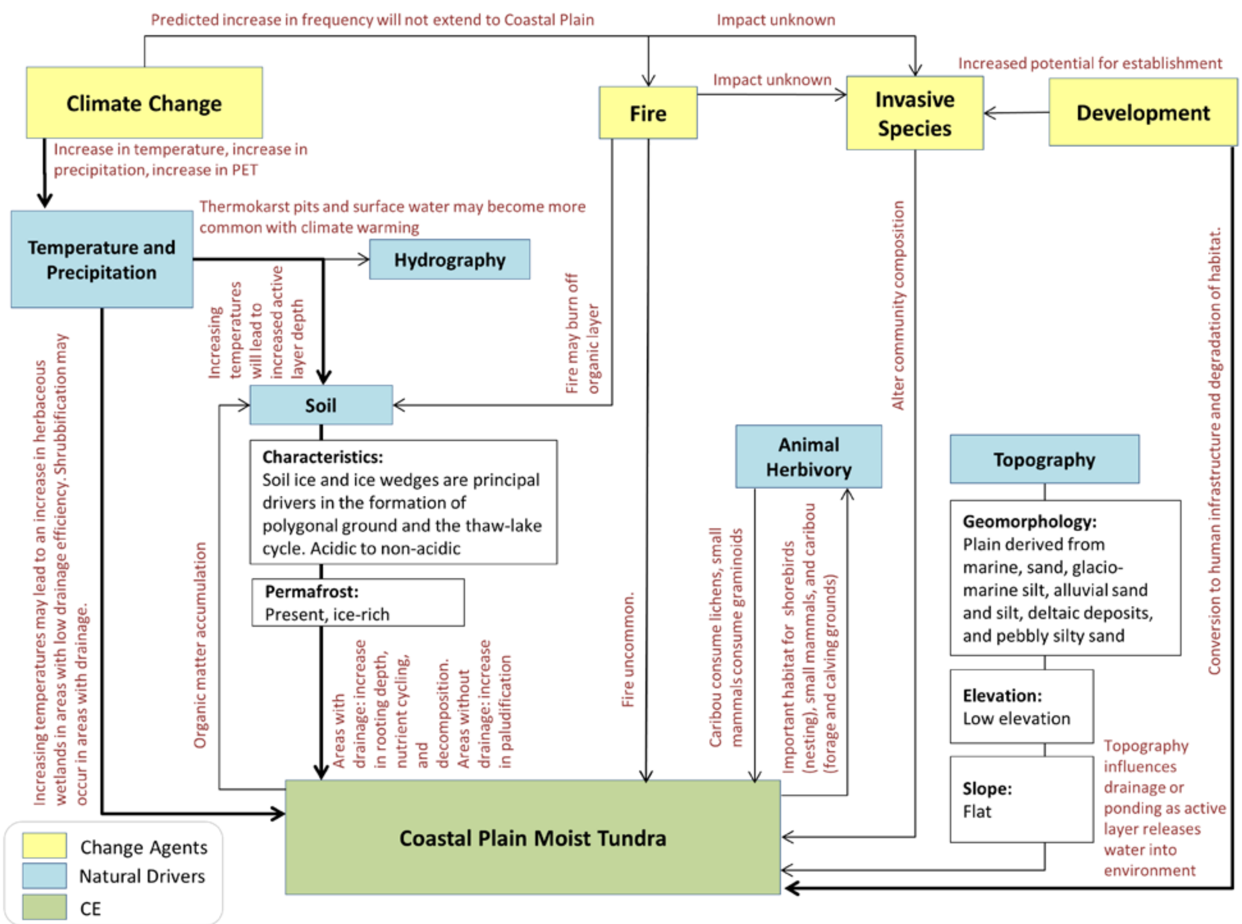

Figure G-17. Conceptual model for coastal plain moist tundra.

2.3. Abiotic Change Agents Analysis

We explored the impact of two climatic change agents on coastal plain moist tundra: temperature (July temperature and length of growing season) and permafrost (active layer thickness and thermokarst predisposition). Fire is not expected to increase on the coastal plain. Warming is expected to affect vegetation communities directly through temperature effects on plant growth and indirectly primarily through changes to the underlying permafrost and soil properties.

Temperature

Increases in July temperature both in the near and long term are not expected to be significant across most of the coastal plain ecoregion. By the 2060s significant increases (> 1.3 °C) are projected for only 6% of the of coastal plain moist tundra distribution (Table G-4). In the long term (2060s) the average projected increase in mean July temperature across the CE distribution is 1.1 °C, and the mean annual increase is predicted to be 2.4 °C (Table G-5). Although the change in July temperature appears to be slight, the average increase in the length of growing season is projected to be 11.2 days (Table G-6). While temperature models show that warmest summer temperatures occur in the in the southern portion of the CE (Figure G-4), the greatest amount of change in the length of growing season is projected to occur in northern portion of the CE, with projected increases of 16 to 18 days in the long term around the communities of Wainwright and Barrow (Figure G-18).

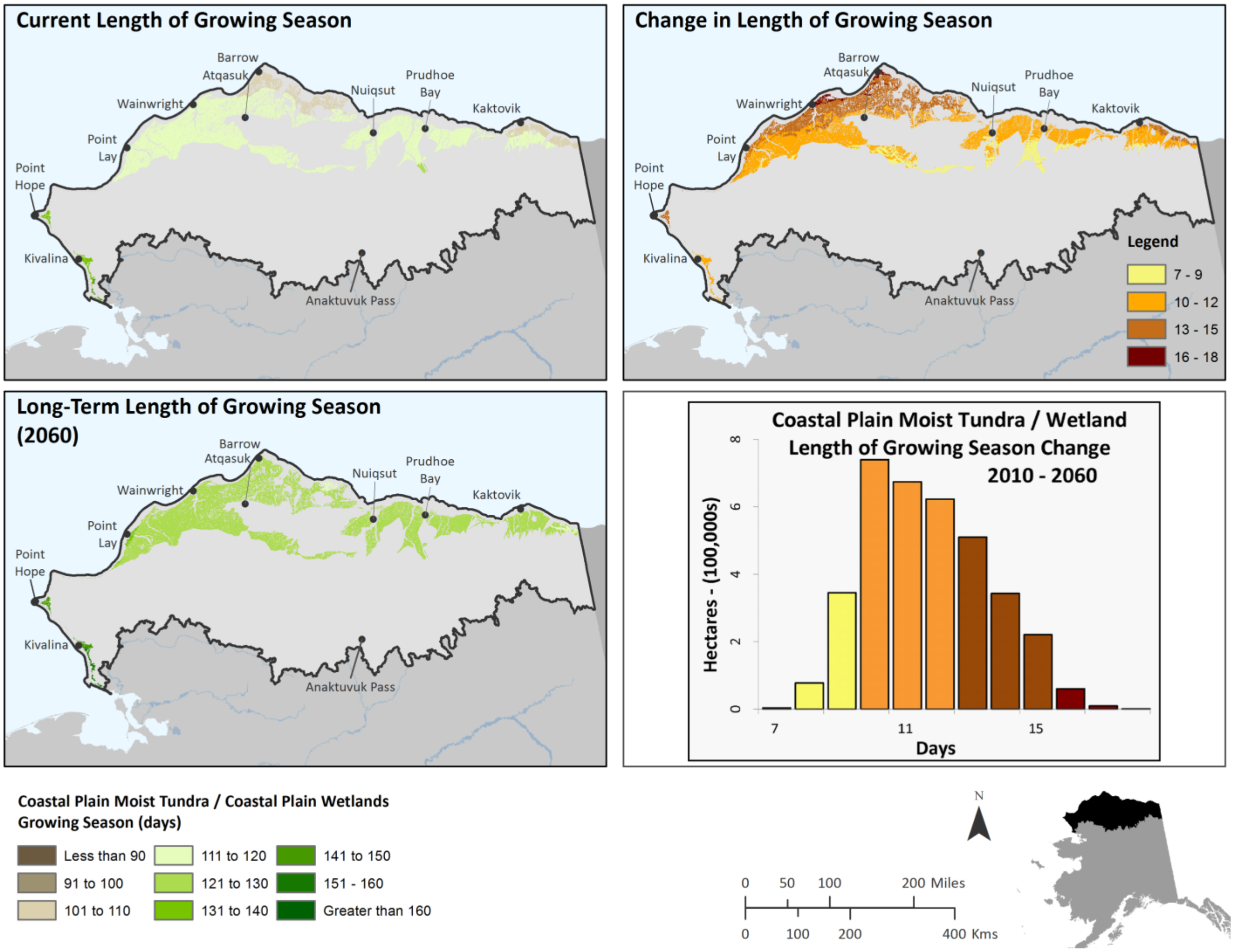

Figure G-18. Length of growing season (LOGS) for current and long-term future and change in LOGS clipped to the coastal plain moist tundra and wetlands CE distributions in the North Slope study area.

Permafrost

Increased temperatures will lead to an increase in active layer thickness (ALT) which will allow an increase in the depth of the rooting zone for vascular plants and will likely lead to increased potential for thermokarst. Current ALT for the coastal plain moist tundra CE is modeled at 0.49 m and is projected to increase to 0.60 m in the long term (Table G-9).

This landscape is characterized by ice-rich permafrost and polygonal features. The thermokarst predisposition model ranks this portion of the coastal plain as highly susceptible to thermokarst (Figure G-14). The surface of the ice wedges are protected from thawing by a thin layer of permafrost below the bottom of the active layer. If the active layer becomes deeper than the protective layer, rapid thawing of the ice wedge can occur (Bolton et al. 2014). Increasing summer temperatures will likely lead to ice wedge degradation and an increase in thermokarst pits resulting in an increase in surface water. This process has been documented in ice-rich polygonal tundra near the Colville River Delta (Jorgenson et al. 2006). If this trend continues, we expect a shift from moist tundra to open water and herbaceous wetlands in areas with low drainage efficiency. Regions that are able to shed excess water may develop drainage networks and deepening polygon troughs with drier polygon centers (McGuire 2013). Tundra in better drained regions may exhibit an increase in shrub height and cover facilitated by increased active layer and longer growing season (Sturm et al. 2001, Wahren et al 2005, Tape et al. 2006).

2.4. Current Status and Future Landscape Condition

Ice roads, seismic exploration, and winter trails can damage moist tundra vegetation, particularly tussock vegetation (Guyer and Keating 2005, Felix and Raynolds 1989). Compression of tussock and bryophytes can lead to changes in active layer depth and can result in a shift from moist tundra to wet sedge vegetation. These changes may lead to changes in drainage networks that may affect adjacent vegetation. Aerial transport and deposition of fine sediment near roads, airstrips, and towns, can alter soil chemistry in adjacent tundra (Walker et al. 1987).

Current infrastructure and exploration is largely concentrated in the coastal plain, though moist tundra is less impacted than wetlands. The overall status of the coastal plain moist tundra CE was assessed by intersecting the Landscape Condition Model (LCM) with the CE distribution model for the current condition and two development scenarios, medium and high. 95.8% of the coastal plain moist tundra CE is in the "very high" condition class. Under the "high development" scenario, it is estimated that 95% of the CE will still be in the "very high" condition class. See MQ TC 1 for more discussion about the impact of development on coastal plain moist tundra.

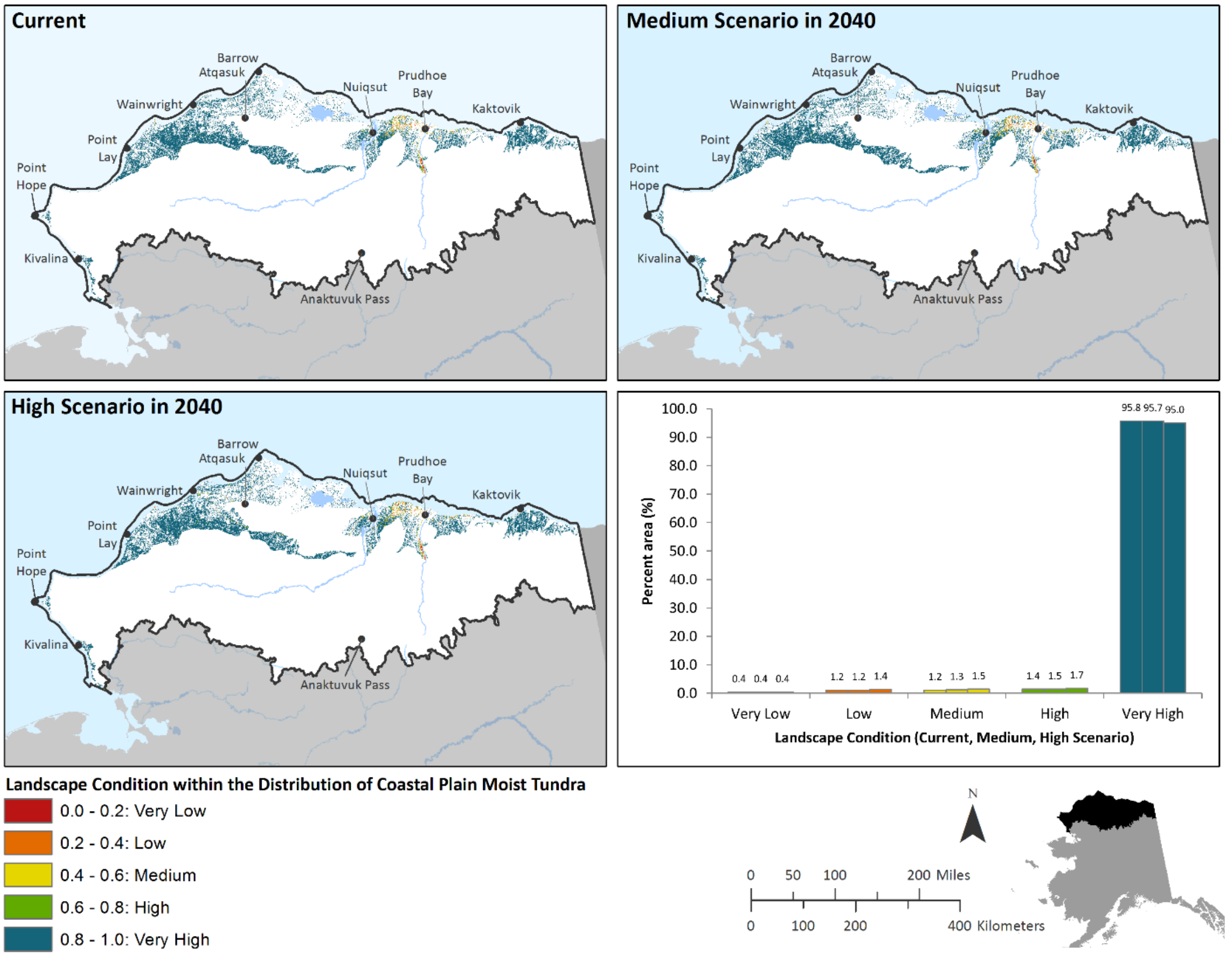

Figure G-19. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of coastal plain moist tundra in the North Slope study area.

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3. Coastal Plain Wetland

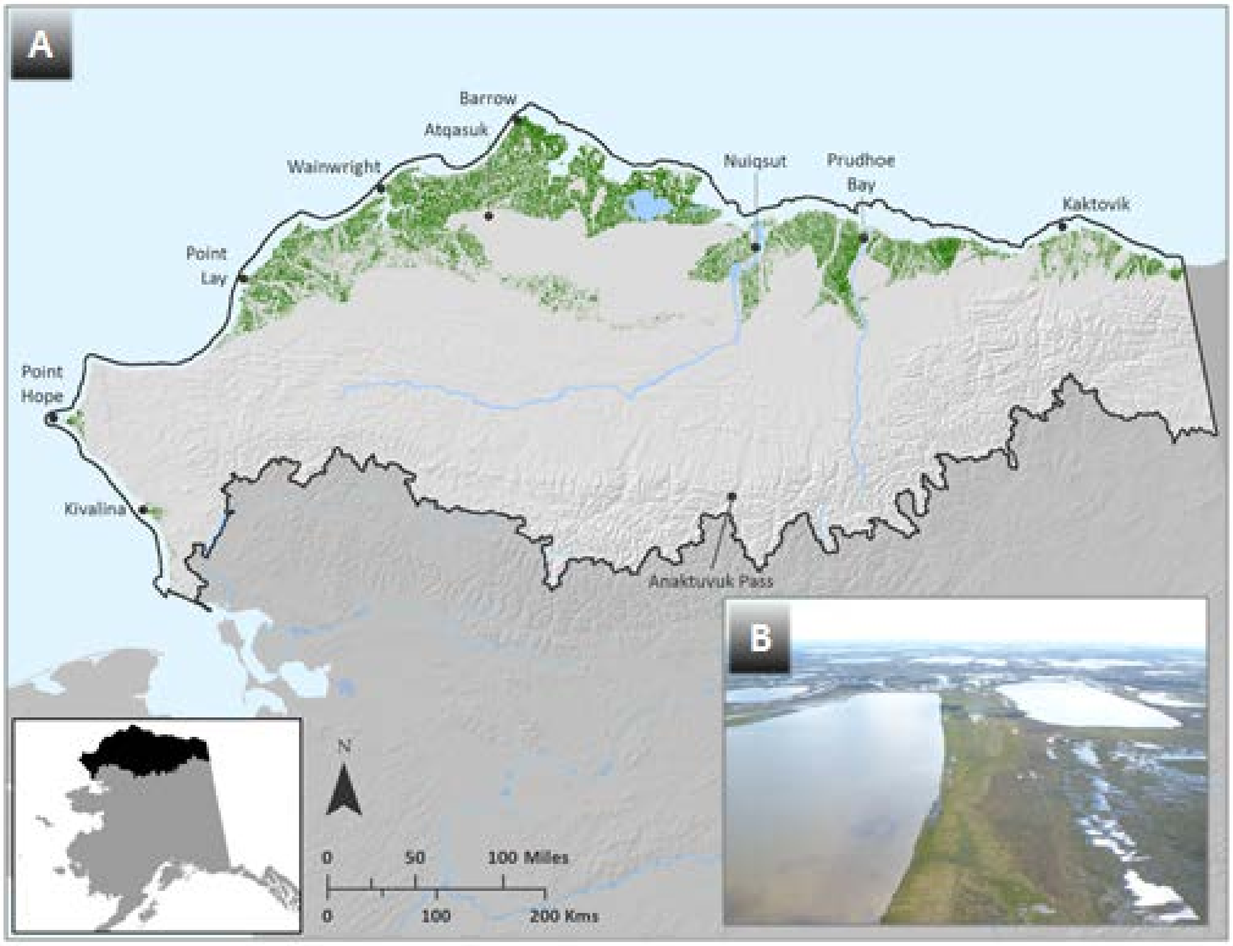

Figure G-20. Current distribution of the coastal plain wetland CE in the North Slope study area (A) and coastal plain wetlands and low-centered polygonal tundra along the margin of an oriented thermokarst lake (B).

3.1. Introduction

Oriented thermokarst (thaw) lakes and basins cover much of the arctic coastal plain. The coastal plain wetland CE occurs along lake margins and in drained lake basins. Soils are saturated, and standing water is usually present during the growing season. A thick organic horizon typically occurs over silty deposits of marine, glacial or alluvial origin. Ice-rich permafrost occurs within 1 m of the surface (Jorgenson and Grunblatt 2013) and forms an extensive pattern of low-centered polygonal terrain.

The distribution of this CE is limited to arctic peaty lowland and arctic silty lowland ecological landscapes within the coastal plain physiographic region (Jorgenson and Grunblatt 2013). This CE is the most abundant landscape type in the oriented thaw lakes region of the coastal plain north of the sand sheet. The thermokarst lake cycle is the dominant landscape process controlling the distribution of wetlands, lakes and moist tundra within this region.

Although the dominant landscape forming processes differ between the coastal plain wetland and sand sheet wetland CEs, vegetation composition within these two types is very similar. Marshes and wet sedge meadows occur in basins and along lake margins. The most common species is *Carex aquatilis*; other diagnostic species include *Carex rotundata, Eriophorum chamissonis, Eriophorum angustifolium,* and *Eriophorum scheuchzeri*. *Carex chordorrhiza* is characteristic of very wet floating sedge peat habitats. Shrubs occur on raised microsites, such as polygon ridges. Common species include *Salix fuscescens, Vaccinium uliginosum, Rhododendron tomentosum*, and *Andromeda polifolia*. Mosses of the genera *Drepanocladus* and *Scorpidium* may be common on circum-neutral sites with standing water; *Sphagnum* spp. may be common on more acidic sites. In deeper water at the margins of ponds and lakes, marsh communities dominated by *Arctophila fulva* may occur; other species of these communities include *Hippuris vulgaris* and *Utricularia vulgaris*, and aquatic mosses, such as *Calliergon* spp.

Thermokarst Lake Cycle

Ice wedges originate from contraction cracks that form in saturated frozen soils exposed to winter freezing. The network of cracks results in a series of shapes or polygons. Snow and water seeps into the cracks and freezes upon reaching permafrost. Each winter cracks re-form and in the spring water enters the crack and re-freezes causing the ice to expand. Through the repeated process of cracking, refilling, and freezing, ice wedges grow in width and depth. If the ice wedge comes in contact with the active layer during summer months, the ice melts and the surface water can form a small pond or thermokarst pit. Water erodes the rims between the polygons, producing a small thaw pond. Wind can also contribute to shoreline erosion. Water conducts heat, further melting the permafrost below the pond, creating a deeper thawed layer under the water than on the adjacent land. If the lake margin erodes, or water level rises sufficiently, the lake can begin to drain. Drainage can be partial, or in some cases, complete. The degree of drainage affects the type of polygonal surface (e.g. high-centered or low-centered) that remains after a lake drains. The cycle begins again as the drained surface re-freezes, and ice wedges re-grow. In some cases unfrozen water under the drained lake can become trapped and eventually pushes up to the surface, creating a pingo.

3.2. Conceptual Model

The conceptual model below (Figure G-21) is based on literature review and describes the relationship between the various change agents and natural drivers for the coastal plain wetland CE. Bold arrows indicate interactions with high ecological relevance and potential management implications, and for which spatial datasets can be intersected with the CE distribution. The primary change agents selected for this CE include: climate change, permafrost, and land use change (i.e. human development).

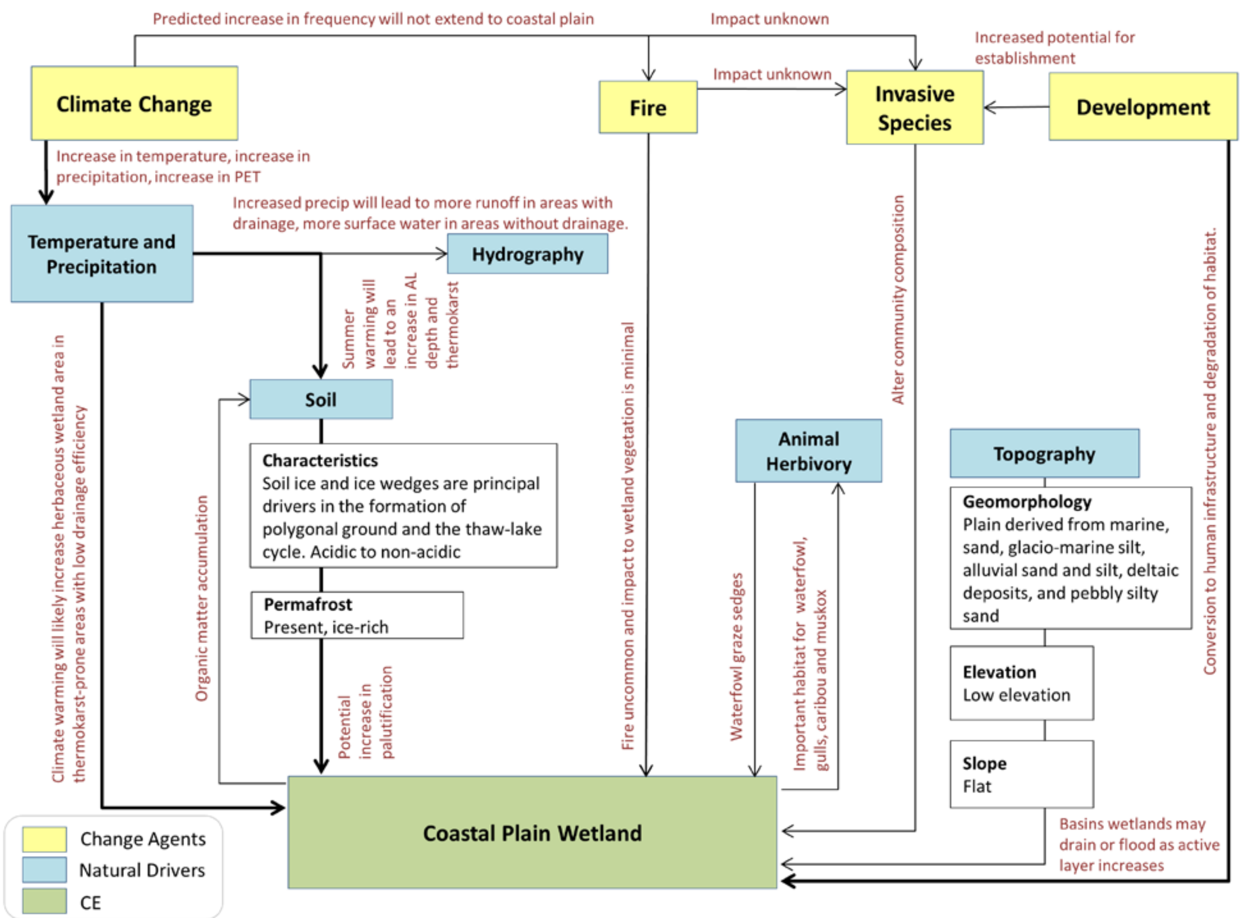

Figure G-21. Conceptual model for coastal plain wetland.

3.3. Abiotic Change Agents Analysis

We explored the impact of two climatic change agents on coastal plain wetlands: temperature (July temperature and length of growing season) and permafrost (active layer thickness and thermokarst predisposition). Fire is not expected to increase on the coastal plain. Warming is expected to affect vegetation communities directly through temperature effects on plant growth and indirectly through changes to the underlying permafrost and soil properties.

Temperature

Increases in July temperature both in the near and long term are not expected to be significant across most of the coastal plain ecoregion. By the 2060s significant increases (> 1.3 °C) are projected for only 2% of the of coastal plain wetland distribution (Table G-4). In the long term (2060s) the average projected increase in July temperature across the CE distribution is 1.0 °C, and mean annual increase is predicted to be 2.5 °C (Table G-5). Although the change in temperature appears to be slight, the increase is projected to lead to a lengthening of the growing season by 12.1 days (Table G-6), driven more by the warming shoulder seasons (Section C-1). While temperature models show that warmest summer temperatures occur in the in the southern portion of the CE (Figure G-4), the greatest amount of change in the length of growing season is projected to occur in northern portion of the CE, with projected increases of 16 to 18 days in the long term around the communities of Wainwright and Barrow (Figure G-18).

Permafrost

Current active layer thickness (ALT) for the coastal plain wetland CE is modeled at 0.50 m and is projected to increase to 0.63 m in the long term (Table G-9). The thermokarst predisposition model ranks this portion of the coastal plain as highly susceptible to thermokarst (Figure G-14).

The effect that increased temperatures and deeper ALT will have on vegetation in this CE is difficult to predict. Warmer conditions and increased evapotranspiration could lead to wetland drying (Smol and Douglas 2007), but this effect could be offset by increased precipitation and increased surface water from the thawing of excess ice in the permafrost. In basin topography, the balance between water added to the system through precipitation and thermokarst and the water lost through evaporation and evapotranspiration will determine whether the net effect is that of wetting or drying of the landscape. The combination of surface subsidence and lack of drainage networks may lead to increased wetland area in this CE.

Warmer temperatures could increase the rate of paludification of wetlands, which could lead to a shift from freshwater marsh habitat to lower productivity acidic bogs (Szumigalski and Bayley 1997, Thormann and Bayley 1997). However, excess surface water and flooding can prevent the establishment of peat-forming mosses such as *Sphagnum* (Granath et al. 2010).

3.4. Current Status and Future Landscape Condition

The wetland environment is susceptible to contamination from oil spills, particularly when the ground is snow-free. When the ground is frozen wetland vegetation is less sensitive to damage from winter travel on ice and snow roads than is moist tundra (Guyer and Keating 2005, Felix and Raynolds 1989). Roads constructed across coastal plain wetlands alter drainage patterns and cause water to pool adjacent to the roadway. Water absorbs solar radiation and can result in the initiation of thermokarst. Road berms also channel water into constriction points which can lead to erosion hot spots. See MQ TC 1 for more discussion about the impact of development on coastal plain wetlands.

Current oil and gas infrastructure and exploration is largely concentrated in the coastal plain, and wetlands tend to have somewhat more impacted area than moist tundra owing to the overall pattern of wetland distribution around the oil fields. The overall status of the coastal plain wetland CE was assessed by intersecting the Landscape Condition Model (LCM) with the CE distribution model for the current condition and two development scenarios, medium and high. The majority (94.1%) of the coastal plain wetland CE is in the “very high” condition class. Under the “high development” scenario, it is estimated that 93% of the CE will still be in the “very high” condition class. See MQ TC 1 for more discussion about the impact of development on coastal plain wetlands.

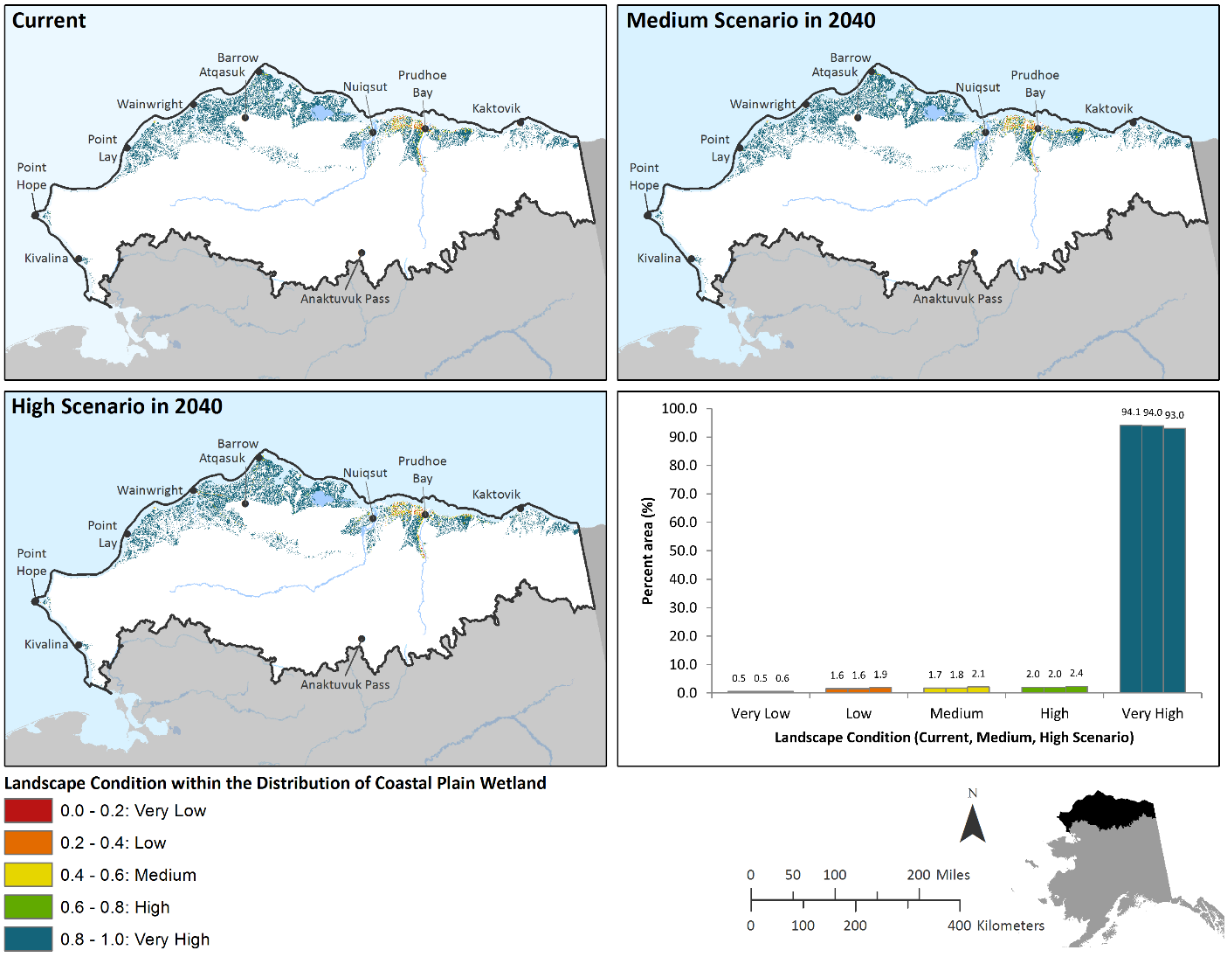

Figure G-22. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of coastal plain wetlands in the North Slope study area.

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4. Sand Sheet Moist Tundra

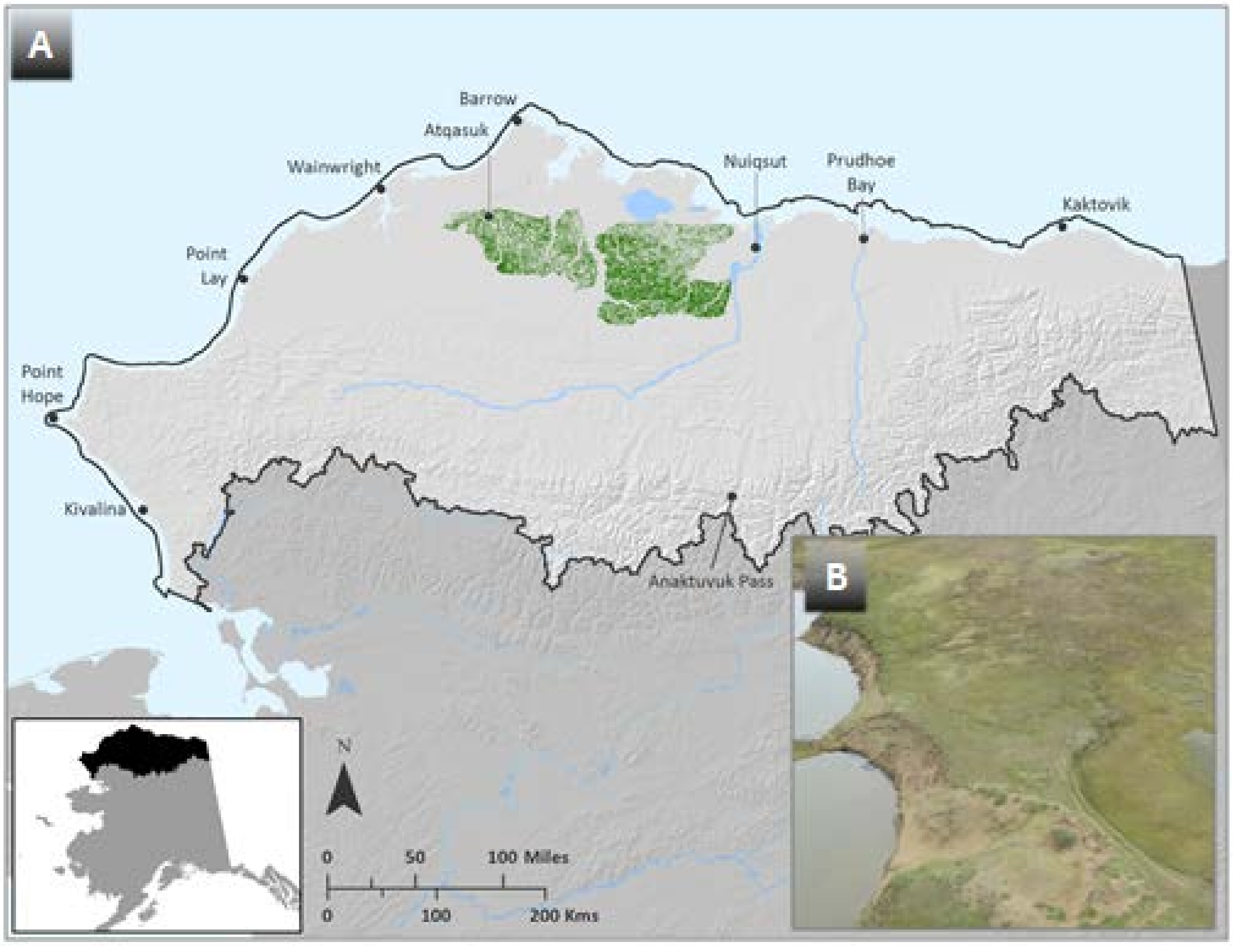

Figure G-23. Current distribution of the sand sheet moist tundra CE in the North Slope study area (A) and sand sheet moist tundra (B).

4.1. Introduction

The sand sheet on the coastal plain is formed by a large deposit of quaternary aeolian sands that lies between the Colville and Meade Rivers. Ancient longitudinal and parabolic dunes form a series of symmetrical and parallel ridges. The boundary of the sand sheet is defined by the Arctic Sandy Lowland ecological landscape (Jorgenson and Grunblatt 2013). Vegetation on the sand sheet is a mosaic of moist tundra and basin wetlands. The sand sheet moist tundra CE occurs in areas where drainage prevents perpetual soil saturation.

Ground-ice content is lower on the sand sheet than it is on the rest of the coastal plain. Permafrost-related surface features such as pingos, ice-wedge polygons, oriented lakes, peat ridges, and frost boils are less common and less pronounced on the sand sheet. The terrain within the CE is flat to gently sloping with a mix of patterned and non-patterned ground. Soils are sandy, acidic, and nutrient poor

(Walker et al 2003). The ancient dunes are mostly stabilized by tundra vegetation; however, where wind or water erosion has re-exposed these sands, inland dunes can develop and persist. These unique ecosystems are home to several species of rare plants (see Nawrocki et al. 2013).

Tussock forming sedges *Eriophorum vaginatum* or *Carex lugens* are often the dominant overstory species, though tussock growth form tends to be small compared to those on the foothills. Average height of herbaceous vegetation within sand sheet moist tundra CE is 23.5 cm, compared with 31.4 in tussock tundra, NPRA AIM plots). Shrubs generally have a prostrate growth form (average height is 14.1 cm, NPRA AIM plots) and cover is variable, but generally exceeds 25%. *Vaccinium vitis-idaea*, *Cassiope tetragona,* and *Rhododendron tomentosum* are the most abundant shrubs. Other common shrubs include *Betula nana* and *Salix pulchra. Arctagrostis latifolia* and *Rubus chamaemorus* occur consistently in the herbaceous layer*.* Common mosses include *Aulacomnium* spp., *Dicranum* spp., *Hylocomium splendens*, and *Polytricum* spp. Lichens are consistently present with low canopy cover; common species include *Flavocetraria* spp., *Cladina* spp., and *Thamnolia vermicularis*.

Vegetation composition on inland dunes is markedly different from that of the surrounding tundra. Willows (*Salix alaxensis, S. glauca,* and *S. niphoclada*) and grasses (*Leymus mollis, Festuca rubra*, *Bromus inermis ssp. pumpellianus*, *Kobresia sibirica*, and *Trisetum spicatum*) make up most of the sparse vegetation cover. Herbaceous cover is sparse, but richness can be quite high. Common herbaceous species include *Artemisia campestris* ssp. *borealis, Astragalus alpinus, Chamerion latifolium, Packera hyperborealis, Oxytropis* spp.*, Minuartia* spp., and *Papaver lapponicum.* Dwarf shrubs including *Dryas integrifolia* and *Arctostaphylos rubra*, become common on more stabilized portion of the dune. Mosses and lichens are uncommon. Rare plants encountered on active inland dunes within NPR-A include *Rumex graminifolius*, *Mertensia drummondii, Poa hartzii* ssp. *alaskana*, *Poa sublanata*, and *Koeleria asiatica*. Interdune slacks feature wetland habitats with species such as *Equisetum arvense*, *Carex aquatilis, Carex maritima, Juncus arcticus* ssp. *alaskanus*, and *Dupontia fisheri*.

The conceptual model below (Figure G-24) is based on literature review and describes the relationship between the various change agents and natural drivers for sand sheet moist tundra. Bold arrows are used to illustrate interactions that have high ecological relevance and potential management implications, and also have spatial datasets that can be intersected with the CE distribution. The primary Change Agents selected for this CE include: climate change, permafrost, and land use change (i.e. human development).

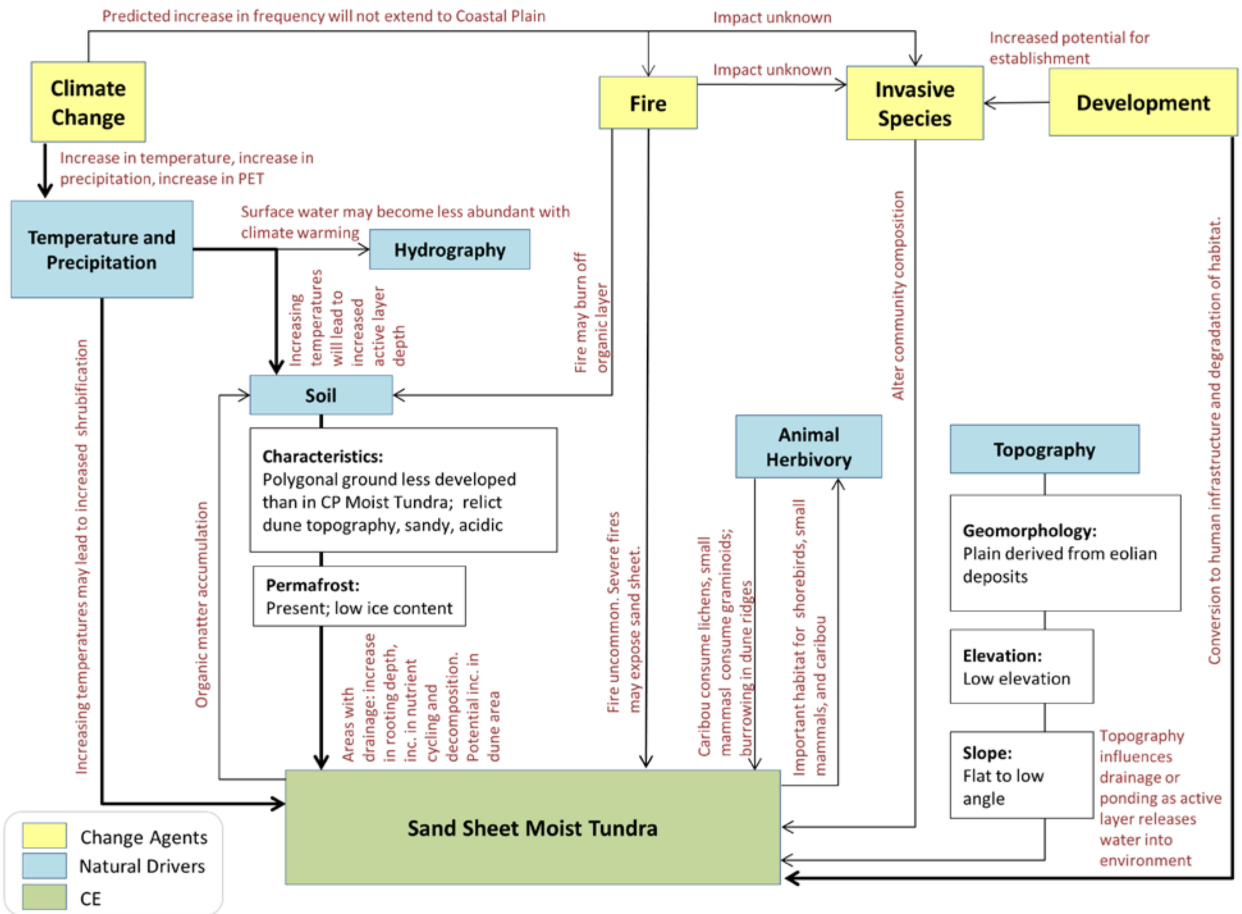

Figure G-24. Conceptual model for sand sheet moist tundra.

4.2. Abiotic Change Agents Analysis

We explored the impact of two climatic change agents on sand sheet moist tundra: temperature (July temperature and length of growing season) and permafrost (active layer thickness and thermokarst predisposition). Fire is not expected to increase on the coastal plain or sand sheet. Warming is expected to affect vegetation communities directly through temperature effects on plant growth and indirectly through changes to the underlying permafrost and soil properties.

Temperature

Increases in July temperature both in the near and long term are not expected to be significant across most of the coastal plain ecoregion, including the arctic sandy lowland region. By the 2060s significant increases (> 1.3 °C) are projected for only 8.1% of the of sand sheet moist tundra distribution (Table G-4). In the long term (2060s) the average projected increase in July temperature across the CE distribution is 1.1 °C (Table G-5). The average projected increase in the length of growing season is 10.1 days (Table G-6), but the amount of change is predicted to be greater in the northern portion of the CE than the southern portion (Figure G-25).

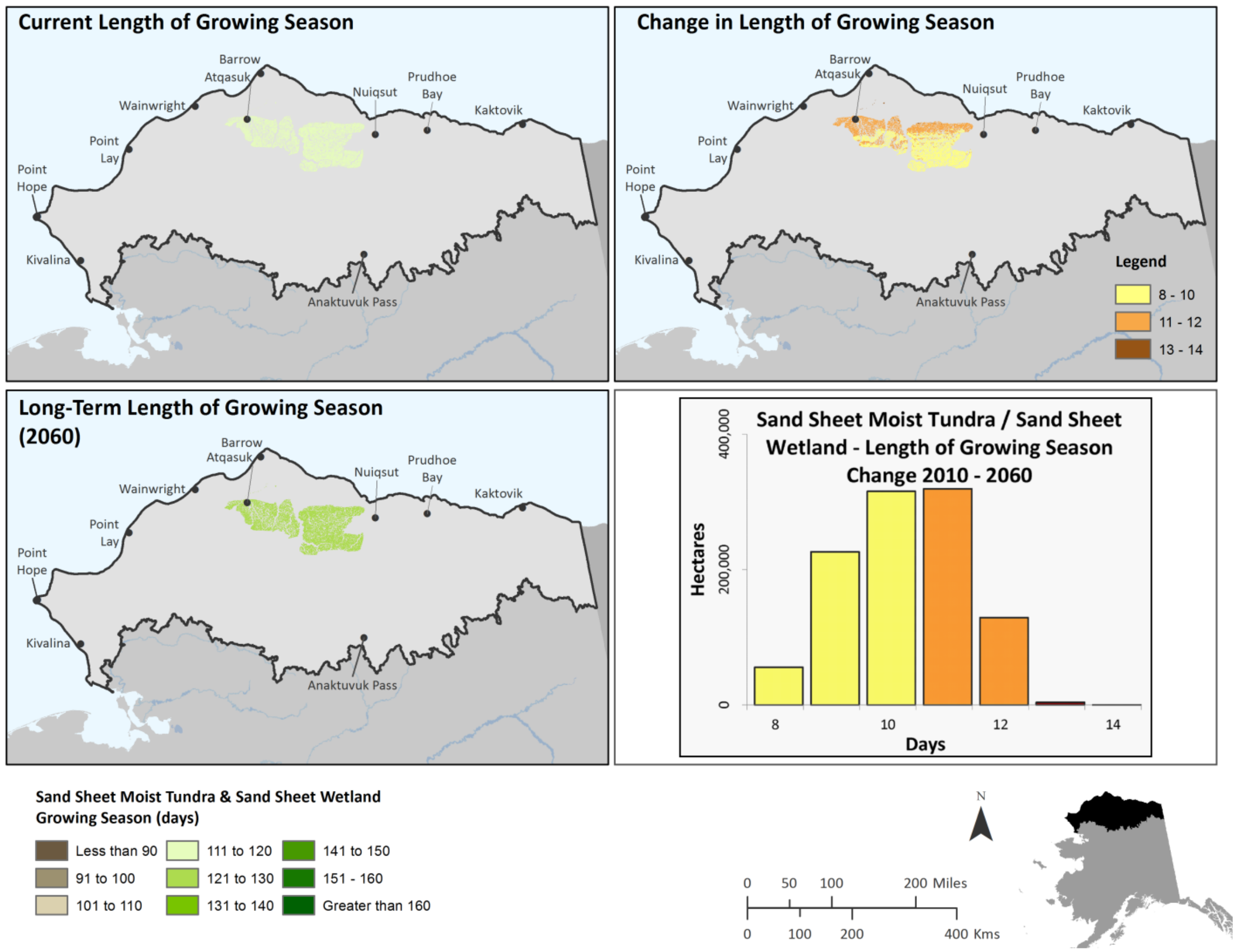

Figure G-25. Length of growing season for current and long term future and change in LOGS clipped to the sand sheet moist tundra and wetlands CE distributions in the North Slope study area.

Fire

Fire is not expected to impact this region; however vegetation transitions driven by climate change are possible. The sand sheet occurs entirely within the Central Coastal Plain sub-region, and the ALFRESCO model predicts very slight changes to the vegetation of this region. From current to long term, shrub canopy cover is predicted to increase from 0.7 to 2.2 % and graminoid tundra is predicted to decrease from 73.6 to 72.1% cover.

Permafrost

Current ALT for the sand sheet moist tundra CE is modeled at 0.61 m and is projected to increase to 0.74 m in the long term (Table G-9). Low ice content of the permafrost indicates that the sand sheet is not predisposed to thermokarst (Figure G-15), and increased permafrost thaw will not likely lead to ground surface subsidence. However, increased ALT may lead to deeper-rooting species becoming established, possibly resulting in a shrubbier landscape.

4.3. Current Status and Future Landscape Condition

Ice roads and winter trails can damage moist tundra vegetation, particularly tussock vegetation (Guyer and Keating 2005, Felix and Raynolds 1989). Aerial transport and deposition of fine sediment near roads, airstrips, and towns, can alter soil chemistry in adjacent tundra (Walker et al. 1987). The human footprint on the sand sheet accounts for a very small amount of the landscape and is comprised of the community of Atqasuk and multiple tundra travel corridors (winter travel routes associated with oil and gas are included in the oil and gas footprint, but not included in the LCM or future scenarios). Early exploratory drilling near Fish Creek (circa 1949) caused severe tundra damage and erosion leaving long-lasting inhibiting influences on sand sheet vegetation (Lawson et al. 1978). This site was abandoned, but has been used to develop models for vegetation recovery after mechanical disturbance.

The overall status of the sand sheet moist tundra CE was assessed by intersecting the Landscape Condition Model (LCM) with the CE distribution model for the current condition and two development scenarios, medium and high (Figure G-26). The LCM is a way to measure the impact of the human footprint on the landscape. 99.8% of the sand sheet moist tundra CE is in the "very high" condition class, and under the "high development" scenario, it is estimated that 98.4% of the CE will still be in the "very high" condition class.

Refer to MQ TC 1 for more discussion about the impact of development on sand sheet moist tundra.

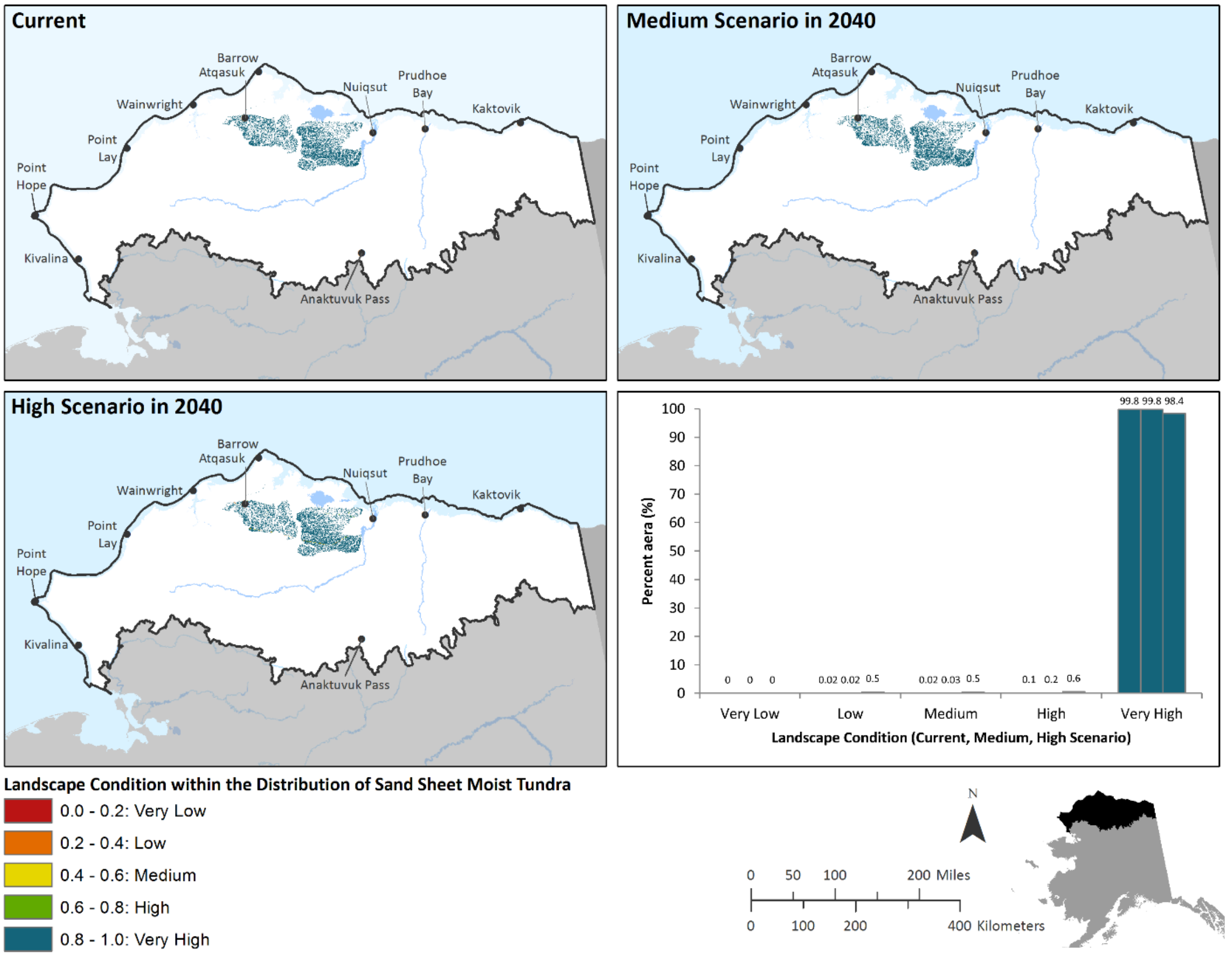

Figure G-26. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of sand sheet moist tundra in the North Slope study area.

4.4. Literature Cited

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5. Sand Sheet Wetland

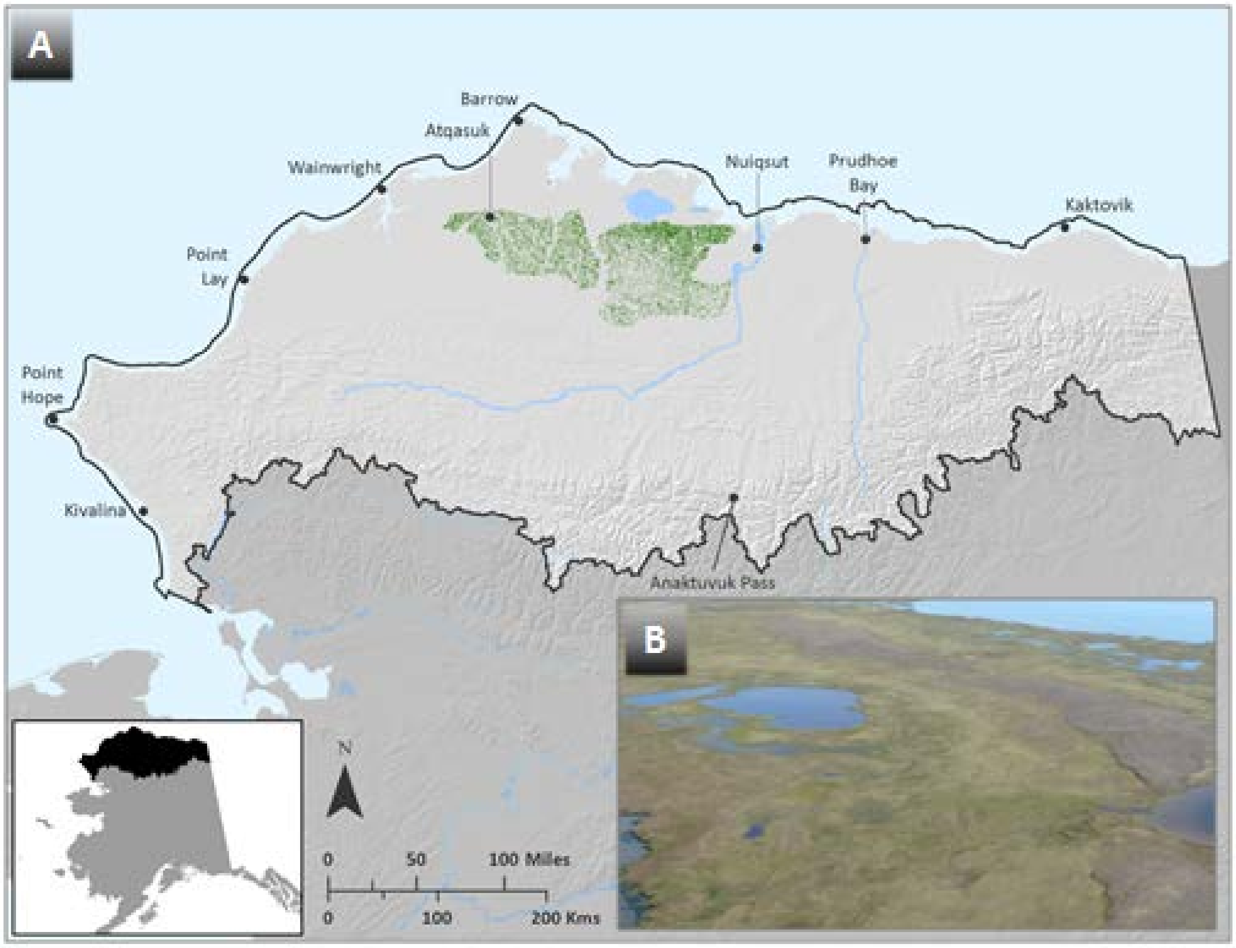

Figure G-27. Current distribution of the sand sheet wetland CE in the North Slope study area (A) and sand sheet basin wetlands separated by an ancient dune ridge (B).

5.1. Introduction

The sand sheet on the coastal plain is formed by a large deposit of quaternary aeolian sands that lies between the Colville and Meade Rivers. Ancient stabilized dunes form a series of low relief ridges, and basin wetlands and lakes occur in the low-lying areas between dunes (Everett 1979, Jorgenson and Shur 2007). Ground-ice content is generally lower on the sand sheet than it is on the rest of the coastal plain, but in basin wetlands and lakes, the redistribution and accumulation of fine deposits facilitates ice aggradation and the formation of ice wedges and polygonal surface patterns (Jorgenson and Shur 2007). Wetland soils are saturated throughout the growing season and typically have a thick surface organic horizon.

Vegetation composition of the sand sheet wetland CE is very similar to that of the coastal plain wetland CE. Marshes and wet sedge meadows occur in basins and along lake margins. The most common species is *Carex aquatilis*; other diagnostic species include *Carex rotundata, Eriophorum chamissonis, Eriophorum angustifolium,* and *Eriophorum scheuchzeri*. *Carex chordorrhiza* is characteristic of very wet floating sedge peat habitats. Shrubs occur on raised microsites, such as polygon ridges. Common species include *Betula nana, Salix fuscescens, Vaccinium uliginosum, Rhododendron tomentosum*, and *Andromeda polifolia*. Mosses of the genera *Drepanocladus* and *Scorpidium* may be common on circum-neutral sites with standing water; *Sphagnum* spp. may be common on more acidic sites. In deeper water at the margins of ponds and lakes, marsh communities dominated by *Arctophila fulva* may occur found; other species of these communities include *Hippuris vulgaris* and *Utricularia vulgaris*, and aquatic mosses, such as *Calliergon* spp.

5.2. Conceptual Model

The conceptual model below (Figure G-28) is based on literature review and describes the relationship between the various change agents and natural drivers for the sand sheet wetland CE. Bold arrows are used to illustrate interactions that have high ecological relevance and potential management implications, and also have spatial datasets that can be intersected with the CE distribution. The primary change agents selected for this CE include: climate change, permafrost, and land use change (i.e. human development).

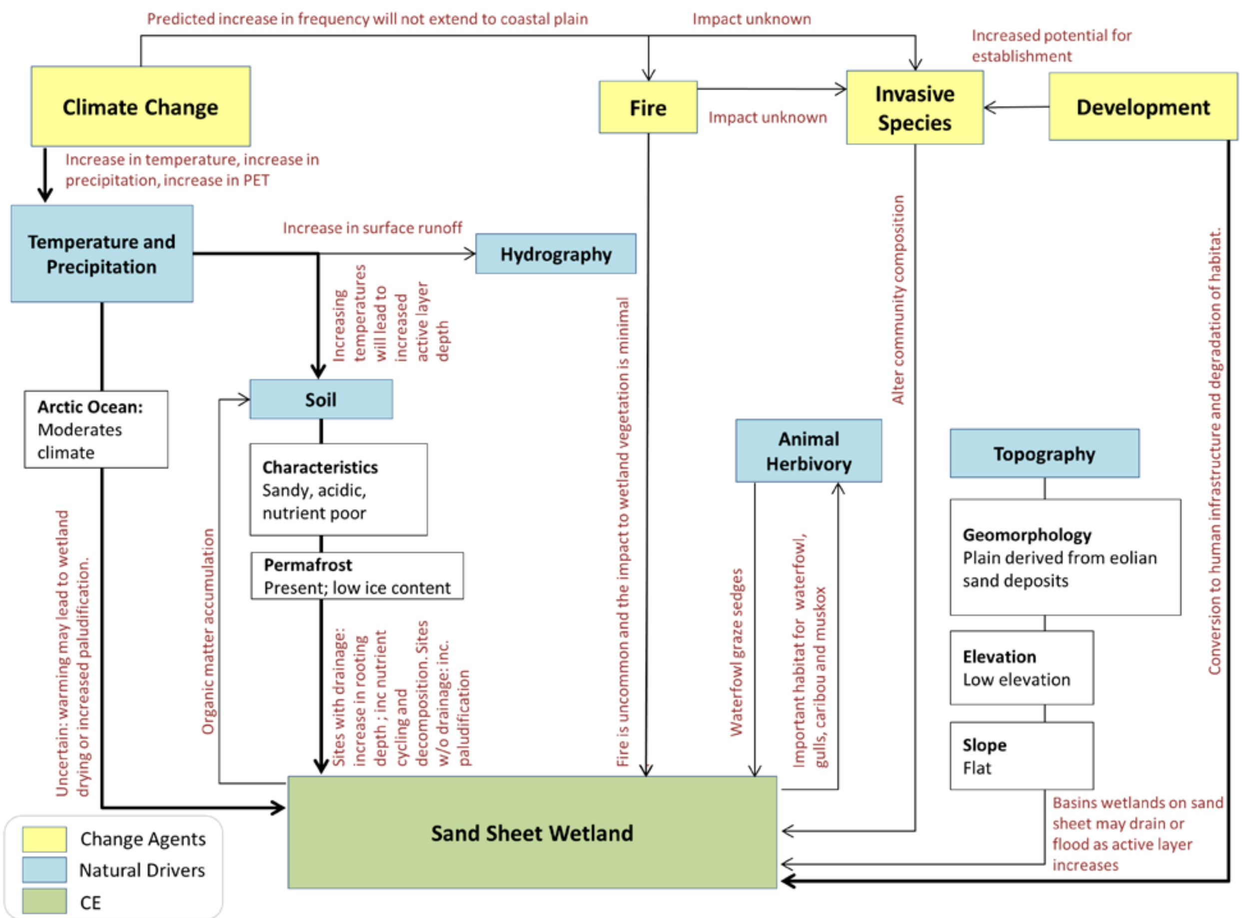

Figure G-28. Conceptual model for sand sheet wetland.

5.3. Abiotic Change Agents Analysis

We explored the impact of two climatic change agents on sand sheet wetlands: temperature (July temperature and length of growing season) and permafrost (active layer thickness and thermokarst predisposition). Fire is not expected to increase on the coastal plain or sand sheet. Warming is expected to affect vegetation communities directly through temperature effects on plant growth and indirectly through changes to the underlying permafrost and soil properties.

Temperature

Increases in July temperature both in the near and long term are not expected to be significant across most of the coastal plain ecoregion, including the arctic sandy lowland region. By the 2060s significant increases (> 1.3 °C) are projected for only 4.2% of the of sand sheet wetland distribution (Table G-4). In the long term (2060s) the average projected increase in July temperature across the CE distribution is 1.1 °C (Table G-5), and the average increase in the length of growing season is 10.5 days (Table G-6), but the amount of change is predicted to be greater in the northern portion of the CE than the southern portion (Figure G-25).

Fire

Fire is not expected to impact this region; however vegetation transitions driven by climate change are possible. The sand sheet occurs entirely within the Central Coastal Plain sub-region, and the ALFRESCO model predicts very slight changes to the vegetation of this region. From current to long term, shrub canopy cover is predicted to increase from 0.7 to 2.2% and graminoid tundra is predicted to decrease from 73.6 to 72.1% cover. No change in wetland area is predicted, but this is likely because drivers identified in the model are not yet active for wetland transitions. Multiple scenarios for changing wetland vegetation are possible including changes associated with paludification or wetland drying.

Permafrost

Current ALT for the sand sheet wetland CE is modeled at 0.63 m and is projected to increase to 0.77 m in the long term (Table G-9). The sand sheet is generally considered at low risk of thermokarst owing to the overall low ice content of the permafrost (Figure G-15). The original formation of sand sheet lakes and wetlands was not driven by thermokarst, but instead occurred through infilling of depressions between ancient dune fields (Jorgenson and Shur 2007). With the aggradation of ground ice within basins over time, some basins have developed thermokarst lake processes, but the impact of thermokarst on this region is not expected to be significant. Although ALT is projected to increase in this region, the impact of this prediction is uncertain. The model does not account for the effects of increased paludification or potential wetland drying that might be associated with a warmer climate. If paludification of wetlands occurs, it would lead to increased thickness of organic soil horizons which could provide added insulation to the active layer and in fact result in less seasonal thaw (Kane 1997). Paludification is thought to be the driving mechanism behind long-term vegetation succession and changes in the active layer thickness in the low arctic (Walker and Walker 1996, Mann et al. 2002). The conversion of shallow water and sedge tundra to more acidic habitats would have profound ecological implications, given that acidification impedes nutrient availability, lowers productivity, and creates favorable conditions for slower-growing sedges and heath shrubs (Szumigalski and Bayley 1997, Thormann and Bayley 1997).

5.4. Current Status and Future Landscape Condition

The human footprint on the sand sheet accounts for a very small amount of the landscape and is comprised of the community of Atqasuk and multiple tundra travel corridors (winter travel routes associated with oil and gas are included in the oil and gas footprint, but not included in the LCM or future scenarios).

The overall status of the sand sheet wetland CE was assessed by intersecting the Landscape Condition Model (LCM) with the CE distribution model for the current condition and two development scenarios, medium and high. The LCM is a way to measure the impact of the human footprint on the landscape. 99.8% of the sand sheet wetland CE is in the “very high” condition class, and under the “high development” scenario, it is estimated that 98.4% of the CE will still be in the “very high” condition class (Figure G-29).

Refer to MQ TC 1 for more discussion about the impact of development on sand sheet wetlands.

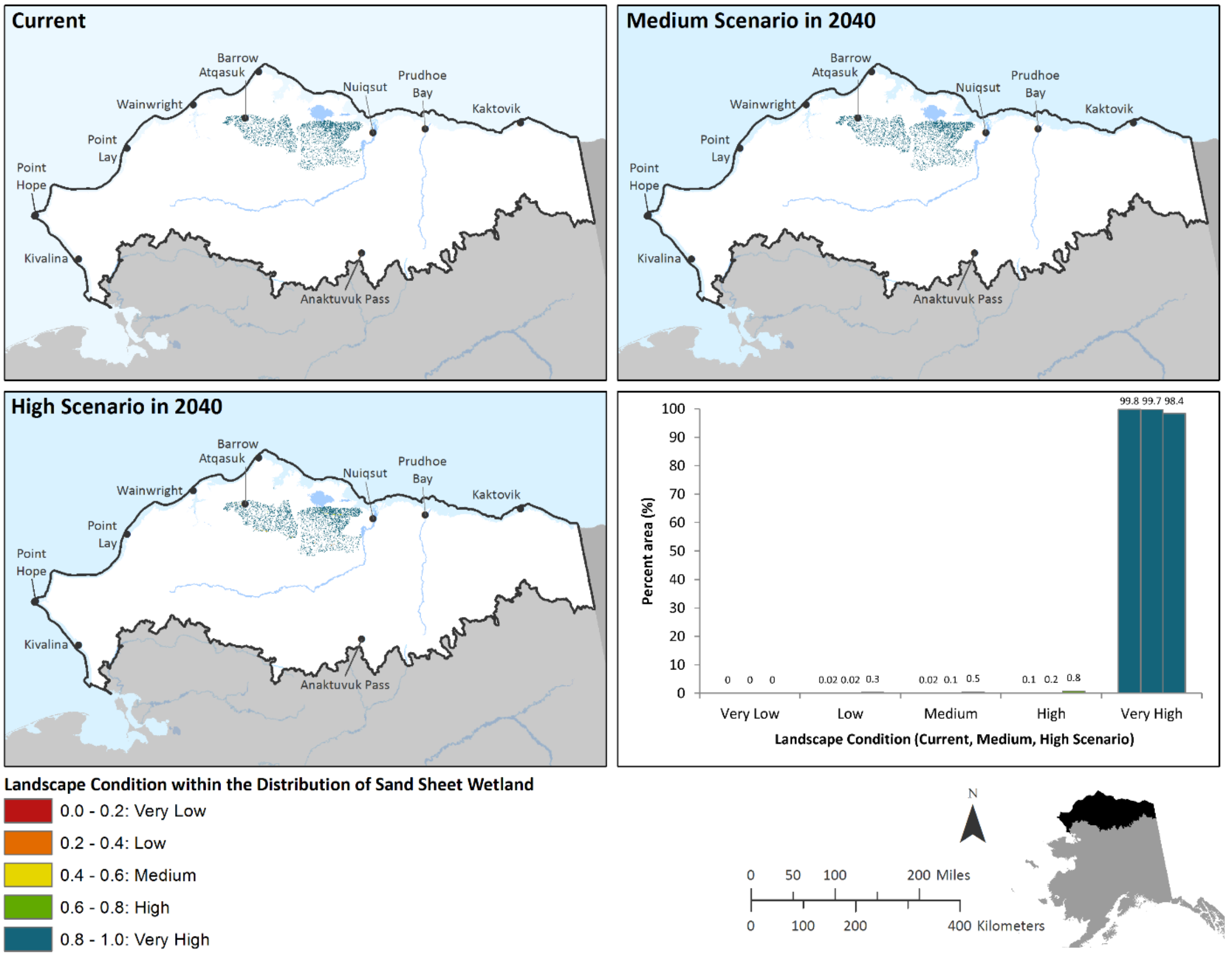

Figure G-29. Figure Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of sand sheet wetland in the North Slope study area.

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6. Foothills Tussock Tundra

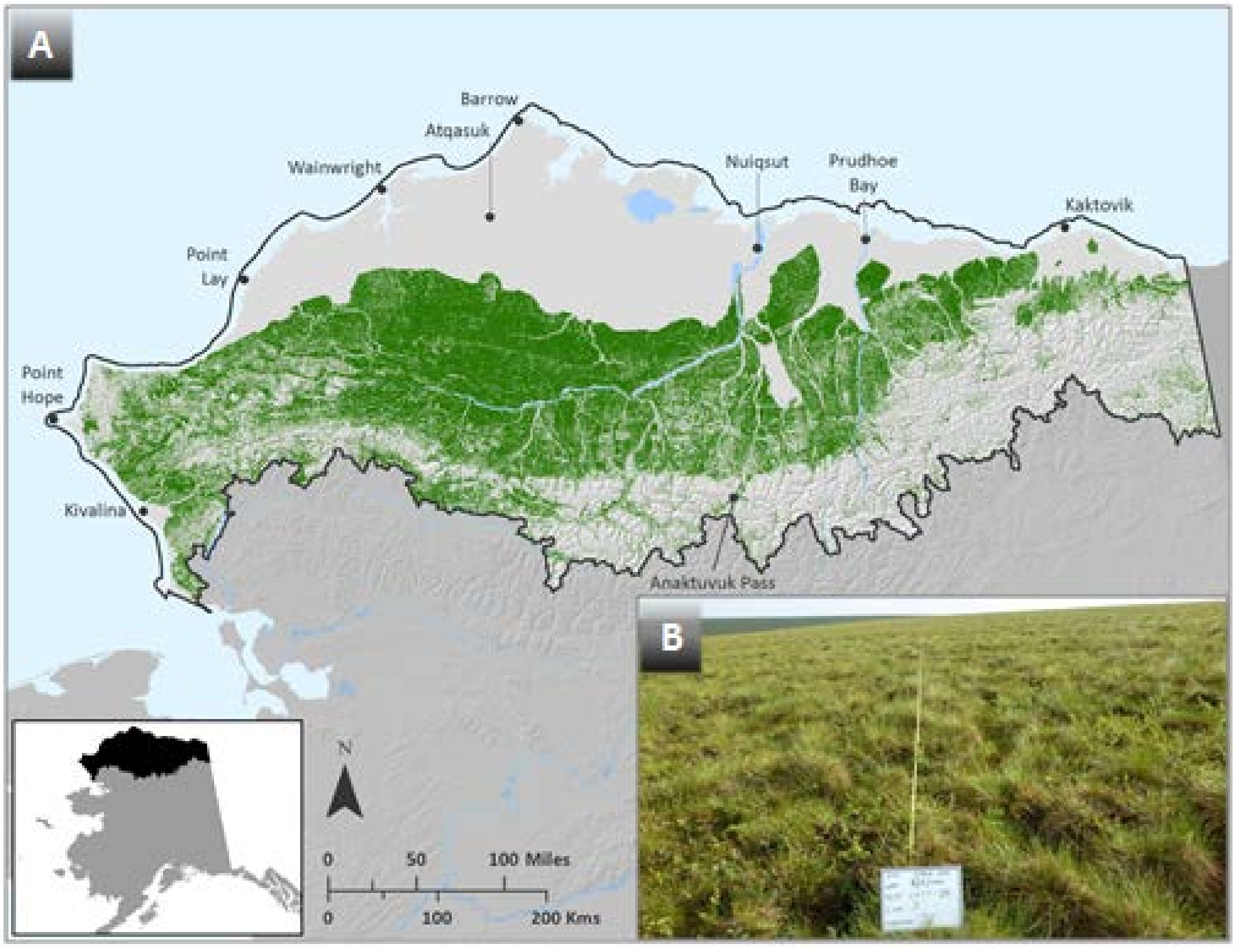

Figure G-30. Current distribution of the foothills tussock tundra CE in the North Slope study area (A) and a vegetation transect in foothills tussock tundra in NPR-A (B).

6.1. Introduction

Arctic tussock tundra is a low-stature vegetation type dominated by tussock-forming sedges and dwarf to low shrubs. Tussock tundra is the zonal vegetation of the Brooks Foothills where it occurs on side slopes, valley bottoms, and low-elevation rolling terrain. It is underlain by colluvium, deep loess and glacial deposits (Jorgenson and Grunblatt 2013) with acidic soils typifying the older landscapes (Walker et al. 1995). Bedrock-controlled summits and ridges within the foothills generally support dwarf shrub tundra and are not included in the foothills tussock tundra distribution.

The sedge *Eriophorum vaginatum* is typically the dominant tussock-former, but dominance may transition to *Carex lugens* on somewhat unstable slopes, often in conjunction with solifluction features (Walker et al. 1994). Shrub cover is variable, but generally exceeds 25% and is comprised of *Betula nana*, *Rhododendron tomentosum*, *Salix pulchra*, and/or *Vaccinium vitis-idaea*. Forb cover and richness are low with *Rubus chamaemorus*, *Petasites frigidus*, and *Polygonum bistorta* commonly represented. The non-vascular community is well-developed and consistent in mature tussock tundra. Common bryophytes include *Hylocomium splendens* and species of the *Sphagnum*, *Aulocomnium* and *Polytrichum* genera; lichens are commonly represented by *Cladina*, *Flavocetraria* and *Peltigera* species.

6.2. Conceptual Model

The conceptual model below (Figure G-31) is based on literature review and describes the relationships among the various change agents and natural drivers for foothills tussock tundra. Bold arrows indicate interactions with high ecological relevance and potential management implications, and for which spatial datasets can be intersected with the CE distribution. The primary change agents selected for this CE include: climate change, permafrost, fire and development.

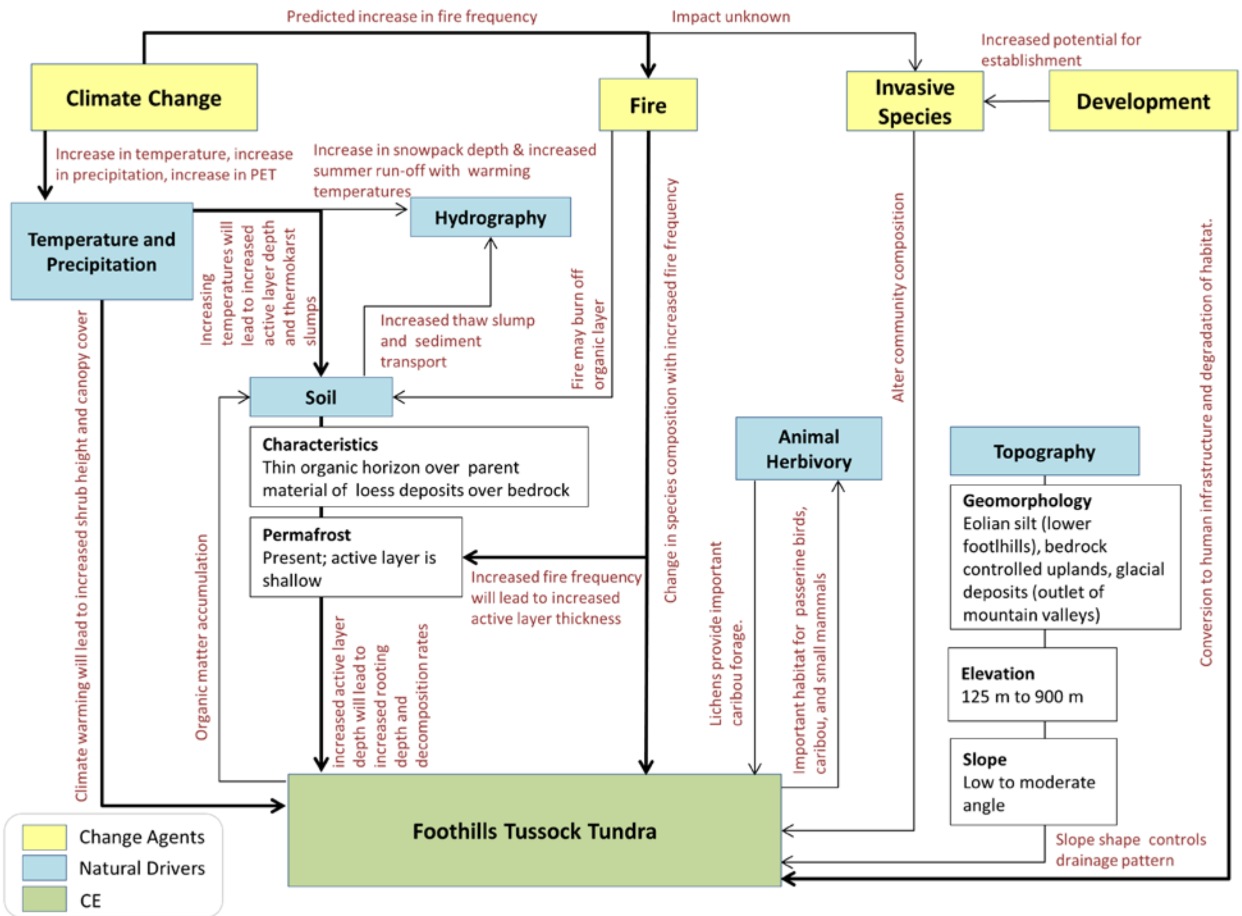

Figure G-31. Conceptual model for foothills tussock tundra.

6.3. Abiotic Change Agents Analysis

We explored the impact of four climatic change agents on foothills tussock tundra: temperature (July temperature and length of growing season), total annual precipitation, permafrost (active layer thickness and thermokarst predisposition), and fire. Warming is expected to affect vegetation communities directly through temperature effects on plant growth and indirectly primarily through changes to the underlying permafrost and soil properties. Precipitation changes linked to snowpack depth will affect the winter thermal regime, and climate-induced changes to fire frequency, successional trajectories, and plant range expansion are also expected to impact CE habitat.

Temperature

Near-term (2020s) increases in July temperature are not expected to be significant; however significant increases are projected across 72% of the of foothills tussock tundra distribution in the long term (2060s) (Table G-4). The average projected long-term increase in July temperature across the CE distribution is 1.4 °C (Table G-5), with a 9.1 day increase in the length of growing season (Table G-6). The warmest regions of the CE occur in the west and center of the distribution, but the greatest amount of change is predicted to occur in the western portion of the distribution and also along the northern portion adjacent to the coastal plain (Figure G-32). A longer and warmer growing season allows for increased vegetative growth and greater reproductive success for plants that tend to produce seeds late in the growing season (Molau 1993, Molau et al. 2005).

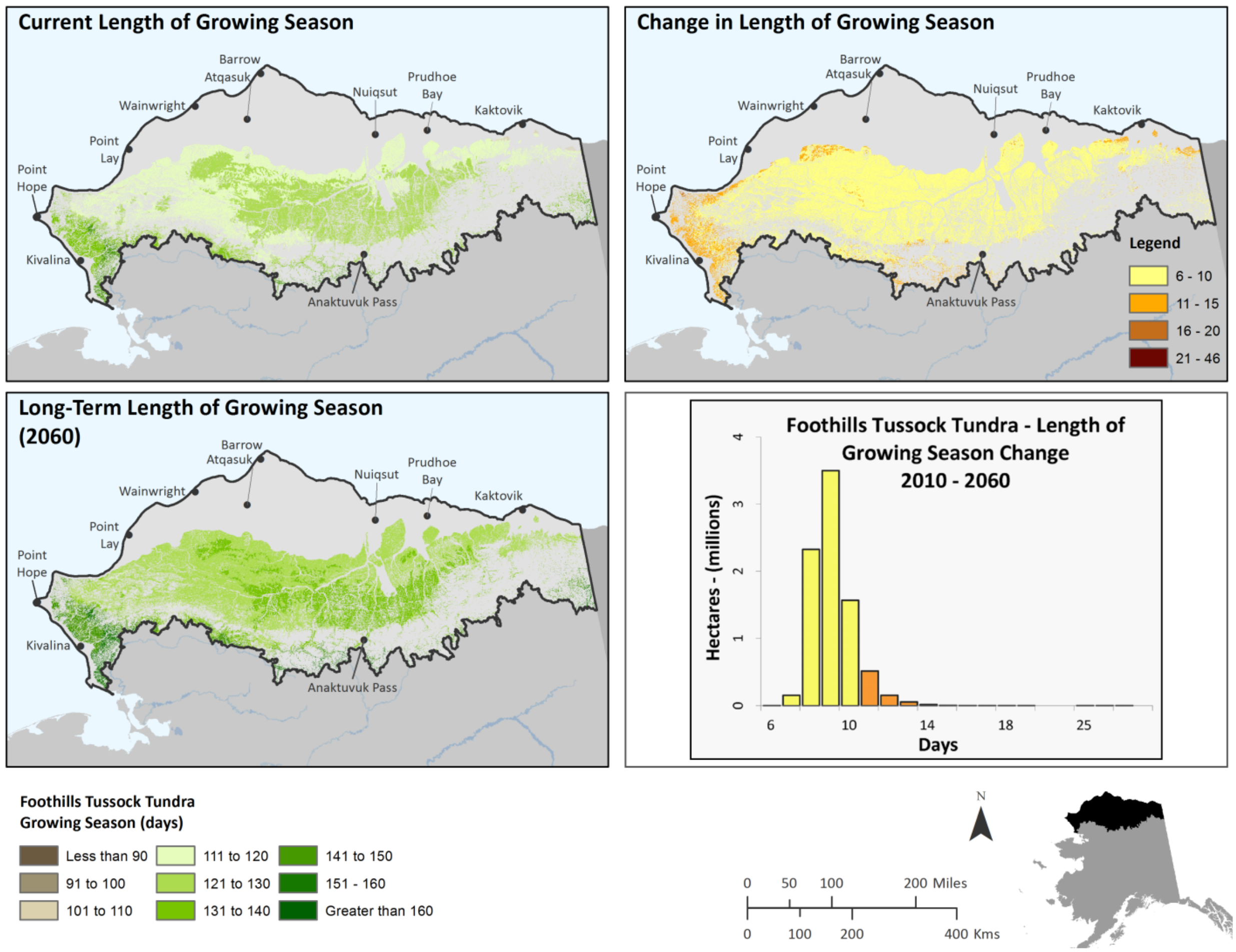

Figure G-32. Length of growing season for current and long term future and change in LOGS clipped to the foothills tussock tundra distribution in the North Slope study area.

Precipitation

Total annual precipitation is projected to increase from 348 mm to 392 mm for this CE (Table G-8), an increase that will impact both winter and summer budgets. Higher winter precipitation will likely result in a deeper snowpack, assuming rain on snow events and changes in sublimation rates are minimal (see greater discussion in Section C-1.3). A deeper snowpack would result in increased thermal insulation and protection from desiccating winter winds. Snow depths correlate closely with shrub canopy height and stem diameter, where shrub growth promotes snow retention, and deeper snowpack further promotes shrub growth (Sturm et al. 2001). Increased moisture during the growing season is not likely to have a substantial impact on tussock tundra, as sites are generally moist throughout the growing season. The potential interplay between the projected increased summer temperatures and changes in precipitation on rates of paludification may result in less seasonal thaw in the future (see Kane 1997).

Fire and Vegetation Succession:

While tundra fires are historically rare on the North Slope, future increases in fire frequency, severity and duration are suggested in a warmer and drier climate (Higuera et al. 2008, Jandt et al. 2012). The recovery of tussock tundra vegetation post fire is largely dependent on the severity of the burn. Unless the surface organic layer is consumed, the effect of fire on tussock tundra is a temporary suppression of plants that are unable to reproduce from vegetative material (Barrett et al. 2012). Thus, the tussock-forming sedges and dwarf to low shrubs that dominate this vegetation type quickly regain their pre-fire presence, whereas the recovery of non-vascular communities is prolonged over decades. *Eriophrum vaginatum* tussocks experience minimal mortality in low severity fires (Jandt et al. 2008) and resprout from meristematic tissue at their base following moderate fires (Wein and Shilts 1976). Severe fires can result in tussock mortality. In 2007, the Anaktuvuk River Fire, the largest fire recorded on the North Slope, burned with uncharacteristically high severity (Jones et al. 2009, Jandt et al. 2012). Eighty percent of the fire area burned with moderate to high severity and tussock mortality was observed on severely burned sites (Jandt et al. 2012). Shrubs such as *Betula nana*, *Salix* spp., and ericaceous shrubs readily resprout after fire, but their cover can remain well below pre-fire levels during the first 6 to 10 years after fire while graminoids dominate (Racine et al. 1987). Owing to the productivity of tussocks, the entirety of vascular plant biomass can recover to pre-fire levels within 10 years (Wein and Bliss 1973, Racine et al. 1987, Fetcher et al. 1984). However, non-vascular communities are largely destroyed by fires in tussock tundra and are slow to recover (Holt et al. 2008, Jandt et al. 2008). Bryophyte communities (e.g. *Sphagnum* spp., *Aulocomnium* spp., *Dicranum* spp., and *Hylocomium splendens*) require at least 25 years to recover to pre-fire species compositions and cover levels (Racine et al. 1987) whereas lichen communities (*Cladina mitis, C. arbuscula* , *C. stellaris*, and *C. rangiferina*) may require 50 to 100 years for full recovery (Swanson 1996). Where the insulating surface organic material is removed, severe fire can increase ALT and potential for thermokarst (Yoshikawa et al. 2002). In this way, both fire and thermokarst can promote shrub expansion (Schuur et al. 2007, Breen et al. 2013).

Both shrub expansion and treeline advance are predicted for the North Slope study area. Increases in the height and canopy cover of shrubs such as *Betula nana* and *Salix pulchra,* and *Alnus* spp. have been observed across the foothills region both in retrospective and prospective studies and have been linked to greater snow retention, higher winter soil temperatures, altered surface water hydrology during melt and the promotion of fire spread (Higuera et al. 2008, Liston et al. 2002, Sturm et al. 2001, Wahren et al. 2005, Tape et al. 2006). Modeled vegetation change suggests that shrub habitats will increase in the long term, presumably at the expense of graminoids throughout much of the study area, with greatest increases predicted in the Brooks Range ecoregion. While increases are also predicted for the foothills, it is likely that the ALFRESCO model underestimates shrub increase for this region because tussock shrub tundra, which is the dominant cover in the foothills, is mapped as a shrub class and for this reason shrub increase within the CE is not captured.

Graminoids, primarily *Eriophorum vaginatum*, dominate the upper canopy layer within the foothills tussock tundra CE. Average graminoid height is 31.4 cm (SD 5.5) and average shrub height is 27.0 cm (SD 7.8) (NPRA Assessment Inventory and Monitoring Program, unpublished data on file with BLM). Given the narrow margin between canopy heights of the two life forms, a relatively small increase in shrub height could shift canopy dominance from graminoid to shrub resulting in cascading effects on composition and habitat with in the CE.

Slight increases in forest cover are predicted in the Western Foothills, Western Brooks Range, and Eastern Brooks Range sub-regions (Table G-9), and this could result in a conversion of tussock tundra or low shrub vegetation to forest. White spruce (*Picea glauca*) encroachment is expected to advance the elevational treeline of the Brooks Range, expanding on well drained slopes and along riparian corridors (Suarez et al. 1999), but a substantial lag time between tree establishment and forest development is predicted based on both models and paleo-reconstructions of tree line (MacDonald et al. 1993, Rupp et al. 2000). Young white spruce have been reported from Galbraith Lake, presumably from seeds transported by vehicles, people and their goods; future distributions of spruce and other native species in the region may be affected by human-mediated dispersal. Transitions occurring above treeline on the southern slopes of the Brooks Range would coincide with highest flammability indices (Figure G-33) and thus may conflate the frequency of fire in these areas.

Table G-9. ALFRESCO projections by sub-region for percent canopy cover of forest for decades representing current, near-term future, and long-term future conditions. Change is represented by the difference between 2060s and 2010s.

Sub-region	Vegetation Type	2010s	2020s	2060s	Change
Western Foothills	Forest	2.9%	3.0%	3.7%	+0.9%
Western Brooks Range	Forest	4.2%	4.2%	7.1%	+2.8%
Central Brooks Range	Forest	7.8%	7.8%	7.8%	0.0%
Eastern Brooks Range	Forest	2.6%	2.9%	3.6%	+1.1%

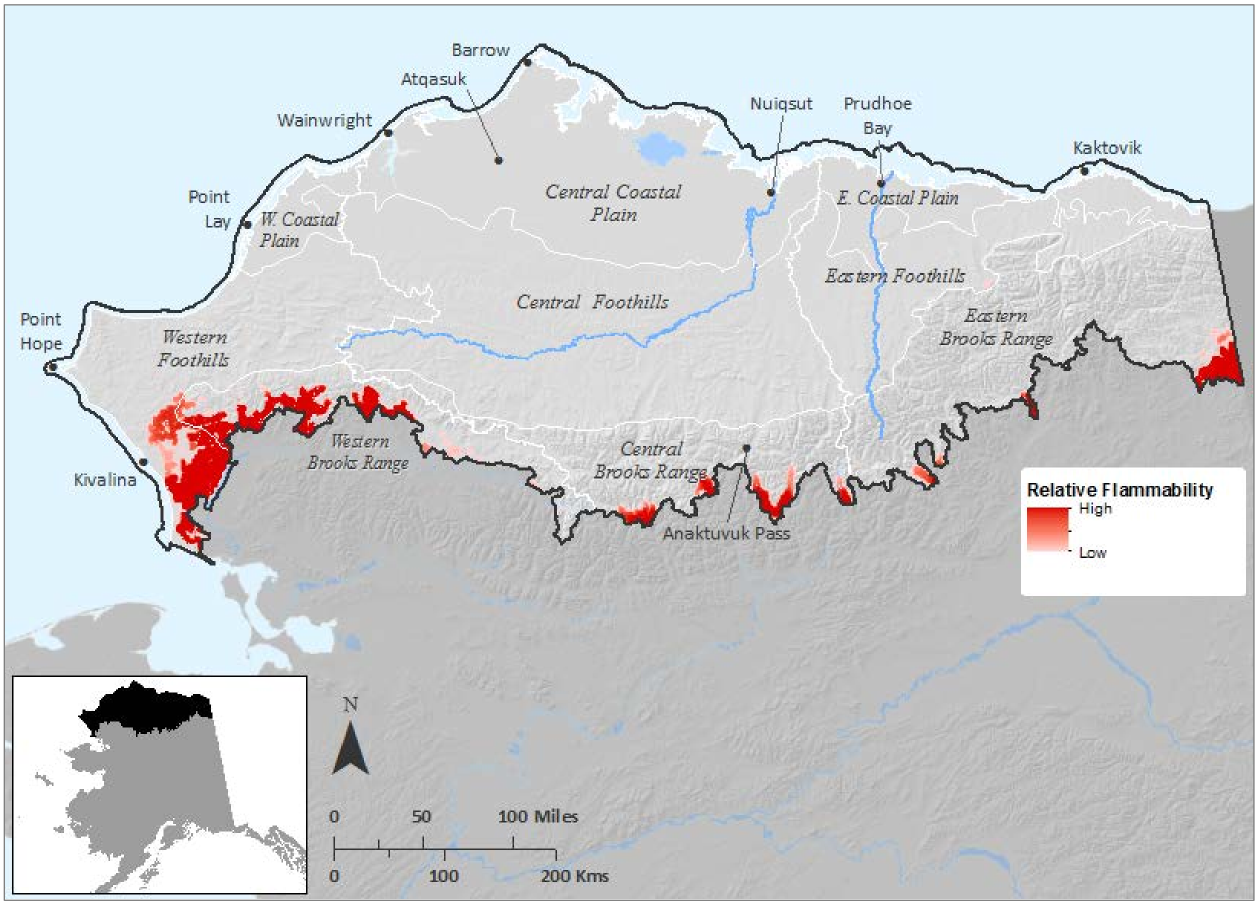

Figure G-33. Projected relative flammability across the North Slope study area.

Currently, tundra fires are infrequent north of the Brooks Range. While fire frequency is expected to increase in the southern portion of the study area, the predicted burned area will remain quite low. The ALFRESCO model (see Section C. Abiotic Change Agents) is directly linked to fire, climate, and vegetation, and incorporates vegetation shifts driven by climate in the absence of fire as well as post-fire successional shifts. The magnitude of climate-driven vegetation change predicted across the North Slope study area is larger than would be expected through fire-driven succession transitions alone, suggesting that climate is the primary driver of vegetation shifts within the project area. However, climate-driven changes, when coupled with tundra fires, can trigger new successional pathways, further facilitating the invasion of tundra by shrubs (Jones et al. 2013).

Permafrost

Increased temperatures will lead to an increase in active layer thickness (ALT) which will allow vascular plants to root at greater depth. Current ALT for the foothills tussock tundra CE is modeled at 0.52 m and is projected to increase to 0.61 m in the long term (Table G-9). Active layer thickness is strongly correlated to species composition, with slight increases in seasonal thaw depth potentially facilitating shifts from tundra to shrubland or from shrubland to forest, depending on the minimum rooting depths of the species in question. Thus, the projected increase of 9 cm in ALT in foothills tussock tundra may transition tussock shrub tundra to a vegetation type dominated by low shrubs. However, these changes are complex in nature; and are linked not only change in the permafrost condition, but also to associated changes in temperature, snow cover, and tundra fire (Myers-Smith et al. 2011; see Section C. Abiotic Change Agents).

Much of the lower foothills region is underlain by deep loess (wind-deposited silt) which supports extremely ice-rich permafrost (termed yedoma) relict from a colder, Pleistocene climate (Carter 1988, Kanevskiy et al. 2011). Ice within this stratigraphic layer has segregated to wide (7 m) and tall (30 m) ice wedges, rendering these terrains highly-susceptible to thermal erosion and thermokarst (Kanevskiy et al. 2011, Martin et al. 2009); melt of these massive ice bodies is responsible for the formation of deep thaw lakes along the Brooks Range foothills.

The Thermokarst Predisposition Model ranks the foothill region as “highly predisposed” to thermokarst based on high ice and organic content of the soil (Figure G-14). Thermokarst failures have been reported from the Noatak Basin and near Toolik Lake (Bowden et al. 2008, Gooseff et al. 2009). Increasing depth and duration of active layer thaw is expected to promote subsurface drainage through the sloping foothill terrain. However, the activity and number of thermokarst failures are expected to increase, especially in areas of the lower foothills where the landscape is characterized by soils with high interstitial and massive ice content.

6.4. Current Status and Future Landscape Condition

Ice roads and winter trails can damage tundra vegetation, particularly tussock vegetation (Guyer and Keating 2005, Felix and Raynolds 1989). Compression of tussocks and bryophytes can lead to changes in active layer depth and can result in a shift from moist tundra to wet sedge vegetation. Associated changes in drainage networks may affect adjacent vegetation (see MQ TC 1 for more discussion about the impact of development on foothills tussock tundra).

The overall status of the foothills tussock tundra CE was assessed by intersecting the Landscape Condition Model (LCM) with the CE distribution model for the current condition and two development scenarios, medium and high. The LCM is a way to measure the impact of the human footprint on a landscape. The human footprint on foothills tussock tundra is currently very low, with 98.9% of the landscape in the “very high” condition class. Under the “high development” future scenario, this percentage is projected to decrease by 0.1%.

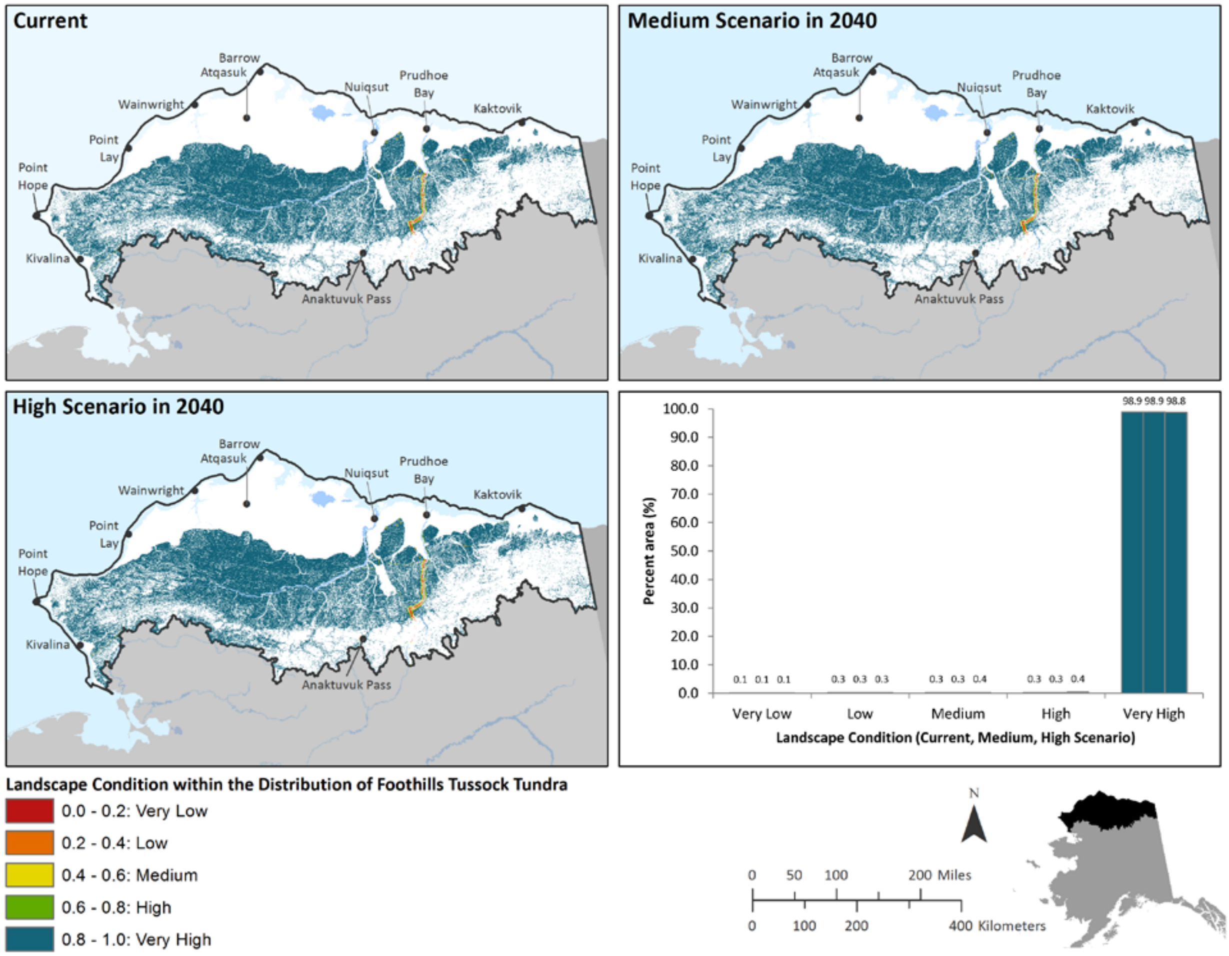

Figure G-34. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of foothills tussock tundra in the North Slope study area.

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7. Alpine Dwarf Shrub Tundra

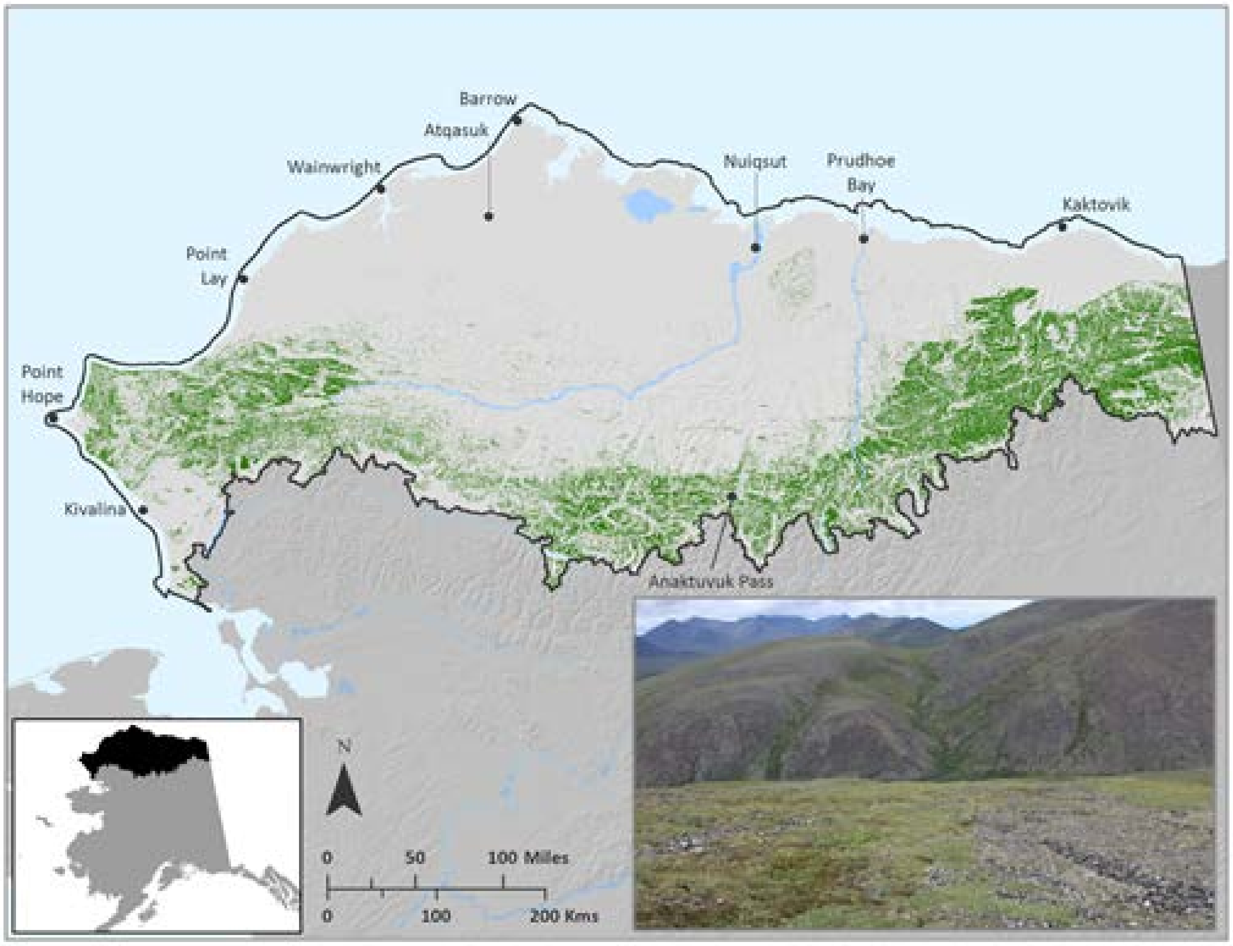

Figure G-35. Current distribution of the alpine dwarf shrub tundra CE in the North Slope study area.

7.1. Introduction

Alpine dwarf shrub tundra is widespread throughout the Brooks Range Mountains and upper elevation foothills. It occurs on side slopes, low summits, and ridges. The substrate ranges from residual bedrock to colluvium, and sites are typically mesic and well drained to very well drained. Slopes range from gently sloping to steep and unstable. On steep colluvial sideslopes patches of dwarf shrub tundra are often interspersed with active scree slopes. Permafrost is typically present, but the active layer may be deep, especially on south facing slopes. Ice content of the permafrost is typically low and bedrock is often near the surface.

The dominant shrubs are *Dryas octopetala, Cassiope tetragona,* and *Salix* spp. (including *Salix reticulata, S. arctica*, *S. phlebophylla*, and *S. pulchra*). *Cassiope tetragona* tends to be more abundant on north-facing slopes and late-lying snowbeds (Bliss 1988), while *Dryas octopetala* is more abundant on south-facing slopes and rounded, wind-swept summits. *Dryas octopetala* typically grows on sites with low snow cover on circum-neutral or basic soils (Komárková 1979). Other common shrubs include *Arctostaphylos alpina, Vaccinium uliginosum, V. vitis-idaea Diapensia lapponica,* and *Loiseleuria procumbens. Carex lugens* can be common on low angle sites with adequate soil moisture. A wide variety of alpine forbs are present with low cover. Common non-vascular species include *Hylocomium splendens, Racomitrium lanuginosum, Dicranum* spp., *Polytrichum* spp., *Umbilicaria* spp., *Cladina* spp., *Peltigera* spp., and *Cetraria* spp.

7.2. Conceptual Model

The conceptual model below (Figure G-36) is based on literature review and describes the relationship between the various change agents and natural drivers for alpine dwarf shrub tundra. Bold arrows are used to illustrate interactions that have high ecological relevance and potential management implications, and also have spatial datasets that can be intersected with the CE distribution. The primary change agents selected for this CE include: climate change, permafrost, fire (ALFRESCO and vegetation change) and land use change (i.e. human development).

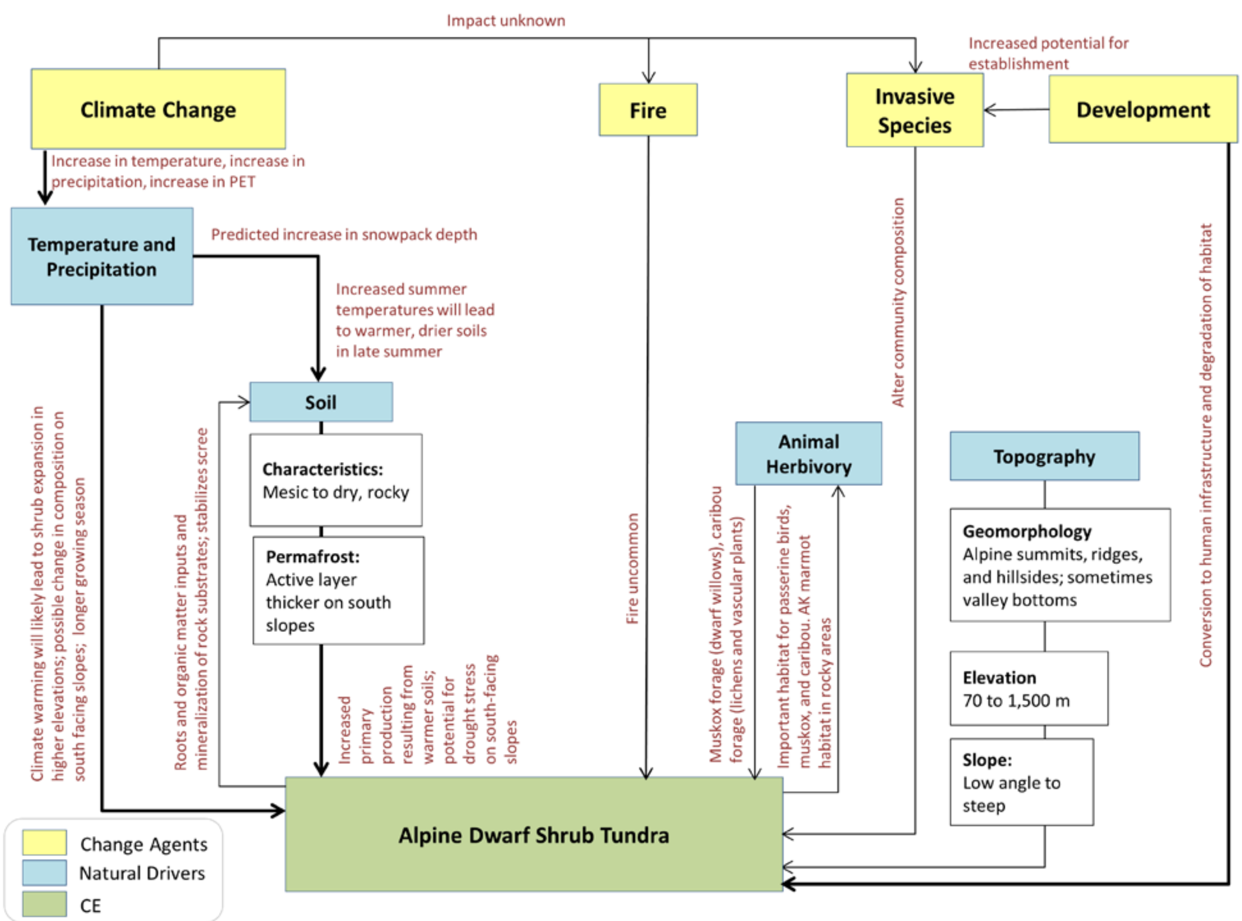

Figure G-36. Conceptual model for alpine dwarf shrub tundra.

7.3. Abiotic Change Agents Analysis

We explored the impact of the following climatic change agents on alpine dwarf shrub tundra: temperature (July temperature, and length of growing season), total annual precipitation, permafrost (active layer thickness and thermokarst predisposition), and fire (vegetation change modeled in ALFRESCO). Warming is expected to affect vegetation communities directly through temperature effects on plant growth and indirectly through changes to the underlying permafrost and soil properties.

Temperature

Near-term increases in July temperature are not expected to be significant, but by the 2060s significant increases are projected across 86% of the of alpine dwarf shrub tundra distribution (Table G-4). In the long term (2060s) the average projected increase in July temperature across the CE distribution is 1.4 °C (Table G-5) and the average annual temperature increase is 2.3 °C. The average increase in the length of growing season is 10.0 days (Table G-6) with a range of 7 to 16 days (**Figure G-37**) across the CE distribution.

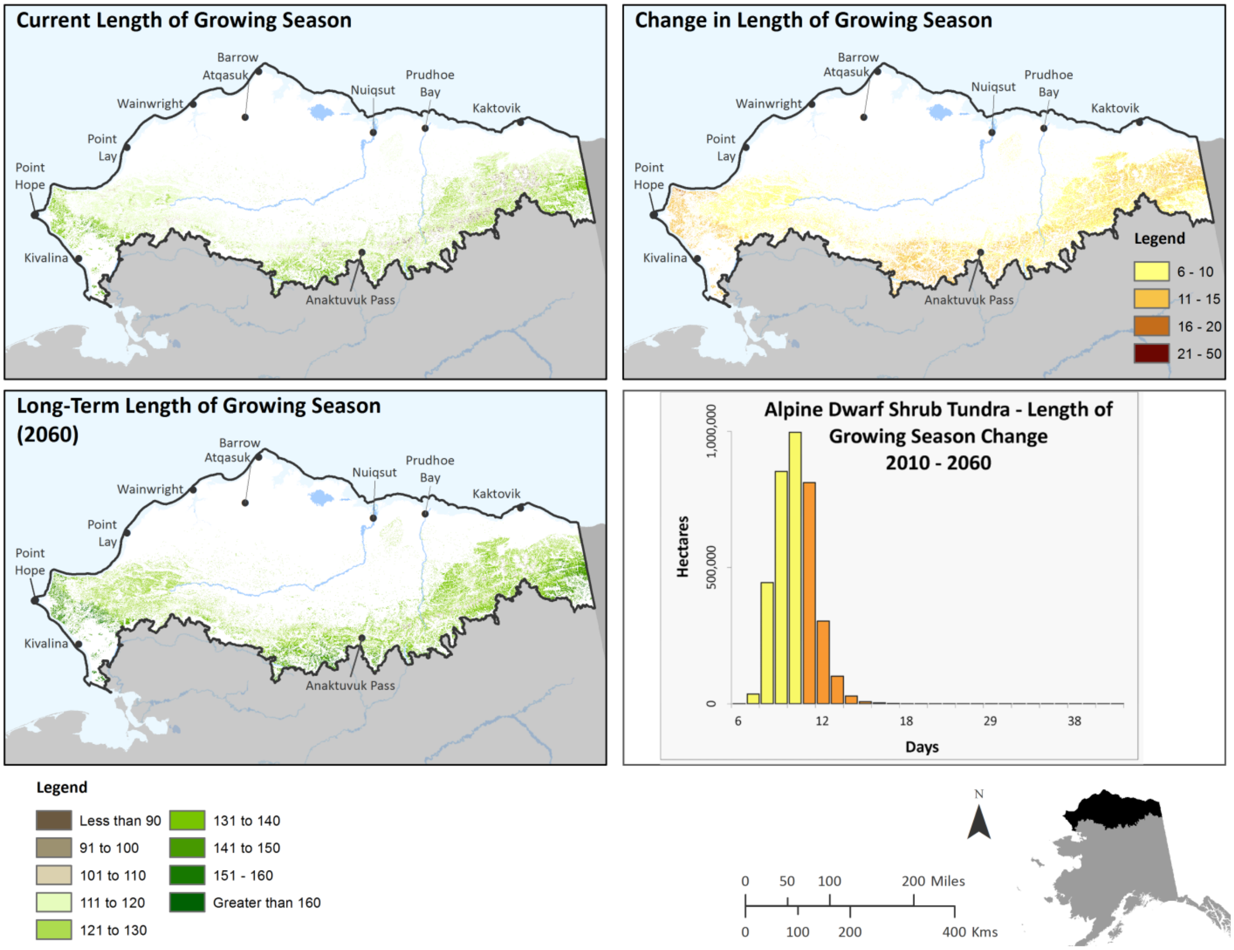

Figure G-37. Length of growing season for current and long-term future and change in LOGS clipped to the alpine dwarf shrub tundra distribution in the North Slope study area.

Precipitation

Total annual precipitation for alpine dwarf shrub tundra is expected to increase from 479 mm (current) to 535 mm in the long term (2060s), an 11.7% increase. Changing moisture regimes may lead to changing shrub composition and phenology within the CE. A deeper snowpack may provide thermal insulation during the winter and contribute additional moisture during the growing season on sites that accumulate snow, but wind-swept summits and south-facing aspects may experience increased drought stress. Warmer summer temperatures may lead to shrub encroachment upslope on sites that are not moisture limited (for example, low shrubs growing in dwarf shrub habitat or dwarf shrub migrating into alpine barrens).

Fire and Vegetation Change

Currently, tundra fires are infrequent north of the Brooks Range. Fire frequency is expected to increase in the southern portion of the study area; however the predicted burned area will remain quite low. Fire is unlikely to have significant impacts on alpine dwarf shrub tundra.

The ALFRESCO model predicts an increase in shrub tundra and a decrease in graminoid tundra across all three Brooks Range sub-regions. The ALFRESCO shrub class does not include dwarf shrubs, so the predicted increase can be interpreted as low shrubs migrating into alpine dwarf shrub habitat. The ALFRESCO graminoid class includes vegetation dominated by dwarf shrubs with lichen and moss. The predicted decrease in graminoid in the Brooks Range can be interpreted as a decrease in the area of dwarf shrub tundra. These predictions at the elevation limits of vegetation bear further inspection because it is unclear whether the model allows for vegetation migration upward in elevation.

Permafrost

Active layer thickness is projected to increase from 0.46 m to 0.54 m for this CE (Table G-9). This increase will provide increased rooting depth and may allow for increased productivity. The thermokarst predisposition model predicts that only 21% of the alpine dwarf shrub distribution is susceptible to thermokarst (Figure G-15). Rocky residual and colluvial soils that dominate the CE distribution are thaw-stable and are not expected to exhibit significant geomorphic change under a warmer climate regime (Martin et al. 2009).

7.4. Current Status and Future Landscape Condition

The overall status of the alpine dwarf shrub tundra CE was assessed by intersecting the Landscape Condition Model (LCM) with the CE distribution model for the current condition and two development scenarios, medium and high. The LCM is a way to measure the impact of the human footprint on a landscape. The impact of the human footprint on alpine dwarf shrub tundra is currently minimal, with 99.1% of the landscape in the “very high” condition class. This is not expected to change in either the medium or high development scenarios (Figure G-38).

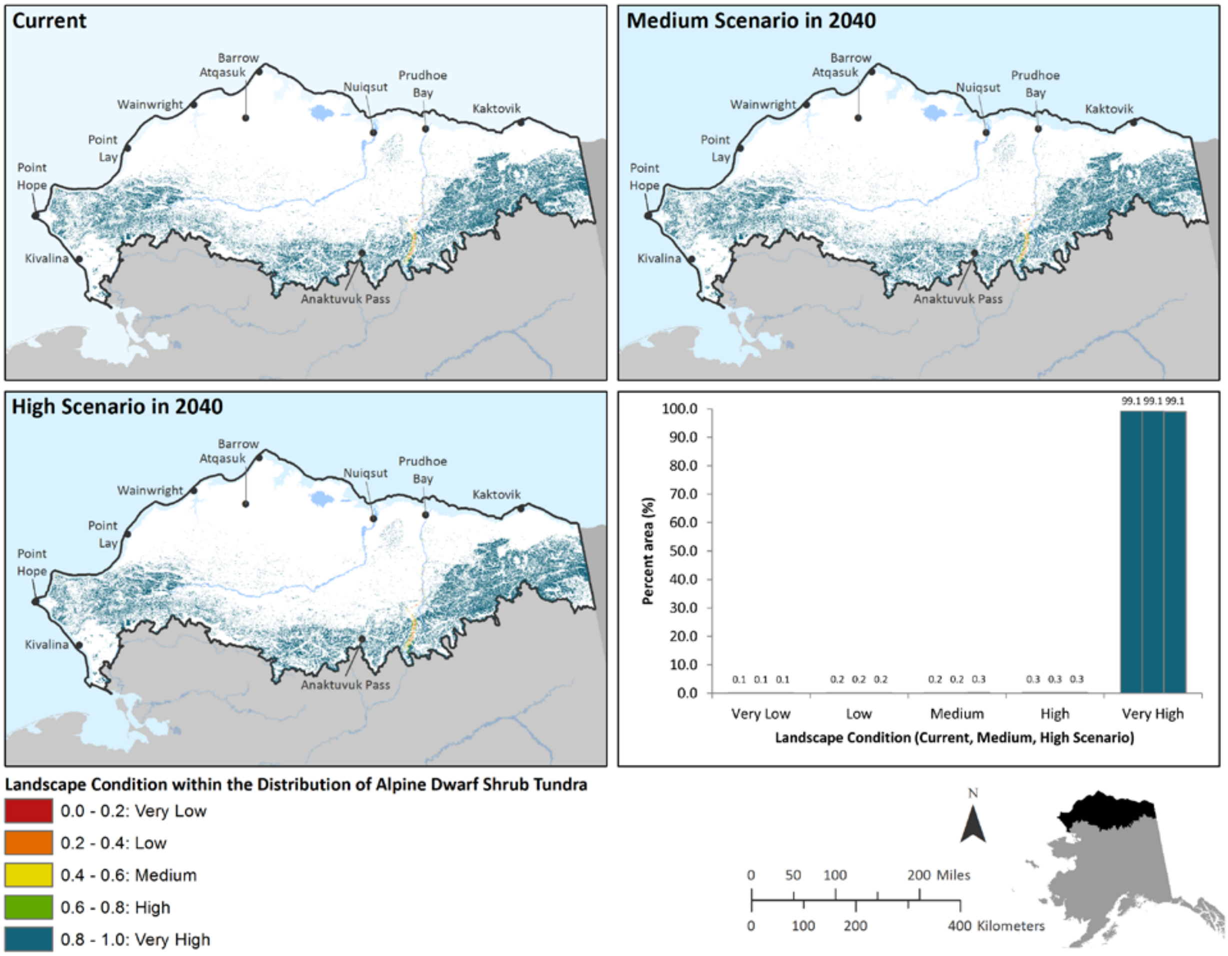

Figure G-38. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of alpine dwarf shrub tundra in the North Slope study area.

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8. Floodplain Shrubland

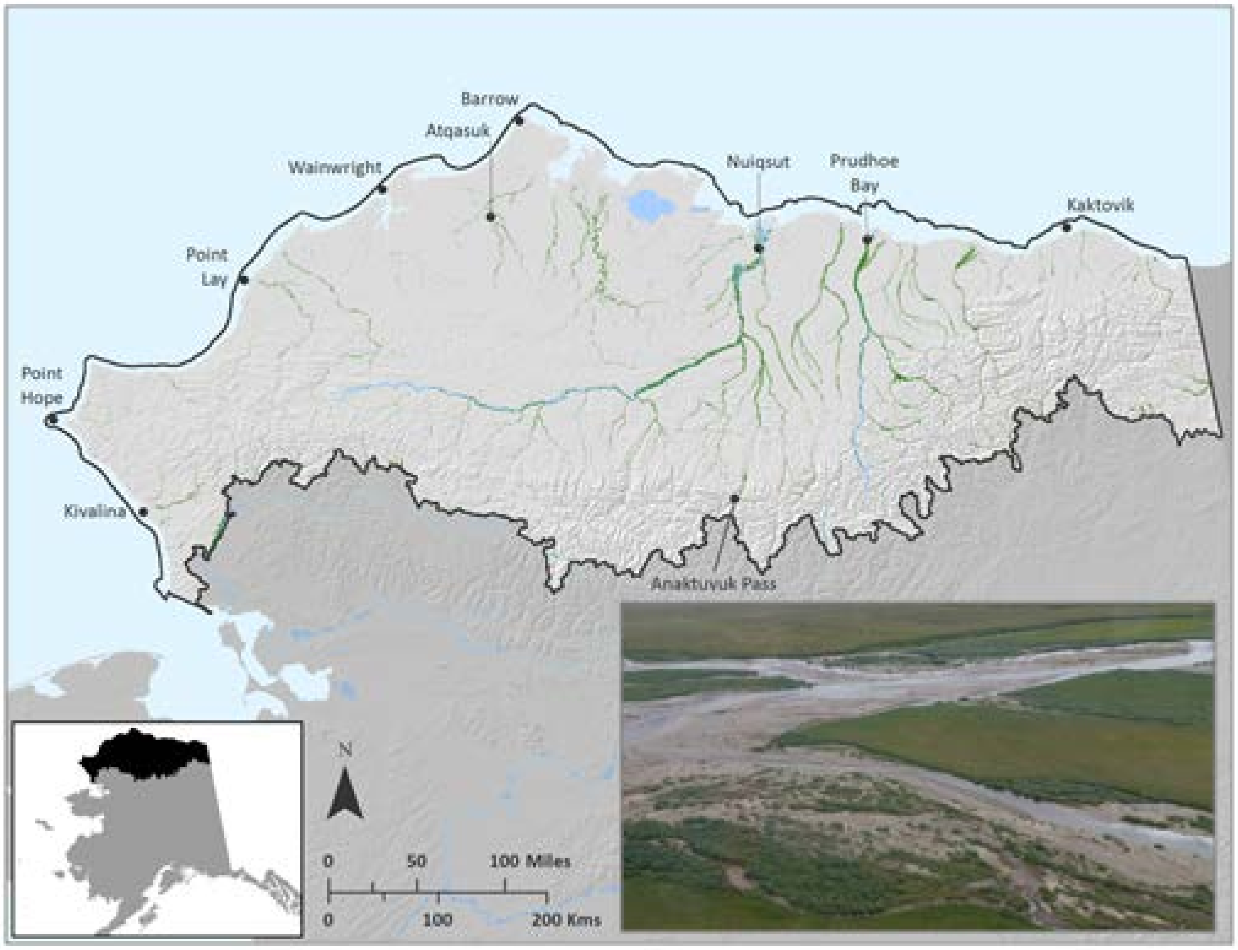

Figure G-39. Distribution model for floodplain shrublands within the North Slope study area.

8.1. Introduction

The Brooks Range, Brooks Range Foothills, and Coastal Plain ecoregions contain many rivers that drain into the Arctic Ocean or Chukchi Sea, including the Kivalina, Utukok, Colville, Canning, and Kongakut rivers. Many of the rivers or their tributaries originate in the Brooks Range as clear-water or occasionally silt-rich glacier-fed streams. These rivers typically have floodplains that support both dry to mesic terraces and also wetlands.

Flooding and erosion create a dynamic and varied environment within the floodplain. This CE includes all stages of vegetation succession that occur on well-drained deposits within the floodplain including terraces, bars, and active channels (floodplain wetlands are excluded). The distribution is defined shrubby to sparsely vegetated landcover classes occurring within the floodplain subsection (Jorgenson and Grunblatt 2013) (Table G-3). Floodplains are widely distributed in the valleys of the Brooks Range and Brooks Range Foothills, and across the Coastal Plain ecoregions.

Narrow high-gradient floodplains originating in the mountains become meandering or braided channels as rivers become larger and emerge on the low gradient topography of the coastal plain. Floodplain deposits vary from coarse gravels in high-energy environments to sand, silt, and layered organics in the lower reaches of the floodplain. The floodplain shrubland CE typically has sandy or gravelly deposits. Fine silts and organic deposits tend to occur in floodplain wetlands, which are not included in the distribution of this CE.

Regular erosion and deposition of sediments creates a pattern of disturbance and vegetation succession within the floodplain. The channel meanders laterally across the floodplain depositing alluvium on the inside of the curve and eroding the outside of the curve. This repeating process provides creating a series of similar bands of alluvial deposits along the floodplain (Leopold et al. 1964, Friedkin 1972, Walker et al. 1982). Vegetation growing on new deposits near the river may be contrasted with that on older deposits inland to recognize and measure successional processes (Walker 1985). Alluvium also is deposited on the soil surface during flooding further raising the soil surface height, but because surface height is a function of floodwater height, it eventually stabilizes (Leopold et al. 1964). Wind-blown sand and silt from the floodplain or adjacent dunes are also deposited on the floodplains and may form dunes or raise the level of the floodplain terrace surface.

Permafrost development is less conspicuous on active floodplains. This is partially due to better drainage in recently deposited alluvium than drainage on the adjacent landscapes, and the redeposition of alluvium by fluvial action tends to mask the more slowly acting permafrost processes. In time, segregated ice and wedges ice form on the older terraces, which deforms the surface, affecting water runoff, and increasing the susceptibility of older terrain to thermokarst (Martin et al. 2009).

Aufeis, or river icing, is another distinct feature on arctic floodplains. These ice bodies form during winter in river sections where there is constriction between the river bed and overlying ice (Walker et al. 1982). The resulting hydrostatic pressure cracks the ice and allows water to flow over the surface, where it freezes in a thin layer. Numerous layers will freeze forming the thick ice deposits, which do not melt the following summer. These features often occur downstream from perennial springs, which supply a constant source of water during the winter (Childers et al. 1977).

During spring breakup, floodplain vegetation can be subjected to intense disturbance when flow from upstream snow melt begins before the onset of melt downstream (Walker 1985). This creates ice dams that result in water spreading over vast areas in arctic river deltas, reconnecting and recharging lakes (Martin et al. 2009).

Early Seral Vegetation Communities

Sparsely vegetated communities of *Salix alaxensis* are common on early seral or recently disturbed floodplain deposits. Other common communities include *Chamerion latifolium–Artemisia alaskana*, and sparse *Salix glauca*. Canopy cover is typically sparse and composition is variable. Common early seral indicators include the dwarf shrub *Arctostaphylos rubra,* and herbaceous species including *Bromus inermis* ssp. *pumpellianus, Festuca rubra* ssp. *arctica, Poa glauca, P. arctica, Elymus alaskanus* ssp.

alaskanus, Eurybia sibirica, Artemisia campestris ssp. *boreale, Lupinus arcticus, Hedysarum alpinum, Astragalus alpinus*, *Oxytropis campestris, O. borealis,* and *Equisetum arvense*.

These sites are very well-drained except during flooding. The soils are typically sand or gravel with no horizon differentiation. Permafrost is generally deeper than 1 m, and pH ranges from 6.9 to 8.5.

Mid Seral Vegetation Communities

More stable sites on active floodplains and small active streams typically support various low and tall willow communities. The most common plant community is *Salix alaxensis*, other communities include *Salix alaxensis/Dryas* spp.*, Salix arbusculoides, Salix glauca, Salix niphoclada, Salix richardsonii*, and *Alnus viridis* ssp. *fruticosa/Arctagrostis latifolia*. The understory species composition is highly variable. Some shrubs may have high cover including *Arctostaphylos rubra* and *Salix reticulata*. Herbaceous cover is often sparse, but in more mesic sites, herbaceous cover may be high including *Anemone parviflora, Equisetum arvense, Eurybia sibirica, Gentianella propinqua, Castilleja elegans, Minuartia* spp.*, Hedysarum boreale* ssp. *mackenziei, H. alpinum, Calamagrostis* spp.*, Koeleria asiatica*, and *Poa arctica*. Exposed sand and gravel is common. Moss cover ranges from sparse to high and lichen cover is typically sparse.

The sites are relatively dry except during flooding, and mesic on some overflow channels. The soil surface is either bare alluvium or a thin organic mat over silt, sand and rocks, and layered fines caused by vertical accretion of silts during overbank flooding, or layered organics and silts created by the accumulation of organic matter between infrequent flooding events (Shur and Jorgenson 1998). Permafrost is generally deeper than 1 m, and pH ranges from 6.7 to 7.7.

Late Seral Vegetation Communities

On dry to mesic floodplain terraces with infrequent flooding, the most common plant community is *Dryas integrifolia* (Jorgenson et al. 1994, Walker 1985, Walker et al. 1997) Species composition is highly variable. *Dryas integrifolia* dominates or co-dominates with other shrubs such as *Arctostaphylos rubra, Betula nana, Salix reticulata* or *Vaccinium uliginosum*. The moss canopy is generally well-developed in this seral stage and may include *Bryum* spp.*, Aulocomium* spp*. Tomentypnum nitens, Distichium capillaceum, Drepanocladus* spp., *Hylocomium splendens* and *Sanionia uncinata*.

These are dry to mesic inactive floodplain terraces. The soils are a thin organic horizon over a sandy C or B horizon. Permafrost may be present but is typically deeper than 40 cm, and pH ranges from 6.4 to 7.1.

8.2. Conceptual Model

The conceptual model below (Figure G-40) is based on literature review and describes the relationship among the various change agents and natural drivers for floodplain shrublands. Bold arrows indicate interactions with high ecological relevance and potential management implications, and for which spatial datasets can be intersected with the CE distribution. The primary change agents selected for this CE include: climate change, invasive species, and land use change (i.e. human development).

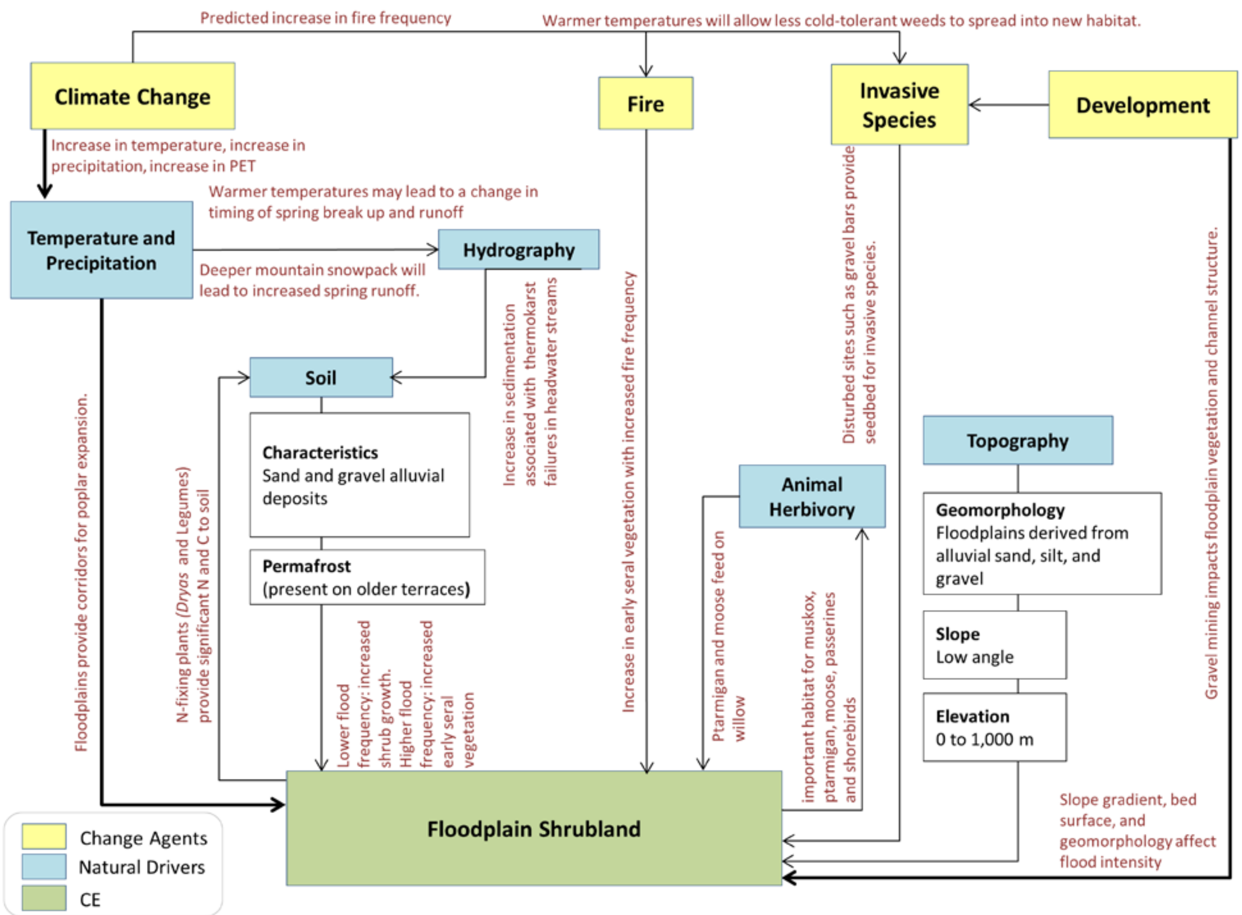

Figure G-40. Conceptual model for the floodplain shrubland CE.

8.3. Abiotic Change Agents Analysis

We explored the impact of changes in temperature and precipitation on this CE qualitatively because the important climate impacts, such as increased mountain snowpack, cannot be evaluated within the narrow confines of the floodplain boundary. Climate-induced changes to flooding, successional trajectories, and plant migration will also impact this CE habitat.

Temperature

The predicted increase in precipitation in the foothills and Brooks Range Mountains could alter the amount and timing of runoff. However, the predicted increase in temperature and subsequent increase in evapotranspiration could offset the increased water availability and runoff later in the growing season. A deeper winter snowpack in the mountains could lead to increased spring and early summer flooding. The associated increase in erosion and sedimentation could lead to an increase in the frequency of disturbance, shifting floodplain vegetation toward earlier successional stages (Marin et al. 2009).

Fire and Vegetation Change

Because floodplains are narrow corridors that bisect all of the North Slope ecoregions, vegetation change projected in ALFRESCO model is difficult to relate to vegetation change within floodplain shrublands. One possible scenario is that the combined effects of increased summer temperature and increased spring runoff could shift vegetation toward more abundant early seral, high-productivity willow stands and away from late-seral dwarf shrub communities, but this is highly speculative.

Isolated stands of balsam poplar (*Populus balsamifera*) occur in the Arctic far north of the boreal forest populations south of the Brooks Range (Bockheim et al. 2003, Breen 2014). The distribution of these stands has been linked to local environmental variables such as sheltered sites and the presence of perennial springs (Viereck 1979, Murray 1980 and 1992). Jorgenson et al. (2004) report that scattered stands occur in northwest Alaska where mean annual temperatures are -6 to -8 °C. Breen (2014) reports that a strong link exists between summer temperature, calculated as the sum of mean monthly temperatures > 0 °C, or summer warmth index (SWI), and the distribution of poplar stands. Eighty percent of the known stands on the North Slope have SWI values greater than 25. Because poplar is a wind-dispersed pioneer and floodplains have a ready supply of exposed mineral seedbed, this species could migrate rapidly and occupy new terrain along floodplains north of the Brooks Range under climate conditions favorable for seedling establishment and survival (Bockheim et al. 2003). Figure G-41 shows the distribution of known poplar stands and current and future SWI projections. Current SWI values >25 occur largely to the south of the coastal plain ecoregion, but by 2060, the area of SWI >25 extends well onto the coastal plain, greatly expanding area of favorable temperature parameters for poplar.

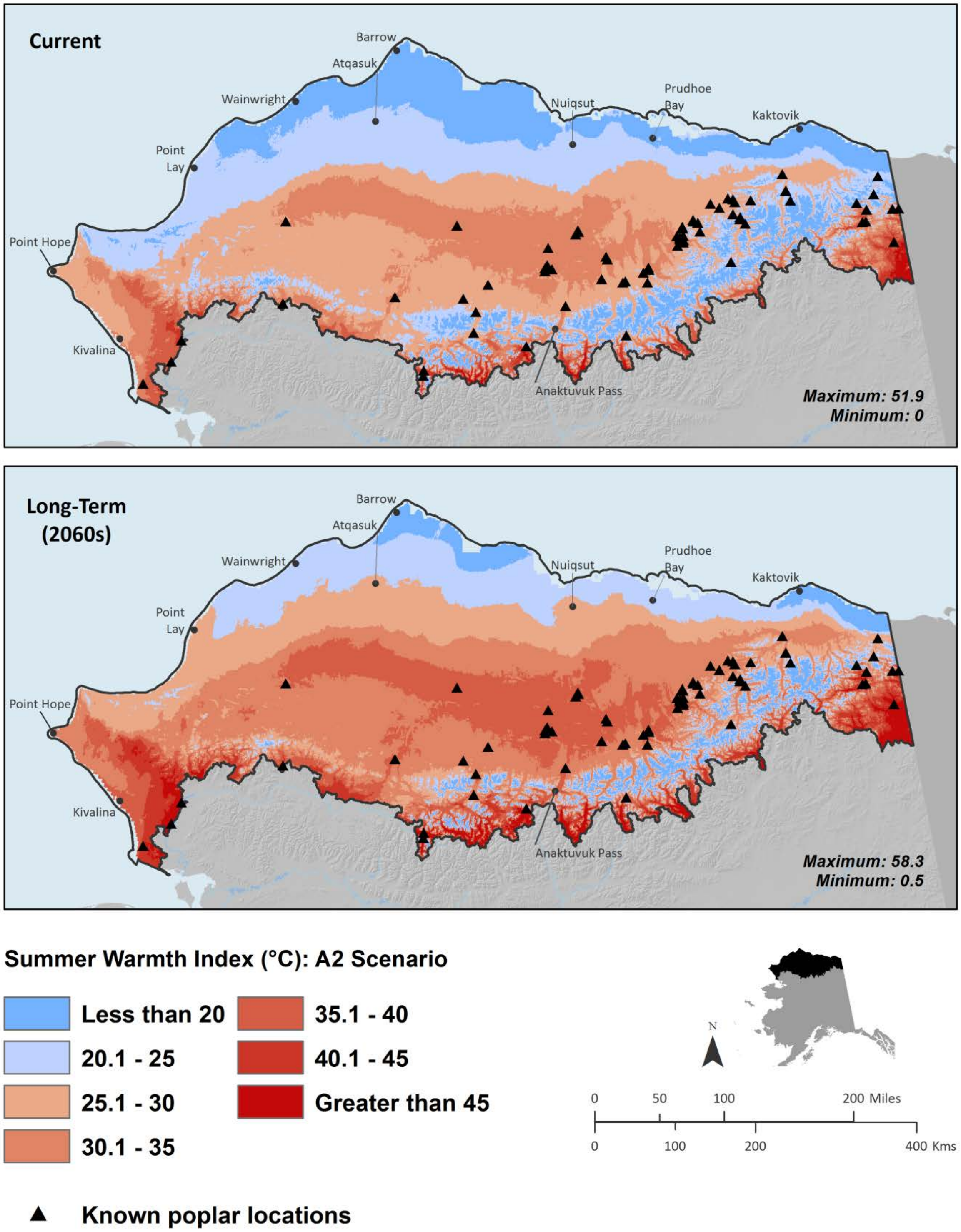

Figure G-41. Known poplar stand locations and Summer Warmth Index for the current and long term future in the North Slope study area.

8.4. Invasive Species

Invasive plant species are currently rare in the North Slope study area, and occur only in developed areas, such as along the Dalton Highway. We hypothesize that length of growing season is a limiting factor in the spread of invasive plant populations in the North Slope study area; however, future warming could create conditions favorable to the establishment of a wider range of invasive plant species. Floodplains provide corridors of frequently disturbed soil which is a requirement for establishment for most invasive weeds, and therefore we included floodplain shrublands as potential corridors for weed dispersal (see Section D. Biotic Change Agents).

8.5. Current Status and Future Landscape Condition

Gravel mining from floodplains was commonly practiced during the early period of oilfield development and pipeline construction. Early gravel extractions were typically shallow scrapes within floodplains, which led to numerous instances of habitat modification, including increased channel braiding, loss of wintering areas for certain fish species, spreading of flow, and restriction of fish movements (NRC 2003). Agency concerns about the physical and biological impact to floodplain habitat led to the development of a set of guidelines designed to minimize floodplain damage from gravel extraction (Joyce et al. 1980). In-stream gravel mining restrictions were enacted in the mid-1970s, shifting much of the extraction to designated multi-user deep extraction sites outside of floodplains. However, more recent studies of the impacts of gravel mining have revealed potential habitat enhancement opportunities for fish and waterfowl species on specific sites. The Alaska Department of Fish and Game has proposed gravel pit performance guidelines for both small-scale extractions and large operations with the goal of minimizing negative impacts and providing secondary habitat enhancements during reclamation (McLean 1993). Although gravel mining has been an important source of disturbance to floodplain habitat, the location of gravel mines is considered a data gap and this layer was not included in the Landscape Condition Model.

The overall status of the floodplain shrublands CE was assessed by intersecting the Landscape Condition Model (LCM) with the CE distribution model for the current condition and two development scenarios, medium and high. Currently 92.7% of the floodplain shrubland CE is in the “very high” condition class. Under the “high development” scenario, this is projected to decrease to 92.4% (Figure G-42). See MQ TC 1 for more discussion about the impact of oil and gas development on floodplain shrublands.

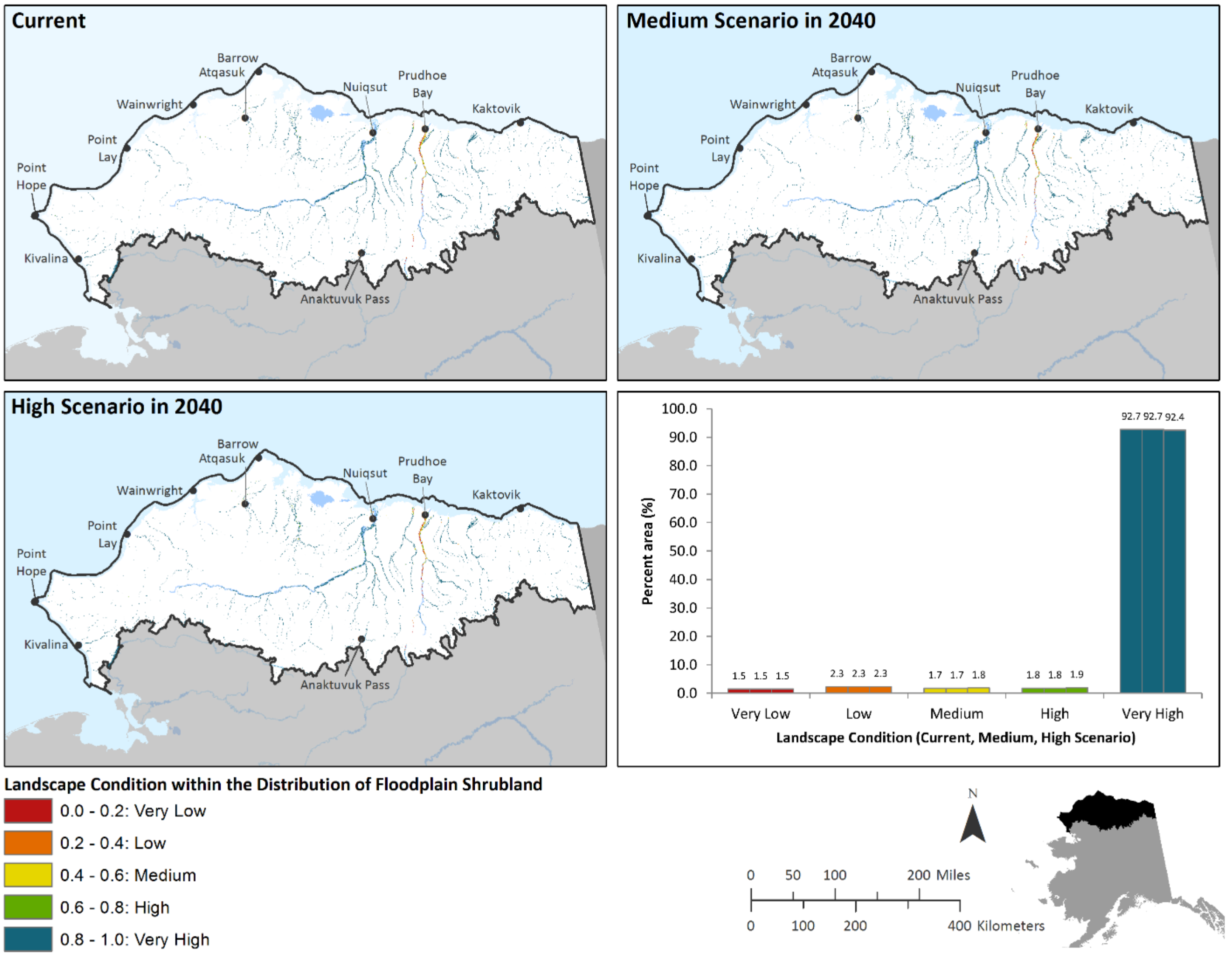

Figure G-42. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the floodplain shrubland distribution in the North Slope study area.

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9. Marine Beach, Barrier Islands, and Spits

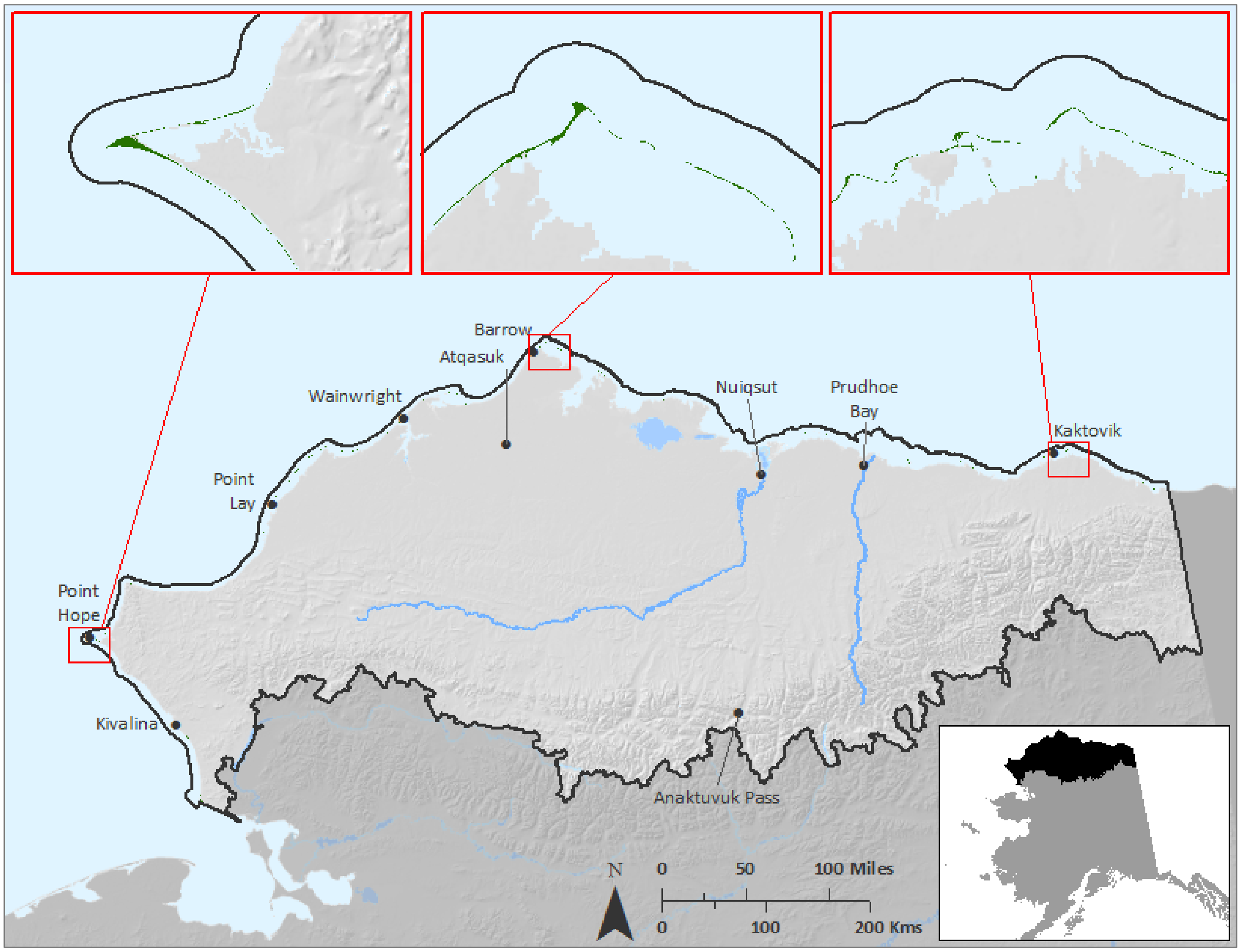

Figure G-43. Current distribution of marine beach, barrier islands, and spits in the North Slope study area.

9.1. Introduction

The barrier islands fronting Alaska's Arctic Coastal Plain are elongate, broadly-arcuate features (Figure G-44) separated from each other by inlets and from the mainland by lagoons, estuaries or bays (Ritter 1986). Both remnant and constructed barrier islands are represented along the Arctic Coast. Remnant barrier islands are relict coastline and support tundra vegetation underlain by permafrost whereas constructed types are comparatively recent depositions of sediment with no to limited development of vegetation and permafrost (Hopkins and Hartz 1978, Morack and Rogers 1981, Short 1979). Remnant barrier islands are restricted to the Beaufort Sea and include, from west to east, the Plover and Jones Islands, from Midway to Flaxman Island and in the vicinity of Barter Island (Jorgenson and Brown 2005, Short 1979). Due to their greater susceptibility and response to coastal erosion, this discussion focuses on the constructed barrier island. Of particular note are the barrier islands enclosing the Chukchi Sea's Kasegaluk Lagoon, which at 185 km, represents one of the longest systems in North America.

Figure G-44. Barrier island and attendant spit, Chukchi Sea (Shorezone).

Constructed barrier islands and spits are temporary in location and shape with their geomorphology controlled by the amount and type of sediment, the magnitude of natural processes and the stability of sea level (Dolan et al. 1980). Along Alaska's Arctic Coast, these islands are low (less than 2 m high), narrow (50-200 m wide) and long (up to 9 km) accumulations of sand and gravel sourced from coastal buffs and the shallow continental shelf (Short 1979). Sediment is delivered by waves driven by prevailing northeasterly winds and transported westward by longshore drift (Hopkins and Hartz 1978, Morack and Rogers 1981, Ritter 1986, Short 1979), but storm events are principally responsible for the sculpting and migration of barrier island complexes (Dolan et al. 1980). In the Arctic, these processes operate in the brief, ice-fee period extending from approximately mid-July to mid-September. Strong northwesterly winds common in the late summer can produce storm surges up to 3.4 m above normal sea level (Reimnitz and Maurer 1979, Talyor 1981) that frequently breach the low-relief barrier islands. During such overwash events, material is transported from the island's high-energy erosive environment on the windward side to the low-energy depositional environment on the leeward side and in this way forms gravel beaches backed by sandy dunes that grade to fine sand beaches and washover fans. The lagoons and estuaries that form between barrier islands and the mainland grade to tidal flats and marshes landward. The multiple, recurved spits attendant to most constructed barrier islands may be deposited and shaped by single storm events that extend the westward terminus of an island past a previously-formed spit (Hopkins and Hartz 1978, Short 1979). These repeated cycles of erosion and deposition result in the migration of barrier islands westward and landward with little net loss of mass (Hopkins and Hartz 1978). Also during the open water period, rafted ice may scour vegetated surfaces and dredge sediment shoreward across barrier islands and beaches creating furrows tens of meters long and ridges up to a meter high (Hopikins and Hartz 1978, Martin et al. 2009).

While barrier islands and spits are largely devoid of vegetation, sparse vegetation may develop in protected dune areas that are older than 30-40 years (Hopkins and Hartz 1978, Short 1979). Pioneer species tolerant of salt and sand accumulation are the first to establish. The beachgrass, *Leymus mollis* is most common on topographic highs, with the succulent, halophytic forb, *Honckenya peploides* occurring on lower, often tidal substrates. Due to the challenges of germination posed by wind and desiccation in a dune environment, most species reproduce vegetatively and quickly develop to clonal stands (Carter 1988, Howard et al. 1977).

Barrier islands affect water circulation and sediment movement on the inner shelf, anchor sea ice and widen the zone of landfast ice, offer shelter to large shorebird populations during the late summer resting period or molt, and, in a few exceptional areas, provide important nesting habitat (Hopkins and Hartz 1978).

Beaches along the Arctic Coastal Plain are narrow (up to 20 m), low-lying, thin (less than 1 m) deposits backed by coastal bluffs and cliffs, which are typically 2-4 m high along the Beaufort Sea Coast and up to 10 m high along the Chukchi Sea Coast (Harper 1978, Hopkins and Hartz 1978, Jorgenson and Brown 2005). Beach sediments are predominantly silt and sand with limited gravel present between the Canning River and Point McIntyre and pebble from Point Hope to Kotzebue (Hopkins and Hartz 1978). Bedrock along the Arctic Coast is extremely limited. Minor outcrops of sedimentary rock ranging from sandstone to slate form cliffs at Skull Cliff southwest of Barrow, Cape Lisburne and Cape Thompson.

Figure G-45. A well-developed beach along the Chukchi Sea coast, southwest of Barrow (Shorezone).

Exposed, newly-formed shores characterized by absent or reduced beaches, low bluff heights and fine, ice-rich sediments allow erosion to occur over a greater range of wave heights and thus return higher rates of erosion. Alternatively, older shores with well-developed beaches and high bluffs and coarser sediments have historically been more resistant to coastal erosion.

9.2. Conceptual Model

A conceptual model (Figure G-46) was developed from literature review to describe the relationships among the various change agents and natural drivers for the Marine Beach, Barrier Island and Spit CE. Bold arrows indicate interactions with high ecological relevance and potential management implications. The primary change agents selected for this CE include: climate change, invasive species and development. Among the agents, climate change is expected to produce the greatest magnitude and extent of impact, where a temperature-induced decrease in sea ice extent and residence will lengthen the open water period and due to greater fetch, strengthen storms. Stronger erosive and depositional forces operating over a longer seasonal period are likely to further decrease the net area of barrier islands, spits and beaches, speed the migration and rotation of barrier islands and increase the frequency of storm events that reset the successional status of the CE to a primary status.

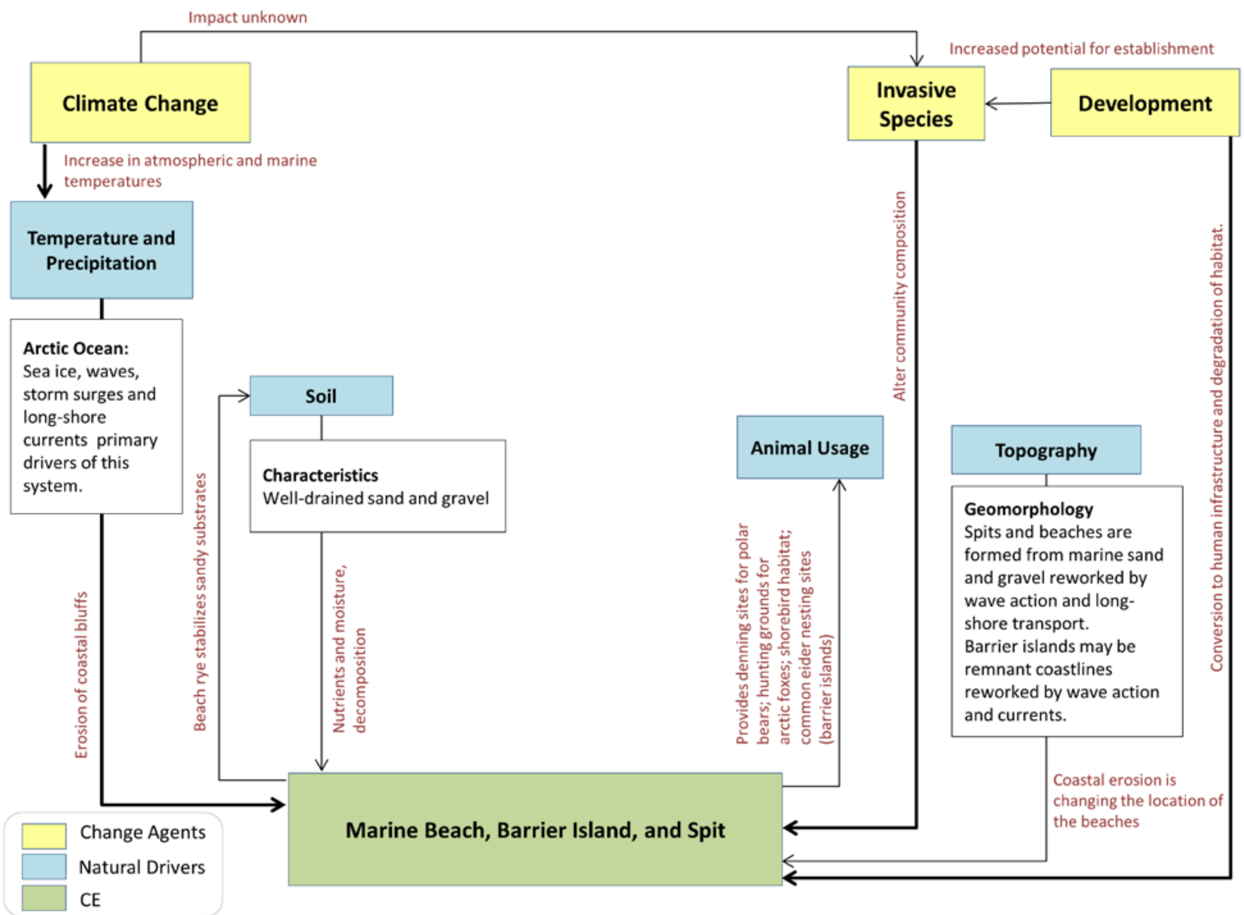

Figure G-46. Conceptual model for marine beach, barrier island, and spit.

9.3. Abiotic Change Agents Analysis

Only 27% of the Marine Beach, Barrier Island and Spit CE is projected to experience significant (with significance indicated by change greater than 1.3 °C, Table G-4) increases in July temperature in the long-term, while the entire CE is projected to experience significant long-term increase in January (long-term increase of 4.3 °C, Table G-5) and annual (long-term increase of 2.5 °C increase, Table G-5) temperatures. These long-term increases in temperature may degrade permafrost in remnant barrier islands and increase the effects of thermal erosion.

Length of growing season is projected to increase from the current period of 119.4 days to 132.7 days in the long-term for the Marine Beach, Barrier Island and Spit CE (Table G-6); this is the greatest increase projected for any CE, however benefits to plant growth derived from a longer warmer future growing season are likely to be offset by the increasing frequency and severity of storm events.

Mean annual precipitation is projected to increase from 263.7 mm to 293.3 mm for the Marine Beach, Barrier Island and Spit CE. The effects of this relatively moderate increase are uncertain, but as these coastal environments are not water-limited, impacts are expected to be minor.

9.4. Current Status and Future Landscape Condition

The overall status of the Marine Beach, Barrier Island and Spit CE was assessed by intersecting the Landscape Condition Model (LCM) with the CE distribution model for the current condition and two future development scenarios, medium and high development. The LCM allows quantification of the impact of the human development on a landscape. Within the North Slope study area, future impacts are driven by changes in oil and gas infrastructure. See Section F. Landscape and Ecological Integrity for a detailed description of methods. Currently, 83% of the Marine Beach, Barrier Island, and Spit CE is characterized by very high landscape condition, a proportion that is not expected to significantly change in the near- or long term (Figure G-47).

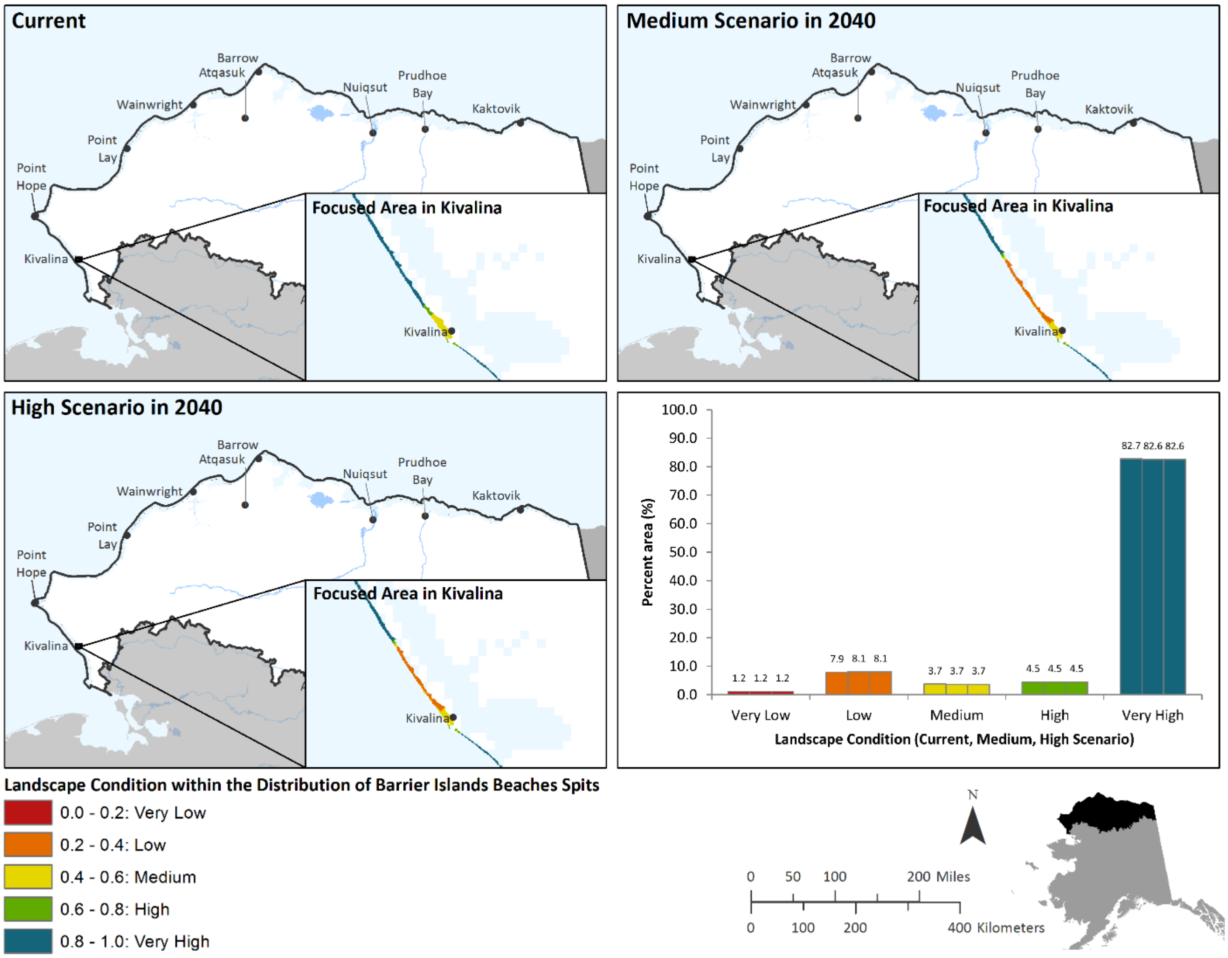

Figure G-47. Landscape condition within the beach, barrier island, and spit CE for the current status and two future development scenarios.

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10. Tidal Marshes

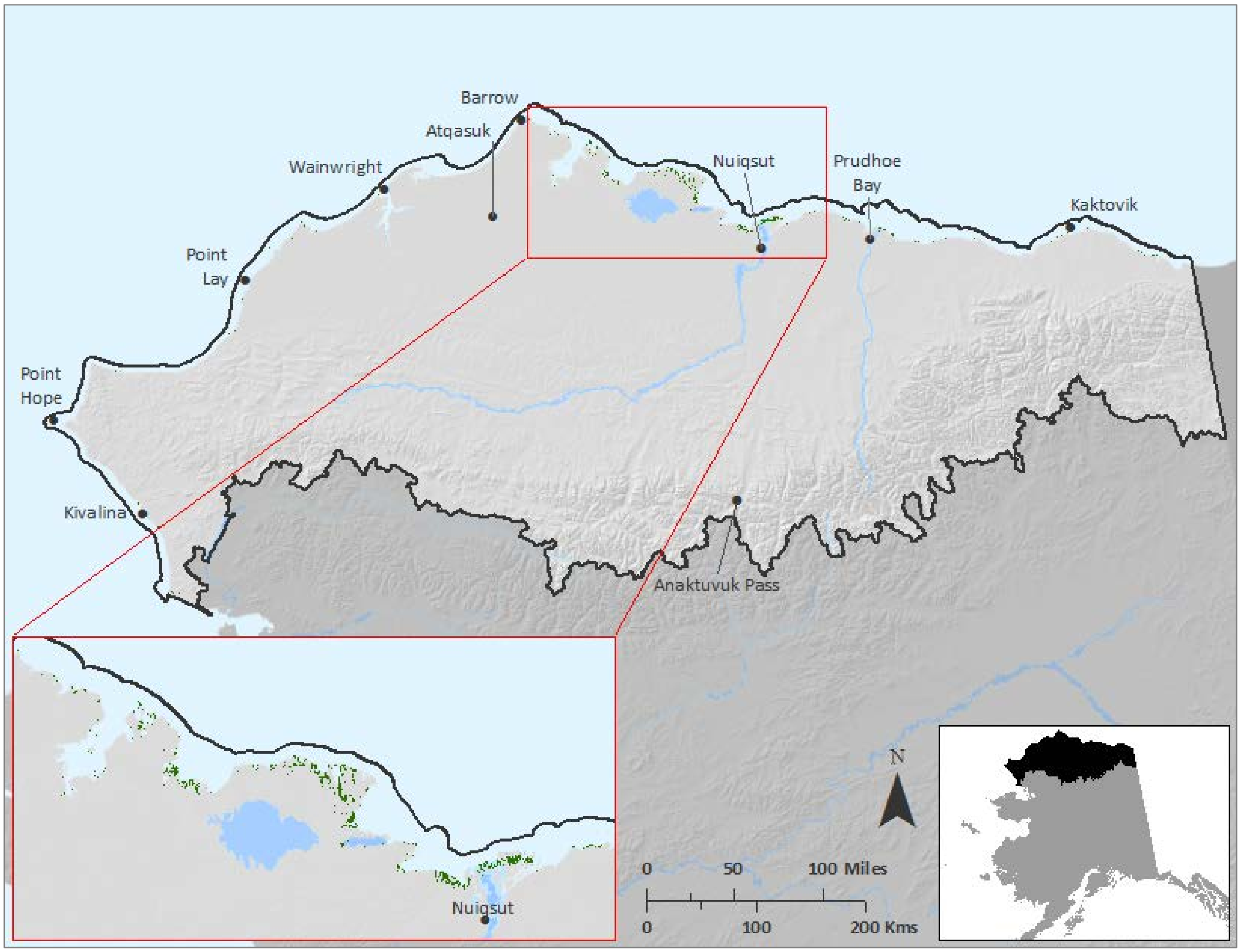

Figure G-48. Current distribution of the tidal marsh CE in the North Slope study area.

10.1. Introduction

Tidal marshes may develop where relatively flat land receives periodic input of tidal waters (Frohne 1953). As an interface between the ocean and land, tidal marshes combine aquatic and terrestrial habitats, anoxic and oxic conditions, as well as saline and fresh waters (Stone 1984). This dynamic environment supports life highly-adapted to saturation and saline conditions.

Figure G-49. Tidal marsh fringing a protected drainage, Chukchi Sea coast (Shorezone).

Arctic tidal marshes receive fresh water from streams and rivers, as well as overland and subsurface flow during spring and summer runoff (Meyers 1985, Kincheloe and Stehn 1991). Water salinity is inversely related to freshwater inputs and is subsequently lower in the spring when freshwater contributions from melting ice and snow are higher (Jefferies 1977). Permafrost is present in most arctic tidal marshes where it promotes inundation of surface waters by restricting drainage (Bergman et al. 1977, Jorgenson et al. 2004 and 2009, Meyers 1985). The fine sediment comprising tidal marshes is chiefly sourced from the large rivers and deltas that empty to the Beaufort Sea (Hopkins and Hartz 1978).

The cumulative area of tidal marshes in Arctic Alaska is low and the plant species they support are often obligate. Along the Beaufort and Chukchi Sea Coasts of Arctic Alaska, tidal marshes form a narrow fringe in protected areas along tidal river channels, inlets and deltas and within tidal lagoons, estuaries and across inundated tundra. The microtidal regime (0.1 m) along the Arctic Coast reduces the elevational range across which tide marshes develop and coastal erosion truncates their seaward expansion; however the low-angle topography of the Coastal Plain expands their inland extent.

Due to the periodic reworking of shoreline sediments by storm events, tide marshes along exposed coastlines develop as small (less than 20 m^2) mosaics of vegetation with up to 80% cover of bare mud and sand. Unvegetated tidal flats are pioneered by the clonal, halophytic grass *Puccinellia phryganodes* with the halophytic, succulent forbs, *Stellaria humifusa* and *Cochlearia officinalis* colonizing the seaward edge (Jefferies 1977). In contrast, extensive marshes with continuous cover of emergent vegetation may develop in sheltered lagoons and estuaries. Here, the salt-tolerant grasses, *Arctophila fulva* and *Dupontia fisheri*, the forb *Hippuris tetraphylla* and the sedge *Carex ramenskii* are frequent; C. *subspathacea* also occurs but is restricted to areas of secondary erosion (Jefferies 1977).

Although tidal marshes and flats occupy only a small portion of the total landscape, they are a critical staging area for wildfowl, particularly Snow Geese (*Chen caerulescens*) and Black Brant (*Branta bernicla nigricans*), and also support several species of conservation concern, such as the Steller's Eider (*Polysticta stelleri*). Tidal marshes are one of Alaska's most impacted habitats due to rapid coastal erosion (Jones et al. 2008, Ping et al. 2011, Forbes 2011) caused by diminishing sea ice, sea level rise and thawing permafrost.

10.2. Conceptual Model

A conceptual model (Figure G-50) was developed from literature review to describe the relationships among the various change agents and natural drivers for the Tidal Marsh CE. Bold arrows indicate interactions with high ecological relevance and potential management implications. The primary change agents selected for this CE include: climate change, invasive species and development. Among the agents, climate change is expected to produce the greatest magnitude and extent of impact, where a temperature-induced decrease in sea ice extent and residence will lengthen the open water period and due to greater fetch, strengthen storms. Stronger erosive forces operating over a longer seasonal period are expected drastically change the distribution and character of tidal marshes.

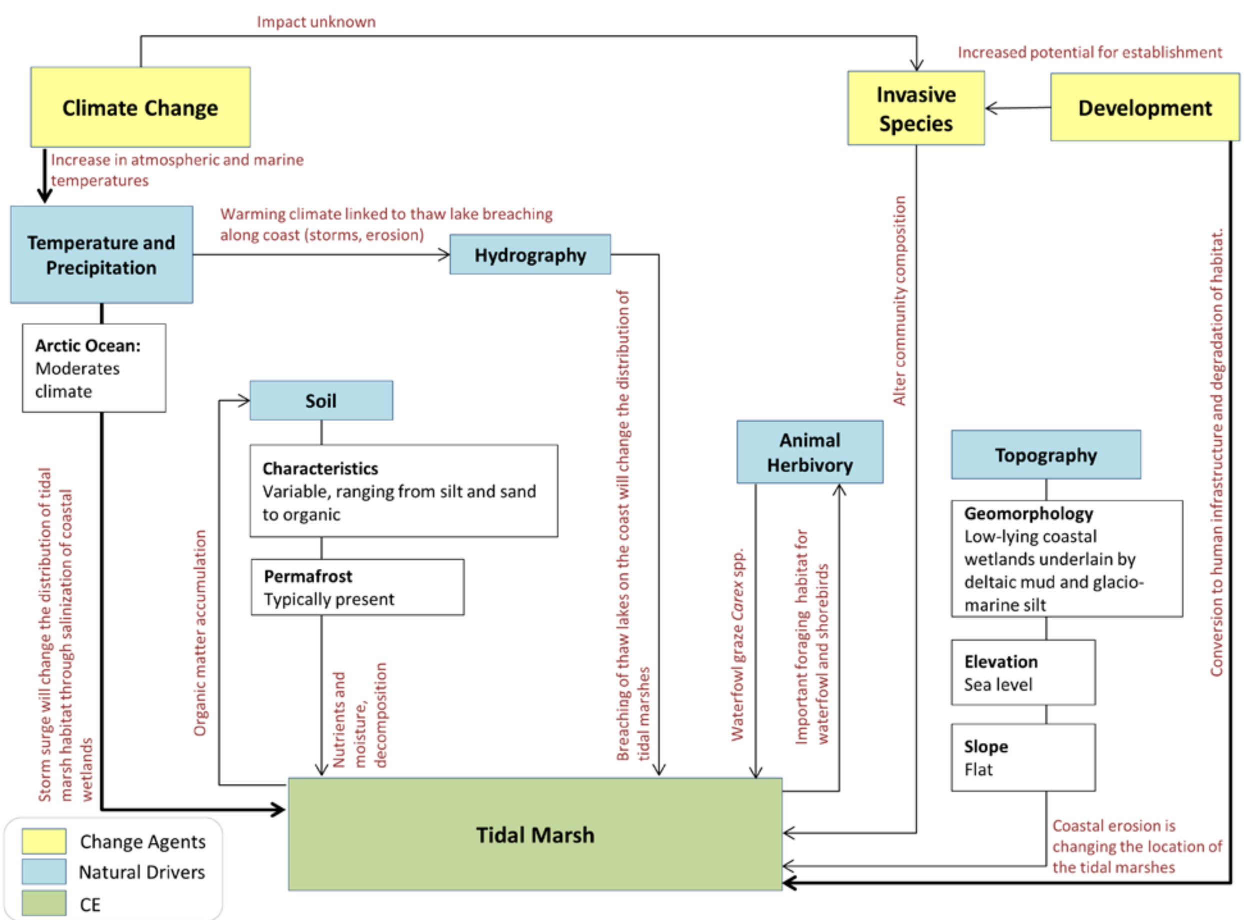

Figure G-50. Conceptual model for tidal marsh.

10.3. Abiotic Change Agents Analysis

Only 5.6% of the Tidal Marsh CE is projected to experience significant increases (> 1.3 °C) in July temperature in the long-term (Table G-4), while the entire CE is projected to experience significant long-term increase in January (long-term increase of 4.4 °C) and annual (long-term increase of 2.5 °C increase) temperatures (Table G-5). These long-term increases in temperature may increase productivity of resident vegetation and increase the effects of thermal erosion.

Length of growing season is projected to increase from the current period of 111.6 days to 124.1 days in the long-term for the Marine Beach, Barrier Island and Spit CE; next to the Beaches, Barrier Islands and Spits CE, this is the greatest increase projected for any CE (Table G-6). It is likely that a longer growing season will promote the growth of resident vegetation and possibly allow colonization by less cold-tolerant species.

Mean annual precipitation is projected to increase from 237.4 mm to 265.5 mm for the Tidal Marsh CE (Table G-8). The effects of this relatively moderate increase are uncertain. Possibly surface water hydrology and salinity may be altered, but as these coastal wetland are not water-limited, impacts are expected to be minor.

10.4. Current Status and Future Landscape Condition

The overall status of the Tidal Marsh CE was assessed by intersecting the Landscape Condition Model (LCM) with the CE-specific distribution model at current, near-(2020) and long-term (2060) time steps. The LCM allows quantification of the impact of the human development on a landscape. Within the North Slope study area, future impacts are driven by changes in oil and gas infrastructure. See Section F. Landscape and Ecological Integrity for a detailed description of methods. Currently, 94% of the Tidal Marsh CE is characterized by very high landscape condition, a proportion that is not expected to significantly change in the near- or long term (Figure G-51).

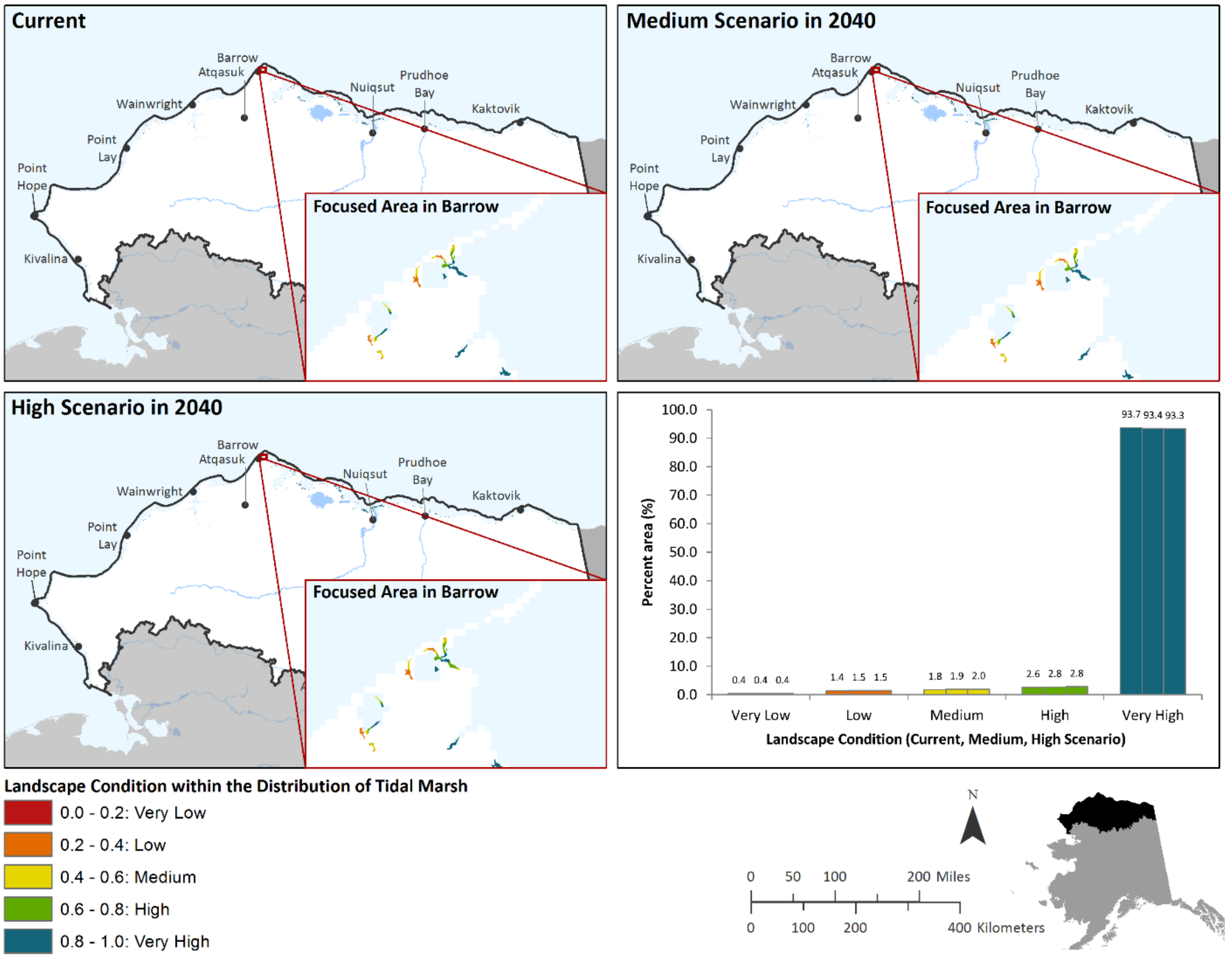

Figure G-51. Landscape condition within the Tidal Marsh CE for the current status and two future development scenarios.

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11. Coastal Erosion and Coastal Salinization

MQ TC 4	What are the expected changes to habitat as a result of coastal erosion and coastal salinization?

11.1. Introduction

The combined effects of rising sea level, declining sea ice, increasing summer ocean temperature, increasing storm power, and subsidence of coastal permafrost have had a dramatic effect on the arctic coastline of Alaska. Several studies have documented the loss of land area due to coastal bluff erosion and the impact to low-lying coastal vegetation from inundation and sedimentation. To answer this question we compiled existing information and conducted a literature review to summarize the expected changes to habitat.

Global sea level rise, warming water and air temperatures, reduction in sea-ice cover and duration, and increased frequency and strength of storms are associated with high-latitude climate change and, in combination, amplify the effects of coastal erosion and salinization in the Arctic (Jones et al. 2009, Ping et al. 2011). Patterns of coastal erosion relate to the interrelated factors of coastline elevation, orientation, geomorphology, sediment size and permafrost nature (Aguire et al. 2008). The average rate of erosion along the Alaska's Arctic Coast is -1.4 m/y with a range of -18.6 to +10.9 m/y (positive rate indicates accretion; Gibbs and Richmond, unpublished data). Analysis of historic aerial photography indicates the rate of erosion along the Beaufort Sea Coast has doubled over the last 50 years (Ping et al. 2011) while thaw subsidence of this low-relief coastline renders much of the nearshore environment increasingly susceptible to salinization (Arp et al. 2010). Where habitat is not directly lost to the sea, it may be converted to more saline types through the cyclic process of thaw subsidence, seawater inundation, and further subsidence. Barrier islands, spits, bluffs, beaches, tidal marshes, coastal wetlands and moist tundra and coastal lakes are the most highly-affected environments.

Erosion

Wind and water (in its many forms) are the driving erosive forces along Alaska's arctic coast. While the erosion of coastal sediments occurs across daily (astronomical tides), seasonal (meteorological tides and storm events) and decadal to centurial (extreme storm events sea level change) timescales, the reworking of coastal sediments is condensed to the brief open-water period from mid-July to mid-September when wind-driven waves and ice blocks lap barrier island and mainland shores. Wave action erodes sediment as part of the daily astronomical tidal cycle and where waves land at angles oblique to the shore, sediment can be transported considerable distances by longshore drift. Along north-facing sections of the Beaufort and Chukchi Sea Coasts, prevailing northeasterly winds move sediment to the west. To a lesser, more localized extent, rafted ice may push gravel to form beach ridges. Meteorological tides coupled with northwesterly storms create surges that reach well above and beyond normal levels and inland extents of high tides. Such high-energy events cause rapid erosion and redeposition of coastal sediment with single storms capable of removing meters of land and forming new spits and inlets in barrier island complexes. Coastal erosion, caused by permafrost thaw and subsidence of polygonal tundra, coupled with new sedimentation, and colonization by halophytic vegetation has occurred along some North Slope estuaries, and is believed to be at least partially responsible for redistribution of molting Black Brant from inland lakes to coastal marshes (Tape et al. 2013).

Unique to arctic environments is the thermal degradation of permanently and perennially frozen sediment. Thermokarst is the thawing of ice-rich permafrost and/or the melting of massive ice resulting in the consolidation and deformation of the soil surface. Thermal erosion combines both thermal and mechanical processes, while thermal abrasion is further associated with the reworking of ocean, river or lake bluffs, and thermal denudation relates to the thaw of frozen slopes that are subsequently mobilized by gravity (Jones et al. 2013).

Along active arctic coastlines, thermal and mechanical processes are rarely separated. The type features produced in a coastal environment by the melting of interstitial ice depends largely on the grain size of sediment. Where ice volume exceeds the natural porosity of the sediment (e.g. fine-grained clays and silts), its loss results in thaw subsidence and thermokarst collapse. Collapse features such as thermokarst lakes, sinkholes and pits that form at low elevation and proximal to a retreating coastline, are likely to be breached or tapped by seawater and rapidly eroded by wave action. Alternatively, where ice volume does not exceed the natural porosity of the sediment (e.g. coarse-grained sands and gravels), thermal erosion will thicken the fronting beach and thus dissipate the energy of incoming waves. In a coastal environment, thermal abrasion of waves can produce horizontal erosional niches at the base of bluffs that when the shear strength of ice-bound sediments is exceeded, or a vertical weakness such as an ice wedge is intersected, can cause failure of house-sized tundra blocks. Thermal denudation of sloping coastlines can initiate retrogressive thaw slumps that degrade permafrost sediments over areas tens of meters wide.

Salinization

Salinization involves the intrusion of saltwater to terrestrial or freshwater systems. Salinization most commonly occurs following the deposition of sediment by saltwater during storm surges but may also result from salt spray. Extreme storm events can result in surges 3.4 m above normal tidal range that due to the low topography of the Coastal Plain can flood low-lying tundra and lakes up to 5 km inland (Reimnitz and Maurer 1979). The introduction of saltwater and sediment to terrestrial and freshwater systems can weaken or kill native species thereby facilitating the colonization of ruderal, salt-tolerant species (Valiela 2006) and affecting the conversion of terrestrial or freshwater aquatic habitats to more saline types.

11.2. Methods

To answer this question we reviewed current studies and compiled available information documenting coastal erosion and inundation. For study sites at which specific rates of erosion have been defined, we classified erosion rates into four categories: stable or aggrading, slow (0 - 1 m/year), moderate (1 - 2 m/year), and rapid (2+ m/year) in order to present a spatial depiction of erosion rates. Projecting future rates of salinization of low-lying habitats is more difficult because inundation is a result of several interacting factors including storm surge and timing, presence of sea ice, and permafrost subsidence. We compiled information on the impact to coastal habitats from inundation and salinization, but conducting a spatial analysis of the expected changes is beyond the scope of this assessment.

11.3. Trajectories of Change

Coastal processes are removing sediment from barrier islands and mainland shores at increasing rates resulting in the direct loss of habitat and facilitating saltwater inundation and thermal erosion. Sediment is perpetually gained and lost along Alaska's Arctic Coast; deltas, spits and promontories show aggradation at rates up to 10.9 m/y while losses along exposed, ice-rich coastal bluffs can reach 18.6 m/y (Gibbs and Richmond, unpublished data).

Figure G-52. Longshore transport of sediment at Point Hope, Chukchi Sea (Shorezone).

Areas of significant sediment aggradation along the Arctic Coast are found in the prograding deltas of the Canning, Shaviovik, Sagavanirktok, Kuparuk, Coville, Ikpikpuk, Topagoruk and Mead rivers (Hopkins and Hartz 1978), as well as the forelands at Point Hope. Sediment accumulates to a lesser and more localized extents as capes attached to mainland coasts, spits attached to most barrier islands, and as ebb and flood tidal deltas that are formed on the seaward and landward sides of barrier island inlets by the exit and entrance of tidewater. The persistence of these prograding features is largely dependent on the degree to which sedimentation keeps pace with sea level rise. Projected increases in temperature and precipitation in arctic Alaska suggest a trend toward increased rates of sedimentation, which for these depositional features may compensate for sea level rise (Martin et al. 2009).

Barrier island systems experience high rates of localized erosion, slight decrease in net area and tendency to rotate and migrate to the southwest with prevailing winds and nearshore currents (Gibbs et al. 2008, Erikson et al. 2012, Ravens and Lee 2007). Total surface area of barrier islands in the central Beaufort Sea (Colville River to Point Thomson) has decreased approximately 4% from the 1940s to the 2000s with the rate of change greatest since 1980 (Gibbs et al. 2008). A similar increase in migration rate is seen for Narwhal Island, a barrier island east of Prudhoe Bay, which in the period from 1955 to 1990 migrated 5 m/y; a rate that increased to 24 m/y for the period from 1990 to 2007 (Martin et al. 2009, Ravens and Lee 2007).

The highest rates of coastal erosion occur along sections of mainland coast comprised of ice-rich, fine-grained sediment that are oriented towards incoming waves and not protected by barrier islands (Jones et al. 2008, Ping et al. 2011). For these reasons, erosion along the Beaufort Sea Coast is an order of magnitude greater (-1.7 m/y) than that along the Chukchi Sea Coast (-0.3 m/y; Gibbs and Richmond, unpublished data, Harper 1978, Hopkins and Hartz 1978, Reimnitz et al. 1985). Mean annual erosion rates by coastline type along the Beaufort Sea Coast, are highest for exposed bluffs (2.4 m/y, with a maximum 16.7 m/y) and lowest for protected lagoons (0.7 m/y, with a maximum of 10.4 m/y). When analyzed by soil type, the rate of erosion is considerably higher for silts (3.2 m/y) compared to sands (1.2 m/y) and gravels (0.3 m/y)(Jorgenson and Brown 2005).

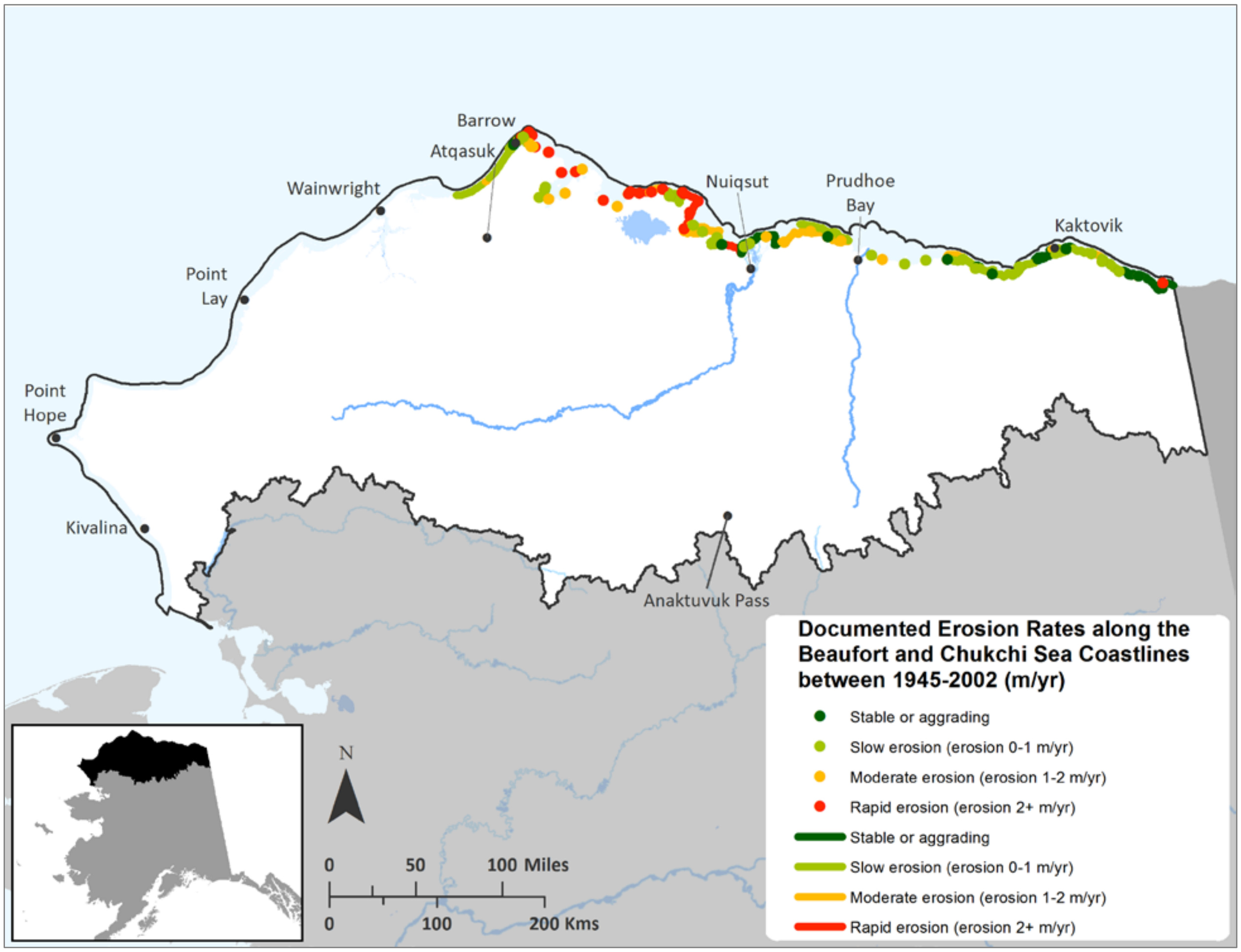

Figure G-53. A compilation of coastal erosion rates documented for the Chukchi and Beaufort Sea coastlines.

As part of the literature review conducted for this management question, 211 records from nine different studies with documented rates of coastal erosion were compiled for the Chukchi and Beaufort Sea coasts. This representation of variable coastal aggradation and erosion clearly shows that the most significant losses are occurring along the north and northeast facing shorelines of the Beaufort Sea Coast (Figure G-53). Likely due to the location of greatest coastal habitat loss and oil and gas development, research on erosion is concentrated along the Beaufort Sea Coast. Rates of habitat gain and loss were categorized in accordance with the Arctic Coastal Dynamics Database (Lantuit et al. 2012) as stable or aggrading, and slow, moderate and rapid erosion. Where coordinates were not available, points and segments were hand-digitized. For multiple, spatially-coincident rates of erosion, the most recent rate is displayed and for this reason may not represent the highest rate of erosion documented for that location.

To compound these net sediment losses, mean annual rates of erosion are shown to be increasing by numerous studies (Arp et al. 2010, Jones et al. 2008, Jones et al. 2009, Ping et al. 2011). Along the Beaufort Sea Coast, average erosion rates (including deltas) have increased from 0.6 m/y for the period from circa 1950 to 1980 to 1.2 m/y for the period from circa 1980 to 2000 (Ping et al. 2011). Along the

Teshekpuk Lake Special Area coastline, which is a low-lying section of ice-rich glaciomarine deposits know for extreme erosion, rates have accelerated from 6 m/y during the period from 1955 to 1979 to 17 m/y during the period from 2007 to 2009 (Arp et al. 2010). In addition to the direct loss of habitat along these sections, the translocation of sediment and freshwater to the marine environment releases large quantities of organic carbon, which may affect biogeochemical processes in the nearshore zones of the Arctic Ocean (Dunton et al. 2006, Hinzman et al. 2005, Ping et al. 2011).

Thermokarst and Thermal Erosion

Mechanical erosion along arctic coastlines is exacerbated by thermal degradation of interstitial and massive ice. Along low-relief, protected coastlines, the thawing of ice-rich polygon centers and/or melting of massive ice wedges causes subsidence of the tundra surface. The subsequent ingress of seawater creates a drowned landscape that is not significantly eroded where wave energy is low. However, unprecedented rates of erosion are shown where these fine-grained, saturated soils are exposed to high-energy waves. Along the unprotected coastline of the Teshekpuk Special Use Area, ground ice content exceeds 80% and a mosaic of thermokarst lakes and drained lake basins occupy 84% of the landscape (Jones and Arp 2015, Hinkel et al. 2005). Here, lake margins may be compromised by tapping (by adjacent streams, lakes or ocean), breaching (by high lake levels), headward gully erosion or thaw slump formation (Jones and Arp 2015). Lake drainage may occur catastrophically. In 2014, an 80 ha lake was drained in 72 hours by the apparent formation of a thermo-erosional gully along an ice-wedge network (Jones and Arp 2015). The unfrozen, saturated sediments of low-lying drained lake basins are rapidly eroded at rates of 12.5–13.5 m/y (Jones et al. 2009) and progressively flooded by saltwater. The majority of coastal habitat loss north of Teshekpuk Lake from 1985 to 2005 resulted from the degradation of permafrost affected by saltwater flooding of nearshore basins and channels (Mars and Houseknecht 2007). It is likely that Prudhoe and Pogik Bays were formed in this manner (Arp et al. 2010, Hopkins and Hartz 1978) and that Teshekpuk Lake awaits a similar fate (Mars and Houseknecht 2007).

Figure G-54. Subsiding tundra showing inland flooding of low-center polygons and block failure of polygonal tundra along the Beaufort Sea coastline (Shorezone)

Thermo-erosional niching occurs when a storm surge contacts the base of a bluff and through thermal abrasion, erodes a horizontal niche (Ravens et al. 2012). Niches grow both horizontally and laterally resulting in undercutting of up to 8 m, which eventually undermines the bluff (Hopkins and Hartz 1978). In its most spectacular form, thermo-erosional niching promoted by the degradation of massive ice along polygon wedges in backshore sediment can cause massive failures (Ravens et al. 2012). Here, house-sized blocks of tundra collapse to the beach where they are gradually eroded by wave action (Hopkins and Hartz 1978, Hoque and Pollard 2008).

Retrogressive thaw slumping involves the backwasting of tundra by the thermal denudation of massive ice or frozen ground resulting in bowl-shaped collapse features tens of meters wide. Slumping at this scale is often initiated by the exposure of frozen sediment or massive ice at the base of coastal bluffs by wave action. The deep seasonal thaw or ablation of this interstitial or massive ice over steepens the bluffs to the point of failure. The resulting thaw slump is typically backed by a near-vertical headwall and fronted by a fluid mudflow that expands to lobes at the toe of slump (Lantuit and Pollard 2008). Well-documented thaw slumps on Herschel Island, located offshore of the Yukon Territory show rates of headwall retreat approaching 10 m/y as well as an island-wide increase in the number, activity and total area of retrogressive thaw slumps between 1952 and 2000 (Lantuit and Pollard 2008).

Succession Following Salinization

The intact, ice-rich permafrost that underlies the thermokarst lakes and polygonal tundra of the Arctic Coastal Plain becomes a liability to the landforms it supports in a warming climate. Because much of the nearshore environment is less than one meter above sea level, higher storm surges across an already subsiding terrain are expected to extend the reach of saltwater flooding and through increased thermal conductivity of saturated soils, further promote thaw subsidence (Jorgenson et al. 2006, Tape et al. 2013). It is estimated that along coastlines experiencing extreme thaw subsidence and erosion, such as that fronting the Teshekpuk Lake Special Area, salt-killed tundra occupies 6% (71 km^2) of the landscape, while 41% (477 km^2) is susceptible to salinization from storm surge flooding (Arp et al. 2010, Jones et al. 2008).

Figure G-55. Drained lake, salt-killed tundra and block failure along the Teshekpuk Lake Special Area, Beaufort Sea coastline (Shorezone).

The introduction of sediment and salts to coastal habitats may weaken or kill resident species through necrosis (Bergman et al. 1977, Jorgenson et al. 1994, Kincheloe and Stehn 1991, Taylor 1981). Yet it is likely that multiple saltwater flooding events are required to shift community composition to salt-tolerant plant species (Tape et al. 2013). Salt-killed tundra is typically colonized by ruderal salt-tolerant graminoids *Puccinellia phryganodes*, *P. andersonii*, *Carex subspathacea*, and *C. glareosa*, the forb *Stellaria humifusa* and the dwarf willow, *Salix ovalifolia* (Jorgenson et al. 1997, Flint et al. 2008).

The conversion of freshwater aquatic habitat to brackish lakes and estuaries has not been the subject of extensive study. Salinity has been shown to be elevated in many nearshore lakes, likely due to the introduction of salts during storm surges. The evaporation of freshwater during the open water season increases salt concentrations in lake systems that are not flushed by freshwater inflow (NSSI 2014). While not documented, the conversion of freshwater lakes to saline waterbodies in the Arctic is likely to alter benthic food webs and energy resources (Arp et al. 2010).

The scale of habitat conversion to saline types is indicated by the notable shift of molting Black Brant (*Branta bernicla nigricans*) from inland freshwater lakes to coastal marshes over the last 30 years. This change in distribution is correlated to expansion of preferred forage (*Puccinellia phryganodes* and *Carex subspathacea*) on saltwater-deposited sediment (Jorgenson and Heiner 2003, Tape et al. 2013). Pure lawns of *Carex subspathacea* maintained by goose grazing also exist (Person et al. 1998). Where grubbing is concentrated, these tidal flats and marshes may be impacted to the extent that they are converted to hypersaline barrens (Gauthier et al. 2006, Jefferies 1977, Jefferies and Rockwell 2002, Tape et al. 2013).

The extent of the landscape that is susceptible to storm surge flooding is not well-known outside of the Teshekpuk Lake Special Area and the variable resilience of the terrestrial and aquatic habitats to salinization is indicated but not formally described (Arp et al. 2010). In the context of unprecedented rates of coastal erosion and extents of saltwater flooding, these uncertain consequences to terrestrial and aquatic systems merit further study (NSSI 2014).

11.4. Limitations

We explored contrasting an older coastline map with a new coastline map to empirically determine what habitats had been lost or gained due to coastal erosion. However, the old coastline map was inaccurate and generating a new coastline is beyond the scope of this assessment. A storm surge model would be needed to evaluate the effects of coastal inundation.

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12. Impacts of Oil and Gas Development on Vegetation

MQ TC 1	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.)

12.1. Introduction

Assessing the impact of oil and gas impacts of oil and gas development on vegetation and hydrology on the North Slope study area involves identifying the accumulation of effects and assessing the relative magnitude of each. Impacts on vegetation include the direct effects associated with the construction of pipelines, roads, gravel pads, and seismic exploration, and also the potential indirect effects of these activities have on the underlying permafrost and active layer primarily. Hydrologic impacts include changes to drainage patterns associated with road construction, alteration of floodplains (gravel mining), and water extraction from lakes and rivers for construction of ice roads. Additional impacts include contamination of terrestrial and aquatic habitats from accidental spills of oil, diesel fuel, and saltwater.

12.2. Methods

To assess the impact of the existing oil and gas footprint, we developed a Landscape Condition Model (LCM) specific to oil and gas infrastructure and associated transportation corridors. The LCM is a simple yet robust way to measure the impact of the human footprint on a landscape (Comer and Hak 2009). The LCM weights the relative influence of different types of footprints based on factors such as permanence and the nature of the activity. Permanent modification is weighted the highest, while temporary uses, like ice roads and winter trails, received less weight. These weights were summed across the landscape and coalesced into a single surface identifying how impacted a given area is due to oil and gas activity (see Section F. Landscape and Ecological Integrity). The process model we used to evaluate the spatial datasets is illustrated in Figure G-56. Datasets, impact scores, and decay distance used to develop the LCM are listed in Table G-14. Impacts for which we did not have spatial datasets, such as changes to drainage patterns and historic seismic exploration, and are examined through literature review.

Table G-14. List of datasets and parameters used to develop the Landscape Condition Model for oil and gas.

Theme	Data Source	Description	Site Impact Score	Est. Relative Stress	Decay Distance (m)
Roads associated with oil and gas	AK DOT, refined using aerial imagery (BDL-GINA)	Local roads within villages	0.2	High	500
Haul Road	AK DOT	Dalton Highway	0.05	Very High	5000
High Density Development	Digitized using aerial imagery (BDL-GINA)	Oil facilities	0.05	High	2000
Ice Roads and Catco Rolligon Trails	ISER, BLM, AOGCC, refined using aerial imagery (BDL-GINA)	Temporary or seasonal transportation corridors	0.7	Medium	500
Powerline/Transmission lines	AK DNR	Current industrial lines	0.5	Medium	500
Oil /gas Wells	Audubon Alaska	Current oil and gas wells	0.5	Medium	500

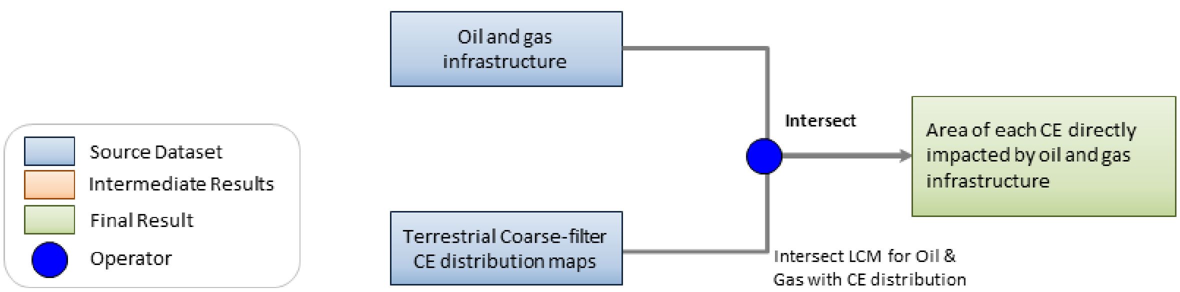

Figure G-56. Process model for MQ TC 1.

12.3. Results

Disturbance associated with oil and gas exploration and extraction affects vegetation and permafrost characteristics differentially across the landscape. Impacts to vegetation include the conversion of habitat to hardened infrastructure and habitat disturbance related to exploration and tundra travel. Infrastructure construction results in the direct loss of habitat, while the impacts of tundra travel and exploration vary in severity across the landscape. The Landscape Condition Model for oil and gas quantifies both the extent of the affected area and the level of disturbance by combining the footprint with the impact score and decay distance for each type of development activity (Figure G-57).

Current infrastructure and exploration is largely concentrated in the coastal plain, and this is reflected in the area impacted within the coastal plain wetland and moist tundra CEs. In coastal plain wetlands, 343 km^2 were scored as *low* or *very low* condition, and in coastal plain moist tundra, 280 km^2 were similarly classified as impacted (Figure G-58). In contrast, the sand sheet portion of the coastal plain was relatively unimpacted by oil and gas activities with most of the disturbance originating from winter travel corridors. The entire distributions of the sand sheet wetland and moist tundra CEs were scored as *high* or *very high* condition (Figure G-59).

Table G-15. Landscape condition displayed as percent total CE area and sq. km for North Slope Terrestrial Coarse-Filter CEs.

Terrestrial Coarse-Filter Conservation Element		Current Oil and Gas Footprint Landscape Condition (% and area in km^2 by CE)				
		Very Low	Low	Medium	High	Very High
Tidal Marsh	%	0.4	1.3	1.6	3.6	93.0
	km^2	1.6	4.5	5.8	12.8	325.2
Barrier Islands, Beaches, & Spits	%	1.2	1.4	1.6	2.3	93.5
	km^2	1.6	2.0	2.2	3.2	131.4
Coastal Plain Moist Tundra	%	0.4	1.1	1.1	2.2	95.1
	km^2	77.6	202.4	213.6	421.8	17918.8
Coastal Plain Wetland	%	0.5	1.4	1.6	3.7	92.7
	km^2	93.2	249.6	278.9	639.4	15955.2
Sand Sheet Moist Tundra	%	-	-	-	1.3	98.7
	km^2	-	-	-	84.5	6585.6
Sand Sheet Wetland	%	-	-	-	3.1	96.9
	km^2	-	-	-	117.3	3711.9
Foothills Tussock Tundra	%	0.1	0.3	0.3	0.4	98.8
	km^2	123.9	189.7	219.6	328.7	82247.5
Floodplain Shrubland	%	1.4	2.1	1.7	1.6	93.1
	km^2	70.8	103.8	80.8	78.9	4544.2
Alpine Dwarf Shrub Tundra	%	0.1	0.2	0.2	0.3	99.2
	km^2	51.2	77.7	82.9	92.6	35652.1

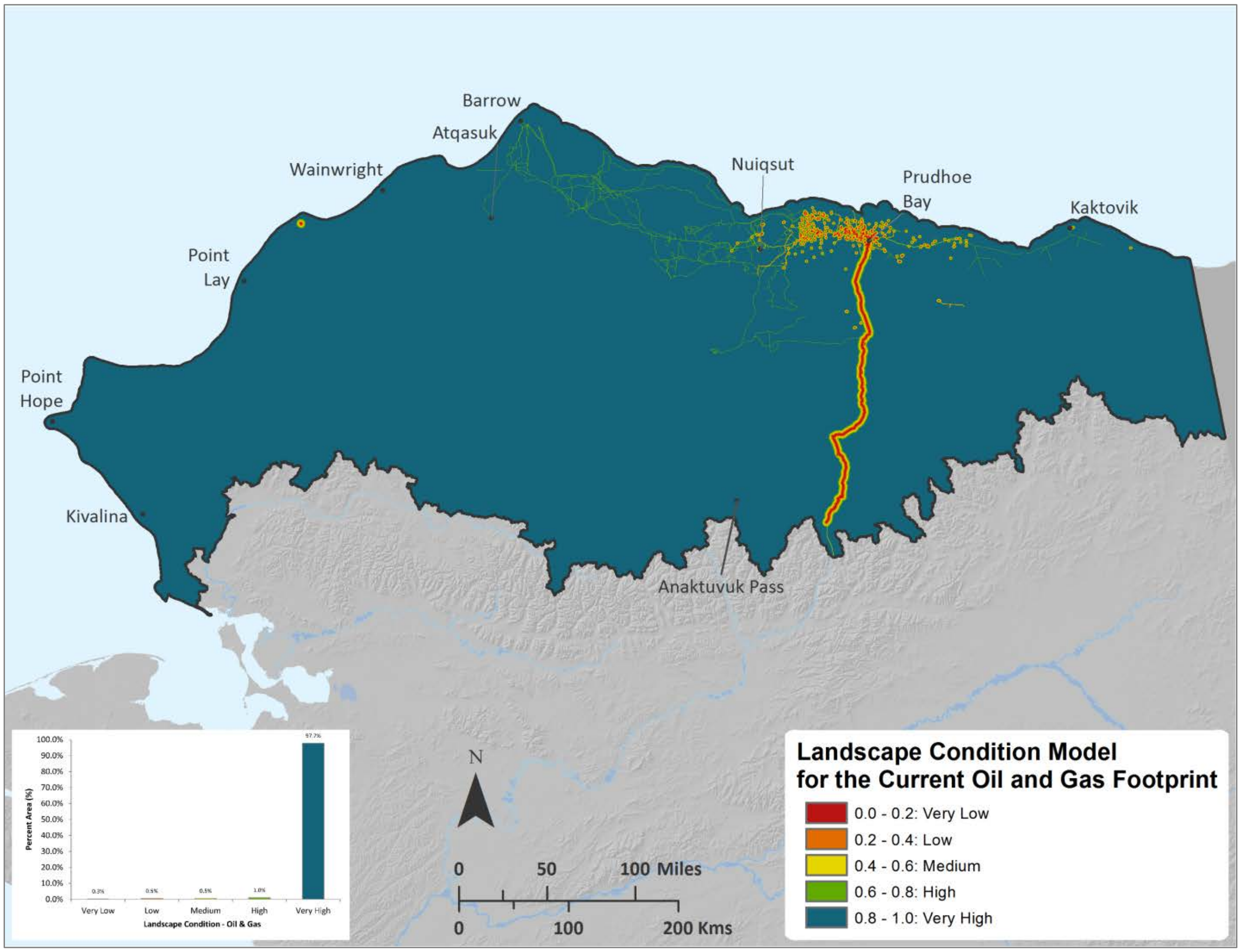

Figure G-57. Landscape condition for the current oil and gas footprint.

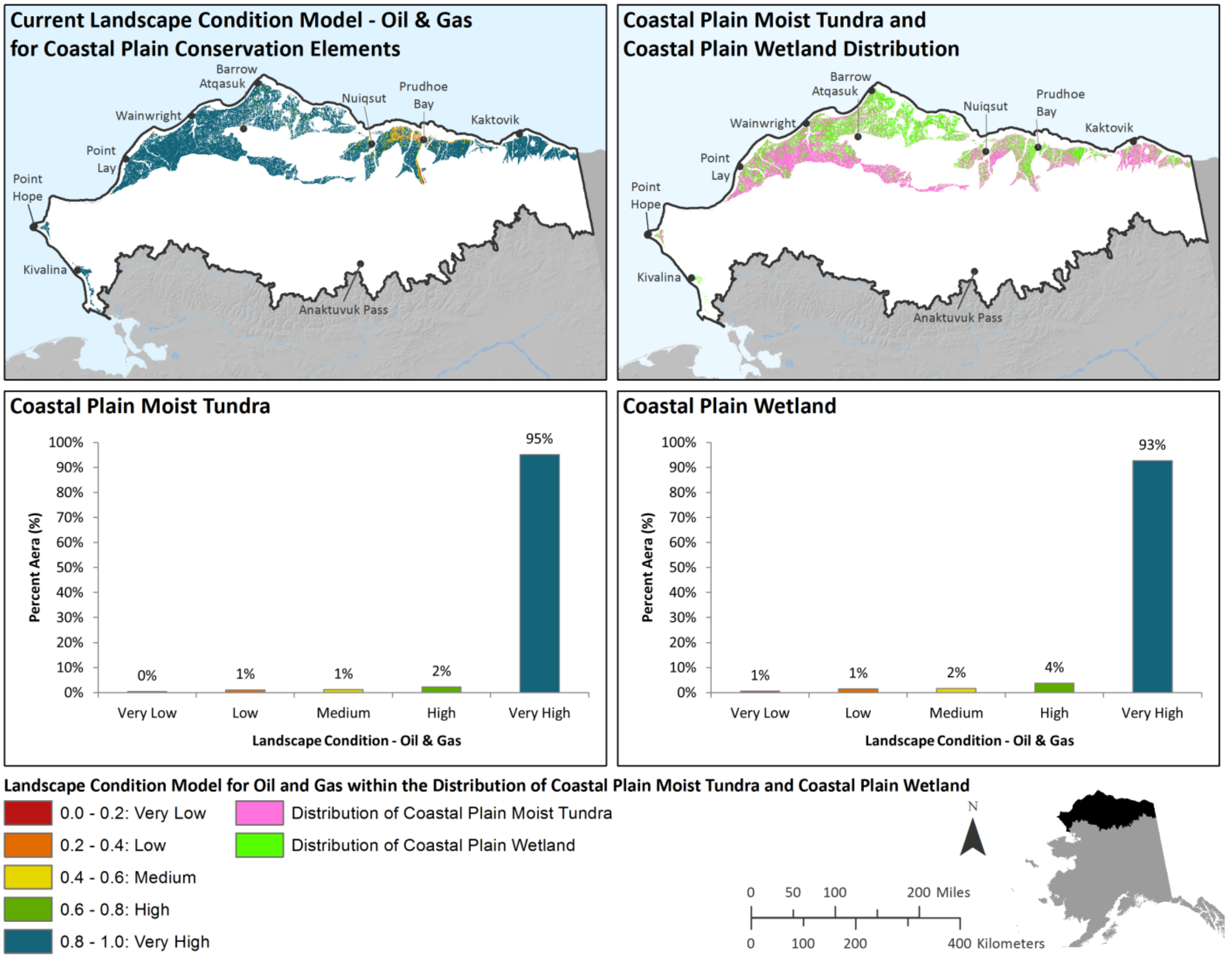

Figure G-58. Landscape condition for the current oil and gas footprint within the distribution of coastal plain wetlands and moist tundra CEs.

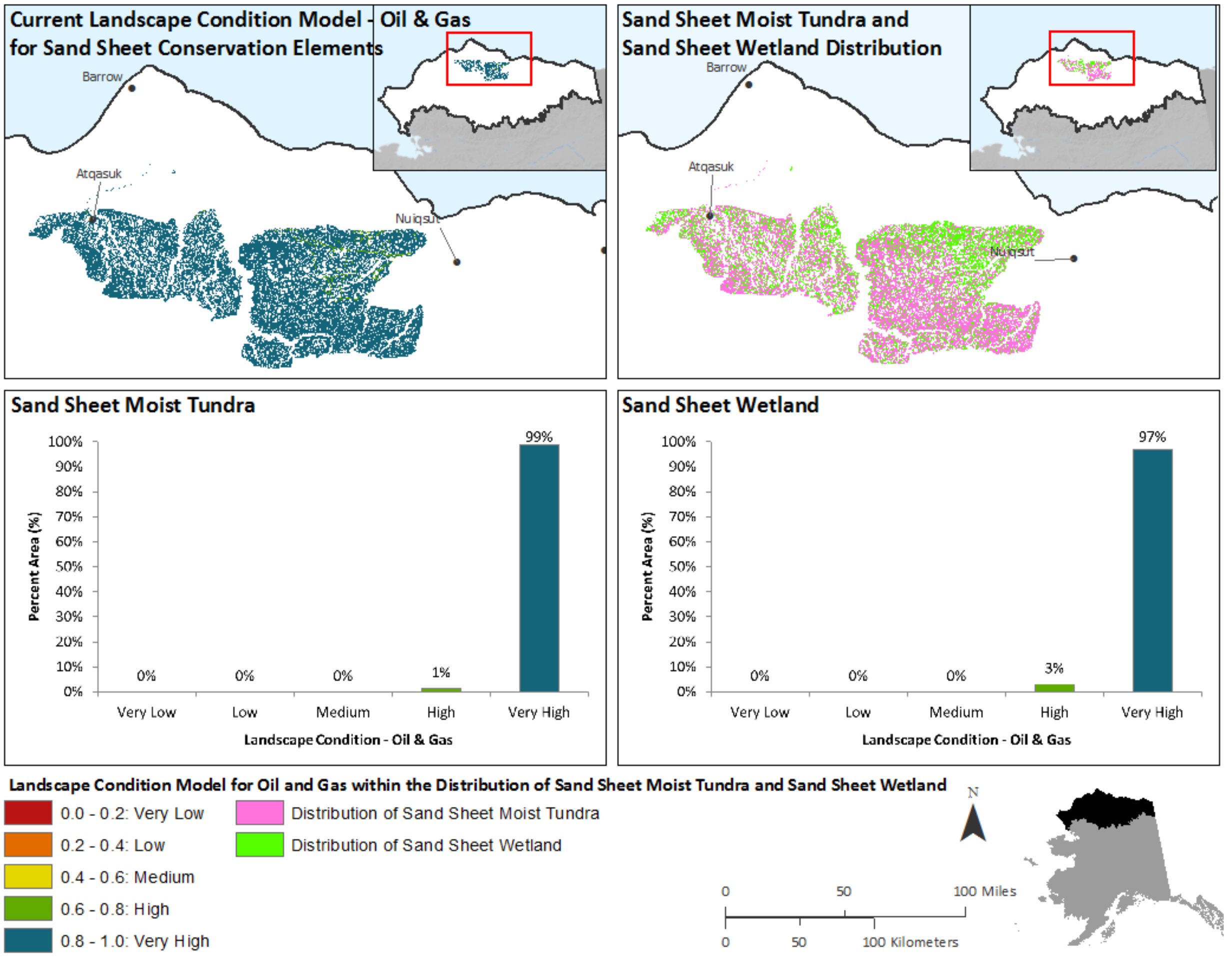

Figure G-59. Landscape condition for the current oil and gas footprint within the distribution of sand sheet wetlands and moist tundra CEs.

Conservation Elements with narrow, linear distributions such as floodplain shrublands, tidal marshes and barrier islands, beaches and spits sustained more impact as a proportion of their distributions than did more widely distributed CEs. Across 3.6% of its distribution, the floodplain shrubland CE scored in the *low* or *very low* condition classes. The proximity of the Dalton Highway to the Sagavanirktok River and Prudhoe Bay oilfield development near the Kuparuk River accounted for most of the impact to this CE (Figure G-60).

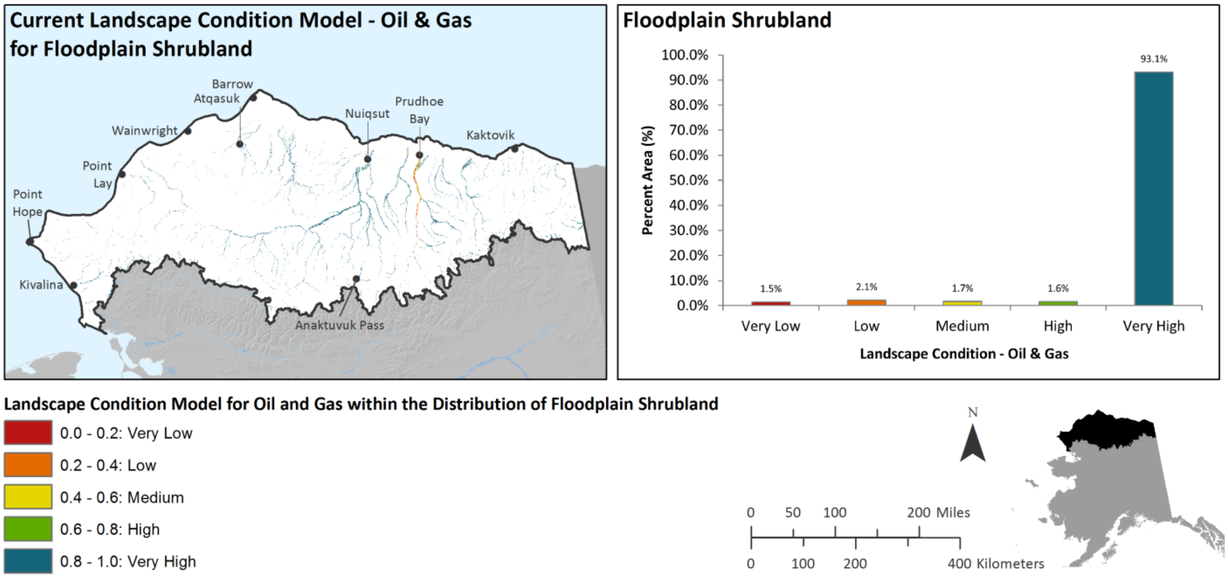

Figure G-60. Landscape condition for the current oil and gas footprint within the distribution of floodplain shrublands.

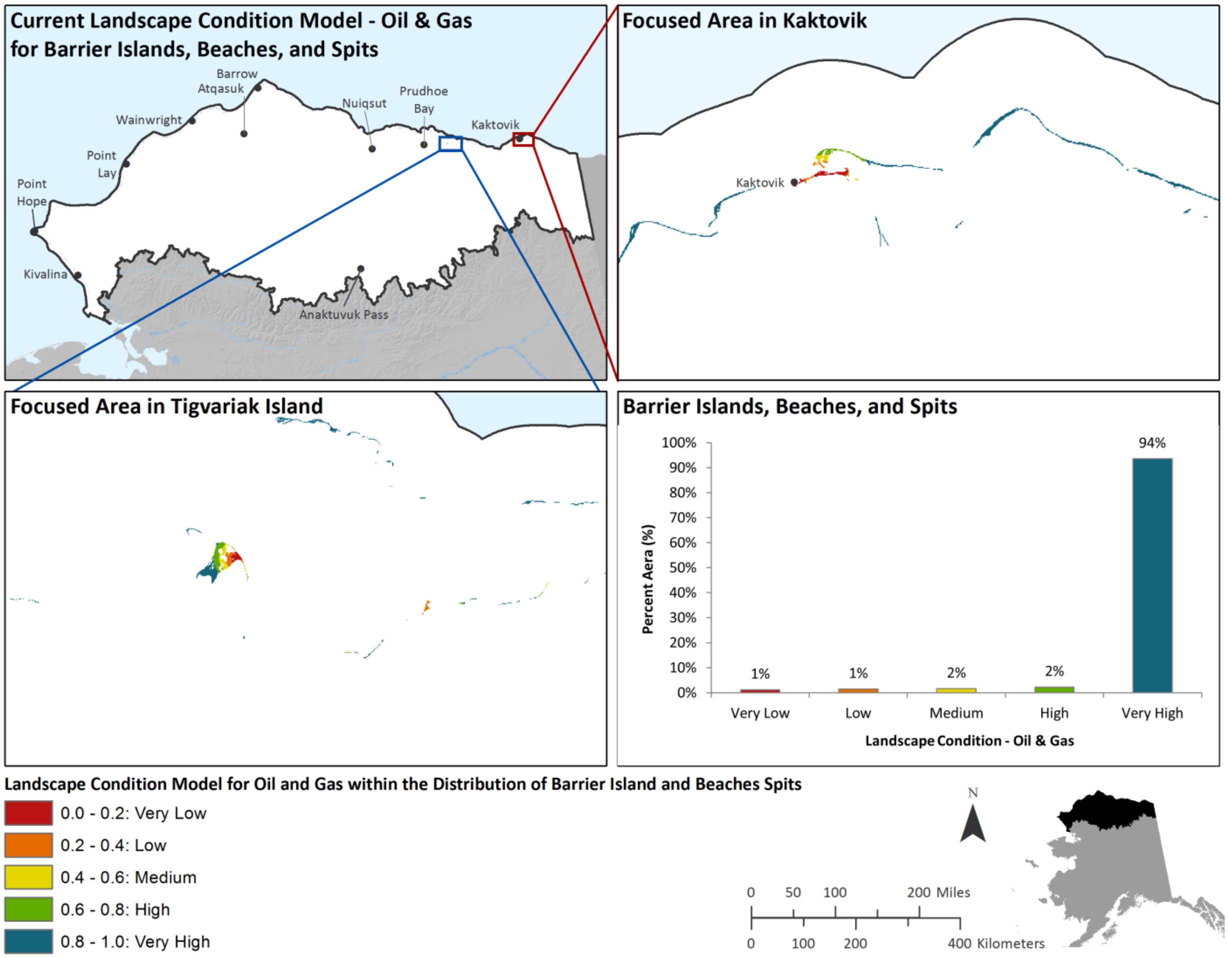

Figure G-61. Landscape condition for the current oil and gas footprint within the distribution of barrier islands, beaches, and spits.

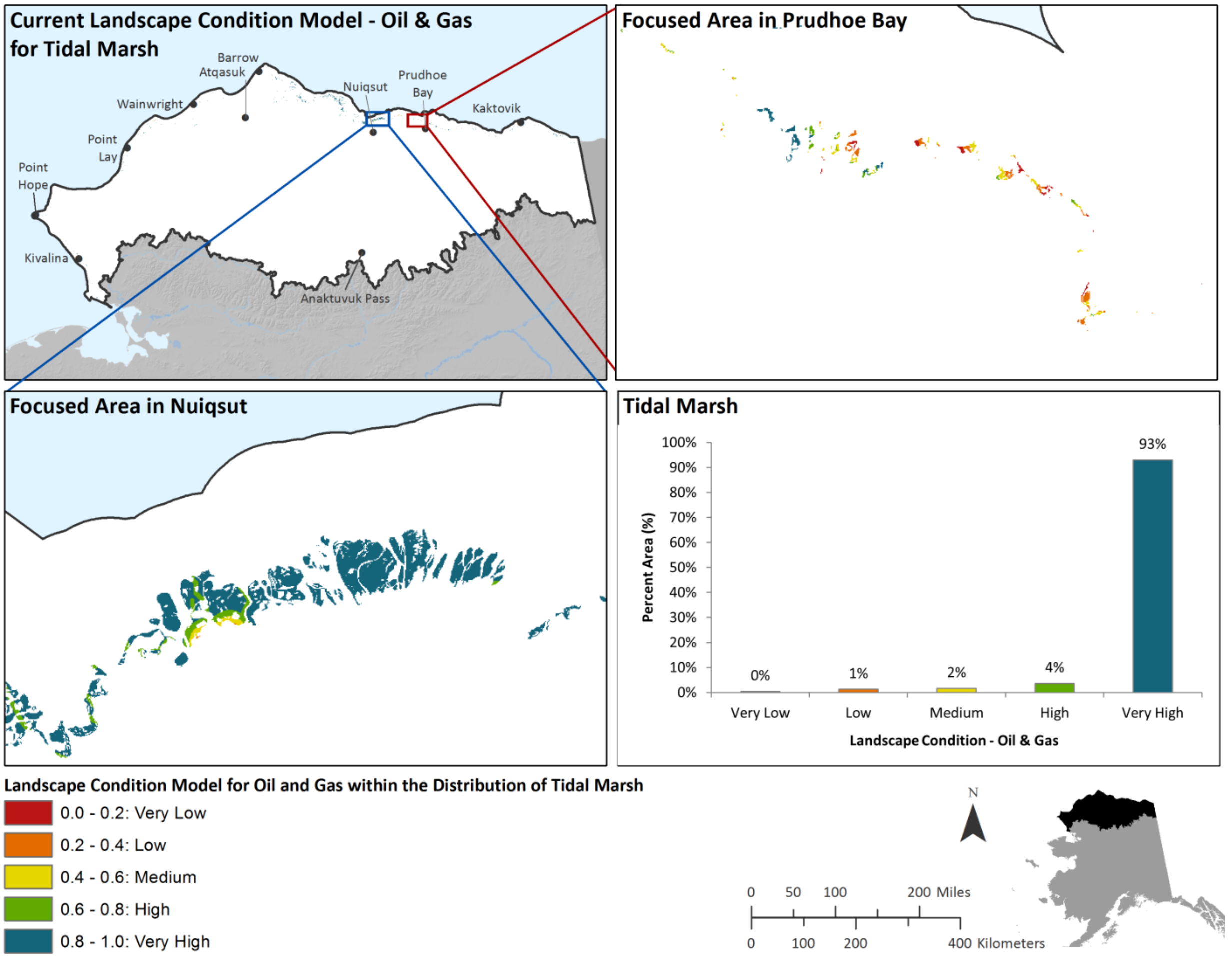

Figure G-62. Landscape condition for the current oil and gas footprint within the distribution of tidal marshes.

Across 1.7% of its distribution, the tidal marsh CE scored in the *low* or *very low* condition classes, and additional 1.6% scored in the *medium* condition class (Figure G-62). Oilfield development near the Sagavanirktok, Kuparuk, and Colville River deltas accounted for most of the impact to this CE.

Across 2.6% of its distribution, the barrier islands, beaches, and spits CE scored in the *low* or *very low* condition classes, and additional 1.6% scored in the *medium* condition class. Nearshore oil fields are the most likely source of impact to this CE, particularly the barrier islands component.

A very low proportion of the foothills and alpine regions of the North Slope study area is currently impacted by oil and gas infrastructure (Figure G-63 and Figure G-64). The Dalton Highway accounts for most of the impact to these two CEs.

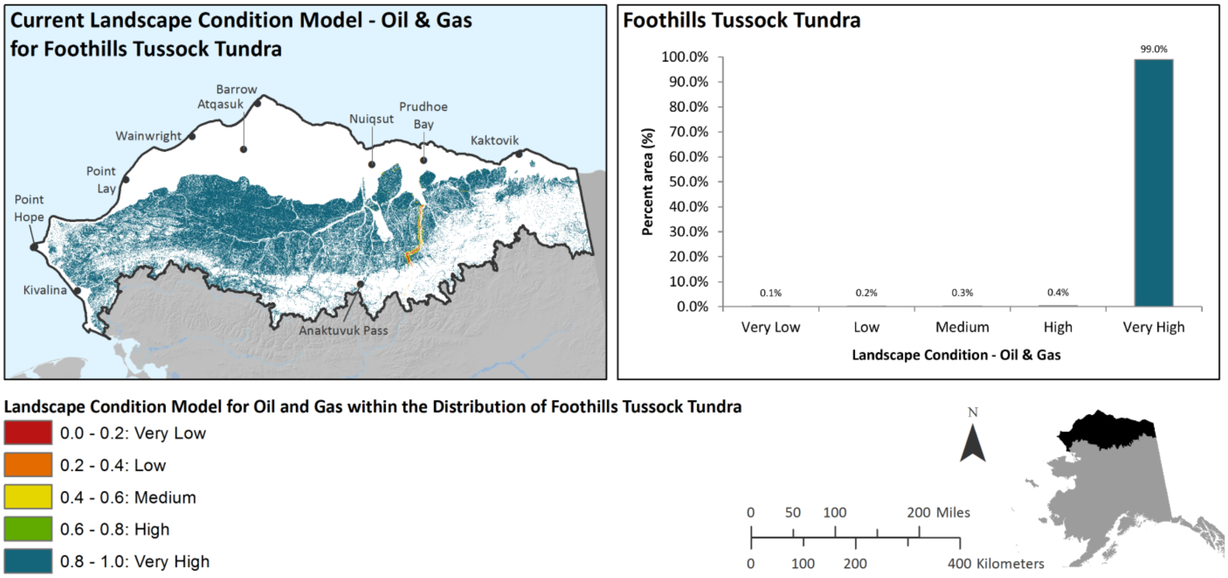

Figure G-63. Landscape condition for the current oil and gas footprint within the distribution of foothills tussock tundra.

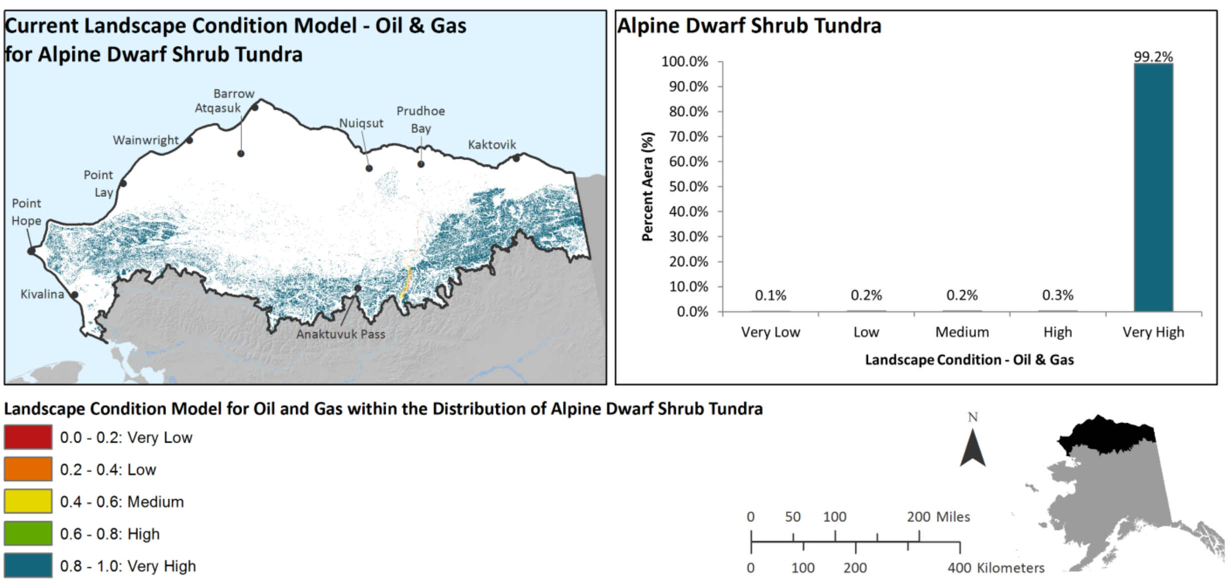

Figure G-64. Landscape condition for the current oil and gas footprint within the distribution of alpine dwarf shrub.

Exploration and Winter Tundra Travel

Oil and gas production industries require off road travel across the tundra in winter for: (1) seismic exploration activity; (2) ice road construction for exploratory drilling; and (3) routine maintenance of infrastructure such as pipelines. Modern exploration techniques and equipment coupled with limitations on the timing of tundra travel have mitigated the most severe impacts on vegetation, active layer, and permafrost characteristics; however, evidence of past practices, such as travel on unfrozen ground or removal of vegetation during seismic testing, remains visible on the landscape today. Current practices specify minimum snow depths and ground hardness before tundra travel is allowed, but impacts to the vegetation and underlying permafrost can still occur. The footprint created by seismic exploration over the past decades covers a larger geographic area than all other direct human impacts combined (NRC 2003). We did not include the historic seismic exploration lines in the current oil and gas footprint, instead we presented a literature review with reference to impacts to the Terrestrial Coarse-Filter CEs.

Several studies of the effects of vehicular travel over frozen tundra have identified critical factors linked to the amount of damage to tundra vegetation. These include vegetation type, terrain, snow cover, ground hardness, total weight and number of passes per each vehicle, and ground pressure of the tire or track (Felix and Raynolds 1989, Emers and Jorgenson 1997, Bader and Guimond 2004, Guyer and Keating 2005, Jorgenson et al. 2010).

Jorgenson et al. (2010) evaluated disturbance after seismic exploration and recovery time of vegetation types across the Arctic National Wildlife Refuge (ANWR). Results differed across the landscape and were generalized by vegetation type. The six types described by Jorgenson et al. (2010) can be cross-walked to habitats that were identified as North Slope Terrestrial Coarse-Filter CEs (Table G-16).

Table G-16. Vegetation types (Jorgenson et al. 2010) cross-walked to North Slope Terrestrial Coarse-Filter CEs.

Vegetation Type (Jorgenson et al. 2010)	Equivalent North Slope CE (or AIM class)
Wet Sedge Tundra	Coastal Plain Wetland
	Sand Sheet Wetland
	Foothills Wetland (AIM class, not CE)*
Sedge-Willow Tundra	Coastal Plain Moist Tundra
	Sand Sheet Moist Tundra
Sedge-Dryas Tundra	Coastal Plain Moist Tundra
	Sand Sheet Moist Tundra
Tussock Tundra	Foothills Tussock Tundra
Shrub Tundra	Foothills Low Shrub Tundra (AIM class, not CE)*
Riparian Shrubland	Floodplain Shrubland

*Classes that were mapped but not selected as CEs are also included in the above table to provide additional information. These classes are as part of the landscape stratification used for the Assessment, Inventory, and Monitoring (AIM) Program in NPR-A.

Impacts to vegetation included mechanical damage and reduced canopy cover in the first years after disturbance and permafrost subsidence in subsequent years. The most severely impacted plant species were evergreen dwarf shrubs, willows, tussocks, and lichens. Permafrost subsidence occurred on sites with more severe disturbance and high ground ice content resulting in saturated troughs in which wetland sedges such as *Eriophorum angustifolium* and *Carex aquatilis* proliferated (Jorgenson et al. 2010).

The most resilient vegetation type was Wet Sedge Tundra. This type generally incurred the least damage and recovered more rapidly than other types. Wetland vegetation is typically water-saturated and, when frozen and snow-covered, vehicular traffic causes little compression of the soil or disturbance to the surface. In contrast, moist vegetation types, such as Sedge-Willow Tundra, Sedge Dryas Tundra, and Tussock Tundra, incurred more initial damage to vegetation and were also more susceptible to long-term damage related to permafrost subsidence. Moist tundra and tussock tundra vegetation types are more prone to damage from compaction than wetlands because the soils are not saturated at freeze-up. Furthermore, the vegetation canopy in these types is composed of tussocks and woody vegetation that is more easily damaged than wetland sedges. Evergreen dwarf shrubs and several species of feather moss showed poor recovery even 24 years after disturbance. Where permafrost subsidence led to shifts in hydrology and vegetation composition, trails remained disturbed after 25 years. The authors concluded that these severely disturbed sites may not revert to the initial vegetation and permafrost condition. In a study of winter travel over tundra on state-owned land on the North Slope, Bader and Guimond (2004) observed similar trends. Disturbance was greater in tussock tundra than in wet/moist sedge tundra.

Ice roads and snowpads have been used to support exploratory drilling and to provide access for maintenance and construction of infrastructure. The construction of ice roads begins with the compaction of the snow layer and subsequent application of water to create a smooth roadbed (Adam 1974, Adam and Hernandez 1977, Johnson and Collins 1980). Compaction of the snow layer removes insulation, changes the thermal properties of the vegetation-snow contact, and facilitates frost penetration into the ground.

Snow cover provides a physical buffer to disturbance and also provides insulation to the vegetation. When undisturbed, the snow layer at the base of the snowpack is highly porous and maintains a warmer microclimate than that of the surface (Pomeroy and Brun 2001). Most of the effects of ice roads are related to direct mechanical disturbance to the vegetation, debris from the road, and destruction of the porous subnivean layer. Three years after construction, observed impacts along the ice road between the Kikiakrorak River and the NPR-A drill site at Inigok included compression and breakage of tussocks and shrubs and damage to the moss and lichen communities between tussocks which appeared to be particularly sensitive to compaction (Walker et al. 1987). Similar results were observed under snowpads used in the construction of the Trans-Alaska Pipeline. Vascular plants recovered after three years, but canopy cover of moss and lichen was reduced compared to the control areas (Johnson 1981). Guyer and Keating (2005) evaluated the Kikiakrorak to Inigok ice road 24 years after initial construction and found that vegetation and active layer depths had recovered completely. They contrasted this with recently-used ice roads (2-3 years after use) where they observed damage to shrubs, forbs, and tussocks, with greater impact on drier sites than wetland sites. They concluded that the damage to tundra from ice roads was short-lived, and complete recovery of vegetation and permafrost is possible after 24 years.

Permafrost Subsidence and Thermokarst

Changes to the active layer and permafrost subsidence can have significant and lasting impacts on vegetation and surface water. Ice-rich permafrost has an ice volume that exceeds the total pore space of the soil. Ground ice in the form of ice wedges and ice lenses can account for 10-45% of the soil volume in these ice-rich sites (Walker et al. 1987, Williams and Smith 1989, Davis 2001). Thawing of excess ice leads to subsidence of the soil surface (Jorgenson et al. 2010). The amount of subsidence is a function of the type of ice and ice content of the permafrost, initial active layer thickness, and severity of disturbance. Thaw settlement after disturbance can have lasting impacts on vegetation and hydrology. High ice-content soils are generally composed of fine-textured deposits (loess or glaciomarine deposits), while porous, well-drained sands and gravels tend to have low ice content (Jorgenson et al. 2008; Jorgenson and Grunblatt 2013). Soils with ice-rich permafrost are susceptible to greater thaw settlement than soils that have lower ice content.

Terrestrial CEs can be characterized according to ice content and permafrost features, allowing for assumptions to be made about the potential risk of thermokarst and subsidence after disturbance (Table G-17). CEs with ice-rich permafrost include: coastal plain moist tundra, coastal plain wetland, and the lower portion of foothills tussock tundra (underlain by deep loess deposits). CEs with ice-poor permafrost include: sand sheet moist tundra and floodplain shrublands.

Table G-17. Ground ice content and permafrost features of North Slope Terrestrial Conservation Elements.

Conservation Element		Ground Ice Content	Permafrost Features and Thermokarst
Coastal Plain Wetland		High	Low-centered polygonal tundra; thaw lake basins
Coastal Plain Moist Tundra		High	High-centered and flat-topped polygonal tundra; pits and troughs
Sand Sheet Wetland		May be high where fine sediments have filled in basins	Low-centered polygonal tundra, non-patterned
Sand Sheet Moist Tundra		Low	Non-pattered or polygonal tundra; pits and troughs
Foothills Tussock Tundra	lower foothills	High (deep loess deposits)	Deep thaw lakes, thaw slumps
	mid-upper foothills	Moderate	Non-pattered or polygonal tundra; Thaw slumps, gullies, water tracks
Floodplain Shrubland		Low	Permafrost generally deeper than 120 cm. soils are porous sands and gravels
Alpine Dwarf Shrub Tundra		Low to variable	Bedrock near surface
Tidal Marsh		High on coastal plain tidal marshes; low in estuarine river deltas	Subsiding polygonal tundra common in Coastal Plain tidal marshes. Estuarine marshes have variable permafrost.

Conservation Element	Ground Ice Content	Permafrost Features and Thermokarst
Barrier islands Beaches and Spits	Barrier islands that are remnants of the old coastline may have high to moderate ice content. Spits and beaches composed of sand and gravel have low ice content	Polygonal features on remnant coastline islands

Source: Alaska Permafrost Map (Jorgenson 2008)

Thermokarst in ice-rich regions of the coastal plain can lead to a dramatic shift in vegetation composition. In the polygonal tundra that characterizes the coastal plain moist tundra CE, thawing can proceed rapidly where water begins to pool on the surface above an ice wedge, converting tundra composed of tussocks and dwarf shrubs to open water or wetland sedge vegetation. Ice-rich portions of the foothills are also prone to thermokarst. In the gently sloping terrain of the region, thermokarst failures, or retrogressive thaw slumps, involve mass movement of the active layer resulting in exposed mineral soil, followed by subsidence and water erosion (Swanson 2012). After initial failure, thermokarst slumps can continue to expand until active layer conditions stabilize. To date, oil and gas development has been concentrated in the coastal plain and not the foothills, and thus thermokarst associated with coastal plain ice wedges and thaw lakes has been the dominant process affecting oil and gas activities. (See the CE descriptions for coastal plain moist tundra, coastal plain wetlands and foothills tussock tundra for a more detailed description of the effect thermokarst on vegetation in these CEs.)

Long-Term Infrastructure Development

Roads and pads can cause the underlying permafrost to melt if the gravel under the roadbed is not sufficiently thick (NRC 2003). Road berms up to 2 m thick are required to prevent thaw. The continuous berms alter natural drainage networks and create water impoundments which absorb solar radiation and lead to a deepening of the active layer causing thermokarst in ice-rich permafrost (Walker 1996).

Heavy vehicular travel on gravel roads can lead to dust accumulation on the adjacent tundra. Everett (1980) measured dust fall during the summer at several locations along the Dalton Highway and recorded dust loads of over 5 kg/m^2 at 8 m from the road bed on the downwind side of the highway. Dust loads were higher in the high density road area around Deadhorse. The alkalinity of the road dust was sufficient to neutralize acidic tundra in some areas and the upper few centimeters of soil had shifted from acidic to alkaline (Everett 1980).

Gravel pads create impacts similar to those created by roads, but the activities related to resource extraction on the pads may create additional adverse impacts. Oil spills, sea water spills, and contaminants are some of the impacts that can occur on and around drilling pads.

Spills

Spills associated with oil and gas exploration, extraction and transportation on the North Slope have involved crude oil, diesel and other refined petroleum products, drilling fluid, and salt water. Bureau of Ocean Energy Management (BOEM) contracted with Nuka Research and Planning Group to compile records for oil spills from the North Slope oil and gas infrastructure including near shore and on-shore spills involving crude or refined oil. The result was a database of 1,577 spills larger than one barrel that occurred between 1970 and 2011, excluding spills from the Trans-Alaska Pipeline (Robertson et al. 2013). The dataset included number and volume of spills, cause, and type of petroleum substance spilled. They reported 32,600 barrels of oil spilled during the 40-year period. Most of the spills were between 1 – 10 barrels, 10 spills were greater than 500 barrels, and two spills were larger than 1,000 barrels. Human error and loss-of-integrity of some portion of the infrastructure were cited as the most common spill causes (Robertson et al. 2010, Robertson et al. 2013).

Crude oil spills are easier to clean up during winter months than during summer when the ground is thawed. In winter, frozen ground and snow cover allow for vehicular access, and prevent oil from contaminating ponds and soil. Winter cleanup typically involves removal of the snow and scraping residual soil off the tundra surface (NRC 2003). Summer cleanup typically involves booming and floating the oil in order to skim it off the surface (NRC 2003, Conn et al. 2001). Where oil has contaminated the soil surface, the tundra is scraped, leaving rooting potions of the plants intact, so that vegetation can resprout the next season. This type of remediation can affect the underlying permafrost and active layer. Sites on ice-rich permafrost are prone to thermokarst, and removal or compression of the vegetation can initiate thaw and subsidence. After removal of the most highly contaminated soils, bioremediation techniques, such as adding nutrients, are sometimes to accelerate the action of naturally occurring soil microorganisms (NRC 2003).

The cleanup of saltwater spills on tundra can be particularly problematic. In summer, spilled saltwater is absorbed in to the soil and mixes with surface water, creating long-term salinization of the site. In winter, saltwater can spread under snow and ice. Clean-up activities include flooding with fresh water and removing large quantities of waste water. Remaining salt levels are not effectively reduced through bioremediation (Conn et al. 2001). Storm surge inundation provides a natural example for the impact human-caused saltwater spills may have on tundra (Simmons et al. 1983). Several authors, including Walker et al. (1987) and Jorgenson and Joyce (1994) have reported on the impacts of storm surge on inland vegetation. Inundation killed salt-intolerant vegetation and drier areas dominated by *Dryas integrífolia* and prostrate willows were particularly susceptible. Salt-tolerant species such as *Braya pilosa, Salix ovalifolia,* and *Dupontia fisheri* colonized the salt-killed tundra. (See MQ TC 4 for a thorough examination of storm surge inundation and associated impacts to vegetation.)

Invasive Plant Species Introduction

Disturbance associated with oil and gas exploration and development creates potential pathways for the introduction of non-native plants. Exposed surfaces provide an easily colonized habitat and the movement of people and equipment provides vectors for seed importation. Currently, occurrences of non-native plants within the REA study area are primarily restricted to the Dalton Highway, however, warming temperatures and new development will increase the chance of invasion in the future (see Section D. Biotic Change Agents).

Impacts on Hydrology

Oil and gas exploration and development have affected the chemistry, flow patterns, and drainage patterns of fresh water within the oilfields of the North Slope (NRC 2003). Water withdrawals from lakes for the construction of ice roads, gravel mining in rivers, alteration of surface flows associated with road construction, and potential contamination of groundwater sources are some of the impacts of oil and gas activities on hydrology (the impacts of oil and gas activities on lakes and fish habitat are discussed in Section I. Aquatic Coarse-Filter Conservation Elements).

Drainage Patterns

Disruption in drainage patterns can occur when roads or pads are constructed in or across wetlands, drainage ways, or riparian areas. In the spring and early summer, melt-water flows over the surface of expansive wetlands before draining into lakes and streams. Interruptions in sheet flow can lead to specific points of high velocity flow, which can inhibit fish movement and cause erosion (Hershey et al. 1999, NRC 2003). Disruption of sheet flow is most likely to impact the Coastal Plain CEs as this region has extensive wetlands and generally flat topography.

Gravel Mining

Gravel mining from floodplains was commonly practiced during the early period of oilfield development and pipeline construction. Early gravel extractions were typically shallow scrapes within floodplains, which led to numerous instances of habitat modification, including increased channel braiding, loss of wintering areas for certain fish species, spreading of flow, and restriction of fish movements (NRC 2003). Agency concerns about the physical and biological impact to floodplain habitat led to the development of a set of guidelines designed to minimize floodplain damage from gravel extraction (Joyce et al. 1980). In-stream gravel mining restrictions were enacted in the mid-1970s, shifting much of the extraction to designated multi-user deep extraction sites outside of floodplains. However, more recent studies of the impacts of gravel mining have revealed potential habitat enhancement opportunities for fish and waterfowl species on specific sites. The Alaska Department of Fish and Game has proposed gravel pit performance guidelines for both small-scale extractions and large operations with the goal of minimizing negative impacts and providing secondary habitat enhancements during reclamation (McLean 1993).

Groundwater Contamination

As part of the oil extraction process, fluids (or natural gas) are often injected into existing wells to enhance oil recovery. In enhanced recovery operations, pressure does not fracture surrounding permafrost or rock formations. There has not been any documented damage to the subsurface reservoirs as a result of enhanced recovery; however, there have been several instances of drilling fluid leaking to the surface, either through over-pressurization and escape, or a cracked well casing releasing fluids near the surface (NRC 2003). Waste fluids are also injected into the ground for permanent disposal. In the case of waste injections, the method involves fracturing the surrounding subsurface features to accommodate the input of liquid waste, which is injected below the impermeable permafrost layer. This method removes the waste fluids from problematic surface pits, which were used in the early years of development, but the contamination of ground water sources is still a potential risk because the method involves fracturing subsurface rock and ice, and the hydrology below the permafrost is poorly understood (NRC 2003). High-volume hydraulic fracturing has not been widely used on the North Slope, but it is considered an option in the Great Bear oil field south of Prudhoe Bay. Small-scale fracturing has long been used in the conventional fields of Prudhoe to release oil from porous sedimentary rocks.

The Alaska Department of Environmental Conservation maintains an online database and web mapping service of contaminated sites that includes information about the source of contamination and the status of cleanup. The database currently lists 427 sites within the NOS study area; these sites include both active and remediated sites. Of the sites listed, 144 are considered “open,” that is, not yet cleaned up or remediated (ADEC webserver accessed 4/23/2015).

Oil and gas development activities have been concentrated in the coastal plain where lakes are common. Development of oil and gas resources in the foothills, where lakes and gravel supplies are more limited, could have a different impact on freshwater habitats.

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H. Terrestrial Fine-Filter Conservation Elements

Tracey Gotthardt[1], Timm Nawrocki[1], and Nancy Fresco[2]

[1]Alaska Natural Heritage Program, University of Alaska Anchorage, 707 A Street, Anchorage, Alaska 99501 [2]Scenarios Network for Alaska & Arctic Planning, 3352 College Road, Fairbanks AK 997

Summary

Section H. *Terrestrial Fine-Filter Conservation Elements* provides the detailed descriptions, methods, datasets, results, and limitations for the assessments of selected animal species considered to be of high ecological importance in the North Slope study area and the potential impacts of CAs on these species.

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1. Introduction to Terrestrial Fine-Filter Conservation Elements

Many northern ecosystems are undergoing major shifts related to climate change. An understanding of this transformation and of the significance of its consequences is critical to anticipating ways in which potential negative and positive effects to wildlife populations may be mitigated or managed for (Berteaux 2013). Yet, as the Arctic continues to warm, our capacity to predict the responses of biological systems and their cascading effects through food webs, and ultimately their effects on humans, remains very limited. In general, we lack comprehensive baseline data on natural systems and are faced with complex interactions between wildlife species and between ecosystems and humans. The goal of the REA is to provide decision makers in the North Slope study area with current baseline data on key resources that will provide a sound basis to better understand the current and anticipated effects of climate change on select arctic wildlife and the habitats that support them.

Fine-Filter Conservation Elements (CEs) provide critical ecosystem functions and services that are not adequately represented by the Coarse-Filter CEs and are deemed important to the assessment of ecological intactness. Seven regionally important wildlife species were selected as Terrestrial Fine-Filter CEs for the North Slope REA (Table H-1). The Terrestrial Fine-Filter CEs are meant to represent key wildlife resources in the ecoregion and were selected because they were 1) identified directly through management questions, 2) provided specific ecological services and/or functions identified in the ecoregional conceptual model, 3) were considered important subsistence resources in the ecoregion, or 4) were suggested specifically by managers for their ecological significance.

Table H-1. Terrestrial Fine-Filter Conservation Elements (CEs), including trophic functional group, and reason for inclusion in the North Slope REA.

Terrestrial Fine-Filter CEs	Functional Group	Reason for Inclusion
Nearctic brown lemming (*Dicrostonyx trimucronatus*)	Small herbivore	Arctic-adapted species. Important in food webs – keystone prey species for wide spectrum of avian and mammalian predators. Major grazing impact; substantial contribution to nutrient cycling.
Arctic fox (*Vulpes lagopus*)	Medium-sized predator	Arctic-adapted carnivore. Opportunistic and significant lemming and egg predator. Highly tolerant of and attracted to human settlement. High potential for competition with the more aggressive red fox.
Caribou (*Rangifer tarandus*)	Large herbivore	Important as primary consumers but also as prey for large and medium-sized predators. Important subsistence resource. Major grazing impacts. Management questions related to seasonal movements and food availability.
Lapland longspur (*Calcarius lapponicus*)	Insectivore	Considered a keystone species of arctic ecosystems for its roles as a major consumer of invertebrates and as prey (including adult birds, eggs, and chicks) for mammalian and avian predators.
Willow ptarmigan (*Lagopus lagopus*)	Herbivore	Keystone species for tundra environments. Major grazing impact on willow habitats. Substantial contribution to nutrient cycling. Provides a prey base that supports populations of mammalian and avian (esp. gyrfalcon) predators. Important subsistence resource.
Greater white-fronted goose (*Anser albifrons*)	Herbivore	Important subsistence resource. Umbrella species for wetland associated geese and ducks.
Raptor concentration areas*	Large-bodied avian carnivore	Top level avian predators. Closely associated with riparian areas.

*Includes gyrfalcon, rough-legged hawk, and peregrine falcon.

2. Methods

For each Terrestrial Fine-Filter CE, we evaluated the potential for change by individual CAs pertinent to that CE at current, near-, and long-term (2010, 2020, and 2060) time steps. The process of intersecting the current distribution of the individual CEs with CAs is considered the core analysis of the REA. These analyses are described spatially by comparing the distribution of each CE with CAs that included: temperature, precipitation, and growing season length. For individual CEs, depending on their biology and habitat requirements, we also explored the relationship with other abiotic variables such as date of thaw, date of freeze, snow day fraction, total snow volume, thermokarst predisposition, and fire frequency. Potential relationships of the Terrestrial Fine-Filter CEs with invasive species were based on literature review.

Below we summarize the methods and results for the core analysis for all Terrestrial Fine-Filter CEs collectively, followed by individual species accounts where we present a more in-depth explanation of our findings. Here we provide a brief overview of those methods, but the focus of this report is on the results of our analysis.

We also answered management questions specific to caribou and landbirds, which required additional data processing beyond the core analysis requirements. Management questions, methods, and results relating to caribou are presented within the caribou CE species account. Management questions, methods, and results relating to baseline data for landbirds are included with the Lapland longspur CE species account.

For each Terrestrial Fine-Filter CE we:

1. Mapped or modeled the **current distribution** of each CE.
2. Created **a conceptual model** based on the ecology of the species and its relationship to CAs and drivers.
3. Identified measureable **attributes and indicators** (environmental predictors) to assist with evaluation of status for each CE.
4. **Intersected the mapped/modeled distribution of each CE with those CAs** identified as potentially significant through the CE-specific conceptual model and assessment of attributes and indicators at three time-steps [current, near-term future (2025), and long-term future (2060)].
5. Assessed current, near-term future (2025), and long-term future (2060) **status** by similarly intersecting the mapped distribution of each CE with the **Landscape Condition Model** (LCM).
6. Assessed the **relative distribution of each CE on public lands** by intersecting the distribution of each CE with general land management status.

2.1. Distribution Modeling

Our goal was to generate a distribution map for each CE using existing datasets. For most Terrestrial Fine-filter CEs, existing distribution models were available from the Alaska Gap Analysis Project

(AKGAP: http://akgap.uaa.alaska.edu). AKGAP models are spatial representations of predicted distribution for a single species, within known range limits, at 60 m pixel resolution. Models were generated through a combination of deductive and inductive modeling techniques, and have been statistically assessed for accuracy and peer reviewed (Gotthardt et al. 2014). The AKGAP models were developed to depict the species (CE) distribution across its full range in Alaska, not specifically within the North Slope study area. Although the distribution models were designed to be used for large-area resource management planning, model accuracy could not be guaranteed once the models were constrained by (clipped to) the North Slope study area. In an effort to establish that the AKGAP models were suitable at the scale of the North Slope study area, we compiled existing occurrence data for each CE to perform an independent accuracy assessment of each model specific to the REA. The contributing occurrence data sources are described within the individual Terrestrial Fine-Filter CE species accounts.

The AKGAP models were clipped to the North Slope study area and then assessed for accuracy using presence (occurrence) data and randomly generated pseudo-absences that were overlaid with model outputs to calculate classification success (CS). CS is a measure of model predictive quality and is defined as the percent of records of known occurrence predicted by the model to fall in suitable environments. Classification success values can range from 0.0 to 1.0, with values of 0.5 considered no better than random, and values ≥ 0.75 considered good model predictive quality.

Classification success values of AKGAP distribution models for greater white-fronted goose, Arctic fox, Lapland longspur, and willow ptarmigan ranged between 0.79 and 0.95, which were considered moderate to high model quality (Table H-2). The model quality was low for the Nearctic brown lemming (classification success value of 0.28). Due to low model confidence, we sought alternative existing models for this species. However, the one alternate model we obtained (Baltensperger, unpubl. data) had an even lower CS values (0.25) than the AKGAP model. The reason for low CS values for both Nearctic brown lemming models may be related to the quality of the occurrence data. The two models were in good agreement with each other, with the Baltensperger model being somewhat more generalized. Cognizant of poor accuracy statistics, we opted to use the AKGAP brown lemming model for the North Slope analysis, while keeping in mind that outputs may be less reliable than those for other species.

Table H-2. Assessment of model accuracy for all Terrestrial Fine-Filter CEs including the total number of occurrence points obtained for the CE, the total number of points used in the accuracy assessment, classification success (CS) values, and model quality summary.

Terrestrial Fine-Filter CEs	# Occurrence Pts	# Assessment Pts	Classification Success (CS)	Quality Summary
Nearctic brown lemming	2688	2688	0.28	Low
Arctic fox	1425	1425	0.95	High
Caribou	n/a	n/a	n/a	n/a
Lapland Longspur	2738	2738	0.95	High
Willow ptarmigan	2827	941	0.95	High
Greater white-fronted goose	31,636	1081	0.79	Moderate
Raptor concentration area	n/a	n/a	n/a	n/a

For the greater white-fronted goose, we obtained a breeding density distribution map developed by the USFWS, specific to the North Slope (Platte, unpublished data). We used the USFWS greater white-fronted goose breeding density distribution instead of the AKGAP model to describe our results because the breeding density distribution identified core (high density) areas important to the species, a feature that the AKGAP model lacked.

We recognized from the onset of the project that the AKGAP distribution models for raptors were of generally poor quality, as cliff nesting features were not mapped well in the base maps used to develop the raptor models (Gotthardt et al. 2014). Instead, we opted to map the distribution of raptor concentration areas using a compilation of existing occurrence data. More detailed methods relating to raptor mapping are described under the raptor concentration areas species account.

Lastly, the AKGAP model for caribou depicted year-round habitat use with no delimitation by herd or season. Since caribou alter their distribution seasonally in response to changing food sources and weather, we recognized that more detailed distribution information would be required for the analysis of caribou to be meaningful to managers. We established a data sharing agreement with the Alaska Department of Fish and Game to obtain annual kernel densities for the Western Arctic, Teshekpuk, and Central Arctic herds for the time period 2004 to 2014 (or to 2013 for the Teshekpuk Herd). We were not able to get seasonal kernel densities for these herds for 2004 to 2014 from ADF&G, nor were we able to get telemetry data for caribou herds to generate methodologically uniform seasonal kernel densities for this assessment. Instead, we hand-delineated general seasonal range maps for calving season, summer, and winter based on a variety of published reports and datasets. Kernel densities for the Porcupine Herd were not available. Instead, we developed seasonal range maps for the Porcupine Herd by hand-delineating general seasonal range maps for summer and winter and by heads-up digitizing an existing calving range map available from the literature. Annual range for the Porcupine Herd was also hand-delineated. More detailed methods for the annual and seasonal distribution of caribou in the North Slope study area are described under the caribou species account.

2.2. Conceptual Models

The CE by CA assessment was aided by the development of CE-specific conceptual models. Conceptual models were developed for each Coarse- and Fine-Filter CE and are essentially “stressor” models, which depict the effects that environmental stress (i.e., Change Agents) impose on key ecological components. The CE-specific conceptual models were used to identify indicators and metrics with high ecological and management relevance for use in the REA, which helped guide the evaluation of potential responses to perceived impacts (Noon 2003, Tierney et al. 2009). The CE-specific conceptual models represent the state of knowledge between the CE, CAs, and other resources. Conceptual models are based on extensive literature review and describe the relationship between the various Change Agents and natural drivers in both tabular and graphical formats. Conceptual models for the Terrestrial Fine-Filter CEs are presented within the individual CE species accounts.

2.3. Attributes and Indicators

Ecological attributes are defined as traits or factors necessary for maintaining a fully functioning population, assemblage, community, or ecosystem. On a species level, they are traits that are necessary for the survival and long-term viability of the species. Indicators are defined as measureable aspects of ecological attributes. For the North Slope REA, we considered attributes and indicators as key elements that allowed us to better address specific management questions, help parameterize models, and help explain the expected range of variability in our results as they relate to status and condition.

For each Fine-Filter CE, we identified a number of attributes derived from the conceptual model, and assigned indicators based on available spatial data layers. Thresholds were set to categorize all data into standard reporting categories (i.e. indicator ratings). For some CEs, numerical measurements delineating thresholds were available from the literature. However, for most attributes/indicators, categories were generalized based on the best available information (e.g., average, greater than average, or lower than average). See Figure H-1 for an example attribute and indicator table. Attributes and indicators were developed for each CE and are presented within the individual Terrestrial Fine-Filter CE species accounts that follow.

The CA driving the associated key attribute

A factor that affects the survival and long-term viability of a CE

A measurable aspect of the key attribute that can be used in analysis

A brief description of interaction between key attribute and CE

Thresholds associated with the indicator that allow us to quantify the level of impact on a CE using 4 distinct categories

CA or Driver	Ecological Attribute	Indicator (unit of measure)	Effect/Impact	Indicator Rating			
				Poor	**Fair**	**Good**	**Very Good**
Anthropogenic	Habitat quality / reproductive success[26]	Landscape condition model	Risk of predation by raven and red fox increases within 5 km of infrastructure.	< 5km	5 - 7 km	> 7 km from	> 10 km

Figure H-1. Example and explanation of attributes and indicators for willow ptarmigan (*Lagopus lagopus*).

2.4. CE × CA Intersections

The CE × CA assessment was aided by the development of CE-specific conceptual models, the development of attributes and indicators tables, and availability of spatial data sets. Specific relationships to CAs that were identified in the attributes and indicators tables were then examined spatially by intersecting the CE-specific distribution model with the associated climatic or anthropogenic data layer. Modeled results are extractions of the CA within the distribution of the CE. When possible, modeled outputs were reclassified to match specific threshold values identified in the assessment of attributes and indicators.

We did not include maps of all the CE × CA intersections in this report, as it would be much too lengthy. When possible, we summarized many of the results for the CE × CA analysis in tables in Section H.3. Results are also presented within the individual CE species accounts. However, all GIS data are provided as a final product for the North Slope REA and will be made publicly available via the BLM data portal (http://www.landscape.blm.gov/geoportal/catalog/main/home.page) for future analyses.

In many cases, however, spatial overlays of the CAs on CEs did not appear to provide additional information beyond that already specified in the conceptual model (i.e., in terms of informing management or research efforts). Thus, for this report, our discussion of the impacts of CAs on the individual CEs includes a combination of quantitative (spatial analysis) and qualitative (conceptual model) results.

2.5. Status Assessments

The overall “status” of each CE was assessed by intersecting the CE-specific distribution model with the Landscape Condition Model (LCM) at current (2010) and future (2040) time steps. The LCM is a measurement of the impact of the human footprint on a landscape. The LCM categorizes human modifications into different levels of impact (site impact score), based on the current state of knowledge about the impacts of specific human land uses (see Section F. Landscape and Ecological Integrity).

For the purpose of this assessment, we assumed a linear distance decay function (gradual decrease in impact as distance from human activity/infrastructure increases until a maximum distance is reached at which the impact is negligible). These values are based on extensive meta-analysis of the impacts on many species/habitats/contexts. For Arctic fox, willow ptarmigan, and Nearctic brown lemming, we used the distance decay values set for the assessment of the landscape as a whole. However, for CEs for which we found actual values in the literature relating to distances associated with impacts, we modified the distance decay values to be more relevant to the CE's biology and avoidance behaviors (Table H-3). We assumed that distance decay values would remain constant across the three time scenarios: current (2010), 2040 medium development scenario (substitute for near-term future), and 2040 high development scenario (substitute for long-term future).

Table H-3. List of human modification variables used in the Landscape Condition Model (LCM) for the current scenario (C) and the future (2040) medium (M) and high (H) development scenarios. Decay scores with an * are modified from the original LCM values based on additional information from the literature. Standard LCM values were used to assess status of Arctic fox, willow ptarmigan, and Nearctic brown lemming. GWFG is greater white-fronted goose.

Scenario	Dataset	Distance Decay (m)				
		LCM	GWFG	Caribou -calving	Raptor conc.	Lapland longspur
C,M,H	Dalton ("Highway" in the dataset)	5000	5000	4000*	5000	5000
C,M,H	Oil Facilities (High Developed)	2000	10000*	4000*	3000*	5000*
H	Wainwright Chukchi Sea Onshore Processing Facility (High Developed)	2000	5000*	4000*	5000*	5000*
M, H	Point Thomson Airstrip (High Developed)	2000	5000*	4000*	5000*	5000*
C,M,H	Mining at Red Dog	1500	1500	1500	1500	1500
C,M,H	Village digitized plus ports(Medium Developed)	1000	5000*	1000	3000*	5000*
H	Barrow US Coast Guard Station (Medium Developed)	1000	1000	1000	1000	1000
C,M,H	Camps 20m buffer (Medium Developed)	1000	5000*	1000	3000*	1000
C,M,H	Secondary Roads	500	3000*	4000*	3000*	500
M, H	Future Roads	500	3000*	4000*	3000*	500
C,M,H	Oil/ gas Wells (AOGCC, Chukchi)	500	10000*	4000*	3000*	500
M,H	Future Drilling Sites	500	10000*	4000*	3000*	500
C,M,H	Industrial Lines (Power Lines, Pipelines)	500	500	500	500	500
M,H	Future Pipelines	500	500	500	500	500
C,M,H	Alt Transportation (Lower Colville River)	500	500	500	500	500
C,M,H	AKEPIC Non-Native Plant Occurrences	200	200	200	200	200

2.6. Relative Management Responsibility

The relative amount of management responsibility on public lands for each CE was assessed by intersecting the CE-specific distribution models with general land management status. Although each state and federal agency has different management mandates and responsibilities for specific fish and wildlife species, this assessment provides an estimate of the proportion of a species distribution that occurs within the boundaries of areas managed by public agencies. This type of information may be useful to managers to promote better collaboration and increase effectiveness of public lands managed for species that migrate across political boundaries.

3. Core Analysis Results

In the next decade, little measurable change can be expected in habitats utilized by Terrestrial Fine-Filter CEs, based solely on climate variables. Larger responses, however, are predicted by 2060, and some significant responses are also predicted for the 2020s (see Section C, Section G, and Section I for more details). A summary of predicted effects of Abiotic CAs on the Terrestrial Fine-Filter CEs are summarized below. Key effects are expanded on in the individual Terrestrial Fine-Filter CE sections.

3.1. Annual Temperature

Both winter and summer temperatures are expected to increase by the 2060s, with the greatest increases occurring during winter months. Significant winter (January) temperature increases of about 4.5 °C (8 °F) are predicted by the 2060s for the eastern part of the North Slope study area. In the western part of the North Slope study area, significant increases of about 4.0 °C (7 °F) are expected. Warming in the near term is also likely to be significantly above average. Summer (July) temperatures are expected to increase, although the warming trend is less pronounced than winter warming. Geographic patterns of summer warming are different than winter, with greater changes along a north-south gradient and less variability along the east-west gradient (see Section C. Abiotic Change Agents).

Of the seven Terrestrial Fine-Filter CEs, the three representative mammals are resident, while the four avian CEs are highly migratory and generally only present in the North Slope study area during the spring and summer seasons. Willow ptarmigan may remain within the North Slope study area, but do move between more northerly summer breeding grounds to mountain passes in the southern Brooks Range during winter.

We selected January (winter) and July (summer) to represent the two temperature extremes species would be exposed to, with winter temperatures only applicable to resident species and summer temperatures applicable to all species. We also looked at change in mean annual temperature as a measure of potential for generalized temperature related effects on all wildlife CEs and their habitats.

Between the current (2010s) and the near-term future (2020s), non-significant increases (< 1.3 °C) in July, January, and annual average temperatures are expected in 100% of the modeled distributions of Terrestrial Fine-Filter CEs (Table H-4). However, warming is expected to accelerate under the A2 scenario after the 2020s. By the long-term future (2060s), both January and annual temperature increases greater than 1.3 °C are expected in 100% of the modeled distributions of Terrestrial Fine-Filter CEs (Table H-4). Significant warming in July temperature is expected by the 2060s, with the greatest amount of change occurring in inland areas (e.g. greatest impact to raptors and willow ptarmigan and lowest impact to greater white-fronted goose) (Table H-4).

Table H-4. Predicted change from current (2010s) to the near-term future (2020s) and long-term future (2060s) in mean July temperature, mean January temperature, and mean annual temperature within the distribution of individual Terrestrial Fine-Filter CEs in the North Slope study area. Values > 1.3°C are considered significant.

Terrestrial Fine-Filter CE		Δ July Temp		Δ January Temp		Δ Annual Temp	
		0 - 1.3 °C	>1.3 °C	0 - 1.3 °C	>1.3 °C	0 - 1.3 °C	>1.3 °C
Nearctic brown lemming	Near Term	100%	-	100%	-	100%	-
	Long Term	52%	48%	-	100%	-	100%
Arctic fox	Near Term	100%	-	100%	-	100%	-
	Long Term	74%	26%	-	100%	-	100%
Caribou- calving range	Near Term	100%	-	100%	-	100%	-
	Long Term	70%	30%	-	100%	-	100%
Caribou-summer range	Near Term	100%	-	100%	-	100%	-
	Long Term	45%	55%	-	100%	-	100%
Lapland longspur	Near Term	100%	-	100%	-	100%	-
	Long Term	43%	57%	-	100%	-	100%
Willow ptarmigan	Near Term	100%	-	100%	-	100%	-
	Long Term	36%	64%	-	100%	-	100%
Greater white-fronted goose	Near Term	100%	-	100%	-	100%	-
	Long Term	96%	4%	-	100%	-	100%
Raptor concentrations	Near Term	100%	-	100%	-	100%	-
	Long Term	26%	74%	-	100%	-	100%

3.2. Growing Season Length

Similar to results for temperature, unfrozen season length (estimated based on the number of days between the dates on which the running mean temperature crosses the freezing point in spring and fall) is not expected to see much change by the near-term future (average increase of 2 days by the 2020s). In the long-term future, however, unfrozen season length – which can also be considered a rough proxy for growing season - is expected to increase by at least a week for Terrestrial Fine-Filter CE distributions. An increase of between one and two weeks in growing (unfrozen) season length is expected in over 96% of the combined distribution of the seven CEs by the 2060s (Table H-5).

Table H-5. Predicted change from current (2010s) to the near-term future (2020s) and long-term future (2060s) in length of growing season within the distribution of individual Terrestrial Fine-Filter CEs in the North Slope study area.

Terrestrial Fine-Filter CE		Change in Length of Above-Freezing Season			
		< 0 Days	0 - 6 Days	7 - 14 Days	> 14 Days
Nearctic brown lemming	Near Term	100%	-	-	-
	Long Term	-	0%	98%	2%
Arctic fox	Near Term	100%	-	-	-
	Long Term	-	-	96%	4%
Caribou-calving range	Near Term	0.3%	99.7%	-	-
	Long Term	-	-	98%	2%
Caribou - summer range	Near Term	0.48%	99.51%	0.01%	0%
	Long Term	-	0%	95%	5%
Lapland longspur	Near Term	100%	-	-	-
	Long Term	-	0%	98%	2%
Willow ptarmigan	Near Term	100%	-	-	-
	Long Term	-	0%	99%	1%
Greater white-fronted goose	Near Term	100%	-	-	-
	Long Term	-	-	96%	4%
Raptor concentrations	Near Term	100%	-	-	-
	Long Term	-	0%	100%	-

Increases in annual temperature and growing season length of the magnitude expected within the North Slope study area by the 2060s could have considerable effects on wildlife species. Temperature-related habitat effects include shrub encroachment and overall increases in shrub abundance and reduced stress during calving and incubation. Growing season length changes include changes in the timing of emergence of insect prey, parasites, and disease; advanced onset of green-up and subsequent changes in forage quality and quantity, and a longer period for migratory species to produce and fledge young. These potential changes and how they relate to the specific CEs are discussed under the individual Terrestrial Fine-Filter CE sections that follow.

3.3. Precipitation

We looked at the relationship between Terrestrial Fine-Filter CEs and annual precipitation, winter precipitation (December, January, and February), and change in spring (March, April, and May) precipitation for all CEs. Changes in spring precipitation are likely to have the broadest impacts: the literature indicated that this was a critical period for many migratory species, including caribou, and that increases in spring precipitation regimes could have potential negative influences on reproduction and survival of many wildlife species.

General geographic patterns of precipitation are likely to remain unchanged across the North Slope study area, even as total precipitation increases slightly in the near-term. As noted in Section C, annual precipitation varies regionally across the REA area, from a minimum of about 300 mm to a maximum of about 900 mm annually. Given that precipitation is so variable both spatially and temporally, model uncertainty is higher than it is for temperature variables, and near-term changes are likely to be insignificant in terms of clear impacts to Terrestrial Fine-Filter CEs. Because of this level of uncertainty, we used ±2 SD (compared to ±1 SD that we used for temperature) to indicate significance in our comparisons of CE distribution to precipitation values (Table H-6). Because winter precipitation plays such a large role in the ecology of mammals, we binned the data at 10 mm intervals in an effort to capture fine-scale differences.

Significant increases in annual precipitation (> 9 mm) are expected to occur within the modeled distribution of all Terrestrial Fine-Filter CEs at both future time steps, although increases are projected to be higher by the 2060s. By the 2060s, significant increases in annual precipitation of > 9 mm are expected throughout 100% of the modeled distribution of all Terrestrial Fine-Filter CEs (Table H-6). Increases in spring precipitation are non-significant in the near-term future for all CEs (Table H-6).

Current mean winter precipitation values (rain-water equivalent) range from 44 to 53 mm along on the Coastal Plain to 70 to 91 mm in the Brooks Range (see Section G). Winter precipitation is projected to increase across the North Slope study area, with the highest projected changes in the central and western portion of the Brooks Range. Increases in winter precipitation of between 11 and 20 mm are expected to occupy the largest percent of total CE area within the distribution of Nearctic brown lemming (31%) and caribou wintering areas (38%) combined.

Table H-6. Predicted change from current (2010s) to the near-term future (2020s) and long-term future (2060s) in annual precipitation, winter precipitation, and spring precipitation in rainwater equivalents within the modeled distribution of individual Terrestrial Fine-Filter CEs in the North Slope study area. Values denoted by * indicate there will likely not be a direct effect on the CE, as they are absent from the area during winter month, but there could be a direct effect to habitats they use.

Terrestrial Fine-Filter CE		Annual Precipitation		March-May Precipitation		December-February Precipitation		
		≤ 9 mm	> 9 mm	≤ 9 mm	> 9 mm	≤ 10 mm	11 - 20 mm	≥ 20 mm
Nearctic brown lemming	Near	71%	29%	100%	-	98%	2%	-
	Long	-	100%	100%	0%	69%	31%	1%
Arctic fox	Near	83 %	17%	100%	-	99.9%	0.1%	-
	Long	-	100%	100%	-	90%	10%	0%
Caribou - calving range	Near	84%	16%	100%	-	98%	2%	-
	Long	-	100%	99.96%	0.04%	78%	22%	0%
Caribou- summer range	Near	71%	29%	100%	-	94%	6%	-
	Long	-	100%	99.7%	0.3%	58%	39%	3%
Caribou – winter range	Near	78%	22%	100%	-	98%	2%	-
	Long	.-	100%	100%	0.01%	57%	38%	5%
Lapland longspur	Near	68%	32%	1000%	-	94%*	6%*	-
	Long	-	100%	99.97%	0.03%	53%*	42%*	5%
Willow ptarmigan	Near	64%	36%	100%	-	97%*	3%*	-
	Long	-	100%	99.99%	0.01%	57%*	41%*	1%
Greater white-fronted goose	Near	98%	2%	100%	-	99.9%*	0.1%*	-
	Long	-	100%	100%	-	86%*	14%*	0 %
Raptor concentrations	Near	51%	49%	100%	-	95%*	5%*	-
	Long	-	100%	100%	-	41%*	58%*	1%*

It should be noted that precipitation may be less important overall in terms of impacts to CEs than hydrologic change driven indirectly by climate, including snow-day fraction, permafrost, and predisposition to thermokarst (see Section C. Abiotic Change Agents). More in-depth exploration of these variables is included within the individual Terrestrial Fine-Filter CE sections that follow.

3.4. Fire

Due to lack of adequate fire frequency and fire return interval data layers at the appropriate spatial scale, we did not intersect the distribution of the Terrestrial Fine-Filter CEs with any fire-related datasets. Instead, we relied heavily on descriptions from the results of the CA Fire Section of this report and quantitative accounts from the literature to describe the expected effects of changes in wildfire on wildlife habitats. We also made correlative inferences about vegetation change affects and their impacts on wildlife based on results of the ALRESCO model. Because ALFRESCO models vegetation succession both with and without fire events, it offers a perspective on climate-driven landscape-level change. Overall, wildfire is expected to become a more frequent driver of change in wildlife habitats in the North Slope study area, although it will remain rare except south of the crest of the Brooks Range. ALFRESCO predicts increased fire frequency in the foothills and Brooks Range sub-regions. Fire is likely to remain absent – or almost absent – from the coastal plain sub-regions. Even with increased fire frequency, the area burned is expected to remain relatively low. Implications for wildlife are varied, and include increased productivity of early successional vegetation, and changes in forage quantity and quality (e.g., reduced lichen abundance in caribou winter range south of the North Slope study area). When applicable, the ramifications of fire are discussed within the individual Terrestrial Fine-Filter CE sections that follow.

3.5. Landscape Condition

Different from other REAs in Alaska, we worked closely with the North Slope Science Initiative (NSSI) Scenarios Project to incorporate future human footprint estimates from their scenario exercises (see Section E. Anthropogenic Change Agents). Instead of near- and long-term futures, we use the interim "Medium" and "High" development oil and gas scenarios generated by the NSSI Scenarios Project. The project is currently ongoing and the development scenarios provided should be considered interim products that may be changed. It is also important to note that the NSSI scenarios show different plausible futures for the year 2040, which is different than our near- and long-term future definitions of 2020 and 2060, respectively. Due to the scope of the NSSI scenarios project that focused on energy development and supporting activities on the North Slope, and the anticipated lack of population change in the villages, the predicted future human footprint for the North Slope study area is largely driven by changes in oil and gas infrastructure. Future oil and gas infrastructure associated with the medium development scenario includes infrastructure at part of the Greater Moose's Tooth region of NPR-A, and further expands the development currently at Point Thompson. The Liberty drilling pads are expanded, and there is a new pipeline built connecting offshore activities to the Point Thompson region. Additionally, we 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 infrastructure 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. Although offshore activities are included in the NSSI scenarios, we did not include those developments given our terrestrial focus. 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 to overall landscape condition.

Most of the North Slope study area is considered relatively pristine (very high condition), with intense impacts being more localized (see Section F. Landscape and Ecological Integrity). When the current distribution of the Terrestrial Fine-Filter CEs was compared to the LCM at current, medium development, and high development, over 96% of predicted habitat for all CEs, except greater white-fronted goose, was considered in very high condition (Table H-7). During the nesting period, greater white-fronted geese have a foraging range of 3-10km and contaminant leaks within the nest vicinity could have a negative effect on individual health and reproductive success (Schoen and Senner 2002). Therefore, distance decay values for greater white-fronted goose in relation to oil and gas activities were higher (10,000 m) than any other CE. Even with this large buffer for oil- and gas-related disturbance, over 81% of predicted habitat for this species was considered in very high condition for all scenarios (Table H-7).

When applicable, the implications of localized impacts due to development are discussed within the individual Terrestrial Fine-Filter CE sections that follow.

Table H-7. Percent of Terrestrial Fine-Filter CE modeled distribution area associated with relative landscape condition (very low to very high) for current, future medium scenario (2040) and future high scenario (2040) in the North Slope study area.

Terrestrial Fine-Filter CE		Relative Landscape Condition (% of CE distribution area)				
		Very Low	Low	Medium	High	Very High
Nearctic brown lemming	Current	0.3	0.6	0.6	0.7	97.8
	Medium Scenario	0.3	0.6	0.6	0.7	97.7
	High Scenario	0.3	0.7	0.8	0.9	97.3
Arctic fox	Current	0.4	0.8	0.8	1.1	96.9
	Medium Scenario	0.4	0.8	0.9	1.1	96.9
	High Scenario	0.4	1.0	1.1	1.3	96.2
Caribou: Western Arctic Herd	Current	0.1	0.4	0.4	0.5	98.7
	Medium Scenario	0.1	0.4	0.4	0.5	98.7
	High Scenario	0.1	0.8	0.8	0.8	97.6
Caribou: Teshekpuk Herd	Current	0.3	1.4	1.4	1.7	95.4
	Medium Scenario	0.3	1.4	1.4	1.7	95.3
	High Scenario	0.3	2.4	2.4	2.8	92.1
Caribou: Central Arctic Herd	Current	1.1	3.2	2.5	2.4	90.9
	Medium Scenario	1.1	3.2	2.5	2.4	90.8
	High Scenario	1.1	3.3	2.8	2.7	90.2
Caribou: Porcupine Herd	Current	0	0	0	0.1	99.9
	Medium Scenario	0	0	0	0.1	99.9
	High Scenario	0	0	0.1	0.1	99.8
Lapland longspur	Current	0.6	1.0	0.9	1.0	96.5
	Medium Scenario	0.6	1.0	0.9	1.0	96.5
	High Scenario	0.6	1.1	1.04	1.17	96.14

Terrestrial Fine-Filter CE		Relative Landscape Condition (% of CE distribution area)				
		Very Low	Low	Medium	High	Very High
Willow ptarmigan	Current	0.26	0.49	0.48	0.50	98.28
	Medium Scenario	0.26	0.49	0.49	0.51	98.25
	High Scenario	0.26	0.55	0.60	0.64	97.94
Greater white-fronted goose	Current	3.10	4.13	2.92	8.05	81.80
	Medium Scenario	3.10	4.12	2.95	8.10	81.73
	High Scenario	3.11	5.54	4.17	9.30	77.88
Raptor concentration areas	Current	0.38	0.67	0.60	0.93	97.42
	Medium Scenario	0.38	0.67	0.60	0.93	97.42
	High Scenario	0.38	0.98	0.94	1.27	96.43

3.6. Distribution on Public and Private Lands

Federal and state agencies are faced with the challenge of balancing needs for resource extraction, energy development, recreation, and other uses with the growing urgency to conserve wildlife. Better collaboration among agencies can increase the effectiveness of public lands management for species that migrate across political boundaries. We used the relative proportion of a species distribution falling within agency boundaries as a proxy for relative amount of management responsibility.

Species distributions in relation to areas managed both publicly and privately reflect the overall ratio of land ownership within the North Slope study area, with the highest percentages of species distributions occurring on BLM land, State Patent land, and USFWS land, respectively (Table H-8). Together, BLM, the State of Alaska, and USFWS are responsible for managing habitats for 79% to 95% of the distribution of the Terrestrial Fine-Filter CEs in this analysis (Table H-8).

Table H-8. Percentage of total CE area by land manager in the North Slope study area.

Terrestrial Fine-Filter CE	BLM	DOD	USFWS	NPS	AK Patent or TA	State Selected	Native Land (Native Patent and Selected)	Private/ Unknown
Nearctic Brown Lemming	51%	0.03%	8%	4%	24%	1%	12%	-
Arctic Fox	61%	0.07%	4%	2%	21%	1%	11%	0.01%
Caribou – Western Arctic Herd	48%	0.03%	0.4%	21%	13%	2%	14%	-
Caribou – Teshekpuk Herd	55%	0.03%	2%	10%	21%	1%	10%	-

Terrestrial Fine-Filter CE	BLM	DOD	USFWS	NPS	AK Patent or TA	State Selected	Native Land (Native Patent and Selected)	Private/ Unknown
Caribou – Central Arctic Herd	7%	0.02%	36%	8%	41%	1%	7%	-
Caribou – Porcupine Herd	0.3%	-	93%	-	6%	0.01%	1%	-
Lapland longspur	38%	0.04%	16%	11%	23%	1%	10%	0.01%
Willow ptarmigan	44%	0.01%	12%	8%	24%	2%	10%	-
Greater white-fronted goose	67%	0.1%	3%	-	20%	-	9%	0.01%
Raptor concentration areas	57%	-	9%	4%	20%	1%	14%	0.01%

Public lands are crucial for maintaining habitats important to Arctic breeding species. Modifications in environmental conditions caused by global climate change, including increased storminess, changes in snow characteristics, changes in hydrological regimes, and expansion of trees and shrubs into sedge-dominated tundra areas, are only some of the challenging long-term threats facing Arctic wildlife. Balancing the need for energy development with the conservation needs of wildlife species is a continuing challenge on public lands in Arctic Alaska.

3.7. Literature Cited

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4. Nearctic brown lemming (*Lemmus trimucronatus*)

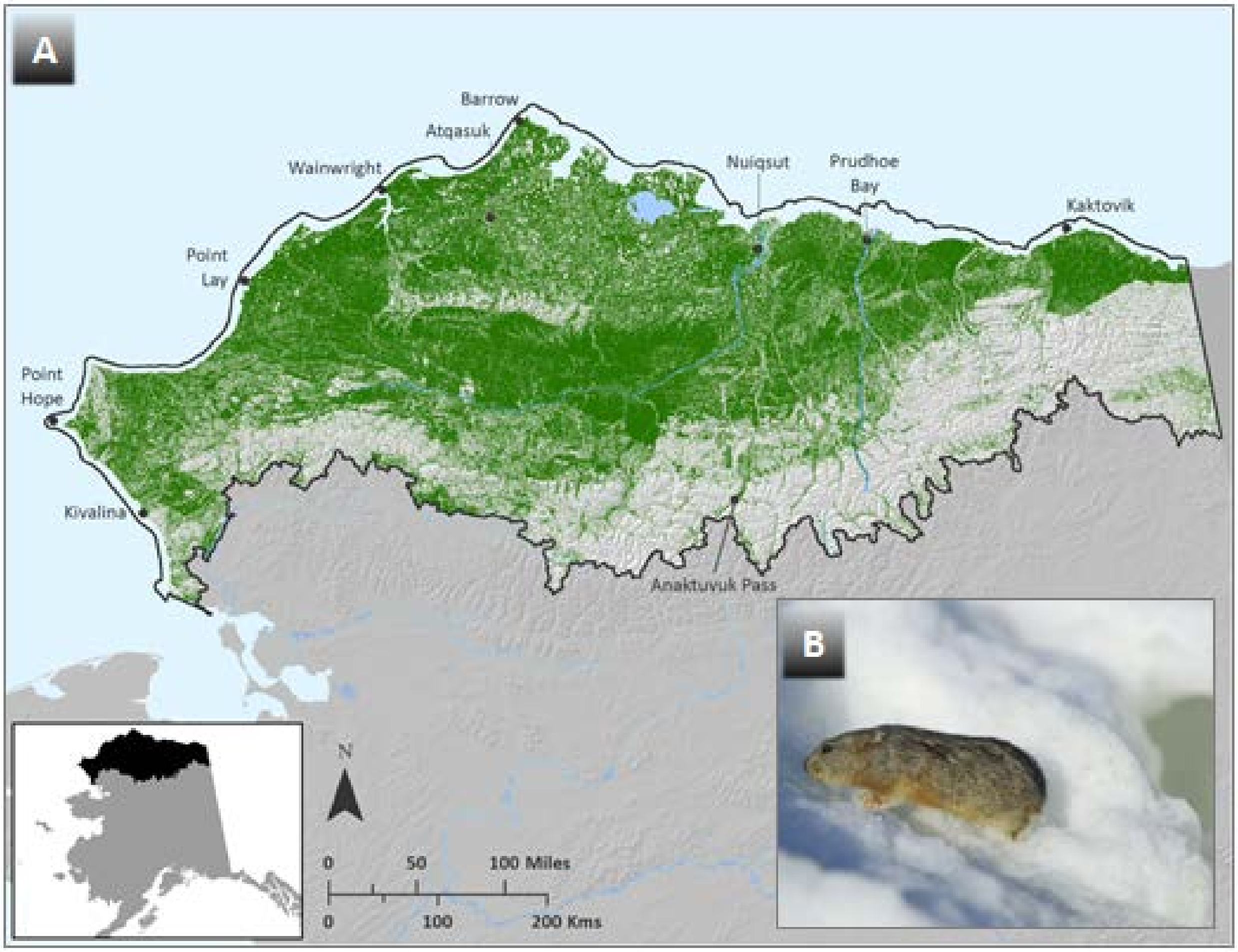

Figure H-2. Current modeled distribution of Nearctic brown lemming (*Lemmus trimucronatus*) in the North Slope study area (A) and a Nearctic brown lemming in snow (B).

4.1. Introduction

The Nearctic brown lemming (*Lemmus trimucronatus*) and Nearctic collared lemming (*Dicrostonyx groenlandicus)* occur throughout the North Slope study area, with brown lemmings more widely distributed and abundant. Lemmings are of particular interest and ecological importance because they are prey for the majority of arctic predators, and in many arctic regions their populations follow multiannual population fluctuations of considerable amplitude (Stenseth and Ims 1993). Lemmings can also affect the species composition and dynamics of tundra vegetation (Olofsson et al. 2012). When abundant, lemmings attract nomadic and migratory predators, support high reproductive success in these and resident predators, and indirectly influence the population dynamics of various alternative prey such as nesting shorebirds and waterfowl (Gauthier et al. 2004, Ims and Fuglei 2005, Gilg et al. 2006). Grazing impacts of lemmings during population peaks are so profound that they can be detected from satellite images (Olofsson et al. 2012). Changes in lemming abundance may dramatically alter the composition of tundra food webs, and the productivity of numerous other birds and mammals, from year to year (e.g., Angerbjörn et al. 1999, Gilg et al. 2009, Robinson et al. 2014).

Because of their role as a keystone prey species in the Arctic, the Nearctic brown lemming was selected as a Terrestrial Fine-Filter CE for this assessment. However, any findings relating to the brown lemming could also apply to collared lemmings, as their life history traits and ecological requirements are very similar.

Populations of Nearctic brown lemmings fluctuate cyclically and although not fully understood, typical cycling of lemming populations is thought to be the result of large population increases under favorable winter snow conditions, followed by increases in predator densities that eventually result in declines in lemming numbers (McLennan et al. 2012). In the Canadian Arctic, Nearctic brown lemmings show population peaks every three or four years (Gruyer et al. 2008). Local predators such as Arctic fox (*Vulpes lagopus*), weasels, and long-tailed jaegers (*Stercorarius longicaudus)* respond to lemming peak years with higher reproduction rates, and wide-ranging species such as snowy owl (*Bubo scandiacus*) migrate across broad distances to take advantage of abundant prey (Therrien et al. 2014).

During winter, the Nearctic brown lemming remains under the snowpack, feeding on moss shoots and leaf bases of perennial grasses and sedges (Peterson et al. 1976). In late spring and early summer when snow melt floods lowland wet meadows, brown lemmings move to uplands. Once waters recede, brown lemmings typically return to lowland wet meadows where preferred forage is abundant (Batzli et al. 1983). However, they are also found in drier upland habitats throughout the summer in years of high abundance. During summer, brown lemmings feed on mosses, grasses, and sedges (Batzli and Pitelka 1983).

Breeding occurs in mid or late July and again at the end of August in some years. Late August breeders are primarily juvenile and subadult animals that reach maturity before the onset of winter (Rodgers and Lewis 1986). Additional breeding occurs during winter under the snow which allows for recovery from low lemming population numbers and heavy summer predation. Early snow fall and adequate snow depth assists winter reproductive success. Graminoid availability at winter nest sites also contributes to reproductive success (Duchesne et al. 2011).

4.2. Conceptual Model

The conceptual model below (Figure H-3) is based on literature review and describes the relationship between the various change agents and natural drivers for the Nearctic brown lemming. The boxes and arrows represent the state of knowledge about the Nearctic brown lemming and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and the Nearctic brown lemming. Change agents selected for this REA and considered in this analysis include: climate change, fire, invasive species, and human use.

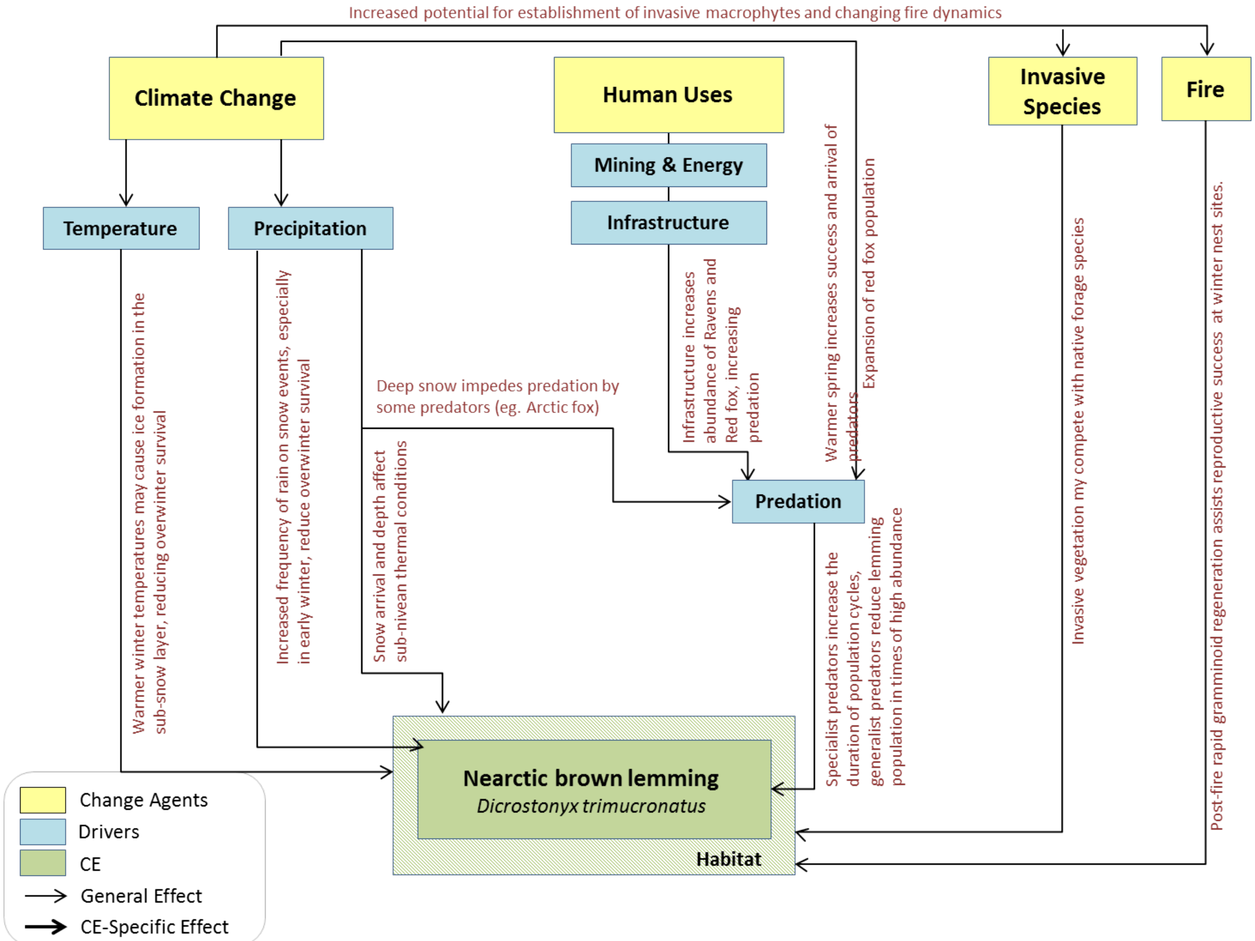

Figure H-3. Conceptual model for the Nearctic brown lemming.

4.3. Attributes and Indicators

Based on the assessment of available indicators, spatial data used to assess the status of the Nearctic brown lemming included: snow volume, date of freeze, snow day fraction, growing season length, annual temperature, and landscape condition (Table H-9).

Table H-9. Attributes and indicators for the Nearctic brown lemming.

CA or Driver	Ecological Attribute	Indicator (unit of measure)	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate (winter)	Habitat availability[1]	Snow volume	Early snow fall and adequate snow depth assists winter reproductive success.	< 60 cm		60 cm	> 60 cm
	Habitat availability[2]	Date of freeze (proxy for date of first snowfall)		Later than average		Average	Earlier than average
	Habitat availability[3]	Snow day fraction	Increased frequency of rain on snow events, especially early in winter, will likely affect overwinter survival.	Snow fraction below 80% for more than one winter month		Snow fraction below 90% for one winter month	Snow fraction over 90% for all winter months
Climate (summer)	Food availability[4]	Growing season length	A longer growing season could result in increased vegetation biomass, allowing for greater winter food storage.	Below average		Average	Above average
Anthropogenic	Habitat condition[5]	Landscape condition model (human footprint)	Potential for increases in avian and mammalian predators associated with human settlement, such as raven and arctic fox	< 1km	1 to 2 km		> 2km

[1] Based on Duchesne et al. 2011, Reid et al. 2011, and McLennan et al. 2012.
[2] Based on McLennan et al. 2012.
[3] Based on Duchesne et al. 2011, Hansen et al. 2011, Reid et al. 2011, and McLennan et al. 2012.
[4] Based on Martin 2012.
[5] Based on Pitelka et al. 1955, Cannings and Hammerson 2004, and Liebezeit et al. 2009.

4.4. Distribution Model

We used predictive models generated by the Alaska Gap Analysis Project (AKGAP) to describe the distribution of the Nearctic brown lemming across the North Slope study area (see Section H.1.1. for details relating to AKGAP models). The Nearctic brown lemming is widely distributed across the Beaufort Coastal Plain and Brooks Foothills within appropriate habitat (Figure H-2). Habitats included in the modeled distribution include wet tundra, wet sedge tundra, polygonal ground wet sedge tundra, wet sedge meadow, herbaceous meadow, tussock tundra, and shrub tundra. The species distribution does not appear to extend into the Brooks Range, where habitats are likely considered unsuitable.

A total of 2,688 occurrence records were obtained from various sources to test the model and generate a model accuracy (classification success) statistic (Table H-10). Classification success (CS) values for the Nearctic brown lemming AKGAP distribution model were 0.28, indicating low model quality. Alternative existing models for this species, however, did not have higher CS values (0.25) than the AKGAP model (Baltensperger, unpubl. data). Cognizant of poor accuracy statistics, we opted to use the AKGAP brown lemming model for the North Slope analysis, while keeping in mind that outputs may be less reliable than those for other species.

Table H-10. Datasets used for Nearctic brown lemming.

Dataset Name	Data source
Gap Analysis distribution model for the Nearctic brown lemming	Alaska Gap Analysis Project, AKNHP
Gap Analysis terrestrial vertebrate occurrence geodatabase database records for Nearctic brown lemming*	Alaska Gap Analysis Project, AKNHP
Museum specimen records for the Nearctic brown lemming	BISON database (http://bison.usgs.ornl.gov/#home)

*Sources for Gap Analysis Vertebrate Occurrence records for Nearctic brown lemming are a compilation of museum records and field survey data obtained from various agencies and researchers. A full bibliography of all data sources for this species is included in the North Slope Data Discovery Memo.

4.5. Abiotic Change Agents Analysis

We explored the relationship between the Nearctic brown lemming and five climatic change agents: snow volume, date of freeze, snow day fraction, growing season length, and annual temperature at three time steps (current, near-term, and long-term). We hypothesized that deeper snow would be beneficial to lemmings during winter and would assist reproductive success, while decreases in snow season length and increases in rain on snow (icing) events, especially during early winter, would be detrimental to lemming survival. Lastly, we explored the relationship between growing season length and potential for increases in food availability.

Snow Volume, Date of Freeze, and Snow Day Fraction

Snow quality and quantity likely play a prominent role in lemming population dynamics (Reid et al. 2013). Warmer temperatures could result in changes in snow dynamics, a shorter snow season, and reduced snow extent in late winter, which could have considerable impact on lemming habitat availability and quality, as this species is active all winter in the spaces between the frozen ground and the snow. During winter, lemmings nest in areas where snow is sufficiently deep to create favorable sub-nivean thermal conditions (McLennan et al. 2012). Recent snow fence experiments on Herschel Island, in the Canadian Arctic, identified a threshold of 60 cm snow depth to create desirable thermal conditions for enhanced sub-nivean reproduction of brown lemmings and tundra voles (*Microtus oeconomus*) (Reid et al. 2011).

The lemming population cycle is dependent on long, cold, stable winters. Mild weather and wet snow can lead to a collapse of sub-nivean spaces, destroying lemming burrows. Furthermore, combinations of milder and shorter winters are predicted to decrease the regularity of lemming cycles (Gilg et al. 2009). For our analysis, we used date of freeze (DOF) as a proxy for date of first snow. DOF refers to the interpolated day on which the running mean temperature crosses the freezing point in the fall. Although true first-snow dates (especially with reference to snow that accumulated rather than melting) would be likely to occur slightly later in the season than DOF, we considered that later than average DOF could result in a shorter (later onset) snow season.

Results indicate that currently, DOF occurs during the 2-week period from 12 – 21 September, and there is little change in these dates by the 2020s (Figure H-4). However, by 2060, climate models predict DOF could be delayed by as much as 14 days, with delays being the most pronounced on the Arctic Coastal Plain and along the western coastal margin between Point Hope and Kivalina. Later than average first snow reduces the amount of time that lemmings can spend in sub-nivean habitats, exposing them to increased predation risk. Conversely, later freeze dates could lead to prolonged plant senescence, allowing lemmings more time to forage and fatten before the winter period.

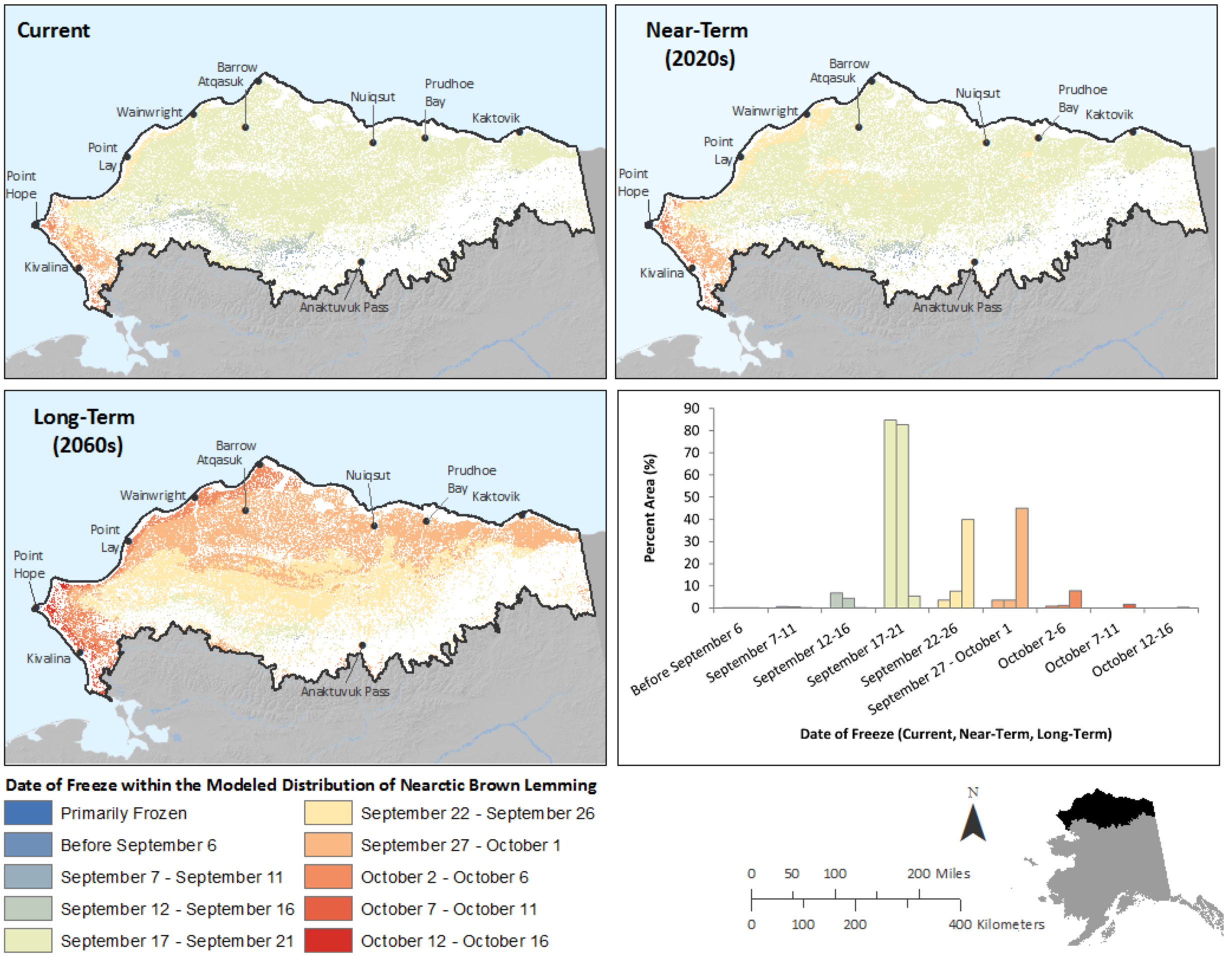

Figure H-4. Modeled change in date of freeze (DOF) at current, near-term future (2020s), and long-term future (2060s) time intervals within the current distribution of Nearctic brown lemming.

Warm winters, low snow accumulation and winter rain events have been indicated as primary factors behind low lemming productivity and high mortality in Greenland and parts of Europe (McLennan et al. 2012), a trend sufficient to suggest the collapse of these cycles (Ims et al. 2008). Freeze thaw cycles caused by warmer winter temperatures may cause ice formation in the sub-snow layer in which Nearctic brown lemmings nest. This could lead to reduced overwinter survival by preventing lemmings from accessing areas of sub-snow vegetation, and is especially critical early in the winter (Duchesne et al. 2011, Reid et al. 2011).

Modeling snow depth and condition is extremely complicated because it requires estimating not only cumulative snowfall, but also effects such as drifting, compaction, thaw, sublimation, and icing. Thus, we lacked a comprehensive spatial layer representing total snow depth to allow a direct comparison between snow depth and lemming distribution. However, we were able to examine estimated snowfall (precipitation x snow day fraction) both on a monthly basis and cumulatively, across the winter season (Figure H-5). Results suggest that while total snow volume is expected to increase by 2060 during the autumn and winter months across the North Slope study area, there will likely be net losses to snow volume in late winter and spring in some sub-regions, particularly on the Arctic coast.

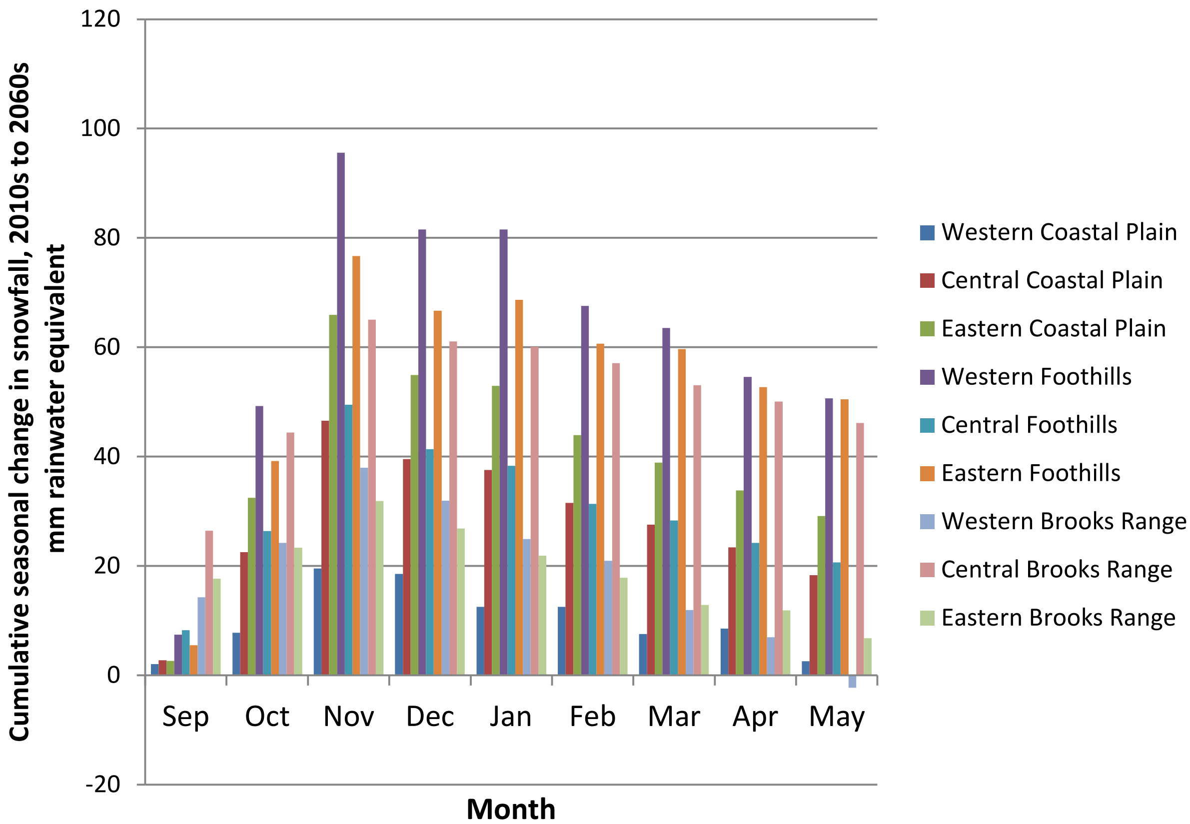

Figure H-5. Seasonal changes in cumulative snowfall (mm rainwater equivalent) for the North Slope study area, summarized by terrestrial sub-region. Note that these data do not account for loss due to thaw or sublimation, and do not predict the depth, compaction, or icing of snow.

We also used snow-day fraction as a proxy for rain on snow events, with an emphasis on early winter icing (October and November). 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 (see Section C. Abiotic Change Agents). Results indicate that throughout the range of the Nearctic collared lemming, almost all (>90%) of precipitation is currently likely to fall as snow for all months from October to April. By the 2060s, conditions in December to April are still expected to be completely snow-dominated area-wide, however, marked changes are expected in the fall. Most notably, occasional October rainfall (≥ 15%) is expected across almost all of the Arctic coast and even in November, precipitation may arrive as rain more than 10% of the time around Kivalina and Point Hope (Figure H-6).

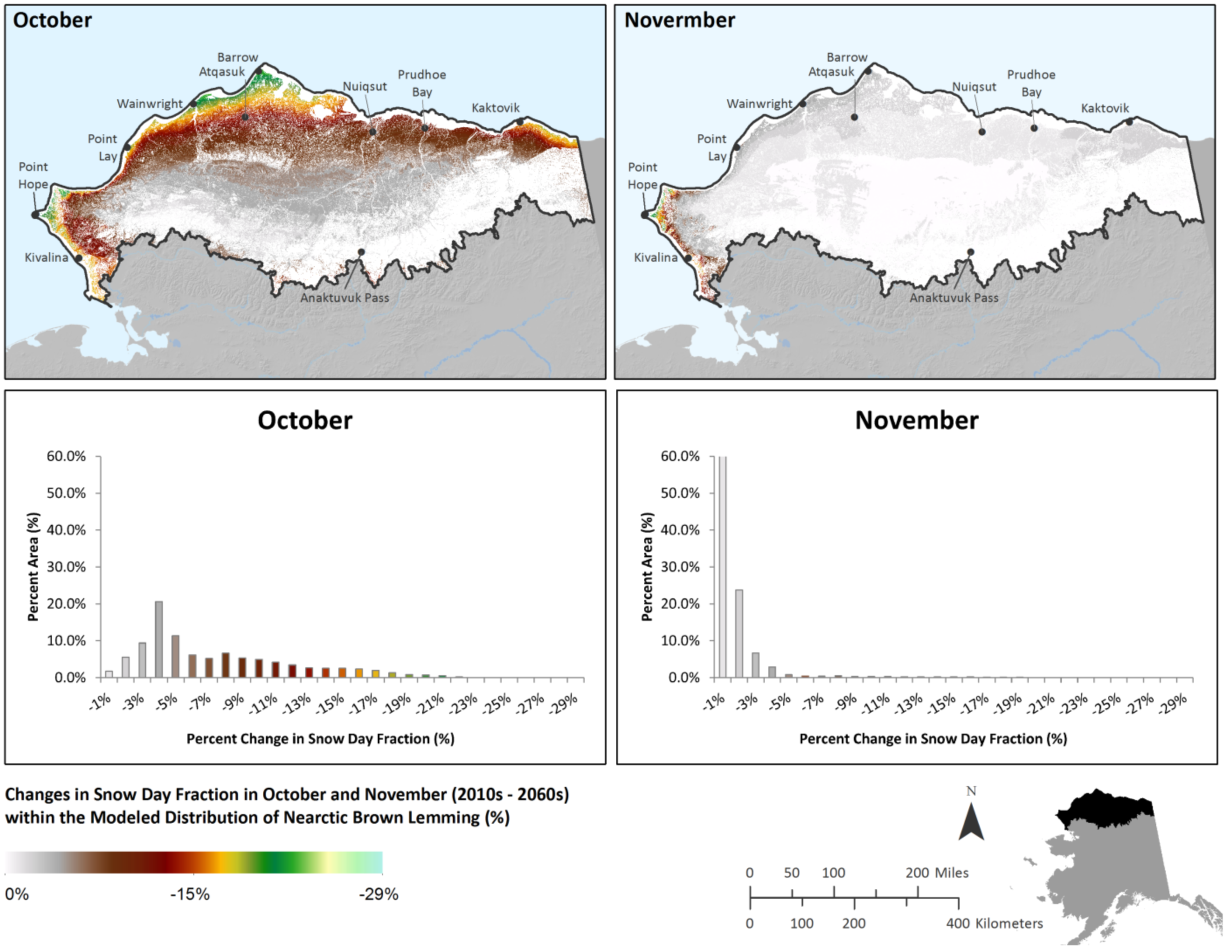

Figure H-6. Modeled change in snow day fraction for October and November between current and long-term (2060) time steps within the current distribution of the Nearctic brown lemming.

Increases in rain on snow events not only restrict access to lemming forage and reduce overwinter survival, they may also result in higher energetic costs, fewer offspring, and higher predation risk (Duchesne et al. 2011, Reid et al. 2011). Modeling the prevalence of rain on snow events by sub-region and month (Figure H-7) suggests that some sub-regions may see substantial increases in snow loss, icing, or compaction due to rain on snow events. These events are likely to vary widely by sub-region, with the Noatak River sub-region seeing the greatest increases, while spring drying in the Porcupine River area suggests less spring rain.

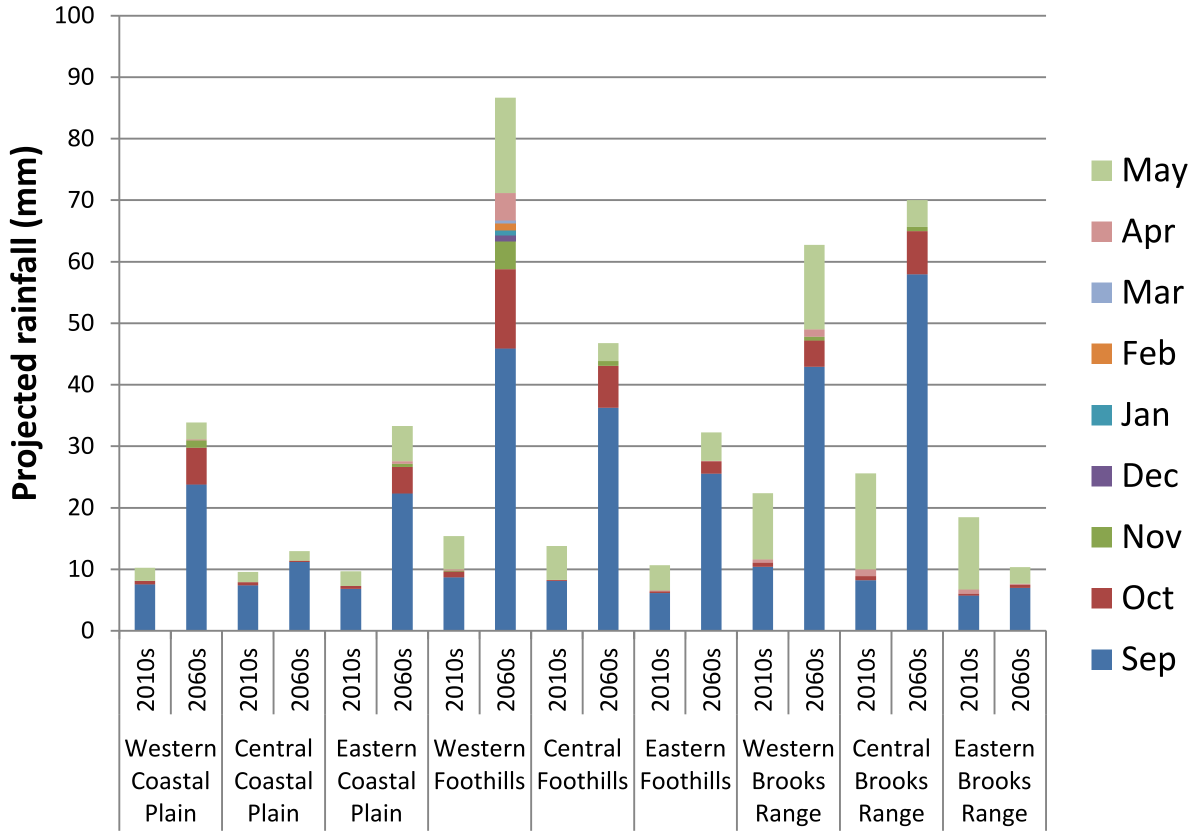

Figure H-7. Estimated current (2010s) and long-term (2060s) shoulder season and winter rainfall by sub-region.

Snow conditions seem particularly influential in this winter breeding species, and early and deep snow provides maximal insulation for the lemmings living in their winter nests (Duchesne et al. 2011; Reid et al. 2011). Our results indicate that snow quality and quantity across North Slope study area are expected to change over the three time-steps considered, which could have implications for lemming population cycling and abundance, as well as direct effects on predator populations. Snow related changes in relation to lemming distribution in the North Slope study area indicate potential for increases in autumn snow depth, but net losses in winter and spring; a shorter snow season as a result of later freezing dates; and an increase in early winter rain on snow events. Snow is expected to accumulate later and start to melt earlier (see Section C. Abiotic Change Agents), and winter rain and thaw can make snow less insulative.

A lemming outbreak depends, at least in part, on winter and spring reproduction under the snow, so winter food availability and thermal conditions are crucial (Reid et al. 2013). Using population models, Gilg et al. (2009) found that decreases in the amplitude of lemming population fluctuations in eastern Greenland could result from longer snow-free periods (later onset and earlier melt) and increases in thaw-refreeze events in winter. These factors have also been implicated in the lengthening of the cycle period on Wrangel Island (Menyushina et al. 2012). Climate related increases in the length of the lemming population cycle could result in decreases in maximum population densities, which is particularly detrimental to predators (e.g. arctic fox, gyrfalcon) that are adapted to make use of the years of greatest prey abundance (Gilg et al. 2009).

At Point Barrow, lemming outbreaks occur every 4 to 6 years (Pitelka and Batzli 1993). It is unclear as to whether the projected increases in rain on snow events and decreases in snow duration could affect brown lemming periodicity of population cycles on the North Slope, which would require monitoring to identify such patterns.

Growing Season Length

Climate models suggest that growing season length (based on estimates of unfrozen season length) is projected to increase, on average, anywhere from 10 to 16 days across the North Slope study area, with the smallest increases seen in more southern and inland communities, and the greatest increases seen in coastal communities to the west. For the Nearctic brown lemming, almost 98% of their current distribution is expected to see an increase of between one and two weeks in the growing season by 2060 (Table H-11).

Table H-11. Predicted change over the near-term (2020) and long-term (2060) in abiotic change agent, length of growing season, within the distribution of the Nearctic brown lemming in the North Slope study area.

Nearctic Brown Lemming	Length of Growing Season (LOGS)		
	0 - 6 Days	7 - 14 Days	> 14 Days
Near-Term Future	100%	-	-
Long-Term Future	-	98%	2%

Over short time scales, a longer growing season would likely be beneficial to lemmings directly through increases in vegetation biomass, which could provide more summer forage and allow for greater winter food storage. However, over longer time scales, longer, warmer growing seasons are projected to alter ecosystem boundaries between the various tundra vegetation communities by increasing the relative abundances and cover of deciduous shrubs species (such as birch, willow and alder) (Walker et al. 2006, Myers-Smith et al. 2011). Results from the ALFRESCO model (see Section C. Abiotic Change Agents) corroborate this finding, with predicted increases in shrub habitats and net losses of graminoid vegetation across the study area by 2060. Losses of graminoid vegetation are predicted to be the most pronounced in the Brooks Range ecoregion. If wet graminoid tundra is replaced by drier shrubbier tundra, this could result in a loss of preferred habitat for brown lemmings, but increases in preferred habitat for collared lemmings.

Climate Summary

Overall, our assessment of abiotic climate variables suggest the Nearctic brown lemmings will be moderately to highly vulnerable to climate change, due to its close association with the snow pack and associated snow dynamics. These changes will be most pronounced in the long-term future (Table H-12). This species relies heavily on snow cover for winter insulation and predator avoidance. Snow volume is predicted to increase during the autumn months across the North Slope study area, yet there will likely be net losses during winter and spring, which can affect overwinter survival. By 2060, DOF is expected to be delayed by 2 weeks, which could be both harmful (less time under snow, increased exposure to predation) or beneficial (greater winter food storage) to brown lemmings. Projected increases in early winter icing events can restrict access to lemming forage and reduce overwinter survival. Projected increases in growing season length and associated warmer temperatures in the near-term will likely be beneficial to lemmings directly through increased vegetation biomass (summer forage) and allow for greater winter food storage, while long-term changes may result in losses of preferred graminoid habitats as they are replaced with shrubbier habitats.

Table H-12. Summary of abiotic change agents used in the assessment for Nearctic brown lemming and projected effects.

Indicator	Short-term trend	Long-term trend	Impact to	Effect
Snow volume	n/a	+	overwinter survival	+/-
Date of freeze (DOF)	negligible	-	habitat availability	+/-
Snow day fraction	+	+	forage availability/ overwinter survival	-
Growing season length, summer temperature	+	+	short-term forage availability, long-term habitat loss	+/-

4.6. Current Status and Future Landscape Condition

The intersection of the Nearctic brown lemming distribution map with the Landscape Condition Model indicates that the majority of lemming habitat in the North Slope study area is classified as being in very high (intact) condition under all scenarios (Figure H-8).

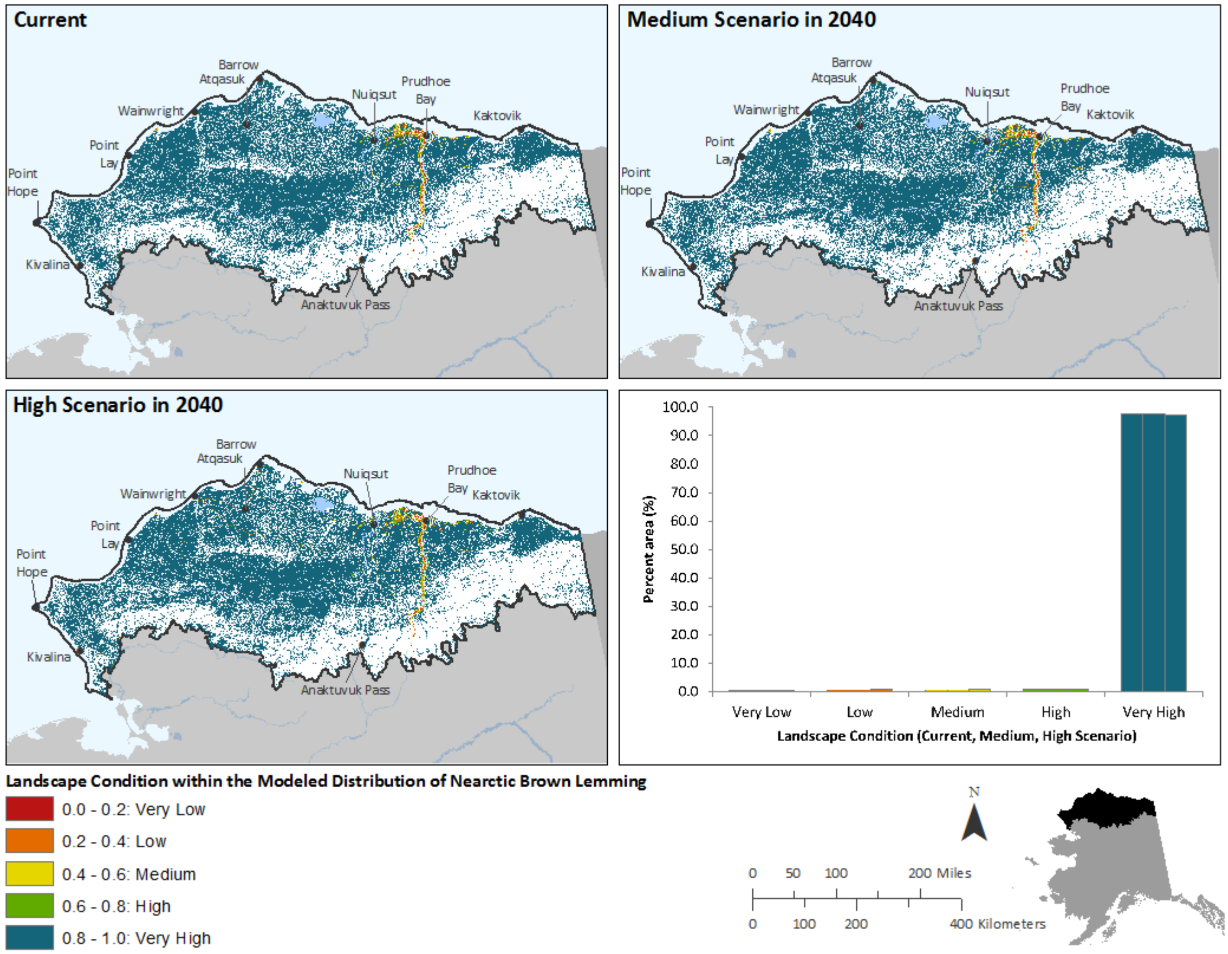

Figure H-8. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current distribution of Nearctic brown lemming in the North Slope study area.

4.7. Limitations and Data Gaps

The AKGAP distribution model for the Nearctic brown lemming was the best available model that we could obtain for this assessment, yet associated accuracy statistics were low. An improved distribution model, or alternative data to test the model are a priority. A suitable snow-depth layer for the North Slope study area would allow for better interpretation and prediction of snow characteristics in relation to sub-nivean habitat availability.

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5. Arctic fox (Vulpes lagopus)

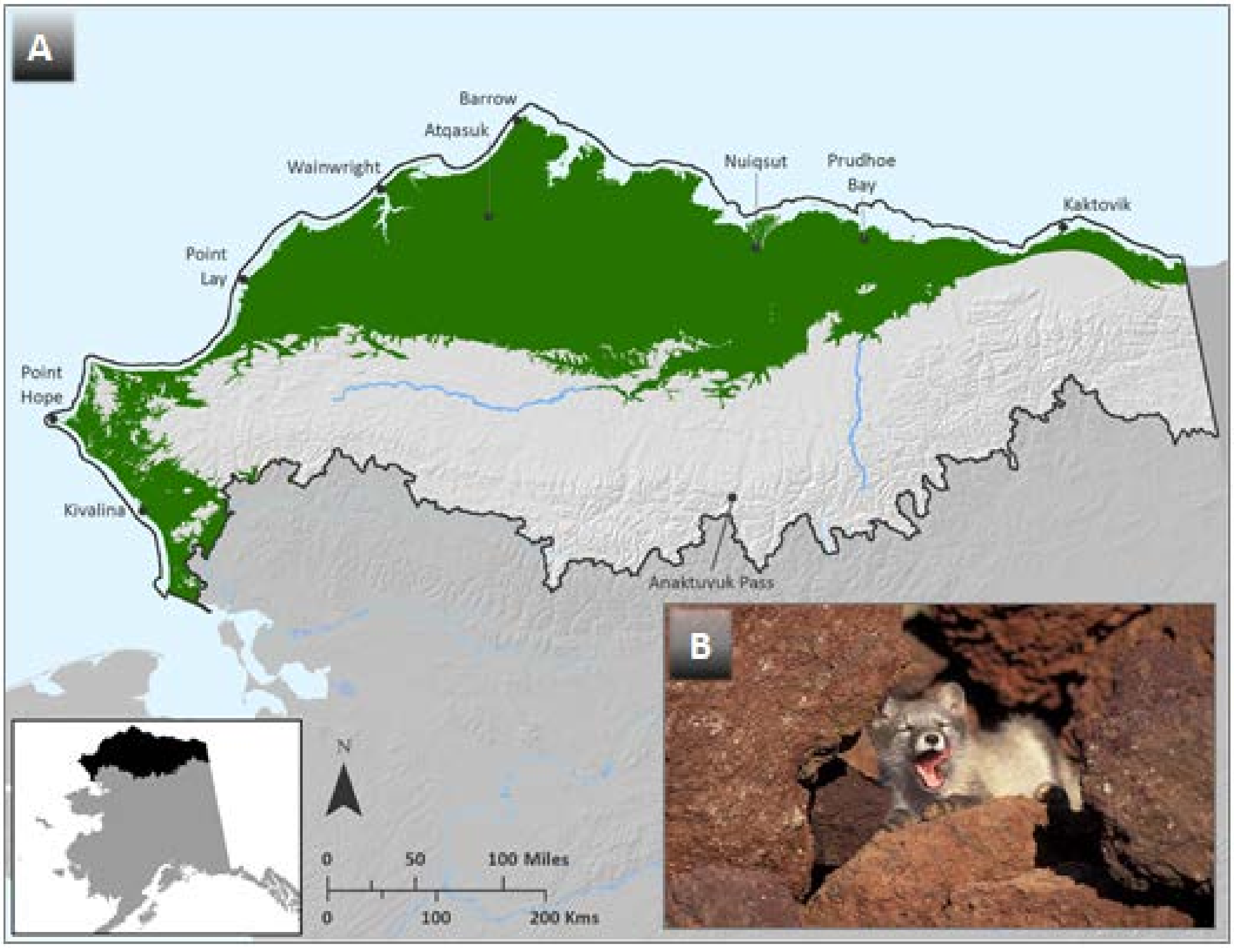

Figure H-9. Current modeled distribution of Arctic fox (*Vulpes lagopus*) in the North Slope study area (A) and juvenile Arctic fox, photo from Animal Diversity Web (B).

5.1. Introduction

The Arctic fox (*Vulpes lagopus*) is a medium-sized canid and opportunistic predator restricted in distribution to the circumpolar tundra biome (Burgess 2000). In Alaska, it occurs throughout the coastal plain north of the Brooks Range and in coastal regions southward as far as the Kuskokwim River Delta. It also occurs on the Aleutian Islands, where it was introduced during the early 1900s by fox farmers (Bailey 1993, Burgess 2000). The southern limit of the Artic fox breeding range is probably determined by the northward range of the red fox (*Vulpes vulpes*), which is aggressive toward the Arctic fox. In many Arctic areas, the Arctic fox is the most abundant mammalian predator, affecting breeding success of migratory birds and possibly also lemming cycles.

The Arctic fox is a year-round resident of the Arctic Coastal Plain. It is highly adapted for survival in such a very cold, strongly seasonal environment (Burgess 2000), where it remains active throughout the 8-9 month Arctic winter. Some of its cold-tolerant adaptations include thick fur, large fat reserves, a specialized heat retaining circulatory systems in its feet, and the ability to lower its metabolic rate to endure periods of starvation.

In North America, the Arctic fox is abundant and the overall population probably ranges in the tens of thousands of individuals (Angerbjörn et al. 2012). An estimate of the size of the Arctic fox population across the North Slope ecoregion is unknown. Most populations fluctuate widely in numbers between years in response to varying lemming numbers (IUCN 2014). In most areas, however, population status is believed to be good. Density estimates within the North Slope study area range from 1/13 km^2 in the Prudhoe Bay Oil Filed (Burgess et al. 1993) to 1/50 km^2 in the Outer Colville Delta (Truett and Johnson 2000).

Breeding occurs in March or April and gestation lasts roughly 52 days. Arctic fox den sites are used each year, though not necessarily by the same breeding pair. Den sites are typically located on mounds, low hills, and low ridges that have a deep active layer and stable surface, and are generally drier than surrounding lowlands with sandy soils (Burgess 2000). Dens are selected based on proximity to good foraging areas and distance from other occupied dens (Szor et al. 2008).

Arctic fox primary prey preferences change between seasons. For much of the year, Arctic fox primarily consume lemmings, voles, and other small mammals (Burgess 2000). Arctic fox populations fluctuate annually, with peaks in abundance occurring every 3 to 4 years in relation to microtine rodent abundance, specifically Nearctic brown lemming (*Dicrostonyx trimucronatus*; Angerbjörn et al. 1999). Fluctuations in lemming abundance generate oscillations in Arctic fox productivity and, consequently in the predation pressure imposed by Arctic fox on secondary prey species such as geese and shorebirds (Gauthier et al. 2004). During winter, foxes may also range out onto sea ice to consume carrion from polar bear kills and other marine mammal carcasses (Burgess 2000, Pamperin et al. 2008).

During the tundra bird nesting season, Arctic fox exhibit a strong preference for eggs and consume eggs even in years when microtine rodents are abundant (Stickney 1991, Bantle and Alisauskas 1998). Egg foraging is most successful in wet meadow habitats where ducks and shorebirds nest in high numbers. These birds are not able to successfully defend against Arctic fox. Arctic fox foraging in pingo habitats also occurs, but nest sites are typically less dense and are primarily occupied by geese, which are better able to defend nest sites.

5.2. Conceptual Model

The conceptual model below (Figure H-10) is based on literature review and describes the relationship between the various change agents and natural drivers for Arctic fox. The boxes and arrows represent the state of knowledge about the Arctic fox and its relationships to each change agent. The arrows and red text represent/describe relationships between the change agents, natural drivers, and primary habitat for the Arctic fox. The primary change agents selected for this CE include: climate change, wild land fire, invasive species, land use change (i.e. human development), and harvest and predation.

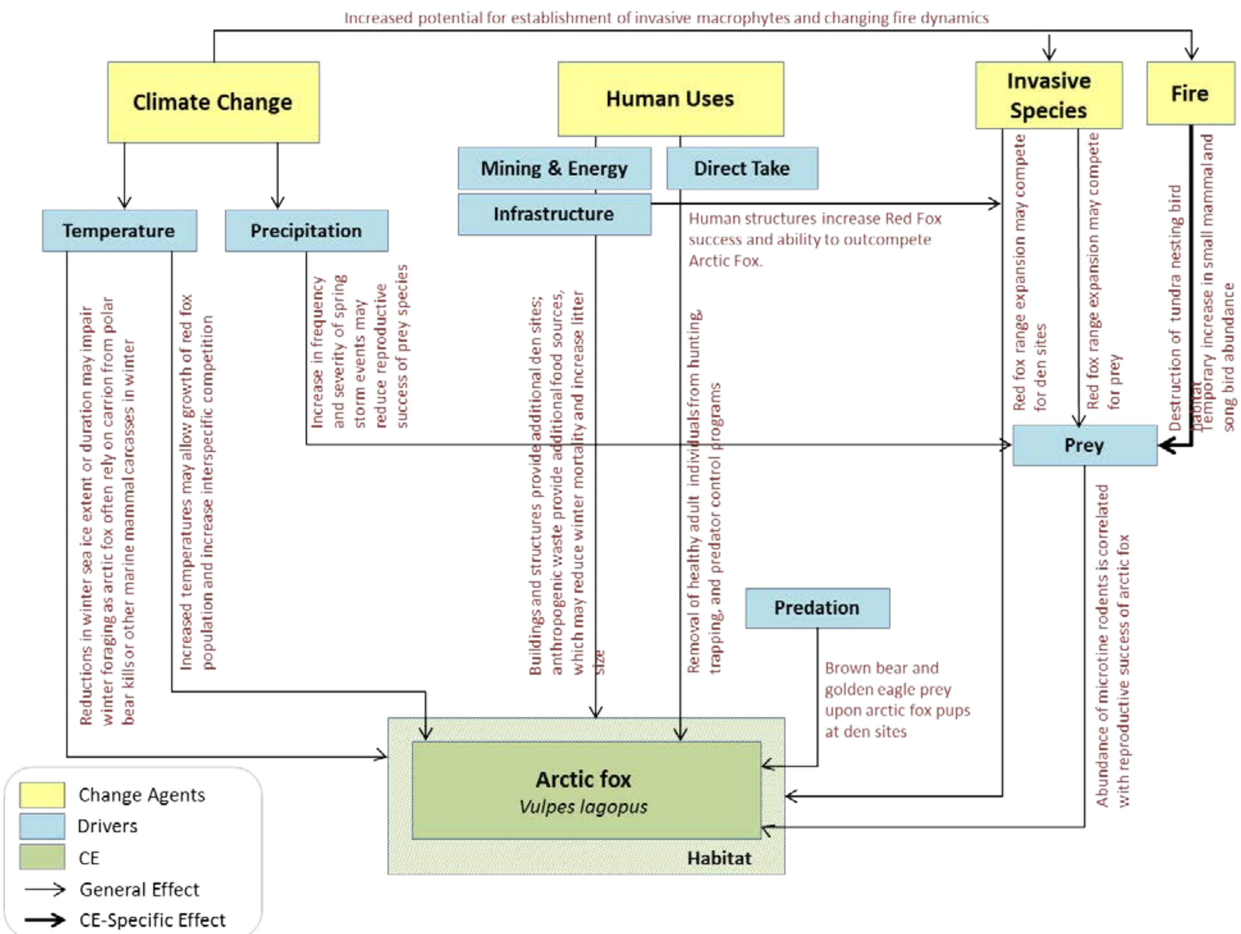

Figure H-10. Conceptual model for Arctic fox (*Vulpes lagopus*) in the North Slope study area.

5.3. Attributes and Indicators

Attributes and indicators helped to define the relationships between CEs and CAs, and, where possible, the thresholds associated with these relationships. Based on the assessment of available indicators, spatial data used to assess the status of the Arctic fox included: mean annual temperature, growing season length, active layer thickness, total snow volume, and landscape condition (Table H-13).

Table H-13. Attributes and indicators for the Arctic fox.

CA	Ecological Attribute	Indicator (unit of measure)	Effect/Impact	Indicator Rating (metric)			
				Poor	Fair	Good	Very Good
Climate	Habitat availability[6]	Annual mean temperature	Warmer temperatures are associated with northern expansion of red fox, which may outcompete Arctic fox for prey and denning sites. May also result in flooding of dens.	Above average		Average	Below average
	Prey availability[7]	Growing season length	A longer growing season could result in higher plant biomass and increased food resources for prey species.	Below average		Average	Above average
	Habitat availability[8]	Active layer thickness	A deeper active layer could result in more denning habitat and increased pup survival.		< 0.5 m	0.5 m	> 0.5 m
	Prey availability[9]	Total snow volume (proxy)	Changes in snow characteristics may alter sub-nivean habitats, access to dens, and may impede access to lemming prey.	Above average		Average	Below average
Anthropogenic	Habitat condition[10]	Landscape condition model (human footprint)	Increased hunting pressure; Increased red fox establishment success.	< 1km	1 to 2 km		> 2km

[6] Based on Hersteinsson and MacDonald 1992 and Pamperin et al. 2006.
[7] Based on Martin et al. 2011.
[8] Based on Tannerfeldt et al. 2003 and Szor et al. 2008.
[9] Based on Duchesne et al. 2011.
[10] Based on Burgess et al. 1993, Burgess 2000, Hammerson and Cannings 2004, and Bart et al. 2013.

5.4. Distribution Model

We used predictive models generated by the Alaska Gap Analysis Project (AKGAP) to describe the distribution of the Arctic fox across the North Slope study area (see Section H.1.1.). The Arctic fox is widely distributed across the Beaufort Coastal Plain (Figure H-9). The species distribution does not appear to extend into the Brooks Foothills or Brooks Range, where habitats are likely considered unsuitable.

A total of 1,425 occurrence records were obtained from various sources to test the model and generate a model accuracy (classification success) statistic (Table H-14). Classification success (CS) values for the Arctic fox AKGAP distribution model were 0.95, indicating high model quality.

Table H-14. Datasets used for Arctic fox.

Dataset Name	Data source
Gap Analysis distribution model for Arctic fox	Alaska Gap Analysis Project, AKNHP
Gap Analysis terrestrial vertebrate occurrence geodatabase database records for Arctic fox*	Alaska Gap Analysis Project, AKNHP
Fox control sites (2010-12)	USFWS
Fox den long term monitoring at Prudhoe Bay	ABR
Museum specimen records for Arctic fox	BISON database (http://bison.usgs.ornl.gov/#home)

*Sources for Gap Analysis Vertebrate Occurrence records for Arctic fox are a compilation of museum records and field survey data obtained from various agencies and researchers. A full bibliography of all data sources for this species is included in the North Slope Data Discovery Memo.

5.5. Abiotic Change Agents Analysis

Temperature

Mean annual temperature within the range of the Arctic fox is expected to increase by as much as 2.9 °C in some areas by the 2060s. Increases will be highest in the northern part of the species range, in the vicinity of Barrow and in the west around Point Hope (Figure H-11). Temperature increases will be most pronounced during winter months (see Section C. Abiotic Change Agents). By 2060, January temperatures are expected to increase by > 1.3 °C throughout the Arctic fox's current range (Table H-15).

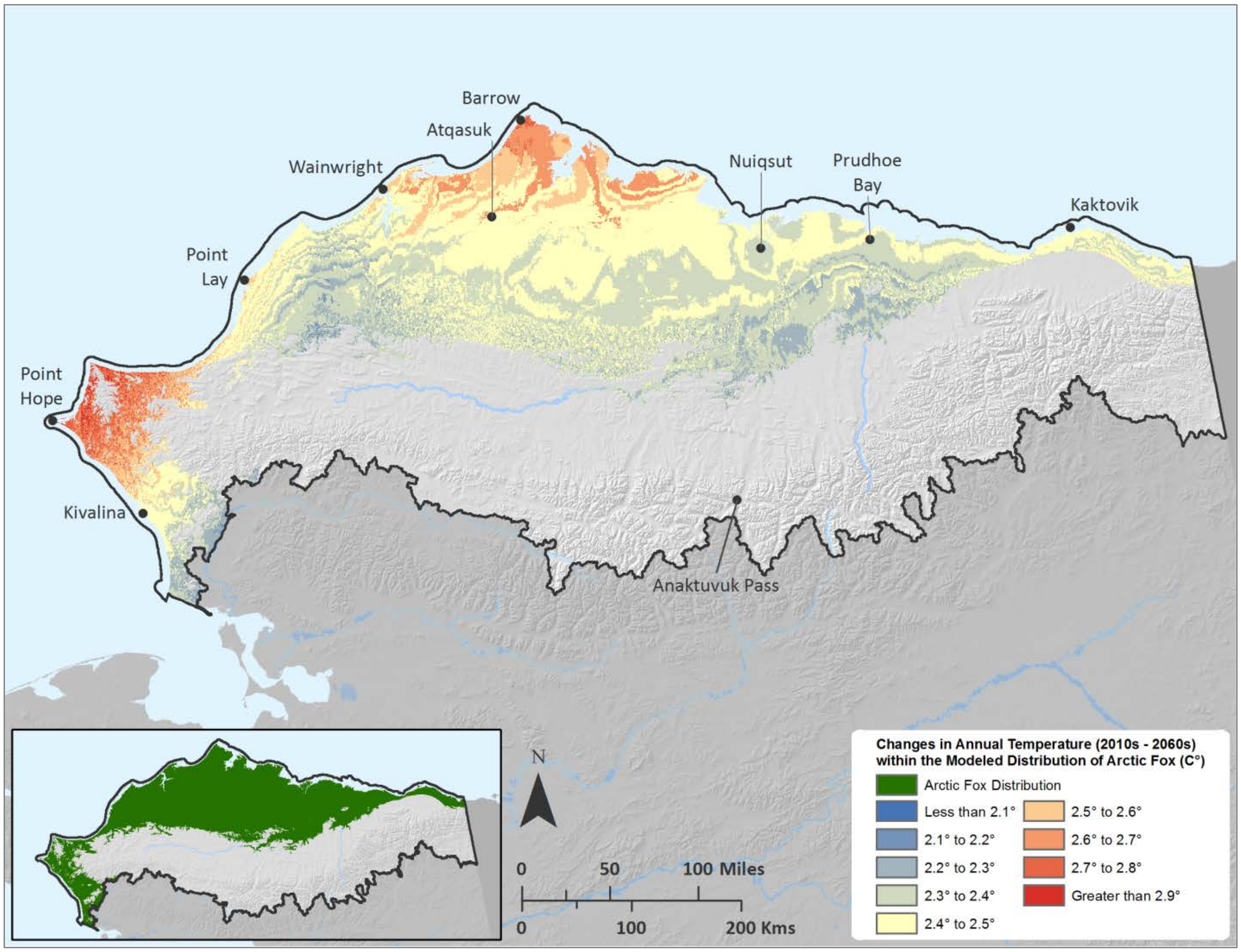

Figure H-11. Changes in mean annual temperature within the modeled distribution of the Arctic fox.

Table H-15. Predicted change over the near-term (2020) and long-term (2060) in abiotic change agents, mean annual temperature, mean July temperature, and mean January temperature, within the distribution of the Arctic fox in the North Slope study area.

Arctic fox	Δ Annual Temp		Δ July Temp		Δ January Temp	
	0 - 1.3°C	> 1.3°C	0 - 1.3°C	> 1.3°C	0 - 1.3°C	> 1.3°C
Near Term	100%	-	100%	-	100%	-
Long Term	-	100%	74%	26 %	-	100%

Regional warming is likely to affect Arctic foxes by impacting habitat condition and availability of prey, primarily through increased competition with red fox (*Vulpes vulpes*) and changes in lemming abundance.

The Arctic fox's greatest predator and competitor is the red fox. Red foxes are superior hunters to Arctic foxes and are known to prey on Arctic fox kits and adults. The southern range extent of Arctic fox on the

North Slope is likely determined by the northern range extent of red fox (Hersteinsson and Macdonald 1992). Red fox are larger than Arctic fox but are currently uncommon outside of river corridors on the Beaufort Coastal Plain. Warming temperatures may increase the suitability of red fox habitat on the Beaufort Coastal Plain which could potentially lead to their expansion in the ecoregion. Where their ranges overlap the two fox species may compete for resources and the red fox is often dominant (Pamperin et al. 2006). This would likely cause increased competition for den sites and the potential for reduction in the Arctic fox population (Burgess 2000, Szor et al. 2008).

The encroachment of the red fox into more northerly habitats has already been reported in Alaska, where the red fox appears to be increasingly common in areas of oil fields that were previously occupied by Arctic fox (Burgess 2000, Stickney 2014). Surveys conducted in the Prudhoe Bay oil fields showed a steady increase of red fox natal dens from two in 2005 to a peak of fifteen in 2011, while simultaneously Arctic fox natal dens declined from a high of eleven in 2005 to two to three since 2010 (Stickney 2014; Figure H-12).

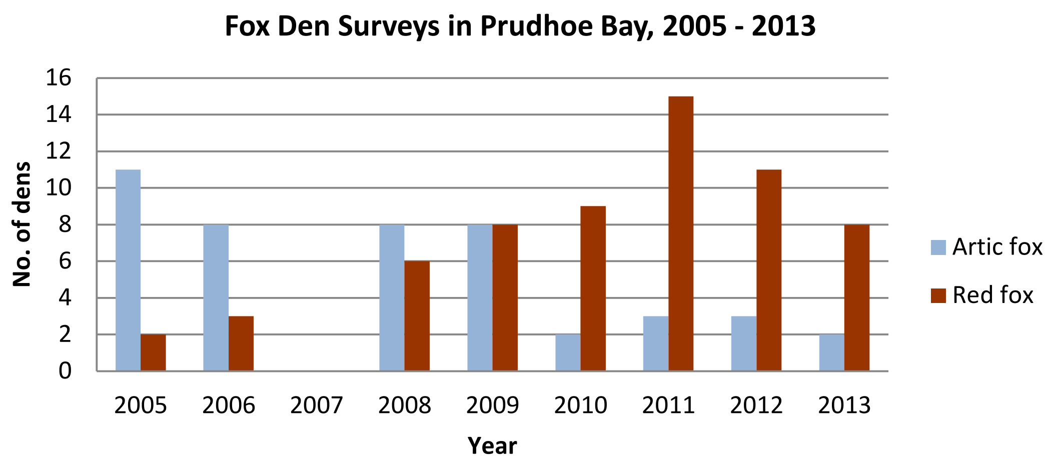

Figure H-12. Number of neonatal dens of Arctic and red foxes in the Prudhoe Bay area, 2005 – 2013 (adapted from Stickney 2014).

Other temperature related impacts include earlier breakup and spring flooding, which may affect Arctic foxes in their winter dens. Warmer temperatures may also result in early emergence from winter dens and the subsequent death of altricial neonatal offspring (Martin et al. 2009).

Snow Volume

Warmer temperatures could result in changes in snow dynamics, a shorter snow season, reduced snow extent in late winter, and changes in snow depth, compaction, and icing. Unfortunately, a spatial layer representing total snow depth was not available for this comparison. Instead, we used projected monthly snowfall (precipitation × snow day fraction) and projected non-summer rainfall for estimating potential changes in snow depth. These results are described in detail above, under the Nearctic brown lemming section. While snowfall is expected to increase during the fall and early winter months across the North Slope study area, there will likely be less snowfall during late winter and spring months (Figure H-13).

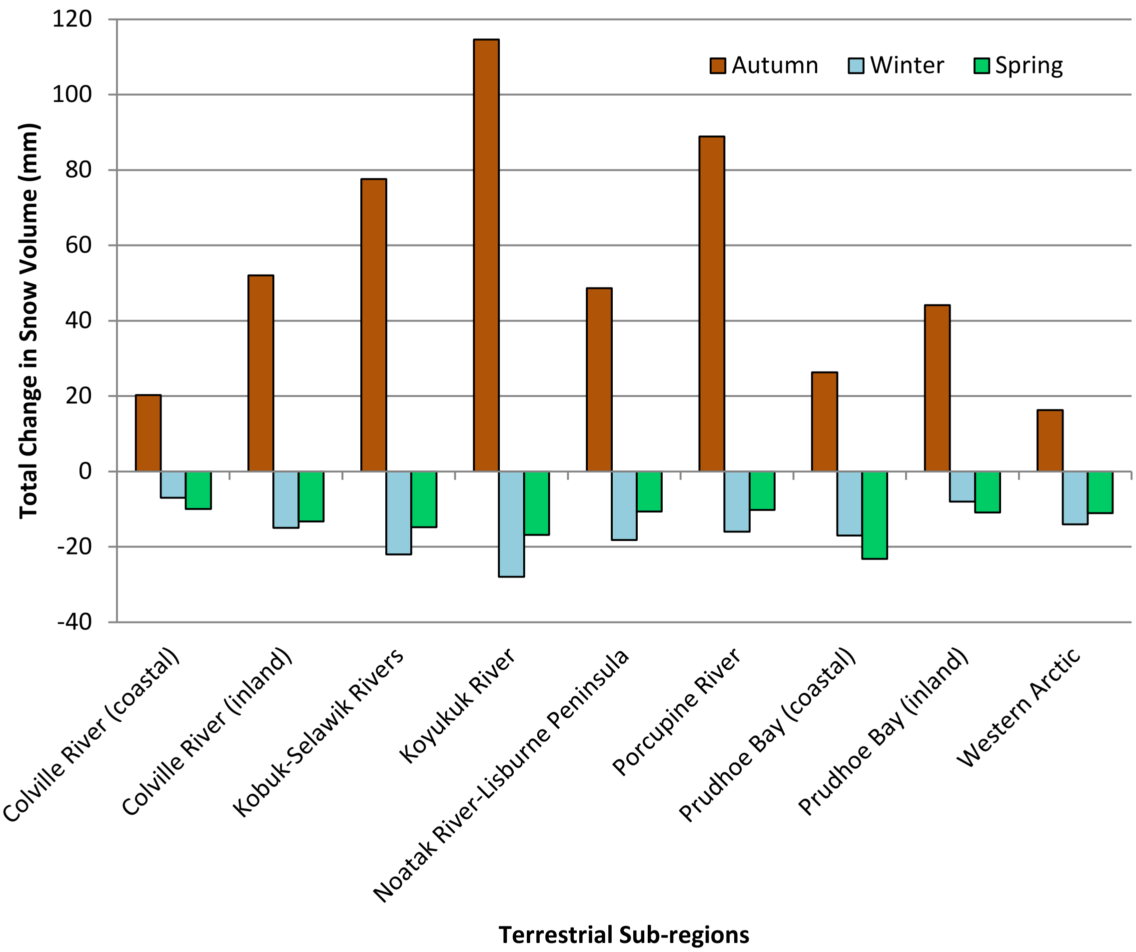

Figure H-13. Projected snowfall (mm rainwater equivalent) summarized by three-month period (SON, DJF, MAM) and ecological sub-region.

An earlier end to the snow season and more frequent rain on snow events are likely to negatively impact lemmings, the primary prey item of the Arctic fox. Lemmings do not hibernate in the winter – instead, they continue to forage in the space between the frozen ground and the snow. The lemming population cycle is dependent on long, cold, stable winters. Mild weather and wet snow lead to a collapse of these sub-nivean spaces, destroying lemming burrows. A combination of milder and shorter winters is predicted to decrease the regularity of lemming cycles (see Section H.2). Declines in Arctic fox numbers have already been attributed to loss of lemming cycling in certain Scandinavian populations (IUCN 2014).

Growing Season Length

By 2060, growing season length is expected to increase by one to two weeks throughout the current range of the Arctic fox (Table H-16). Increases in growing season length could indirectly have positive implications for the Arctic fox by resulting in increases in plant biomass, which allow for more food to be readily available to prey species. Conversely, warmer temperatures and a longer growing season will likely increase the abundance of parasites and disease that could potentially negatively affect fox populations.

Table H-16. Predicted change over the near-term (2020) and long-term (2060) in abiotic change agents, mean July temperature and length of growing season, within the distribution of the individual Terrestrial Fine-Filter CEs in the North Slope study area.

Arctic fox distribution	Length of Growing Season			
	< 0 Days	0 - 6 Days	7 - 14 Days	> 14 Days
Near-Term Future	100%	-	-	-
Long-Term Future	-	-	96%	4%

Active Layer Thickness

Den sites are typically located in sites that have a deep active layer, and are generally drier than surrounding lowlands with sandy soils (Burgess 2000). According to Tannerfeldt et al. (2003), the permafrost layer in the Arctic tundra represents a physical barrier for Arctic foxes trying to dig new dens in spring. Den sites may then be limited to areas where the active layer is sufficiently deep and where soil conditions allow burrowing (Szor et al. 2008). A deeper active layer as a result of warming could potentially allow for more denning habitat, which could result in higher pup production.

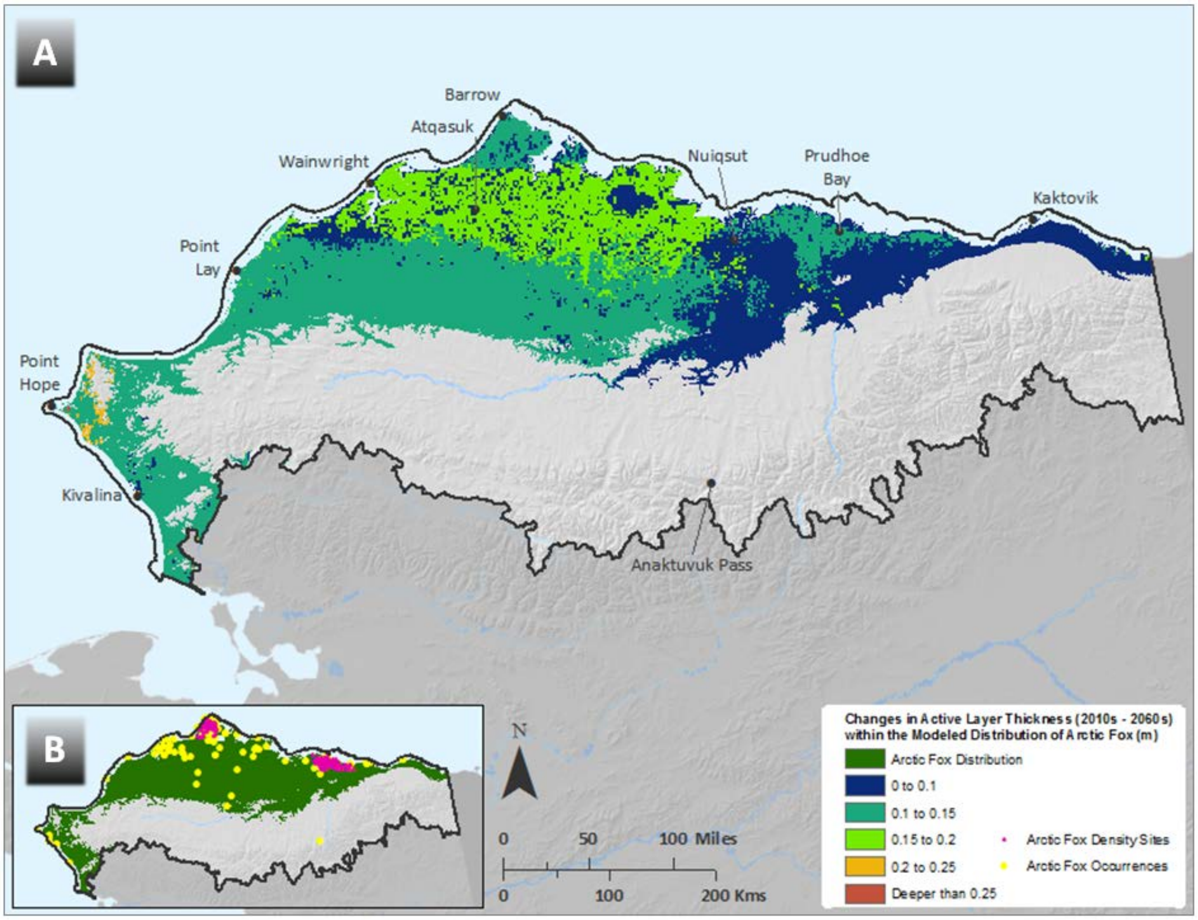

Figure H-14. Projected changes in active layer thickness within the modeled distribution of the Arctic fox (A), and distribution of fox den sites and known occurrences (B).

Average active layer thickness for the arctic subzones in the North Slope study area range from 0.44 m to 0.55 m (Walker et al. 2003). Because subtle differences in active layer thickness (ALT) can yield large differences in land cover and vegetation (McMichael et al. 1997, Walker et al. 2003) we chose to categorize changes in ALT in Figure H-14 by increments of 0.05 m. ALT changes in known areas of high den densities are expected to increase by an average of 0.1 to 0.15 meters by 2060. To the south of these areas, above the sand sheet, ALT is expected to increase, on average, by 0.15 to 0.2 m. This may allow for more denning habitat to become available in areas adjacent to known denning areas, but other factors that also influence the distribution of fox dens, such as access to prey abundant prey resources, may limit expansion into these areas. Moreover, it should be noted that ALT varies widely across relatively small spatial scales, as can be seen based on maximum and minimum ALT values by sub-region (see Section C. Abiotic Change Agents). Overall increases in ALT may yield new denning sites even in regions with very shallow permafrost, given this spatial variability.

Climate Summary

Overall, our assessment of abiotic climate variables suggest the Arctic fox will be moderately vulnerable to climate change, with positive and negative impacts creating a complex overall picture. Denning sites are likely to be more readily available, but competition with red foxes for these sites may be more intense and more widespread. Prey availability may increase, based on greater overall ecosystem productivity, but unreliable snow conditions may sometimes decimate sub-nivean prey, perhaps exacerbating the amplitude of existing predator-prey cycles (Table H-17).

Table H-17. Summary of abiotic change agents used in the assessment for Arctic fox and projected effects. An * denotes a significant trend.

Indicator	Short-term (2020) trend	Long-term (2060) trend	Impact to	Effect
Annual temperature	+	+*	Increased competition with red fox	-
Snow volume	n/a	+	Loss of lemming prey	-
Growing season length	No change	+	More food for prey species, increases in parasites and disease	+/-
Active layer thickness	+	+	Denning habitat availability, higher pup production	+

5.6. Current Status and Future Landscape Condition

The intersection of the Arctic fox distribution map with the Landscape Condition Model indicates that the majority of habitat in the North Slope study area is classified as being in very high (intact) condition under all scenarios (Figure H-15).

Development does not appear to have a direct negative impact on Arctic fox and the species is not deterred from human-use areas. Past and current industrial activities on the North Slope have probably increased the availability of shelter and food for the Arctic fox. Developed sites within the Prudhoe Bay oil field are used by foxes for foraging on garbage and handouts, and for resting. Foxes do not avoid human activity. In the Prudhoe Bay oil fields, specific individuals have become exceptionally tolerant of development activities and habituated to humans (Eberhardt 1977), and successful litters of pups have been raised within 25 m of heavily traveled roads and within 50 m of operating drill rigs. Foxes use culverts under roads, underground utility corridors in camps, and sections of natural gas pipe as dens (Eberhardt et al. 1982).

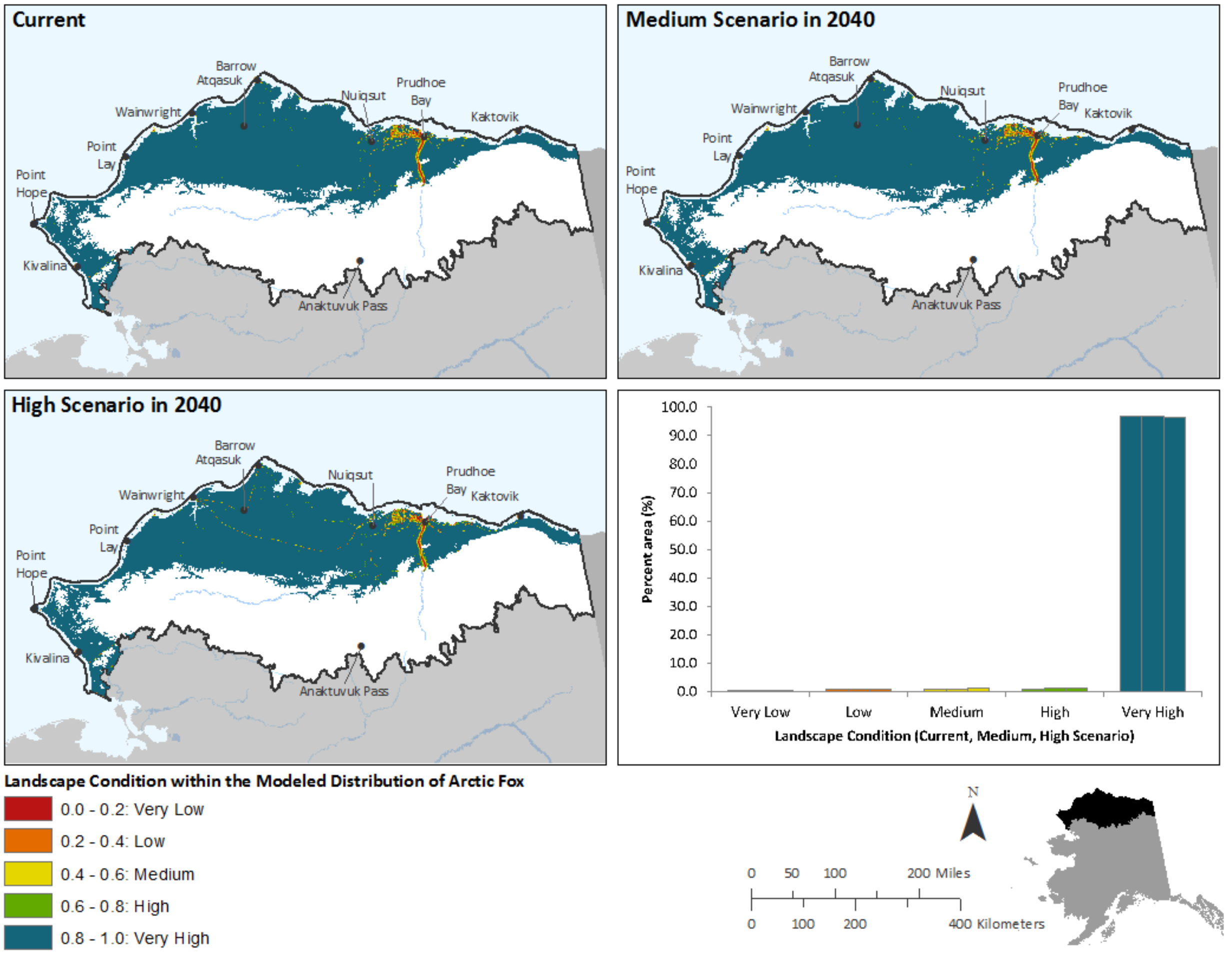

Figure H-15. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current distribution of Arctic fox in the North Slope study area.

Development activities in the Prudhoe Bay oil fields have led to increases in fox numbers and productivity. Studies have indicated that both den density and the rate of den occupancy are higher in the oil field than in adjacent undeveloped areas to the east and west (Eberhardt et al. 1983, Burgess et al. 1993). The availability of garbage as a food source, especially during winter, has been identified as a likely factor responsible for higher densities.

Concern related to higher fox densities includes the possibility of transmission of diseases, especially rabies to humans (Burgess 2000). Recent studies indicate that the increasing ambient temperatures in Alaska and other regions of the Arctic may influence the incidence and distribution of zoonotic and parasitic infections in humans by changing the population density and range of wild and domestic animals and insect hosts. Arctic fox are a potential disease and parasite vector for humans. They are known to carry giardia, toxoplasmosis, and cryptosporidium, which can be transmitted to humans or human water supplies (or humans can transmit them to foxes). Furthermore, rabies is enzootic among the fox populations of northern and western Alaska, with periodic epizootics documented every 3–5 years (the last epizootic in Alaska was in 2006–07) (Hueffer et al. 2013). In early spring, Arctic foxes tend to move inland off the sea ice, increasing the likelihood of coming into contact with domestic animals or humans. Dogs can readily serve as a transmission vehicle of the rabies virus from wildlife to humans (Hueffer et al. 2013). Reductions in sea ice (see data gaps) could force foxes inland much earlier in spring, increasing encounter rates with humans and domesticated pets. Long-term higher densities of foxes could result in reduced nesting success and smaller regional populations of some species of birds (Burgess 2000).

5.7. Limitations and Data Gaps

We did not explore the relationship of Arctic fox and sea ice extent, as this was beyond the scope of the REA. However, sea ice reduction has been cited as one of the leading threats to Arctic fox living in more northerly areas. A reduction in winter sea ice extent or duration may negatively impact Arctic fox by limiting their ability to forage for the carrion of polar bear kills and other marine mammal carcasses in winter. Climate wrought changes in sea ice extent and timing of break-up and freeze-up have already impacted polar bear survival and ring seals are also expected to decline due to climate change (IUCN 2009). A reduction in carrion prey for the Arctic fox as a result of declining sea ice will likely impact their winter survival and reproductive success in years where small mammal abundance on land is not sufficient (Pamperin et al. 2008).

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6. Barren Ground Caribou (*Rangifer tarandus granti*)

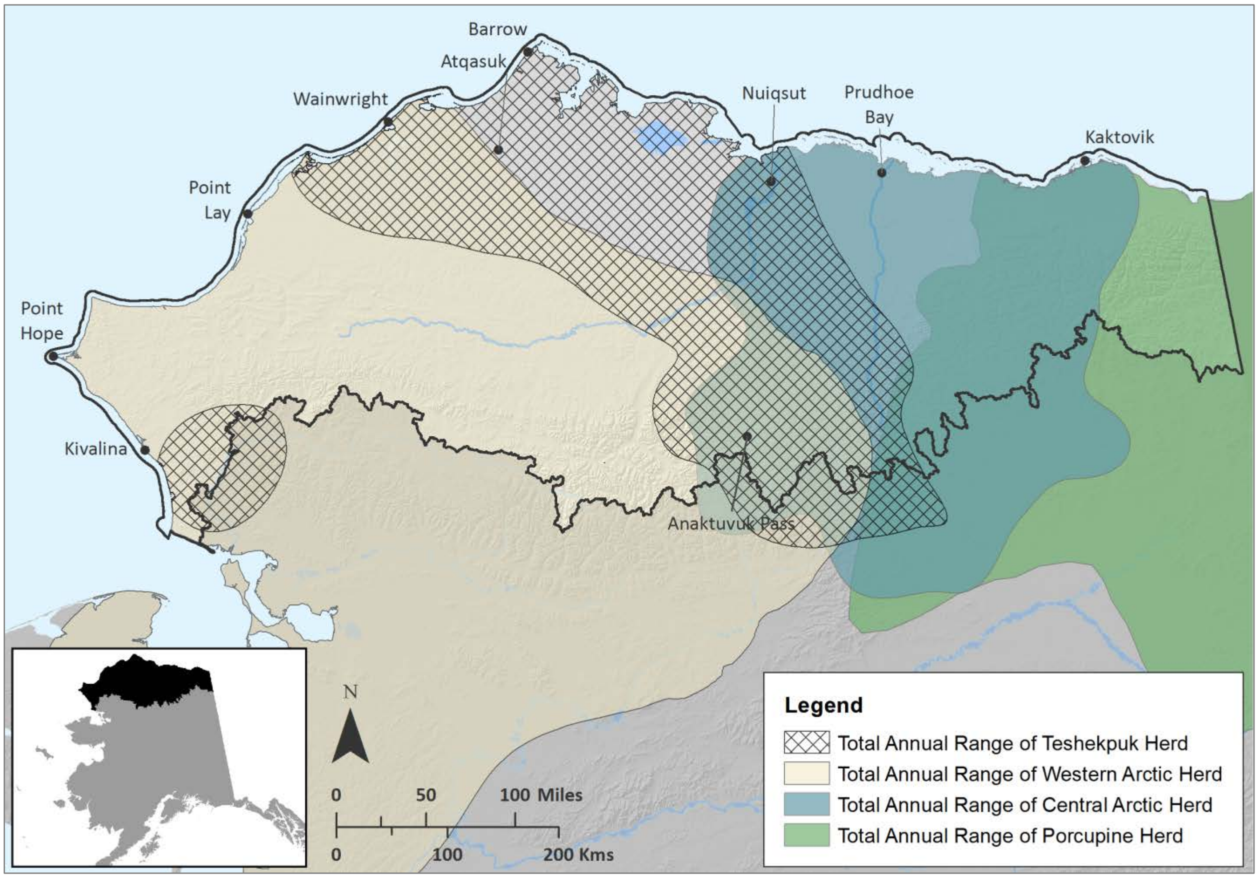

Figure H-16. Generalized range maps for the four barren ground caribou herds present in the North Slope study area: Western Arctic Herd, Teshekpuk Herd, Central Arctic Herd, and Porcupine Herd.

6.1. Introduction

Caribou are circumpolar in their distribution, occurring in arctic tundra and boreal forest regions in North America and Eurasia (MacDonald and Cook 2009). In Alaska, there are 31 recognized caribou herds. Four herds of barren ground caribou (*Rangifer tarandus granti*) use habitats within the North Slope study area for at least part of their annual life cycles: the Western Arctic Herd occupies the western portion of the study area, the Teshekpuk Herd occupies the western-central portion of the study area, the Central Arctic Herd occupies the eastern-central portion of the study area, and the Porcupine Herd occupies the eastern portion of the study area and ranges into Yukon and Northwest Territories (Figure H-16). These herds support a wealth of predator biodiversity and are an important source of food sustaining the health and culture of northern communities (McLennan et al. 2012).

Population size and trends are highly variable between the four herds (Table H-18). The Western Arctic Herd is the largest caribou herd in Alaska and one of the largest in the world, with a population estimate of 235,000 animals as of 2013 (Dau 2013). The population of this herd has been declining since 2003, with a rapid decline since 2011. Similarly, the Teshekpuk Herd was estimated at 32,000 caribou in 2013, less than half of the highest count of 68,000 in 2008 (Parrett et al. 2014). Although the reasons behind the declines are not easily identifiable, poor calf production, poor calf survival, and spikes in adult female mortality are contributing to the declines in both herds. Poor nutrition appears to be playing a role in the Teshekpuk Herd declines whereas caribou of the Western Arctic Herd have maintained good body condition during the population decline (Parrett et al. 2014).

To the east, the population trend for the Central Arctic Herd is less certain. In July 2013, over 70,000 animals were counted, which is similar to their peak in 2010 (Parrett et al. 2014). The 2013 population estimate for the Porcupine Herd was over 197,000 animals, which is the highest ever observed for that herd (Porcupine Caribou Technical Committee 2014). The population last peaked in 1987 at 178,000 caribou, and declined to 123,000 caribou by 2001 (Lenart 2007).

Table H-18. Summary of caribou population size and trend by herd in 2013.

Herd Name	Population Estimate	Population Trend
Western Arctic	235,000	declining
Teshekpuk	32,000	declining
Central Arctic	70,000	stable to increasing (?)
Porcupine	197,000	increasing

Each herd migrates long distances using seasonally available forage resources that are often widely distributed. Seasonality, a function of climate, is the overriding annual variable influencing caribou ecosystem components. Quantity and quality of forage species are governed by the rate of summer growth, whereas in winter, snow depth and density conditions alter availability of forage. Climatic conditions also strongly affect the distribution and abundance of parasites, insects, and diseases that exert varying levels of influence on caribou population dynamics.

6.2. Methods

The Alaska Department of Fish and Game (ADF&G) maintain radio collar and satellite telemetry data for the Western Arctic, Teshekpuk, and Central Arctic herds. ADF&G summarized the telemetry data as kernel densities to delineate the total annual distributions of the three caribou herds. Collar location data points were extracted from the entire annual cycle from 2004 to 2013 for the Teshekpuk Herd and 2004 to 2014 for the Western Arctic and Central Arctic herds (Table H-19). For each day, the location point closest to noon was selected, with no more than one location every six days per individual. The resulting set of points served as the input for kernel density calculations. Kernel density was calculated for individual years and the results were summed to capture annual variability in caribou habitat use. Through a data sharing agreement between ADF&G and AKNHP, these kernel densities were available for the North Slope REA. Kernel densities are based on the daily positions of a small subset of individuals from the total herd. For example, no more than 0.03% of the Western Arctic Herd has been collared. No kernel density or radio/satellite-collar data was available for the Porcupine Herd because of shared management with Canada. The 1983 to 2001 annual range of the herd reported in Griffith et al. (2002) was digitized for this assessment.

Because the ADF&G kernel densities summarize only the annual distributions of each caribou herd, they were not sufficient to address questions related to seasonal range. Neither telemetry data nor seasonal kernel densities were available from ADF&G for this project. The calving range of the Porcupine Herd was digitized from the 1983 to 2001 calving range reported in Griffith et al. 2002. All other seasonal range polygons were hand-delineated based on a variety of past reports and datasets.

Table H-19. Pre-existing datasets selected for analysis of caribou herd distribution (other datasets were digitized from Griffith et al. 2002 or hand-delineated based on a variety of sources).

Dataset Use	Dataset Name	Data Source
Western Arctic Herd	Annual Kernel Density of Western Arctic Caribou Herd 2004 to 2014	ADF&G
Teshekpuk Herd	Annual Kernel Density of Teshekpuk Herd 2004 to 2013	ADF&G
Central Arctic Herd	Annual Kernel Density of Central Arctic Herd 2004 to 2014	ADF&G

6.3. Conceptual Model

The conceptual model below (Figure H-17) is based on literature review and describes the relationship between the various change agents and natural drivers for caribou. The boxes and arrows represent the state of knowledge about the caribou and its relationships to each change agent. The arrows and red text represent/describe relationships between the change agents, natural drivers, and primary habitat for caribou. The primary change agents selected for this CE include: climate change, wildland fire, invasive species, land use change (i.e. human development), and harvest and predation.

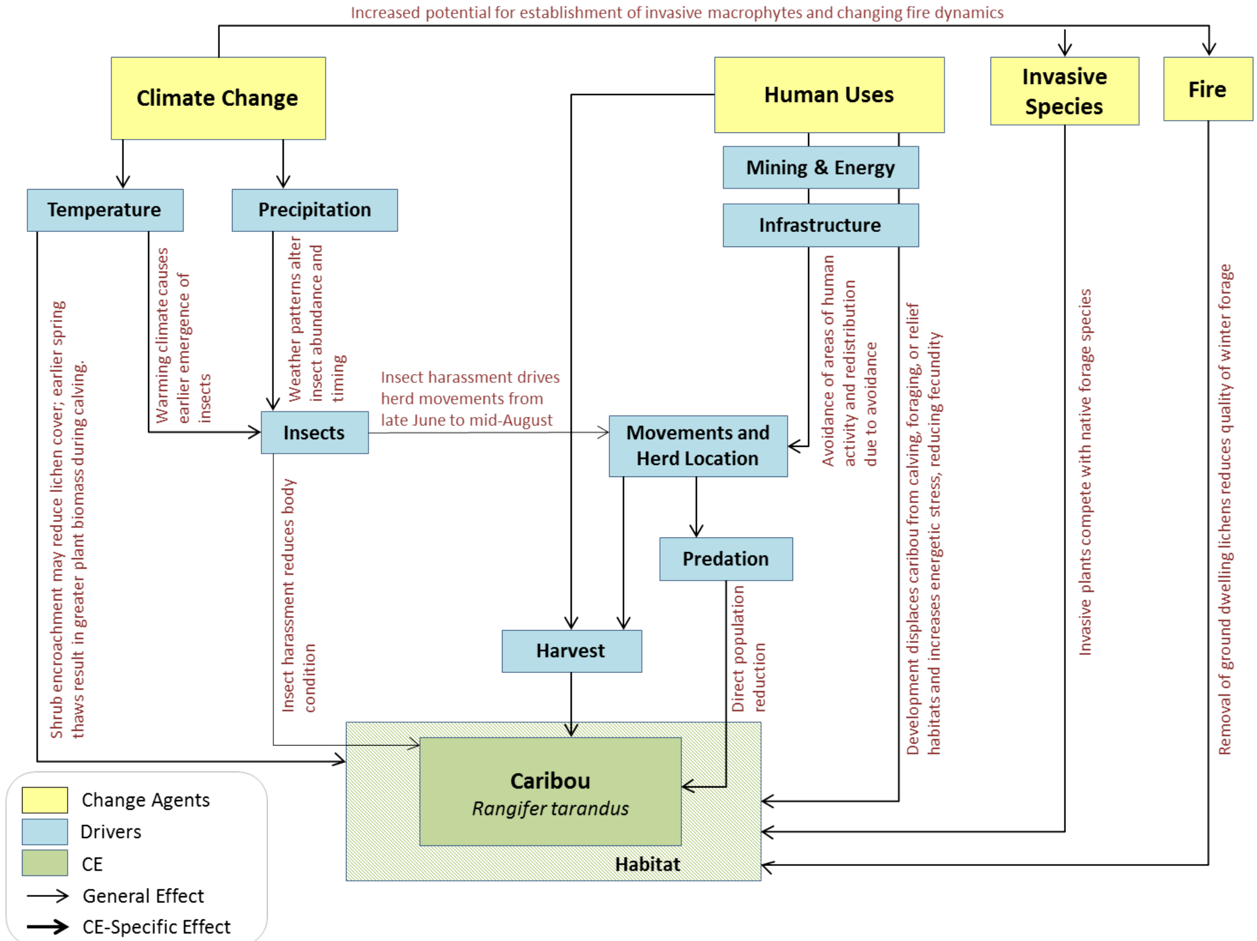

Figure H-17. Conceptual model for caribou in the North Slope study area.

6.4. Attributes and Indicators

Based on the assessment of available indicators, spatial data used to assess the status of caribou included: date of thaw, mean May temperature, growing season length, and landscape condition (Table H-20).

Table H-20. Attributes and indicators for caribou.

CA or Driver	Ecological Attribute	Indicator (unit of measure)	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Forage quality and availability[11]	Growing season length	Earlier spring thaw and a longer growing season could likely result in earlier parturition (Post et al. 2003) and increased calf survival (Griffith et al 2002).	Less than average		Average	More than average
	Forage availability[11]	Date of thaw (snowmelt onset)		Later than average		Average	Earlier than average
	Winter forage availability[12]	Snow day fraction	Icing or rain on snow events can harden the snow pack and restrict access to forage	Snow fraction below 80% for more than one winter month (thresholds unclear)	Snow fraction below 80% for one winter month	Snow fraction below 90% for one winter month	Snow fraction over 90% for all winter months
	Winter forage availability[13]	Snow depth	Areas with low snow levels provide easy travel and easy access to forage.	Above average		Average	Below average
	Insect emergence[14]	Frost-free days	Annual change in daily abundance of arthropods is determined by the number of frost-free days (temp. > 32°F). Earlier hatches can cause insect harassment earlier in the season.	Above average		Average	Below average

[11] Based on Griffith et al. 2002, Sparks and Menzel 2002, Stone et al. 2002, and Post et al. 2003. However, see Section H.7. Caribou Seasonal Forage for discussion of possible reverse effect from trophic mismatch.
[12] Based on Hansel et al. 2011.
[13] Based on Joly and Klein 2011.
[14] Based on Bolduc et al. 2013.

CA or Driver	Ecological Attribute	Indicator (unit of measure)	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	Insect abundance[15]	Mean daily temperature between DOT and DOF	Can also cause an increase in insect populations. Insect abundance (pests) is directly influenced by mean daily temperature. Increased pest-insect abundance (mosquitoes, blackflies, etc.) can cause increased/altered movement of herds and reduction in body condition for individual caribou.	Above average		Average	Below average
Fire	Forage quality[16]	Fire return interval	Lichen is often destroyed by even light burn severity wildfires. Lichens have a much longer recovery time compared to vascular plants (180 yrs until complete recovery).	< 60 years between burns	60 years between burns	180 years between burns	Unburned
Anthropogenic	Habitat quality[17]	Landscape condition	During calving, cows and calves avoid roads, even with low traffic use (<100 vehicles per day), and as a result, are not typically found within one km of the roadway. Proximity of roads to caribou ranges and migration routes increases human access and predation pressure.	LCM = 0 on calving grounds			LCM = 1 on calving grounds

[15] Based on Downes et al. 1985, Witter et al. 2012, and Bolduc et al. 2013.
[16] Based on Jandt et al. 2008.
[17] Based on Cronin et al. 1994.

6.5. Seasonal Distribution and Movement Patterns

MQ TF 4	What are caribou seasonal distribution and movement patterns and how are they related to season and weather?

Barren ground caribou cover large ranges and move long distances seasonally (Figure H-18). Although the exact patterns of movement vary between herds, the factors driving seasonal migrations are relatively constant across the North Slope. The current timing of annual cycle events and migrations, along with factors that drive both the timing and spatial distribution of the annual cycle, are reviewed with a focus on season and weather. The seasonal distributions and movements of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds are described in relation to current and potential future season and weather. Seasonal distribution of the four herds are assessed during calving, summer (insect relief), and winter. Movement patterns are assessed during spring migration to calving grounds and fall migration to winter ranges. The general life cycles of barren-ground caribou herds in the North Slope study area are summarized in Figure H-19. The historic (pre-2004) ranges of the four caribou herds vary, sometimes largely, from the ranges presented in this section.

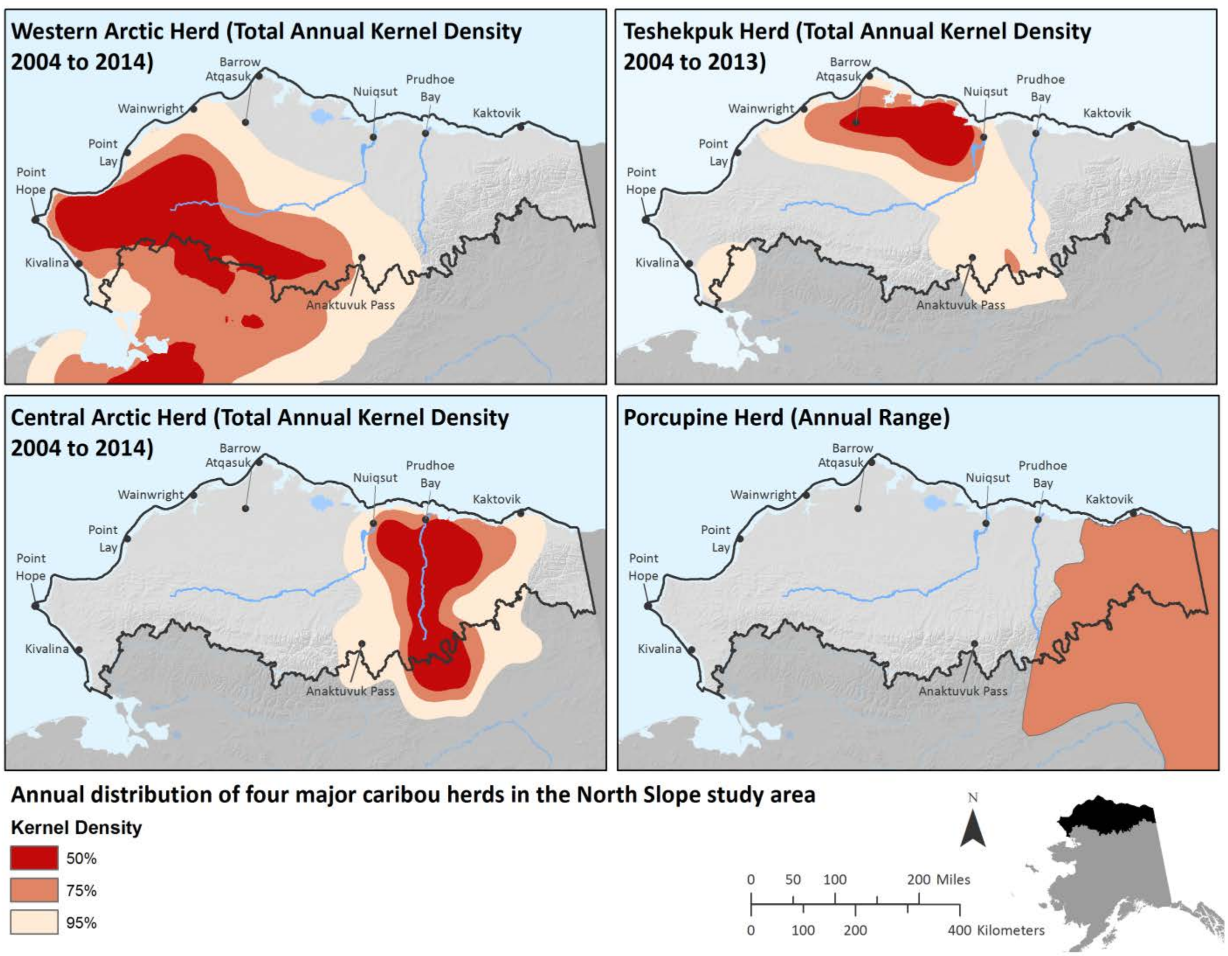

Figure H-18. Annual distribution of Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds.

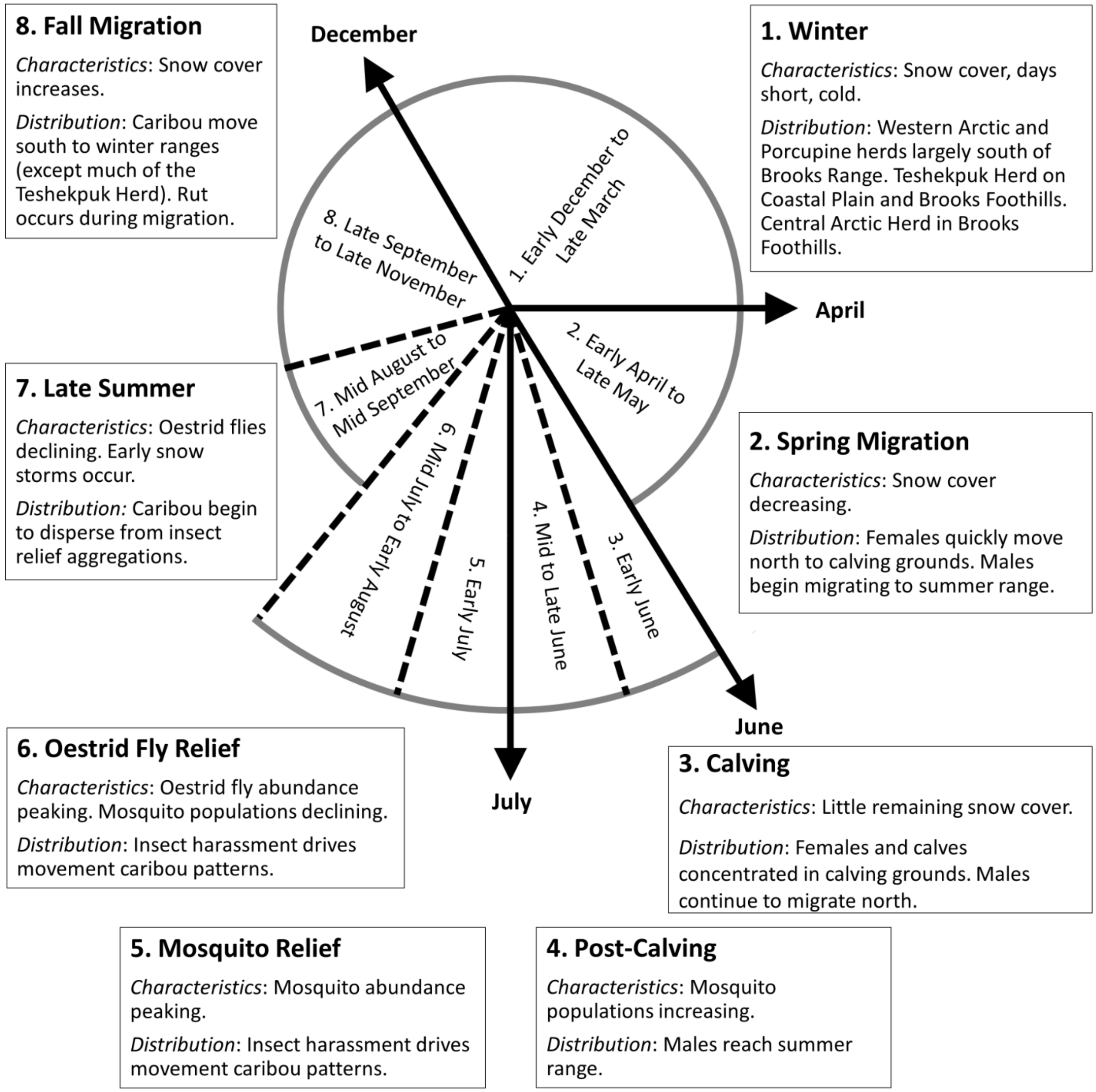

Figure H-19. Generalized movement patterns of North Slope caribou herds by approximate date range.

Calving

Parturient caribou arrive on calving grounds in early June and remain for approximately two weeks or less. Calving is highly synchronized in the North Slope study area, which likely reduces the number of calves taken by predators before calves have developed the physical abilities to avoid or escape predation. Their arrival coincides with or occurs just before emergence of new vegetation in the calving grounds (Person et al. 2007), a time at which the energy reserves of parturient caribou are at an annual minimum. This is the time of peak lactation, and the energy and protein requirements of the female caribou are high as a result (White and Luick 1984, Parker et al. 1990 in Griffith et al. 2002). Because maternal protein reserves are low during calving season, calving habitats are especially important to female and calf protein budgets (Griffith et al. 2002). Males and non-parturient females continue their spring migration during the calving season (Dau 2013).

Parturient females of the Western Arctic Herd calve in the Utukok River Uplands of northwestern Alaska (Dau 2013). The Teshekpuk and Central Arctic herds calve in dense aggregations on the northern Beaufort Coastal Plain. The Teshekpuk Herd calving grounds surround Teshekpuk Lake. In 2011 and 2012, caribou of the Teshekpuk Herd also calved between Atqasuk and Teshekpuk Lake, west of their traditional calving grounds (Parrett 2013). The calving grounds of the Central Arctic Herd are bisected by the high-development corridor associated with Prudhoe Bay oilfields, with one calving area located between the Colville and Sagavanirktok rivers and the other located to the east of the Sagavanirktok River (Lenart 2013). Although in some years the Porcupine Herd calves in Yukon, often caribou calve on the coastal plain of the Arctic National Wildlife Refuge (1002 Area). Unlike caribou ranges at other times of the year, the calving grounds of parturient females do not generally overlap between herds (Figure H-20).

Calving ground size is not correlated with herd size, availability of snow-free habitat, or availability of new plant growth (Griffith et al. 2002). There is much inter-annual variation in extent of calving area; for example, from 1983 to 2001, 0% to 92% of parturient females of the Porcupine Herd calved in the coastal plain of the Arctic National Wildlife Refuge (1002 Area). However, the proportion of parturient females calving in the 1002 area is positively correlated with the availability of new plant growth (Griffith et al. 2002). Calf survival is negatively correlated with snow cover during calving (Griffith et al. 2002). There is some evidence, at least for the Porcupine Herd, that the Arctic Oscillation effects the calving distribution of parturient females. For the Porcupine Herd, when the previous winter (approximately 15 months prior) was accompanied by a positive Arctic Oscillation, there was a greater tendency for females to calve in the 1002 area. This pattern is likely driven by effects the Arctic Oscillation has on caribou forage availability and timing rather than on the caribou directly (Griffith et al. 2002).

In addition to weather and growing season related factors, the distribution of predators influences the selection of calving areas. The predominant predators of caribou calves are wolves, brown bears, and golden eagles. Eagle nests and wolf dens are primarily concentrated in the Brooks Foothills and Brooks Range. Brown bears are also more concentrated in the foothills (Young and McCabe 1997). In comparison, the coastal plain has relatively few predators and provides low-risk calving habitat. Parturient females avoid floodplain habitats during calving season because riparian corridors generally have higher predator densities (Jakimchuk et al. 1987). Unlike the calving grounds of the other three herds in the North Slope study area, the calving grounds of the Western Arctic Herd occur in a more predator dense region than the Beaufort Coastal Plain to the north.

The future construction and operation of industrial infrastructure has the potential to alter seasonal distribution of caribou, especially during calving season. Abundance of calving caribou in the Central Arctic Herd is less than expected within 4 km of roads and declines exponentially as road density increases. High density calving areas of the Central Arctic Herd have shifted south away from the

Kuparuk Development Area to inland areas of lower forage quality since construction and operation of industrial infrastructure began (Cameron et al. 2005). Currently, impacts of industrial activity during calving season are only relevant for the Central Arctic Herd, which overlaps the developed Prudhoe Bay and surrounding oilfields. However, it is possible that future development within NPR-A may alter the calving distribution of the Teshekpuk Herd.

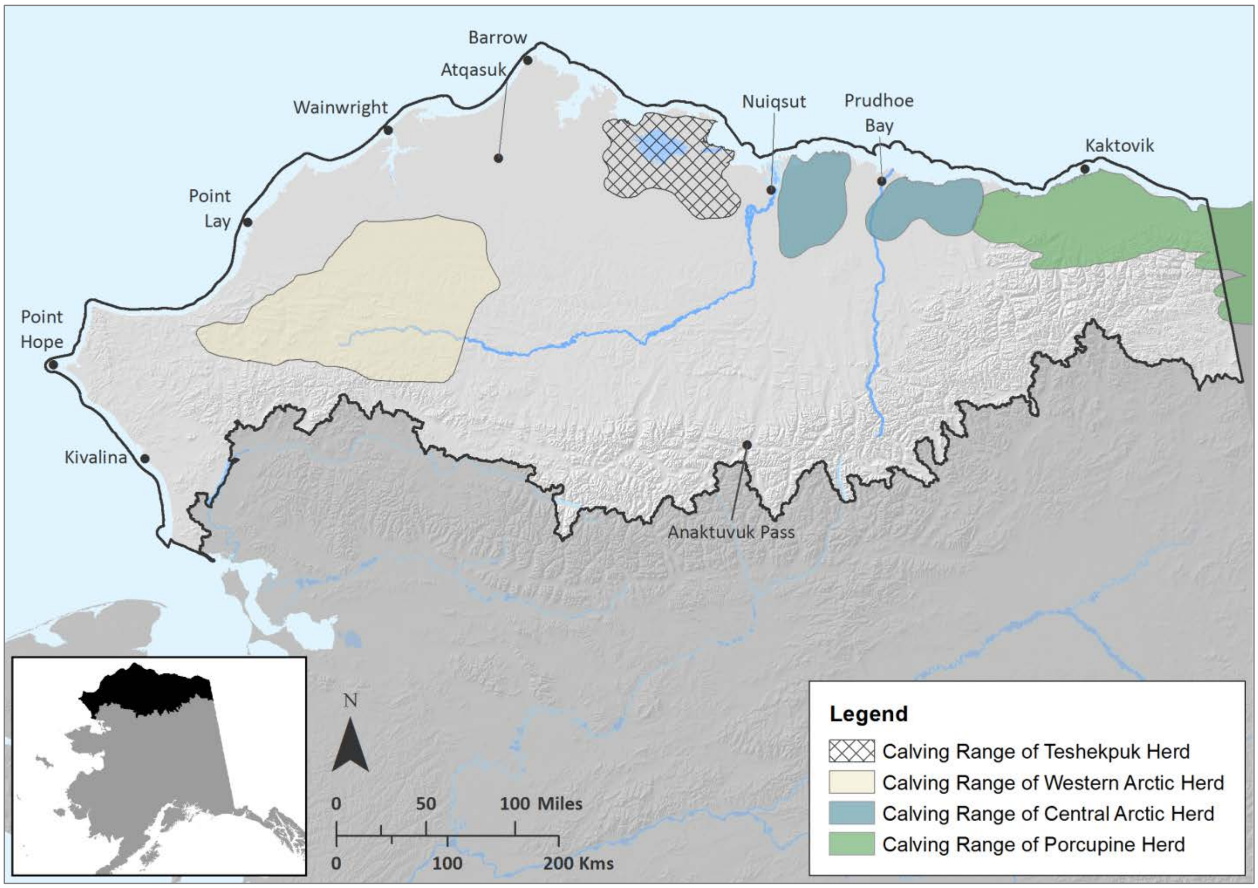

Figure H-20. Generalized calving distribution of parturient females and calves of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds.

Insect Relief

Post-parturient females and calves disperse from high-density calving areas in mid to late June. Bulls and non-parturient females join the post-parturient females and calves in their summer range, and caribou begin to form small groups. As the abundance of mosquitoes (*Culex* spp.), and later oestrid flies (*Hypoderma* spp. and *Cephenemyia* spp.), increases, caribou begin to aggregate to avoid insect harassment (Jakimchuk et al. 1987, Person et al. 2007). The density of insect pests is reduced at the centers of aggregations (Downes et al. 1985).

Caribou seek insect relief habitat: terrain where conditions are consistently unfavorable for flying insects. The movements of caribou during July and early August are driven by insect avoidance and the need to seek high quality forage. Therefore, caribou neither remain stationary at the highest quality forage sites until available forage has been consumed nor do they access relatively insect-free zones such as alpine barrens in the Brooks Range. Instead, they constantly move among areas of good to moderate forage quality and nearby insect relief habitats or microhabitats. During July and early August, caribou spend a significant but variable portion of their time on energy-consuming avoidance behaviors such as standing, running, and walking rather than foraging or resting (Downes et al. 1985). Because of avoidance behaviors and movement to forage sites, daily rates of movement are highest in July (Fancy et al. 1989).

The abundance and activity of mosquitoes peaks in early to mid-July, while that of oestrid flies peaks during mid-July to early August. During mid-July both mosquitoes and oestrid flies are active. The duration and frequency of winds in summer determine the intensity of caribou avoidance behavior. Wind naturally disperses insects, reducing the need for caribou to avoid insects through movement and terrain selection. During windy days, caribou move to optimal forage sites. However, when winds are not sufficient to disperse insects (less than approximately 25 km/h; Lenart 2013), caribou move to coastal areas in the Beaufort Coastal Plain or to hill ridges in the Brooks Foothills. The selection of insect relief sites is herd-dependent, with the Porcupine Herd favoring elevated sites and ridges and the Central Arctic and Teshekpuk herds favoring coastal areas (Dau 1986, Griffith et al. 2002, Lenart 2013). The Western Arctic Herd often splits between favoring the coast and favoring the foothills. Habitats or microhabitats such as late lying snow patches or floodplain barrens, serve as insect relief areas for all herds (Downes et al. 1985, Lenart 2013). Individual caribou often return to the same insect relief sites over multiple years (Griffith et al. 2002).

Road and pipeline density affect herd movements during the insect relief season. Caribou of the Central Arctic Herd have reduced success navigating the landscape for insect avoidance in areas of high density development such as roads and pipelines (Cameron et al. 2005). It is possible that future oil and gas infrastructure development in NPR-A could adversely impact insect avoidance for the Teshekpuk Herd in a similar manner.

Late Summer

By mid-August, populations of oestrid flies are in decline and insect pests cease to be a dominant factor driving the movements of caribou. Herds begin to disperse and cover larger ranges than during the early summer (Fancy et al. 1989, Dau 2013). Caribou may begin to slowly move toward winter ranges, but they still spend a large proportion of time feeding.

The majority of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine herd summer ranges occur within the North Slope study area (Figure H-21). The summer range of the Western Arctic Herd extends from the Northwest Coast to the central Brooks Range (Dau 2013). The Teshekpuk Herd summer range includes the Beaufort Coastal Plain and lies mostly west of the Colville River to Wainwright, with concentration near the coast during insect relief season (Parrett 2013). The Central Arctic Herd occupies the Beaufort Coastal Plain and Brooks Foothills from the Colville River to east of Kaktovik (Lenart 2013). The Porcupine Herd occupies the Arctic National Wildlife Refuge and northern Yukon from the Beaufort Coastal Plain to the south side of the Brooks Range (Caikoski 2013).

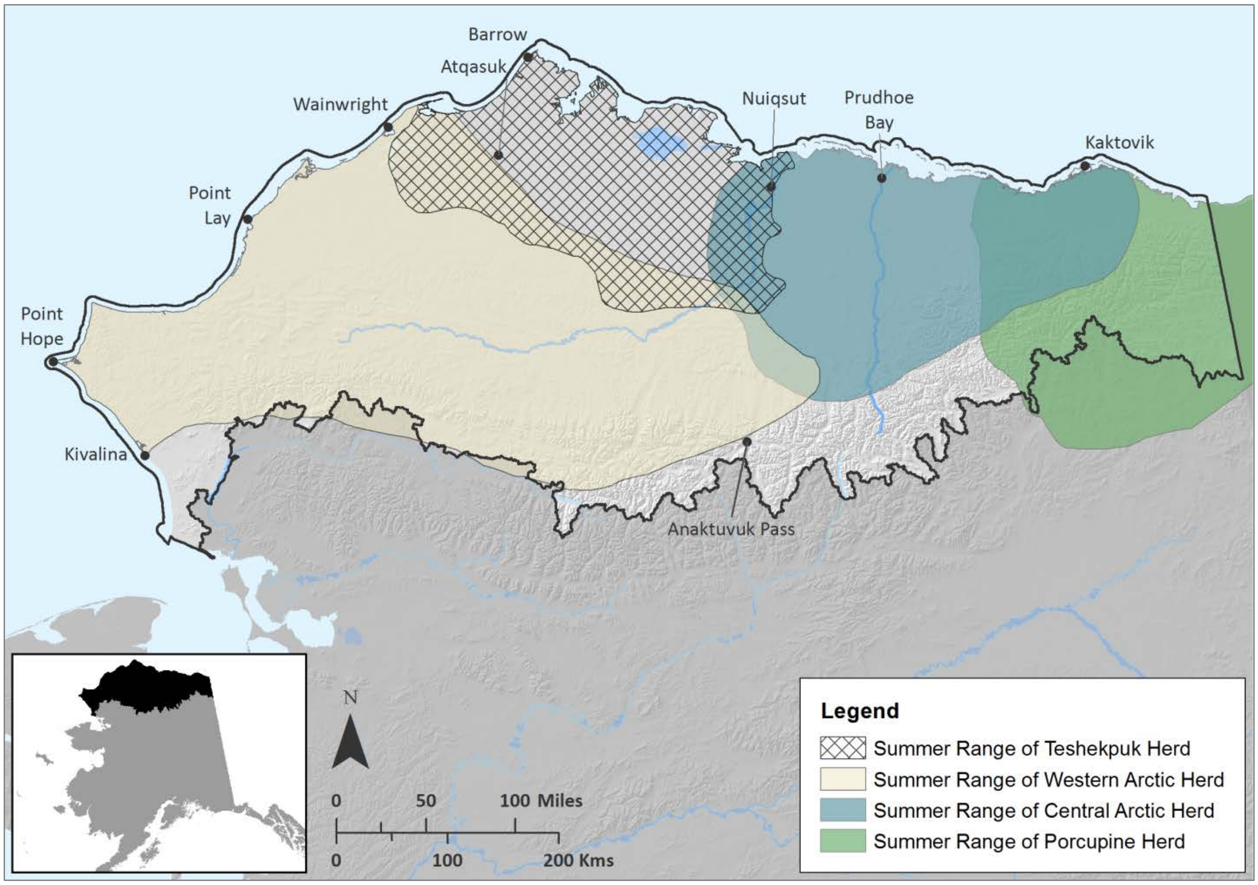

Figure H-21. Generalized summer (post-calving to late summer) distribution of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds.

Fall Migration

Migration is loosely defined here as the seasonal movement between discrete areas not used by the herd at other times of the year. Caribou move from summer ranges to winter ranges from late September to the end of November. Rut occurs in October during fall migration (Dau 2013, Lenart 2013). Migration distance varies between herds, between years, and between individuals. Some individuals of the Teshekpuk Herd remain within the herd summer range and do not migrate. Of the individuals that do migrate, patterns are highly variable with some individuals moving south towards the central Brooks Range and others moving to the Chukchi Sea coast (Parrett 2013). Caribou of the other three herds generally move south from their summer ranges. All herds have overlap between their summer and winter ranges. The proportion of time spent travelling per day in October and November is high while proportion of time spent feeding is low (Russell et al. 1993).

Winter

Caribou on the North Slope move significantly less in mid-winter than during the fall or spring migration (Joly 2008), and have the lowest daily rates of movement in February and March (Fancy et al. 1989). Snow depth limits or hinders movement of caribou in winter where wind-deposits of snow accumulate.

Caribou avoid snow depths greater than 0.5 to 0.6 m because the energetic cost of movement becomes high above those depths (Duquette 1988).

Storm events alter caribou movement patterns throughout winter. Caribou foraging on slopes and ridges descend to low elevations and seek protected terrain at the onset of warm temperatures, which usually precede major storm events. Caribou cease movement and feeding when wind speeds exceed 11 m/s. Once wind speeds decrease, caribou move back to optimal foraging sites (Henshaw 1968). Areas of the shallowest snow packs are optimal foraging sites. Cratering (digging) into shallow, loose or thinly crusted snow represents the energetic equivalent of a slow walk (Fancy and White 1985). As snow depth increases above 10 to 15 cm, caribou movement patterns transition from continual movement and foraging to intermittent movement, allowing time for individuals to crater the snow and access lichens underneath. At snow depths of greater than 25 cm, caribou seek out shallow and soft snow areas as forage sites (Henshaw 1968). Deterioration of forage quality from sustained long-term foraging can cause range shifts, especially for winter range because of slow lichen regeneration times (Joly et al. 2010).

Annual snowfall and snow accumulation affect winter range on a large scale. Because caribou seek areas of low snow depth, regions with low snowfall or accumulation are favored. The winter range of the Porcupine Herd, for example, includes the Richardson Mountains and the Ogilvie and Hart rivers region, both of which receive less snowfall than surrounding areas (Russell et al. 1993). Winter snow depth also affects predation, as deep snow allows caribou to be more susceptible to predation from wolves (Dau 2013).

Three of the four herds remain in lichen-rich habitats south of the Beaufort Coastal Plain during winter months (Figure H-22). Much of the Teshekpuk Herd winters on the Beaufort Coastal Plain within its summer range. However, the winter range of the Teshekpuk Herd is far more dispersed than its summer range. A sizable portion of the herd winters in the Brooks Foothills or Brooks Range and a small portion of the herd winters on the Chukchi Sea coast in northwestern Alaska in the vicinity of Cape Krusenstern and Kobuk Valley (Parrett 2013). The Western Arctic Herd predominantly winters south of the North Slope study area, with only a small portion of the herd wintering in the central Brooks Range. During some years, a small subset of caribou winter in the vicinity of Point Lay but this is not mapped as winter range because overall use is low (Dau 2013). The majority of the winter range is located in the Seward Peninsula and Nulato Hills. The Central Arctic Herd winters from the Brooks Foothills to the southern Brooks Range and Davidson Mountains (Lenart 2013). More than half of the Porcupine Herd winter range by area occurs outside of the North Slope study area. Most of the herd winters south of the Brooks Range or in the Richardson Mountains or Ogilvie Mountains of the Yukon (Parrett 2013).

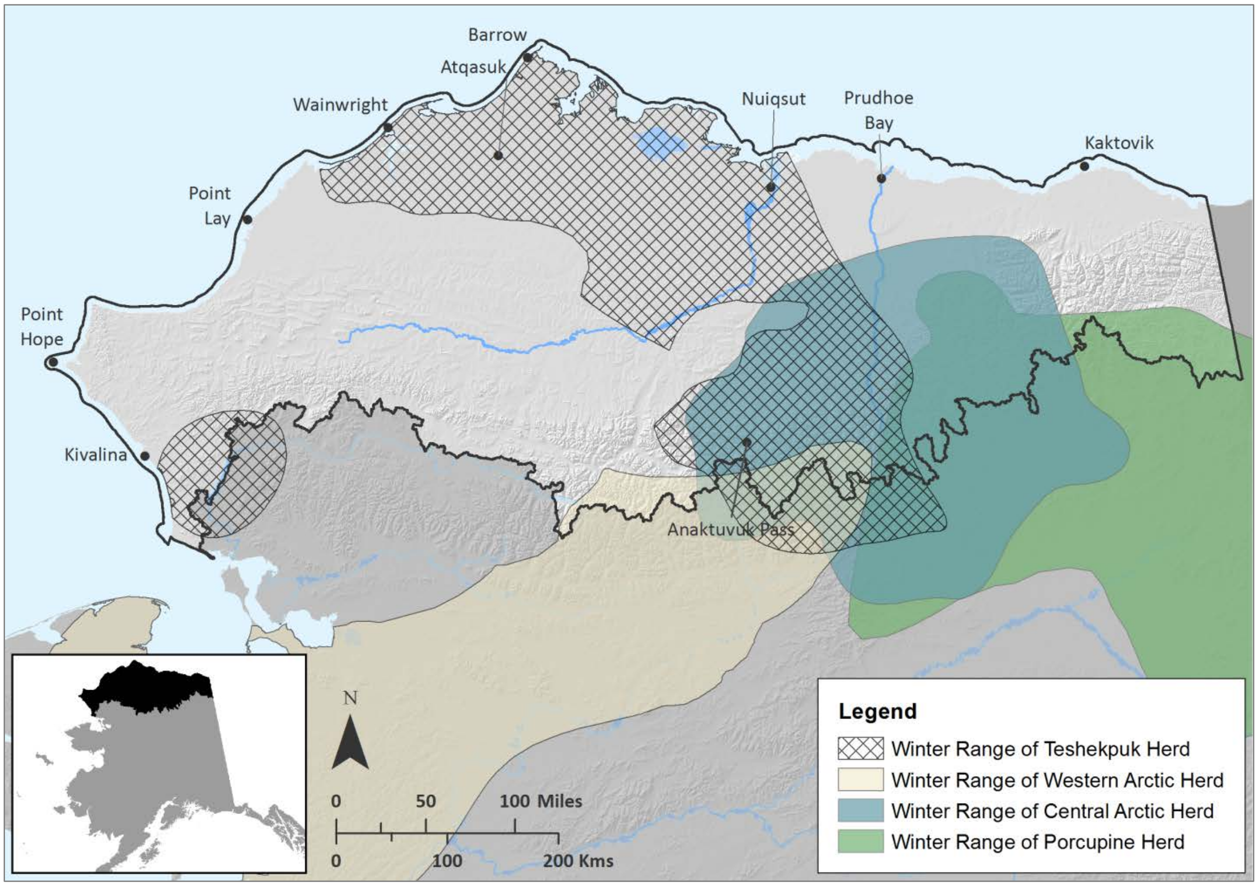

Figure H-22. Generalized winter distribution of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds.

Spring Migration

Female caribou begin migrating to calving grounds in April prior to movement of males to summer habitat (Joly 2008) and commonly cover 7 to 24 km per day (Fancy et al. 1989). Initiation of spring migration is temperature dependent (Dau 2013). Snow depth and hardness influence the behavior of caribou during migration. As average daily temperatures warm above freezing, snow settles and forms hard refreeze crusts during early spring along a south to north gradient. Initially, caribou likely move north along the refreeze gradient seeking softer snow for foraging. During spring cold snaps when all snow becomes hard temporarily, movement may cease until thaw resumes (Pruitt 1959). The proportion of time spent moving per day is high in April while proportion of time spent feeding is low (Russell et al. 1993).

In general, caribou movements are not limited to narrow corridors within the North Slope study area. The terrain in the Beaufort Coastal Plain and Brooks Foothills is not rugged enough to constrict freedom of movement. Migration corridors exist to some extent in the Brooks Range and in the Richardson and Ogilvie Mountains of Yukon (for the Porcupine Herd), where terrain is complex, but this should not be exaggerated. Much of the migratory ranges of the Western Arctic and Porcupine herds occur to the south of the North Slope study area. For the Porcupine herd, much of the migratory range also occurs in

Yukon. The Western Arctic Herd migrates through the Kotzebue Sound Lowlands and Kobuk Ridges and Valleys to move from winter range to calving grounds/summer range within the North Slope study area.

Many individuals of the Teshekpuk herd do not need to move large distances between winter range and calving grounds or summer range because these individuals remain on the Beaufort Coastal Plain year-round. The caribou of the Teshekpuk Herd that winter in the Brooks Foothills and Brooks Range do migrate back to the Beaufort Coastal Plain, but migration routes are highly variable. Spring migrations of the Teshekpuk Herd are more independent, individuals move along routes, while fall migrations often consist of small clusters of caribou (Parrett 2013).

The summer and winter ranges of the Central Arctic Herd overlap. Migration consists of the herd shifting from the Brooks Foothills and Brooks Range north to the Beaufort Coastal Plain for parturient females or to the Brooks Foothills and Beaufort Coastal Plain for males and non-parturient females. The migration corridor of the herd narrows slightly at a terrain constriction formed by the mountains where the Sagavanirktok River exits the Brooks Range. However, much of the spring migration occurs in the Brooks Foothills and Beaufort Coastal Plain where caribou are not funneled into migration corridors by terrain.

No spatial data was available for the Porcupine herd to show caribou distribution during migration season. Hand-delineation of general migration areas for the other three herds was problematic because the migration areas are transitions between summer and winter ranges and therefore include both, at least partially. Migration areas would be best represented by kernel density analysis for a specified subset of dates and years rather than by generalized range polygons. For these reasons, no spatial extent of migration areas is presented here for any of the four herds.

Sexual Segregation

Male and female caribou favor different habitats during much of their annual cycles. In the Central Arctic Herd, females favor habitats closer to the coast while males tend to remain further inland except during winter and post-calving. Female caribou generally avoid riparian habitats during spring migration and calving, and they forage in riparian corridors at a lower rate than males for the remainder of the annual cycle. Predators are more common along riparian corridors and therefore female caribou, and especially parturient caribou during spring and calving, avoid these predator-dense habitats. Sexual segregation does not occur during July and early August when large aggregations of males and females form in response to insect harassment (Jakimchuk et al. 1987).

The timing of migrations differs for males and females. In spring, males migrate later and more slowly to the north than do females, and they do not aggregate in the calving areas (Jakimchuk et al. 1987, Dau 2013). Their movements are more closely correlated with the emergence of new plant growth (IPCB 1993). Sexual segregation is highest during spring migration and calving. Females remain closer to the coast in August prior to rut (Jakimchuk et al. 1987, Dau 2013). During rut, males and females occupy the same habitats. During winter, caribou of some herds have shown sexual segregation patterns at a coarse scale (Kelsall 1968).

Herd-Specific Factors

Caribou of the Western Arctic and Porcupine herds migrate long distances seasonally between widely separated calving, summer, and winter habitats. Both of these herds are present in the North Slope study area primarily for the calving and summer portions of their annual cycles. Caribou of the Teshekpuk and Central Arctic herds migrate comparatively short distances, and the majority of their seasonal habitats and migrations occur within the North Slope study area.

Currently, industrial development and resource extraction only occurs within the range of the Central Arctic Herd. The calving areas and summer habitat of the Central Arctic Herd coincide with industrial development on the North Slope. The construction of roads, pipelines, and facilities 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).

The post-calving migration is important in the Teshekpuk Herd because caribou move through narrow corridors along the shores of Teshekpuk Lake to access insect relief habitats for the majority of the summer (Person et al. 2007). The three other caribou herds that occur in the North Slope study area do not have a constricted post-calving migration pattern. During years of early snowmelt, calving of the Teshekpuk Herd shifts north of Teshekpuk Lake (Carroll et al. 2005). Caribou generally return to the same calving grounds annually, though emigration to new calving grounds has been observed at low frequencies. For example, in the Teshekpuk Herd from 1990 to 2005, 6.9% of collared caribou included in the study joined the Central Arctic or Western Arctic herds (Person et al. 2007).

Emigration between herds occurs in the North Slope study area when female caribou switch their calving range. Although herd ranges overlap during much of the year, emigration is not frequent. The Central Arctic Herd, for example, frequently intermixes with the Teshekpuk Herd in both summer and winter, and a small portion of radio-collared females have been observed switching their calving ground annually between the Teshekpuk Herd and Central Arctic Herd (Lenart 2013).

6.6. Abiotic Change Agents Analysis

Caribou movements between and within seasonal ranges are triggered by weather conditions and events throughout the year. Examples include wind events that relieve stress from insect pests, snow events in late summer and early fall that trigger migration to winter ranges, winter storms that cause caribou to seek sheltered terrain at low elevations, and spring thaw that drives migration to calving grounds and summer ranges. Future climate change will likely impact all aspects of weather patterns. However, it is likely that climate change will not impact herds uniformly because of the complexity of weather patterns on the North Slope and the variety of terrain occupied by the herds. Large scale climate patterns such as the Pacific Decadal Oscillation and Arctic Oscillation will modify the effects of climate change, creating variety in local impacts (Joly 2011).

Warming temperatures and the associated earlier snowmelt and earlier onset of plant growth will alter the abundance and timing of caribou forage and insect pests (Sparks and Menzel 2002; Stone et al.

2002). For the four North Slope herds combined, mean July temperatures are expected to increase significantly (>1.3°C) within 30% of their calving range and 55% of total summer range by 2060, while mean January and mean annual temperatures will increase significantly across 100% of both calving and summer ranges by 2060 (Table H-21).

Table H-21. Change in summer, winter, and annual temperature from 2010s to 2060s for caribou calving and summer ranges.

Terrestrial Fine-Filter CE		Δ July Temp		Δ January Temp		Δ Annual Temp	
		0 - 1.3°C	>1.3°C	0 - 1.3°C	>1.3°C	0 - 1.3°C	>1.3°C
Caribou- calving range	Near Term	100%	-	100%	-	100%	-
	Long Term	70%	30%	-	100%	-	100 %
Caribou-summer range	Near Term	100%	-	100%	-	100%	-
	Long Term	45%	55%	-	100%	-	100%

Predicted changes in temperature may lead to changes in insect abundance and vegetation phenology resulting in changes in the summer habitats used by caribou as they seek insect relief habitats and high or moderate quality forage. For a discussion of Abiotic Change Agent impacts to caribou forage, see Section H.7. Caribou Seasonal Forage. Earlier spring thaw and warmer spring temperatures may result in earlier insect emergence, which may cause a longer season of mosquito harassment. Higher than average July temperatures, as projected, are likely to contribute to increased insect harassment in the future (Fancy 1983; Murphy and Lawhead 2000; Witter et al.2012).

Increases in growing season length may increase the duration of mosquito and oestrid fly activity in the North Slope study area. Warmer summers may increase levels of harassment by warble flies (*Hypoderma tarandi*) and nose-bot flies (*Cephenemyia trompe*), resulting in increased caribou agitation and more time spent in avoidance behaviors (Vors and Boyce 2009 in Reid et al. 2013). Change in the frequency of winds adequate to alleviate insect harassment has not been assessed because of the complexity of climate-weather interactions.

Warmer temperatures in winter will likely result in an increase in freeze-thaw cycles and the number of rain-on-snow (icing) events, as suggested by changing snow day fractions for winter months (See Section H.7. Caribou Seasonal Forage for discussion on rain on snow effects and caribou forage).

6.7. Current Status and Future Landscape Condition

Resource extraction and infrastructure development have caused the fragmentation of caribou habitat throughout Alaska. Patch sizes are likely to decrease with increased development. 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). In addition, human activities can result in increased vigilance and avoidance behaviors which increase energy expenditure of individuals (Fancy 1983; Wolfe et al. 2000). Human activity may also cause a redistribution of animals on the landscape (Wolfe et al. 2000).

The Central Arctic Caribou herd has coexisted with oil field development around Prudhoe Bay for more than three decades. Construction of oil field infrastructure can displace caribou from the area. In the Milne Point Road area, caribou density decreased as road density increased, despite the overall concurrent population growth of the Central Arctic herd (Noel et al. 2004, Joly et al. 2006). 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 breeding, foraging, and relief habitats causes energetic stress, then affected cows will likely respond with lower fecundity (Murphy and Lawhead 2000, Vistnes and Nellemann 2008). Birth rates for female caribou in the Central Arctic herd exposed to areas of oil development were 10-20% lower than those not exposed to oil development (Cameron et al. 2005). The Western Arctic Caribou herd currently has little contact with industrial infrastructure, except around the Red Dog Mine. The Teshekpuk Lake and Porcupine herds do not have significant contact with industrial infrastructure in Alaska, although the Porcupine herd does encounter road corridors in the Yukon Territory (Murphy and Lawhead 2000).

Caribou of the Western Arctic herd that come into contact with the Red Dog Mine Road during fall migration are significantly diverted by that road such that subsequent to eventually passing the road they double their movement speed until they catch up with the rest of the herd. During 2011, caribou that came into contact with the road took an average of 44 days before crossing the road, first traveling 100 miles to the north or northwest. A small subset of caribou did not successfully cross the road and turned back to the north. Data from other years suggest that during some migration seasons, caribou are not diverted by the road (Dau 2013).

The intersection of the caribou herd annual range maps with the Landscape Condition Model indicates that despite infrastructure within the ranges of some herds, the majority of habitat (>90%) in the North Slope study area is classified as being in very high (intact) condition under current and future scenarios (Figure H-23 and Figure H-24, respectively). As described above, the Central Arctic herd is currently the only herd that co-occurs with oil infrastructure. Currently, 90.9% of the herds range is considered in very high condition (see Table H-7). Assuming that all current oil infrastructure would continue to operate into the future, this value deceases to 90.2% under the high development scenario (2040) (Table H-7, Figure H-24), suggesting that impacts from future development for the Central Arctic herd will not be greatly different than present. The high development scenario projection for 2040 indicates potential for increased interactions with industry in the future.

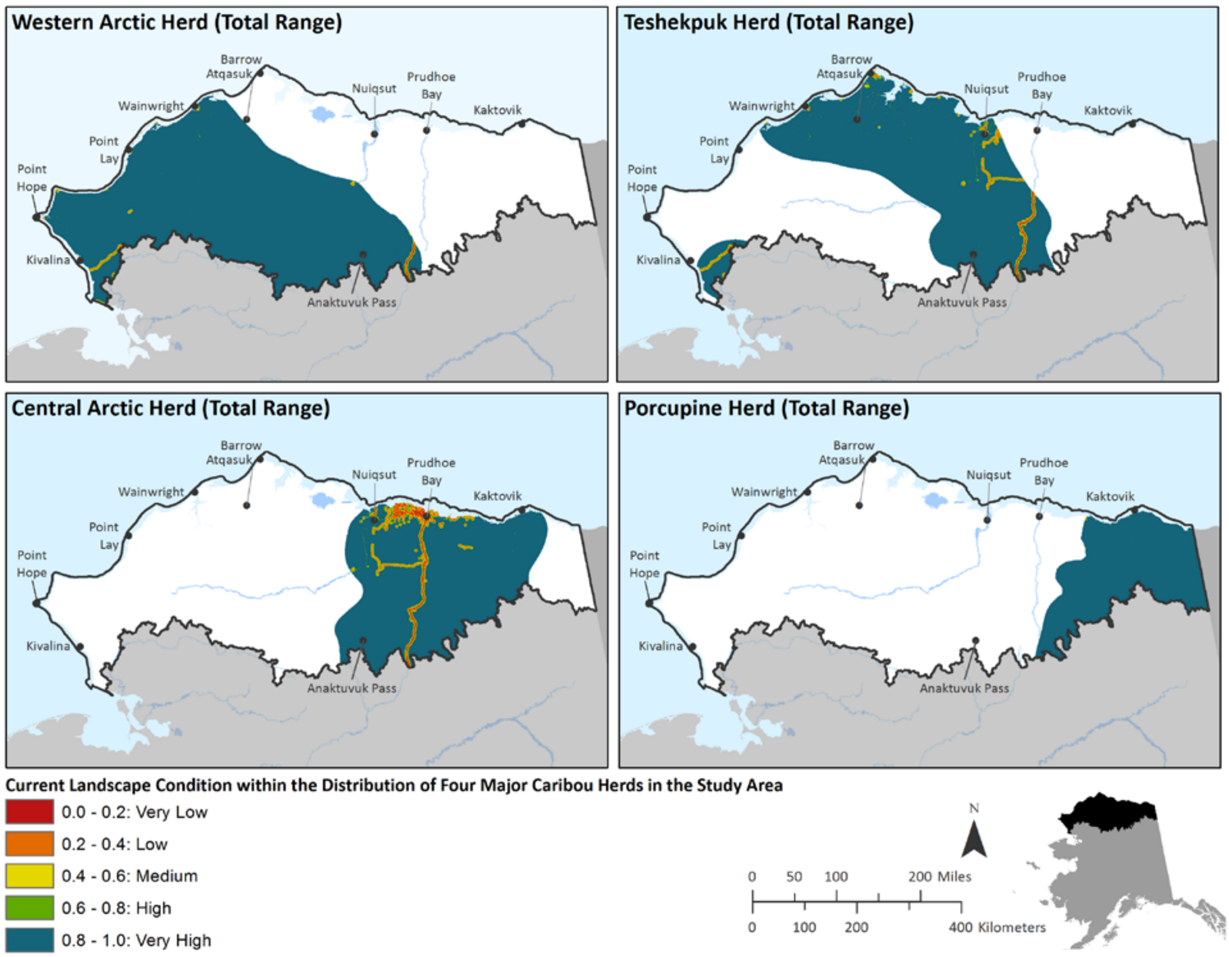

Figure H-23. Current landscape condition within the current total annual range of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds in the North Slope study area.

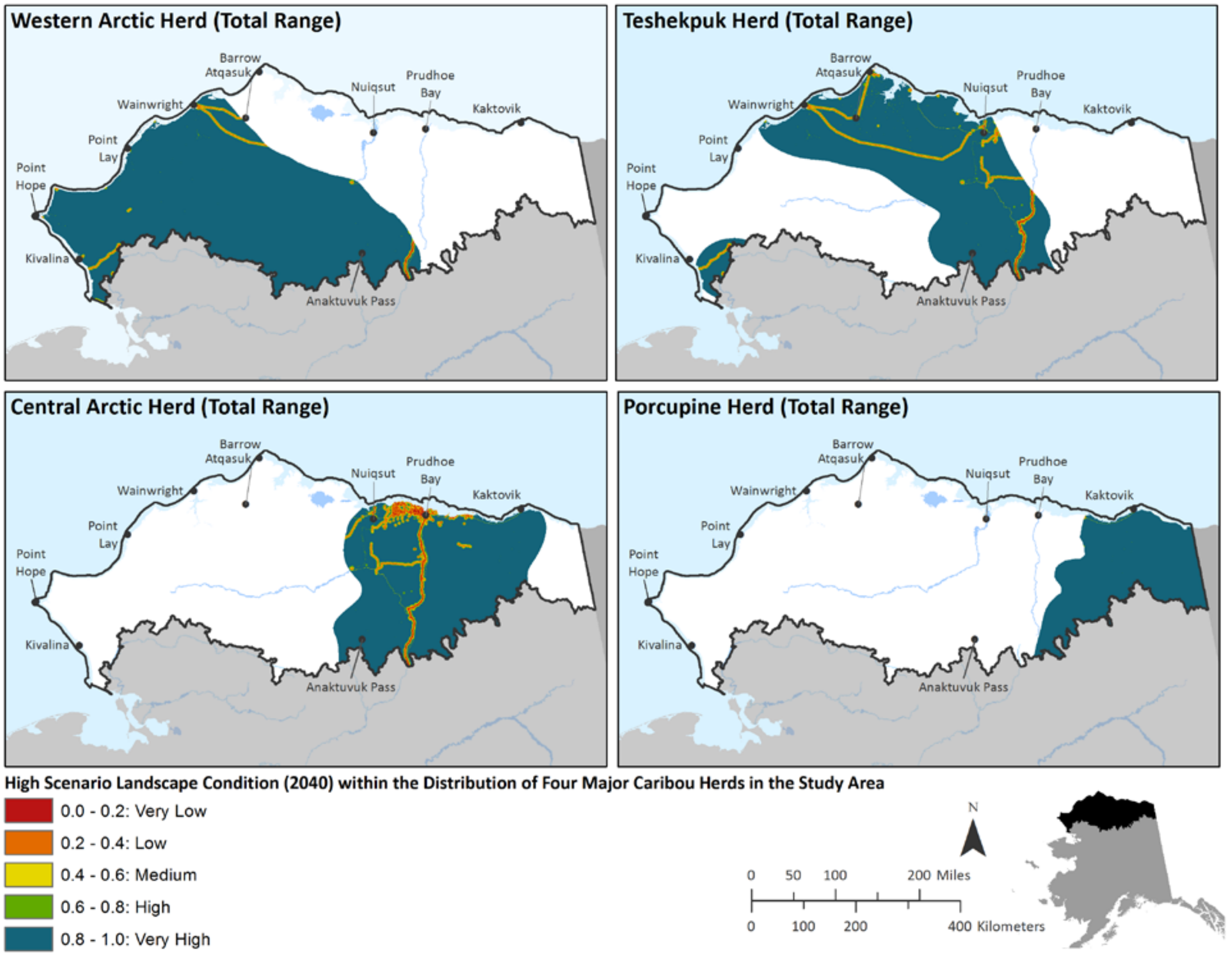

Figure H-24. 2040 high-development scenario landscape condition within the current total annual range of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds in the North Slope study area.

6.8. Harvest and Predation

Caribou are important in the North Slope study area to subsistence hunters and sport hunters. Human harvest tends to remove larger healthier animals of both genders. All herds receive some hunting pressure, with the majority of animals taken from the Western Arctic Herd. Increased road development under future scenarios (Figure H-24) may allow for increased access to caribou ranges, which may increase hunting pressure on the herds.

Gray wolves (*Canis lupus*), grizzly bears (*Ursus arctos*), and Golden eagles (*Aquila chrysaetos*) feed on caribou, although grizzly bears and Golden eagles primarily feed on calves. Predator densities are lower on the Beaufort Coastal Plain than the Brooks Foothills or Brooks Range (Murphy and Lawhead 2000).

6.9. Limitations

The spatial representations of caribou seasonal distribution are based on the best available and obtainable information. This included kernel density polygons obtained through a data sharing agreement with ADF&G for the Western Arctic, Central Arctic, and Teshekpuk herds. Such fine-scale data were not available in summary format for the Porcupine Herd. This herd is managed jointly between Alaska and the Yukon Territory, therefore a separate data request was necessary to obtain raw radio-collar data for that herd, which was deemed beyond the scope of the REA.

The annual kernel densities provided by ADF&G show the year-round importance of habitat by specific herd, but they do not identify seasonal use. As such, they lack specificity for determining habitats that are highly important to the caribou life cycle but are only occupied intensively for a small portion of the year, such as calving ranges. Furthermore, annual kernel densities do not directly show migration routes. Migration routes can sometimes be inferred when viewing the annual kernel densities, especially for the Western Arctic Herd, but migration routes cannot be isolated from other seasonal use. Therefore, fall and spring migration areas were not mapped for this assessment.

Caribou ranges vary widely from year to year and inter-annual variability of habitat use is significant. The total annual kernel densities selected for the North Slope REA are a multi-year synthesis of radio-collar telemetry locations that are intended to show patterns in current caribou distribution. Because the annual kernel densities include 95% of collared caribou and only a small subsection of herds are collared, the annual kernel densities cannot be considered total annual range. Annual kernel densities are only accurate for the years of collar data included in the analyses (2004-2014 for the Western Arctic and Central Arctic herds, 2004-2013 for the Teshekpuk herd).

The seasonal range polygons provided for this assessment should be considered coarse-scale approximations of areas of known use. Hand-delineated range polygons were generalized based on multi-year patterns in caribou distribution. The distribution of caribou in a particular season from a single year will not exactly match the generalized seasonal ranges and may also fall outside of the depicted total annual kernel densities. Future distribution of caribou is likely to differ from the annual kernel densities and seasonal range polygons provided for this assessment.

Inferring future climate effects on the distribution of caribou is complex, since caribou encounter a wide range of habitats during migration and distribution is influenced by many competing factors. Biotic and abiotic factors known to influence the distribution and demography of caribou include snow depth, lichen cover, insect avoidance, and predator avoidance (Sharma et al. 2009). Icing effects on vegetation are difficult to predict spatially or temporally from broad-scale temperature and precipitation data, and the correlations that we draw from these analyses are speculative. No suitable snow depth layer exists currently for the North Slope study area. We therefore were unable to analyze areas where snow depth might preclude caribou travel or limit migration routes in early spring.

Caribou exhibit considerable plasticity in their ability to adapt and utilize habitats in unexpected ways. For example, animals from the Nelchina herd were transplanted to Adak Island, where they achieved body sizes larger than typical for Alaska caribou (Valkenberg et al. 2000). Due to their plasticity, compounded by the complexity of herd dynamics, generalizations about where herds can and cannot thrive based on climate-driven modeling should be considered hypotheses to be tested with empirical data (Murphy et al. 2010).

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7. Caribou Seasonal Forage

MQ TF 2	What are caribou preferences for vegetation communities? Where do these vegetation communities exist?

7.1. Introduction

Caribou have adapted a life cycle that favors nutrient and energy conservation in the winter months and rapid growth and energy/nutrient storage in summer months. Preferred forage species are highly dependent on season (Figure H-25). Nutrient and digestible energy content in plants is linked to growth stage. Seasonal forage preferences of caribou correlate to the plants species, plant parts, and growth stage that contain the highest available nutrients and energy at the time. Vegetation communities preferred by caribou are thus seasonally dependent. We review caribou forage patterns and show how those forage patterns relate to the use of the landcover classes mapped by the Ducks Unlimited 2013 North Slope Science Initiative (NSSI) Landcover Map and the Boggs et al. 2012 Vegetation Map of Northern, Western, and Interior Alaska in calving season, summer, and winter. The resulting caribou forage maps suggest that neither forage availability nor quality are ever major factors affecting herd seasonal ranges except perhaps in winter for the Western Arctic, Central Arctic, and Porcupine herds.

Calving

During calving, the inflorescences of *Eriophorum* spp. form the major component of diet for the barren ground caribou in Alaska, especially of females and young (White and Trudell 1980, Thompson and McCourt 1981, Griffith et al. 2002). For example, during the calving season of 1973, *Eriophorum* spp. composed 77% of the diet for the Porcupine herd (Thompson and McCourt 1981). Other estimates have similarly shown *Eriophorum* inflorescences to be the preferred forage during calving (White and Trudell 1980, Griffith et al. 2002). Inflorescences of *Eriophorum* spp. elongate immediately after snow melt, typically in late May and early June for recent years, at which time they also contain their highest concentrations of nitrogen, phosphorous, and digestible energy and their lowest concentration of fiber (Kuropat and Bryant 1980, Kuropat 1984, Jorgenson and Udevitz 1992, White et al. 1992). In terrain with varied patches of snowmelt, *Eriophorum* inflorescences emerge over a wider period of time (Nellemann and Thomsen 1994). In years of early snowmelt, female caribou will track late-melting snow patches for the nearby recently emerged inflorescences (Wilson et al. 2012).

The forage preferences of male and female caribou differ during calving season. Both males and females use *Eriophorum*- and *Carex*-rich habitats and consume emerging *Eriophorum* inflorescences. For male caribou, however, *Salix* leaves and inflorescences also contribute a large portion of the diet and are preferentially sought in floodplain and riparian habitats, in which *Salix* spp. are prevalent. *Salix alaxensis, S. glauca, S. pulchra*, and *S. richardsonii* are common forage species. *Salix reticulata* is also a preferred forage and occurs outside of riparian areas in tussock tundra and dwarf shrub tundra (White and Trudell 1980, Klein 1990). In the Central Arctic Herd, males were observed foraging more in riparian corridors than were the females. Females primarily foraged in *Eriophorum*- and *Carex*-rich habitats but avoided riparian habitats, likely because brown bears and wolves are more commonly encountered along the riparian corridors (Jakimchuk et al. 1987). In other herds as well, young leaves and inflorescences of *Salix* spp. contribute a sizable component of caribou diet during calving season. Although males may consume more *Salix*, females also browse *Salix* preferentially (Thompson and McCourt 1981). In addition to *Eriophorum* and *Salix,* caribou also forage *Carex aquatilis* and other *Carex* spp., but not as a major component of the diet (White and Trudell 1980). Caribou consume relatively small amounts of *Equisetum* spp. in riparian habitats (Jakimchuk et al. 1987). In areas with low availability of *Eriophorum* and *Salix*, caribou have been observed consuming mosses and evergreen shrubs during calving season; however, these plants are not easily digestible and are not preferred forage (Griffith et al. 2002).

Summer

Shifts in diet correspond to plant phenology so that forage species are consumed during their most nutritious stage. As *Eriophorum* spp. mature, caribou shift their dietary intake to a greater reliance on leaves and inflorescences of *Salix* spp. and a variety of herbaceous plants (White and Trudell 1980, Thompson and McCourt 1981, Walsh et al. 1997, Griffith et al. 2002). *Salix* spp., a wide variety of forbs, and *Carex aquatilis* and other *Carex* species including *bigelowii* ssp. *lugens* make up the bulk of caribou forage during late June and July (White and Trudell 1980, Klein 1990, Russell et al. 1993). Forbs are selected for at a rate 5 times their availability and *Salix* spp. at a rate 3 times their availability in summer (White 1983). Numerous forbs are consumed by caribou during this time: *Pedicularis* spp., *Bistorta* spp., *Lupinus arcticus*, *Artemisia arctica*, *Artemisia tilesii*, *Chamerion* spp. *Oxyria digyna*, *Rumex arcticus*, *Hedysarum alpinum*, *Oxytropis viscida*, *Anemone parviflora*, *Petasites frigidus*, *Boykinia richardsonii*, *Geum glaciale*, *Stellaria longipes*, and *Sanguisorba officinalis* (White and Trudell 1980, Klein 1990). Floral parts at anthesis of both forbs and *Carex* spp. have higher nitrogen, phosphorous, and digestible energy than leaves of the same species, and the floral parts are preferentially selected by caribou (Klein 1990).

The leaves of *Eriophorum* spp. contain peak nitrogen levels in early July and new growth is preferentially consumed when available in abundance after disturbance (Chapin et al. 1980). However, consumption of *Eriophorum* leaves in general is low under normal conditions because the large amount of retained dead leaves on *Eriophorum* spp. deters caribou (White and Trudell 1980). After anthesis, the nutritive value and digestibility of *Eriophorum* inflorescences declines and by late June, *Eriophorum* spp. become a minor component of the diet. Caribou graze some grasses and mushrooms as a minor component of their diet. Evergreen shrubs are avoided in summer except for infrequent consumption of *Vaccinium vitis-idaea* (White and Trudell 1980).

During summer, the sexual segregation regarding riparian habitats weakens and female caribou increase their foraging along rivers, although in general males still make greater use of riparian habitats (Jakimchuk et al. 1987). Both males and females forage heavily in sedge meadow habitats, lake margins, upland ridges, tussock tundra, and high-center polygons. Of these habitats, sedge meadow habitats, lake margins, and upland ridges are selected for at a rate greater than their availability while tussock tundra and high-center polygons are used at a rate roughly equivalent to their availability. Within high-center polygonal tundra, the *Carex*-rich wet troughs are preferentially foraged (Jakimchuk et al. 1987, Wilson et al. 2012). Caribou avoid standing water; they therefore avoid foraging in low-center polygons and freshwater marshes, regardless of whether dominated by *Carex aquatilis* or *Arctophila fulva* (White and Trudell 1980, Wilson et al. 2012).

August and Autumn

In August, caribou continue to prefer foraging in sedge meadow habitats, lake margins, and riparian corridors. Tussock tundra is foraged, but at rates lower than or equivalent to its availability (Jakimchuk et al. 1987). *Salix* spp., a wide variety of forbs, and *Carex* spp. continue to dominate caribou diet, but the use of these components decreases through autumn as the plants decline in available nitrogen and digestibility. Consumption of *Salix* spp. and forbs tapers more quickly than consumption of *Carex* spp. Concurrent with the declining use of summer forage, consumption of primarily lichens but also mosses increases during fall migrations (Thompson and McCourt 1981, Klein 1990).

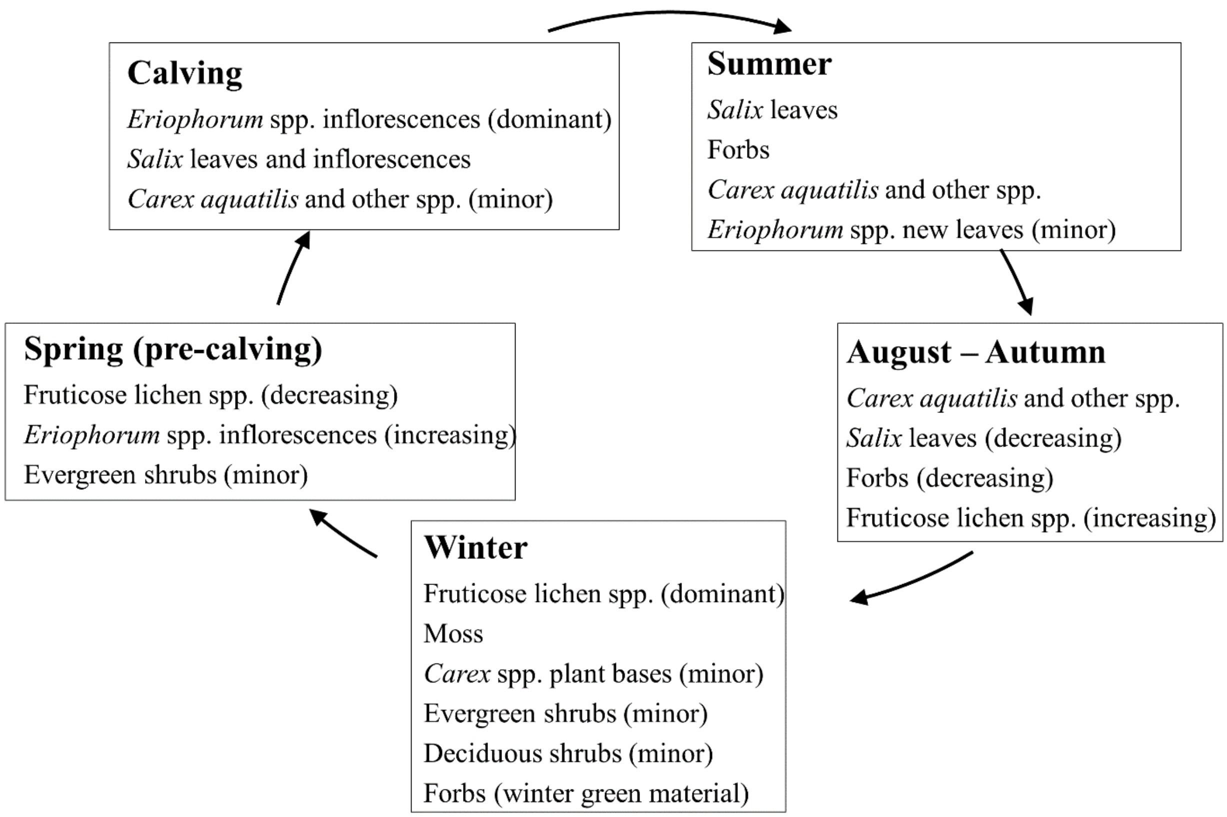

Figure H-25. Conceptual diagram of general caribou foraging preferences by season.

Winter

Throughout winter, barren ground caribou in Alaska rely heavily on fruticose lichen spp., especially *Cladina mitis*, *Cladina rangiferina*, *Cladina stellaris*, and *Cladonia uncialis*. Additional frequently foraged lichen species are *Flavocetraria cucullata*, *Cetraria ericetorum*, *Cetraria islandica*, *Flavocetraria nivalis*, *Cladonia amaurocraea*, and *Cladonia gracilis* (Joly et al. 2010). During the winter of 1973, for example, lichen spp. composed 67% of the diet for the porcupine caribou herd (Thompson and McCourt 1981). Fruticose lichens composed 63% to 83% of winter fecal pellets from caribou of the Western Arctic herd

(Jandt et al. 2003). Similarly, diet compositions for the Central Arctic Herd and Western Arctic Herd from 2006 to 2008 varied for lichens from 47% to 76% (Gustine et al. 2012).

Because caribou depend on lichen, they require large areas of undisturbed late successional vegetation for high quality winter range (Gustine et al. 2014). Caribou strongly avoid areas burned within the past 60 years in tundra habitats during winter. Fires remove lichens and restructure vegetation communities in favor of graminoid and dwarf shrub plant species, resulting in low quality winter range for caribou in burned areas for several decades (Joly et al. 2007a, Jandt et al. 2008). Lichens require decades after a disturbance such fire to return to pre-disturbance cover levels (Jandt et al. 2008).

Fruticose lichens contain high levels of digestible energy, but are low in nitrogen and other nutrients (Barboza and Parker 2008, Joly et al. 2010). Although lichens comprise the bulk of the winter diet, caribou require other food sources as well to obtain all necessary nutrients (Thompson and McCourt 1981). To meet nutritional demands, caribou also consume mosses such as *Sphagnum* spp., the live bases of *Carex* spp., *Equisetum* spp., and *Selaginella* spp., various winter green forbs, evergreen shrubs, and deciduous shrubs (Thompson and McCourt 1981, Klein 1990, Gustine et al. 2012). These minor dietary components likely provide necessary minimal nitrogen, calcium, and phosphorous intake in winter and are necessary for maintaining the microorganisms in the rumen for the digestion of lichens (Klein 1990, Ihl and Barboza 2007, Gustine et al. 2012). Lower lichen consumption, such as is sometimes caused in years of high snowfall, correlates with increased overall diversity of the diet (Gustine et al. 2012).

Occasionally, mosses contribute a relatively large portion of the diet, as observed in the Central Arctic Herd during the winters of 2007 and 2008 with moss contributing 23% and 24% of the diet, respectively (Gustine et al. 2012). In overgrazed winter forage areas, caribou may increase their intake of mosses. In winter ranges with low cover of lichens, caribou or reindeer often consume large amounts of moss. Wild reindeer and Peary caribou in Svalbard and the Canadian arctic consume large and sometimes dominant amounts of moss because their winter ranges are lichen-poor (Parker 1978, Staaland et al. 1993). However, there is also evidence that caribou in Alaska ingest moss independently of lichen availability, at least to some degree (Ihl 2010). The presence of moss in caribou diet itself is not indicative of poor winter range conditions (Ihl and Barboza 2007).

Sites associated with high winter use typically have higher dwarf shrub cover and lower tall shrub and low shrub cover than sites that are not frequently foraged by caribou in winter (Joly et al. 2010). In late winter, caribou use riparian habitats and tussock tundra at rates higher than their availability and sedge meadow habitats at rates less than their availability (Jakimchuk et al. 1987). The consumption of evergreen shrubs, mainly *Dryas* spp., *Rhododendron tomentosum* ssp. *decumbens*, and *Vaccinium vitis-idaea*, often increases in late winter when snow depth and hardness are at their maximums, although lichens remain the dominant forage (Klein 1990). Consumption of evergreen shrubs for the Central Arctic and Western Arctic herds from 2006 to 2008 ranged from 3% to 10% (Gustine et al. 2012). The overall carrying capacity of the ranges for the four barren ground caribou herds on the North Slope may be driven by the availability and quality of winter forage, although successful reproduction is strongly linked to weight gains achieved during summer (White 1983).

Spring (Pre-Calving)

During spring, prior to calving, lichens remain a significant portion of the diet, but *Eriophorum* spp. and *Carex* spp. become increasingly important as the inflorescences emerge after snow melt (Thompson and McCourt 1981). Caribou also consume the overwintering berries of *Vaccinium vitis-idaea* as they are uncovered by snowmelt, along with other evergreen shrubs (White and Trudell 1980, Klein 1990). As caribou migrate to their calving grounds, the snow melts revealing patches of tundra and the diet becomes dominated by *Eriophorum* inflorescences (White and Trudell 1980, Thompson and McCourt 1981, Griffith et al. 2002).

7.2. Methods

Vegetation components preferred by caribou per season (calving, summer, and winter) were identified through the literature review presented in the introduction above. A North Slope landcover map was created from the NSSI Landcover Map and the Vegetation Map of Northern, Western, and Interior Alaska (see Section G for a discussion of the North Slope landcover map). Landcover classes in which the identified components dominate, co-dominate, or are prevalent were selected from the North Slope landcover map and rated as either good or moderate quality depending on the overall prevalence of desirable forage.

A "Forage Quality" field was added to the North Slope landcover map. The North Slope landcover map was then attributed in three different versions: a calving version with the forage quality field reflecting the prevalence of *Eriophorum* spp., *Salix* spp., and *Carex aquatilis* and *Carex bigelowii* ssp. *lugens*; a summer version with the forage quality reflecting the prevalence of *Salix* spp., forbs, and *Carex aquatilis* and *Carex bigelowii* ssp. *lugens*; and a winter version with the forage quality reflecting the prevalence of lichen spp. (Table H-22). Freshwater Marsh: *Carex aquatilis* was considered low forage quality despite being dominated by *Carex aquatilis* because caribou avoid foraging in standing water. The forage quality ratings assigned were intended to represent the major components of caribou diet, but these ratings often account for the minor diet components as well.

Table H-22. Forage quality attributes by season appended to the landcover classes in the North Slope landcover map.

Vegetation Class	Calving	Summer	Winter
Bare Ground	Low	Low	Low
Sparsely Vegetated	Low	Low	High
Open Water	Low	Low	Low
FWM: Arctophila fulva	Low	Low	Low
FWM: Carex aquatilis	Low	Low	Low
Wet Sedge	High	High	Low
Wet Sedge- Sphagnum	High	High	Low
Mesic Herbaceous	Moderate	High	Low
Tussock Tundra	High	Moderate	Low
Tussock Shrub Tundra	High	High	Moderate
Mesic Sedge-Dwarf Shrub Tundra	Moderate	High	Moderate
Dwarf Shrub - Dryas	Low	Moderate	High
Dwarf Shrub - Other	Moderate	Moderate	High
Birch Ericaceous Low Shrub	Low	Low	High
Low-Tall Willow	High	High	Low
Alder	Low	Low	Low
Marine Beach/Beach Meadow	Low	Low	Low
Coastal Marsh	Low	Moderate	Low
Ice / Snow	Low	Low	Low
Burned Area	Moderate	Moderate	Low
Open Needleleaf	Low	Low	Low
Woodland Needleleaf	Low	Low	Moderate
Open Mixed Needleleaf / Deciduous	Low	Low	Low
Deciduous	Low	Low	Low
Aquatic Bed	Low	Low	Low
Unclassified	Low	Low	Low

7.3. Distribution

Forage quality is assessed here independently of caribou distribution. Only forage quality within the North Slope study area, rather than within the total herd ranges, was considered for this analysis. The overall percent of the study area classified as good or moderate quality caribou forage was 58% for calving season, 69% for summer, and 58% for winter (Table H-23). Good and moderate quality seasonal forage are generally present within corresponding herd seasonal ranges for caribou herds in the North

Slope study area (see Section H.4.6). The existence of high or moderate quality forage outside of herd seasonal ranges emphasizes that factors other than forage availability drive caribou distributions year-round. Because good or moderate quality forage is present across the North Slope study area, it is not a spatially limiting factor for herds.

Table H-23. Percent of study area occupied by good, moderate, or low quality caribou forage per season.

Season	Percent of Study Area		
	Good	Moderate	Low
Calving	47%	11%	42%
Summer	43%	26%	32%
Winter	28%	30%	42%

Calving Season Forage Quality

The following descriptions of the landcover classes are based on the Ducks Unlimited 2013 NSSI Landcover Map Report and are discussed here to explain their importance relative to caribou forage. Good and moderate quality forage during calving season is located mainly in the Beaufort Coastal Plain and Brooks Foothills (Figure H-26).

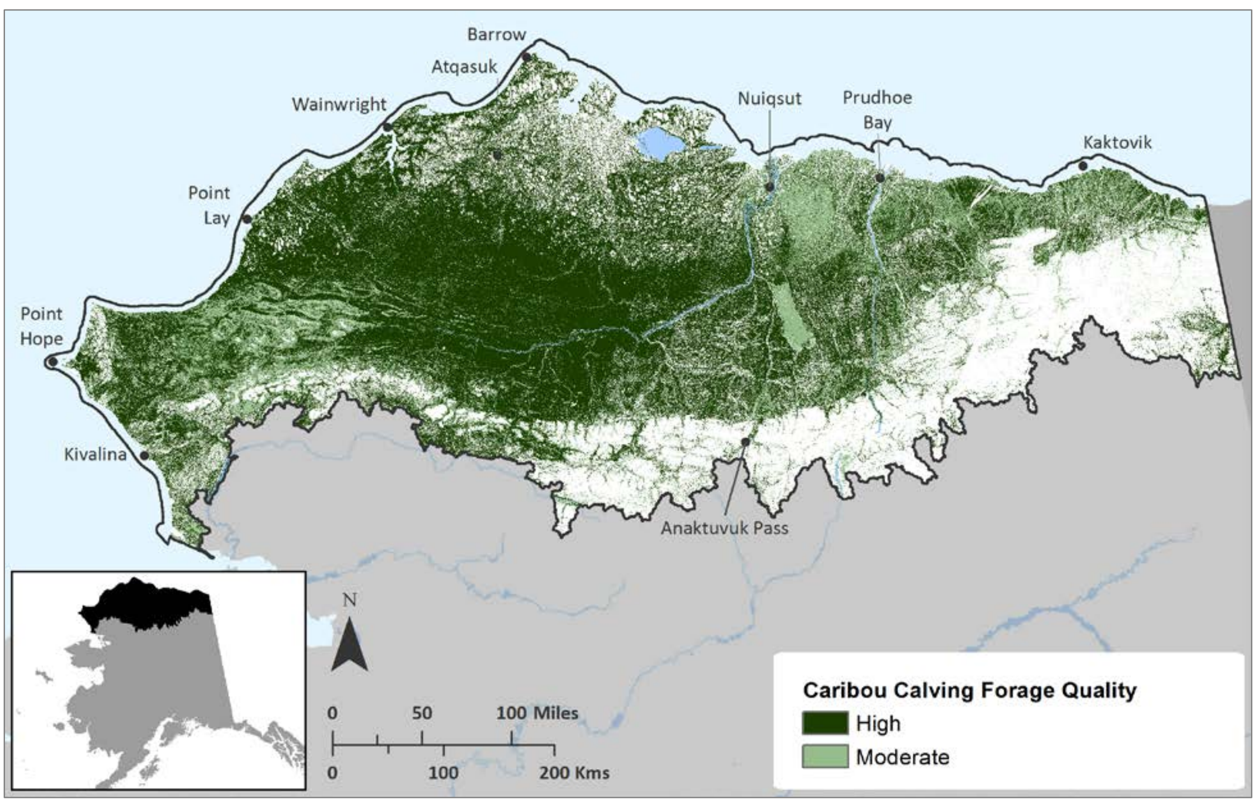

Figure H-26. Good and moderate quality caribou forage during calving season within the North Slope study area.

Wet sedge and wet sedge-*Sphagnum* are common on the Beaufort Coastal Plain adjacent to ponds, lakes, and streams and on low-centered polygons (Figure H-27). These landcover classes do not include *Carex aquatilis* freshwater marshes, which caribou generally avoid. Wet sedge and wet sedge-*Sphagnum* are high quality forage during calving season because of the prevalence of *Eriophorum angustifolium* and *E. chamissonis*, either of which co-dominate with *Carex aquatilis* at some sites. *Eriophorum vaginatum* is dominant on the elevated edges of low-centered polygons. *Salix pulchra* and *S. fuscescens* commonly occur as dwarf shrubs (less than 20 cm tall) or low shrubs (20 to 130 cm tall) in these landcover classes.

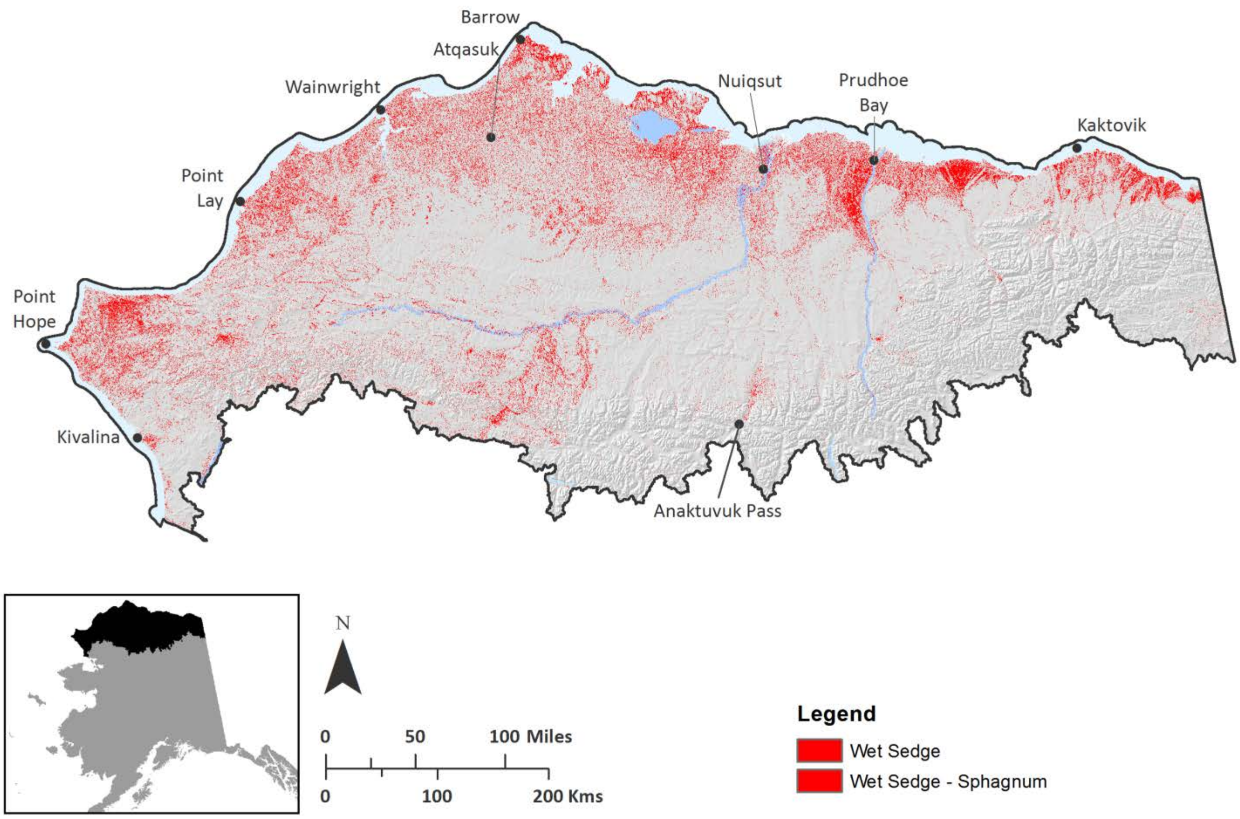

Figure H-27. Distribution of wet sedge and wet sedge – *Sphagnum* in the North Slope study area.

Tussock tundra is dominated by *Eriophorum vaginatum*. In flat topography, tussock tundra is usually associated with high-centered polygons. The troughs of high-centered polygons, which are foraged by caribou at rates greater than their availability, are dominated by *Eriophorum angustifolium* or *E. chamissonis* along with *Carex aquatilis. Carex bigelowii* ssp. *lugens* is common and sometimes co-dominant on the high-centers. *Salix pulchra* is a common component of the shrub layer. Although low and tall shrubs have cover less than 25%, dwarf shrub cover often exceeds 25%. The prevalence of these forage species, especially *Eriophorum*, in tussock tundra provides caribou with high quality forage during calving season. Tussock tundra may be more common in Northwest Alaska than in Northeast Alaska (Figure H-28), and therefore it would likely be more important for the Western Arctic and Teshekpuk herds. However, this apparent regional distribution may be an artifact of differing regional mapping methodologies.

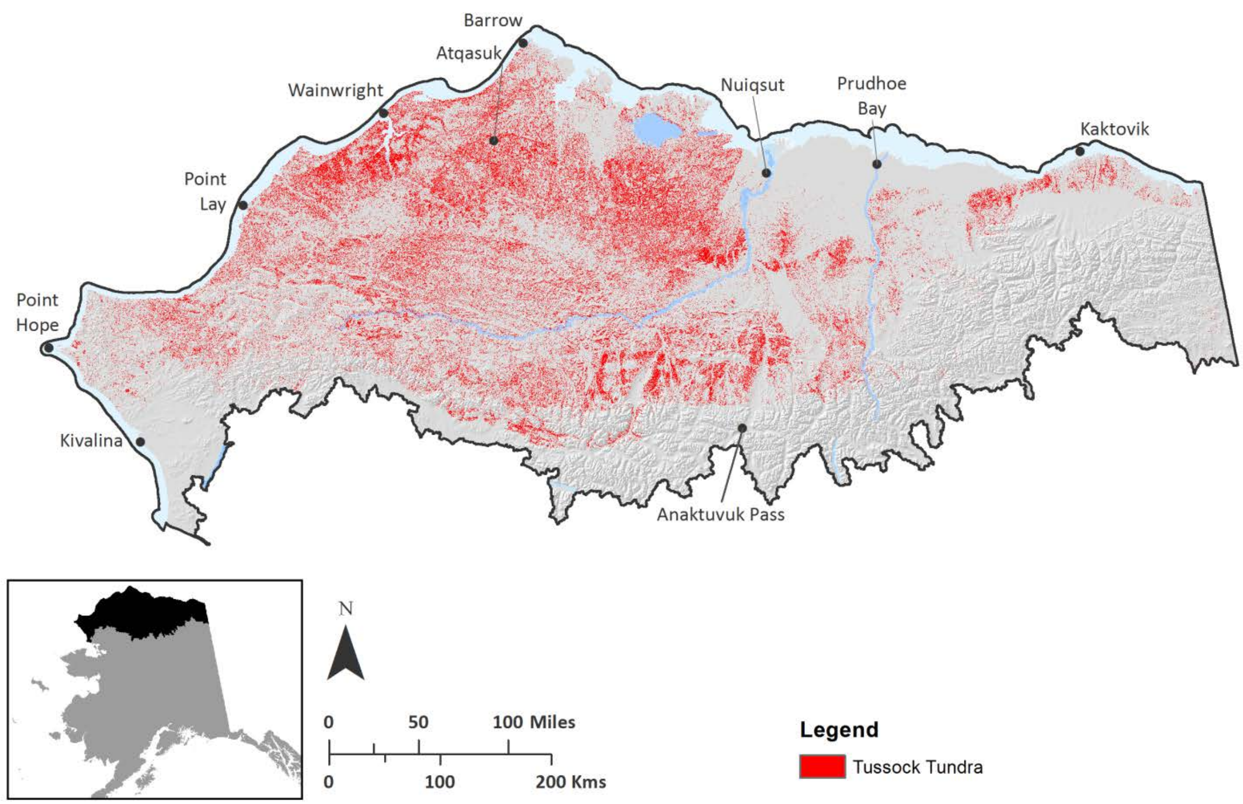

Figure H-28. Distribution of tussock tundra in the North Slope study area.

Tussock shrub tundra (Figure H-29) is similar in site characteristics and species composition to tussock tundra except that shrubs over 20 cm tall have greater than 25% cover. *Salix pulchra* is often dominant or co-dominant with other low and tall shrubs. *Eriophorum* spp. remain highly prevalent in tussock shrub tundra, and therefore tussock shrub tundra also provides caribou with high quality forage during calving season.

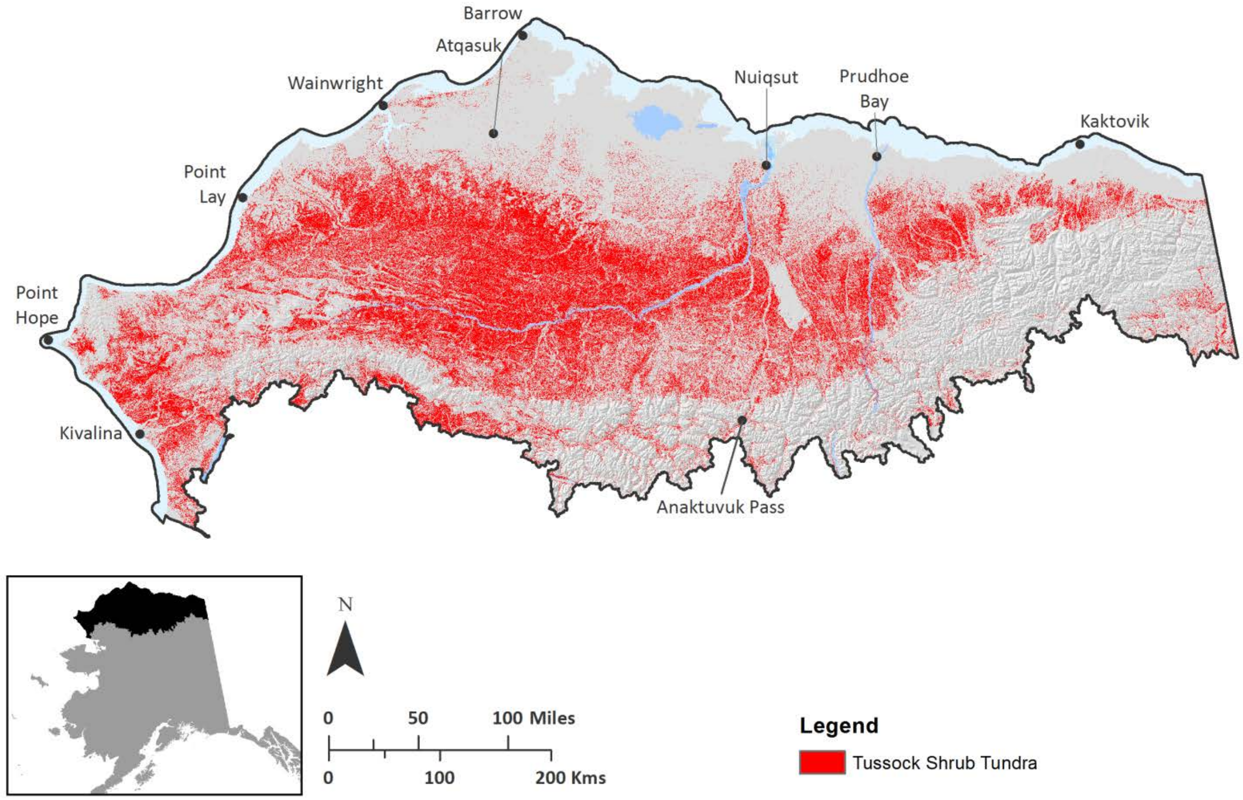

Figure H-29. Distribution of tussock shrub tundra in the North Slope study area.

Low – tall willow (Figure H-30) is a *Salix*-rich landcover class, providing high quality forage during calving season and summer. Low – tall willow occurs along rivers and streams in all ecoregions of the study area and also along lake margins in the sand sheet. The cover of shrubs over 20 cm tall is greater than 25% and *Salix* spp. dominate the shrub layer. *Salix alaxensis*, *S. glauca*, *S. pulchra*, and *S. richardsonii* are common dominant shrubs in this landcover class, providing leaves and inflorescences for caribou during calving season. *Eriophorum angustifolium* and *Carex aquatilis* are common species in the understory of wet sites dominated by *Salix pulchra*. *Equisetum* spp. are common in floodplain habitats are also consumed by caribou.

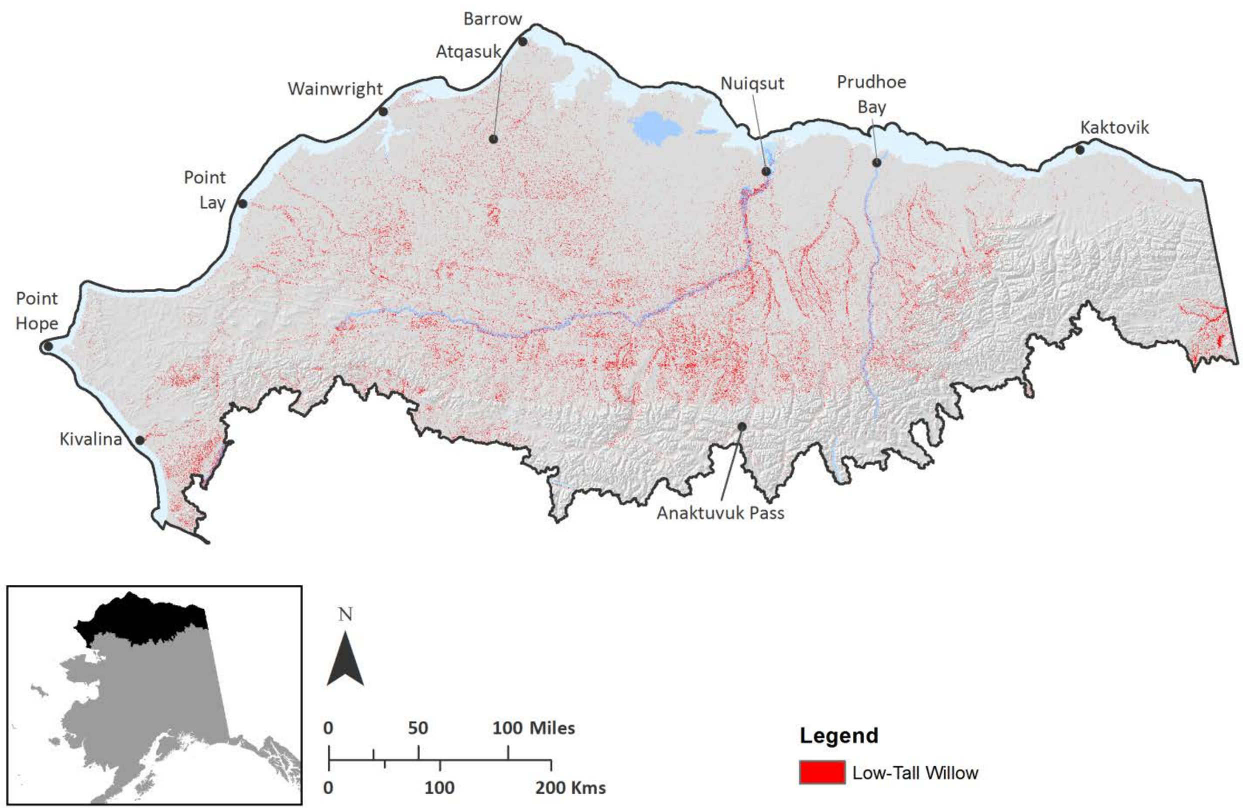

Figure H-30. Distribution of low – tall willow in the North Slope study area.

Mesic herbaceous and mesic sedge-dwarf shrub tundra (Figure H-32) are dominated by *Carex* species and, in the case of mesic sedge-dwarf shrub tundra, dwarf and low shrubs. On flat-topped polygons, *Salix pulchra* is common or co-dominant. *Eriophorum angustifolium* is sometimes dominant in the troughs of flat-topped polygons, but these microsites are not common enough within these landcover classes to warrant assigning high quality forage overall. Instead, because of the patchy distribution of *Eriophorum* and the prevalence at some sites of *Salix pulchra*, mesic herbaceous and mesic sedge-dwarf shrub tundra provide moderate quality forage for caribou during calving season. In addition to *Salix pulchra*, *S. arctica*, *S. phlebophylla*, *S. reticulata*, and *S. rotundata* are common in these landcover classes.

Dwarf shrub – other was identified as moderate forage quality during calving season because of the prevalence of *Salix* species. *Salix arctica, S. phlebophylla, S. pulchra, S. reticulata,* and *S. rotundifolia* occur commonly in dwarf shrub – other. Burned areas also support moderate quality forage during calving season and summer because of the increased cover of *Salix* spp. after wildfire. The affect is temporary, however, as the *Salix*-rich early successional communities yield to late successional tundra communities.

Summer Forage Quality

During summer, forage is distributed throughout the study area, although good quality forage exists primarily north of the Brooks Range (Figure H-31). Within the Brooks Range, moderate quality forage predominates. Both the Western Arctic and Porcupine herds use habitats within the Brooks Range during summer.

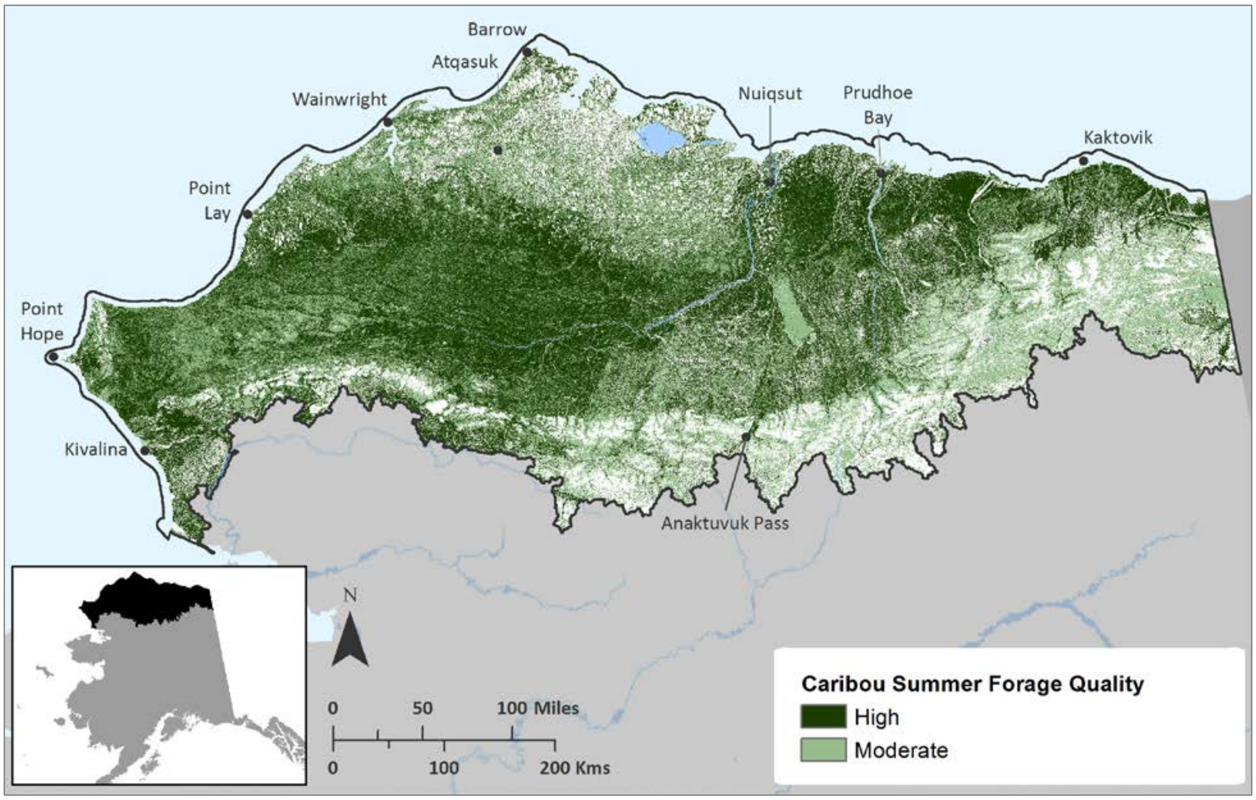

Figure H-31. Good and moderate quality caribou forage during summer (late June through early August) within the North Slope study area.

Wet sedge and wet sedge-*Sphagnum* (Figure H-27) remain high quality forage during summer because of the prevalence of *Carex aquatilis*, *C. chordorrhiza*, *Carex bigelowii* ssp. *lugens*, *Salix pulchra*, and *S. fuscescens*. Tussock shrub tundra (Figure H-29) remains high quality forage during summer because of the prevalence of *Salix* species. Forbs are sometimes common. *Carex bigelowii* ssp. *lugens* is often co-dominant in drier sites or on high-centers. *C. aquatilis* is often dominant or co-dominant in wet troughs. Similarly, low-tall willow (Figure H-30) remains high quality forage during summer because of the dominance of *Salix* species. Many forbs that are consumed by caribou are common in the floodplain habitats mapped as low-tall willow.

Mesic herbaceous and mesic sedge-dwarf shrub tundra provide high quality forage for caribou during summer. The mesic herbaceous landcover class is a minor component of the study area and contributes much less to the distribution shown in Figure H-32 than mesic shrub-dwarf shrub tundra. These two landcover classes often grade into one another and contain similar species composition. They are therefore lumped together here. Mesic herbaceous and mesic sedge-dwarf shrub tundra may be more prevalent in Northeast Alaska than Northwest Alaska, and therefore it would likely be more important for the Central Arctic and Porcupine herds. However, this apparent regional distribution may be an artifact of differing regional mapping methodologies. Flat topped polygons are dominated by *Carex aquatilis* and *Salix pulchra* in the centers and *Carex aquatilis* in the troughs. *Salix pulchra*, *S. arctica*, *S. phlebophylla*, *S. reticulata*, and *S. rotundata* are common in these landcover classes. Species diversity is often high at these sites and many forbs consumed by caribou are present.

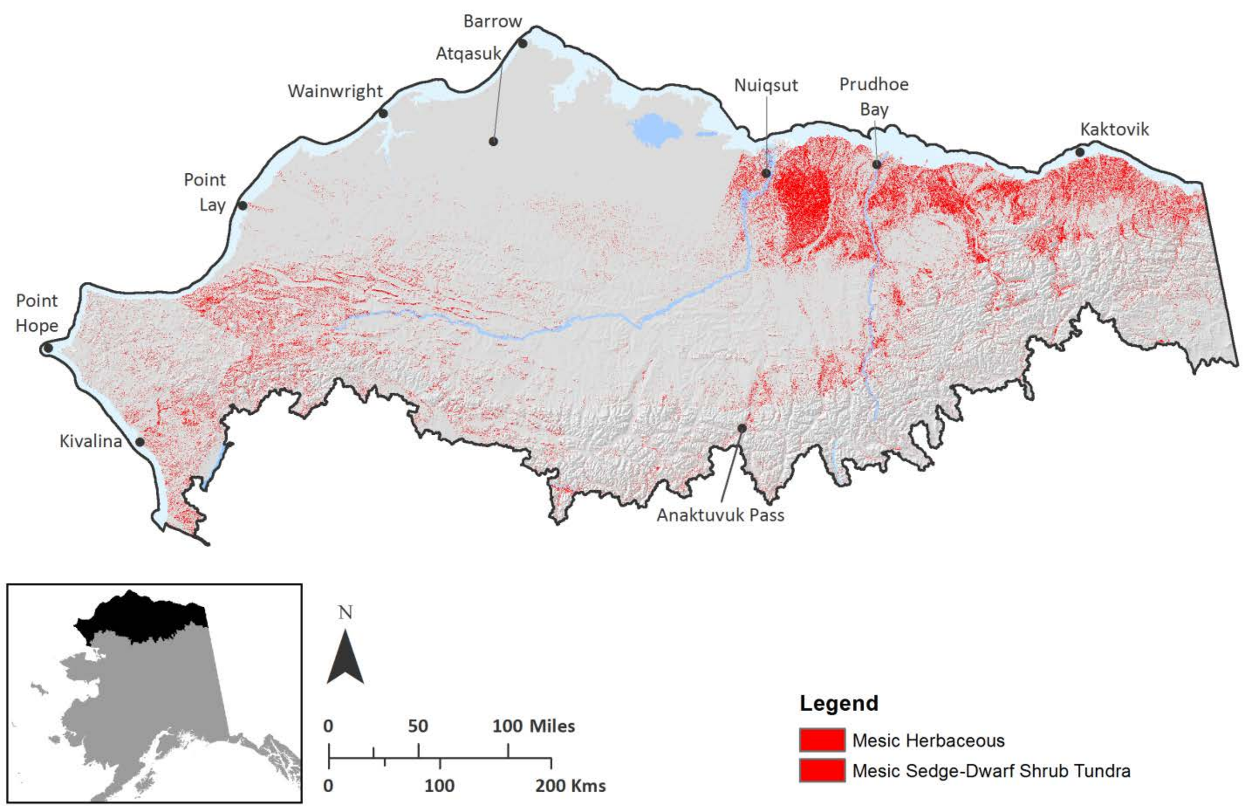

Figure H-32. Distribution of mesic sedge-dwarf shrub tundra and the mesic herbaceous landcover class in the North Slope study area.

Tidal marshes occur in flat terrain near sea level and require periodic inundation with tidal waters. They form a narrow fringe along much of the coast on the Beaufort Coastal Plain, often only 10 m wide or less. Tidal marshes provide moderate quality forage in summer because of the prevalence of halophytic forbs and *Carex* species. Tidal plant communities may provide higher quantities of sodium in the diets of caribou.

Dwarf shrub – other and dwarf shrub – Dryas provide moderate quality forage during summer because of the availability of *Salix* species and many forbs that are consumed by caribou. Tussock Tundra provides moderate availability of *Salix* species and *Carex aquatilis* and is moderate quality forage during summer. Burned Areas provide moderate quality forage during summer because of the temporary increase in cover of *Salix* species, as discussed in the calving season section above.

Winter Forage Quality

During winter, good quality forage is concentrated in the Brooks Range while moderate quality forage occurs in the Brooks Foothills (Figure H-33). The Beaufort Coastal Plain generally has low lichen availability and therefore provides low quality winter forage. However, many caribou of the Teshekpuk Herd overwinter in Beaufort Coastal Plain. It is likely that either the land cover classes selected for the NSSI landcover map do not adequately classify lichen abundance in the Beaufort Coastal Plain or that caribou overwintering in the Beaufort Coastal Plain rely on other sources of winter forage.

Within the North Slope study area, important winter ranges exist primarily for the Teshekpuk and the Central Arctic herds. The Western Arctic and Porcupine herds use little winter range within the North Slope study area. The Porcupine Herd winter range extends south of the Brooks Range into boreal ecosystems and includes large areas of Yukon and Northwest territories. The winter range of the Western Arctic Herd primarily exists south of the North Slope study area on the Seward Peninsula and in the Nulato Hills and middle Yukon-Koyukuk region. Winter forage quality within the North Slope study area has the largest impact on the Western Arctic and Porcupine herds during migration seasons.

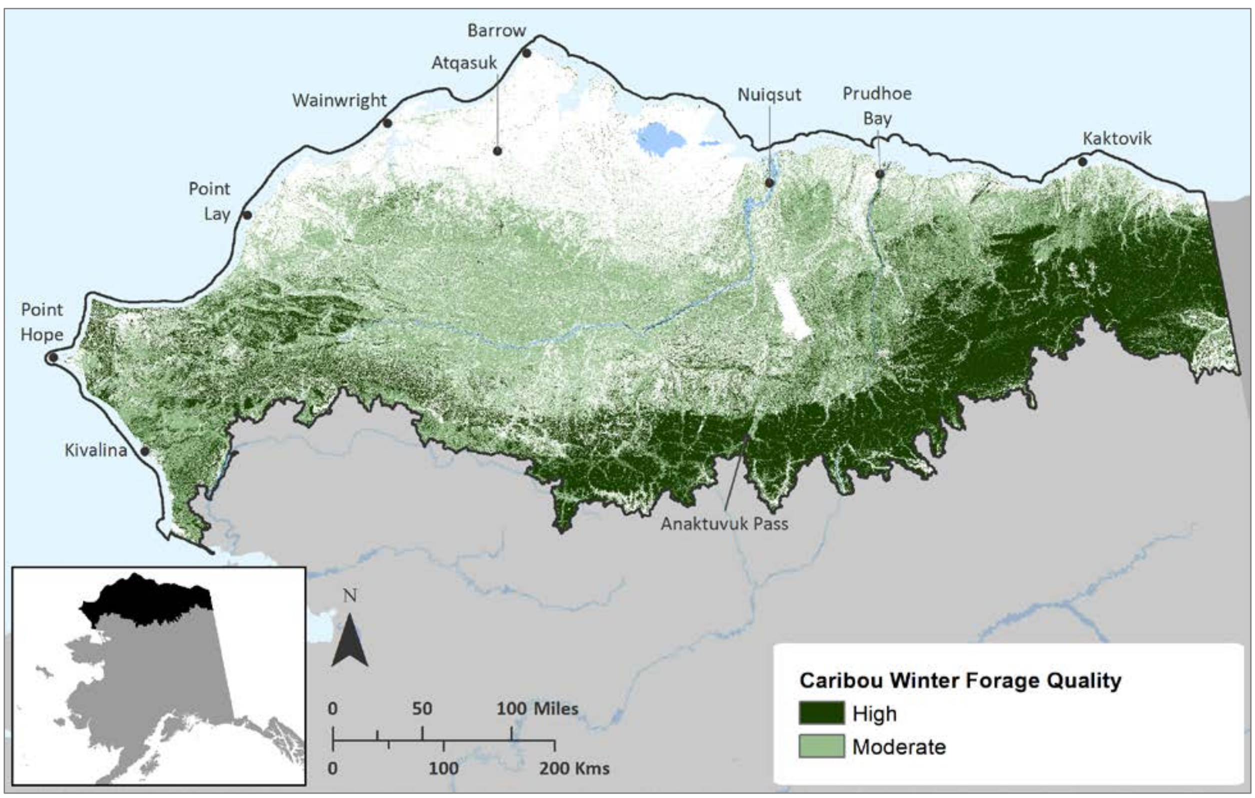

Figure H-33. Good and moderate quality caribou forage during winter within the North Slope study area.

Birch ericaceous low shrub occurs in the Brooks Foothills and Brooks Range (Figure H-34). *Cladina rangiferina* is common in this landcover class making it high quality winter forage. Evergreen ericaceous shrubs and mosses are also highly available. *Carex aquatilis* is common in the troughs of high-centered polygons.

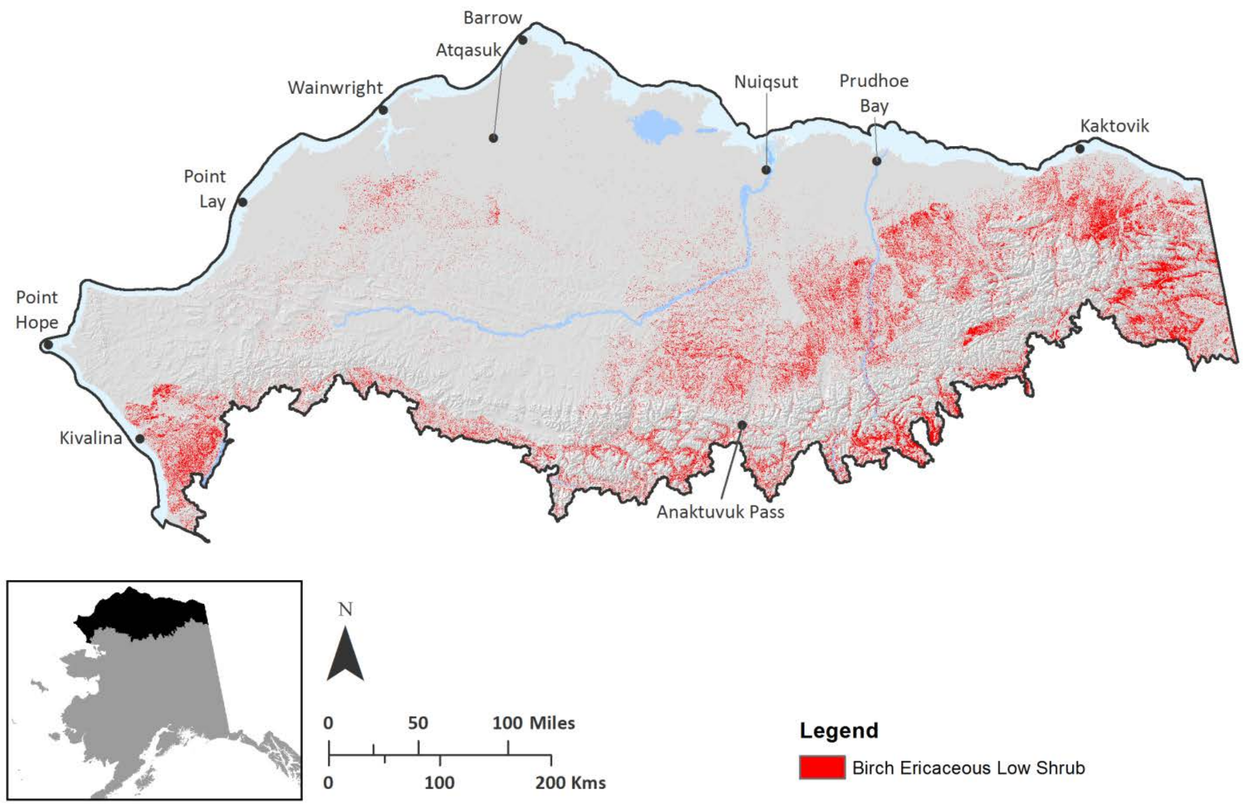

Figure H-34. Distribution of birch ericaceous low shrub in the North Slope study area.

Dwarf shrub – *Dryas* and dwarf shrub – other (Figure H-35) are common in the Brooks Range and Brooks Foothills. Cover of fruticose lichens is high in dwarf shrub landcover classes, including *Cladina*, *Cetraria*, and *Flavocetraria* species. *Carex scirpoidea* and *C. bigelowii* ssp. *lugens* are common along with a wide variety of mosses, evergreen shrubs, and forbs.

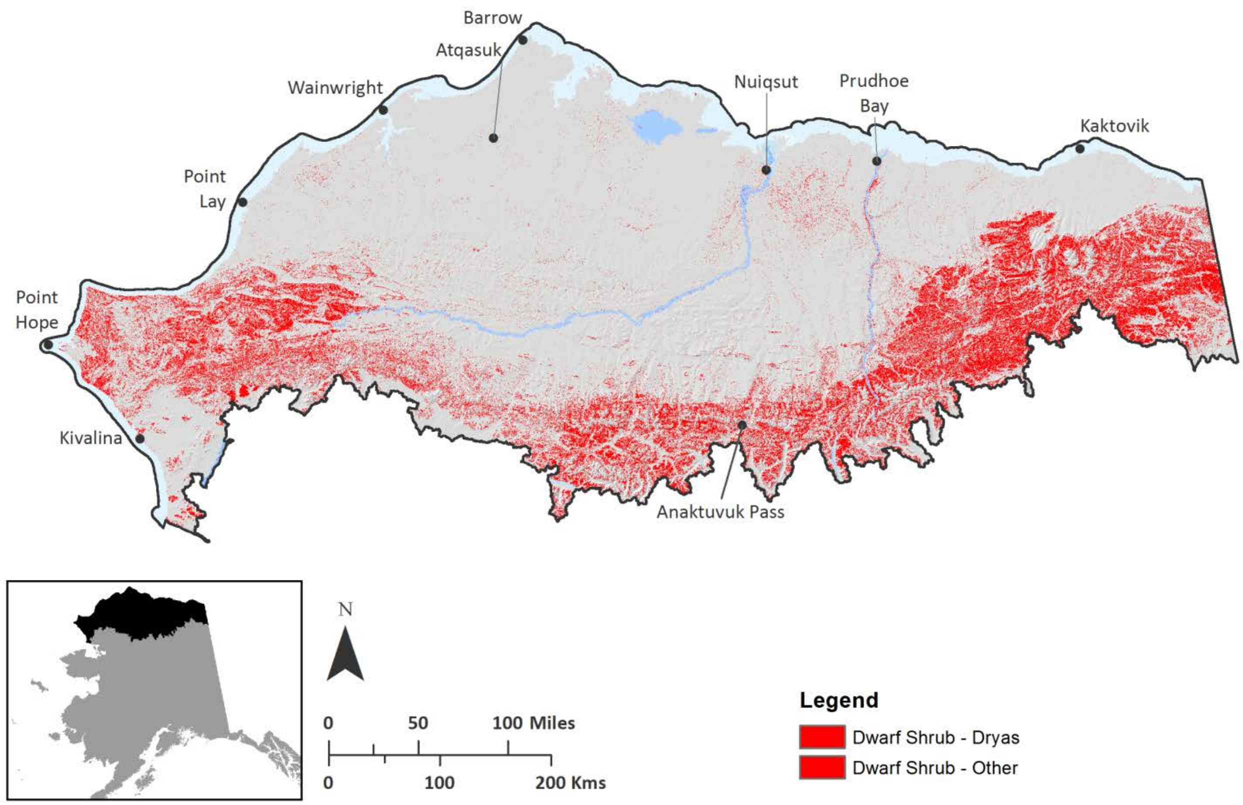

Figure H-35. Distribution of dwarf shrub – *Dryas* and dwarf shrub – other in the North Slope study area.

The sparsely vegetated landcover class as delineated by the NSSI landcover map includes alpine sites in the Brooks Range and Foothills that provide high quality winter forage for caribou. It also includes a variety of sites that are of low value relative to caribou winter forage: inland dunes, coastal dunes, floodplains, river deltas, and recently drained lakes. These low value habitats occur mainly on the Beaufort Coastal Plain (Figure H-36). Despite the inclusion of some low quality forage in the Beaufort Coastal Plain, the entire sparsely vegetated landcover class is considered high quality forage during winter because it primarily consists of alpine sites. Although the cover of vascular plant species is low, between 10% and 25%, the cover of lichen species can be high. Some sparsely vegetated sites are dominated by lichens, although these are less common. *Cladina* spp. are common in sparsely vegetated alpine. In lichen dominated sites, *Cladina stellaris* and *Flavocetraria* spp. are often prevalent. Cover of moss species can also be high, with mosses exceeding 25% cover at some sites. Evergreen shrubs are sometimes also present.

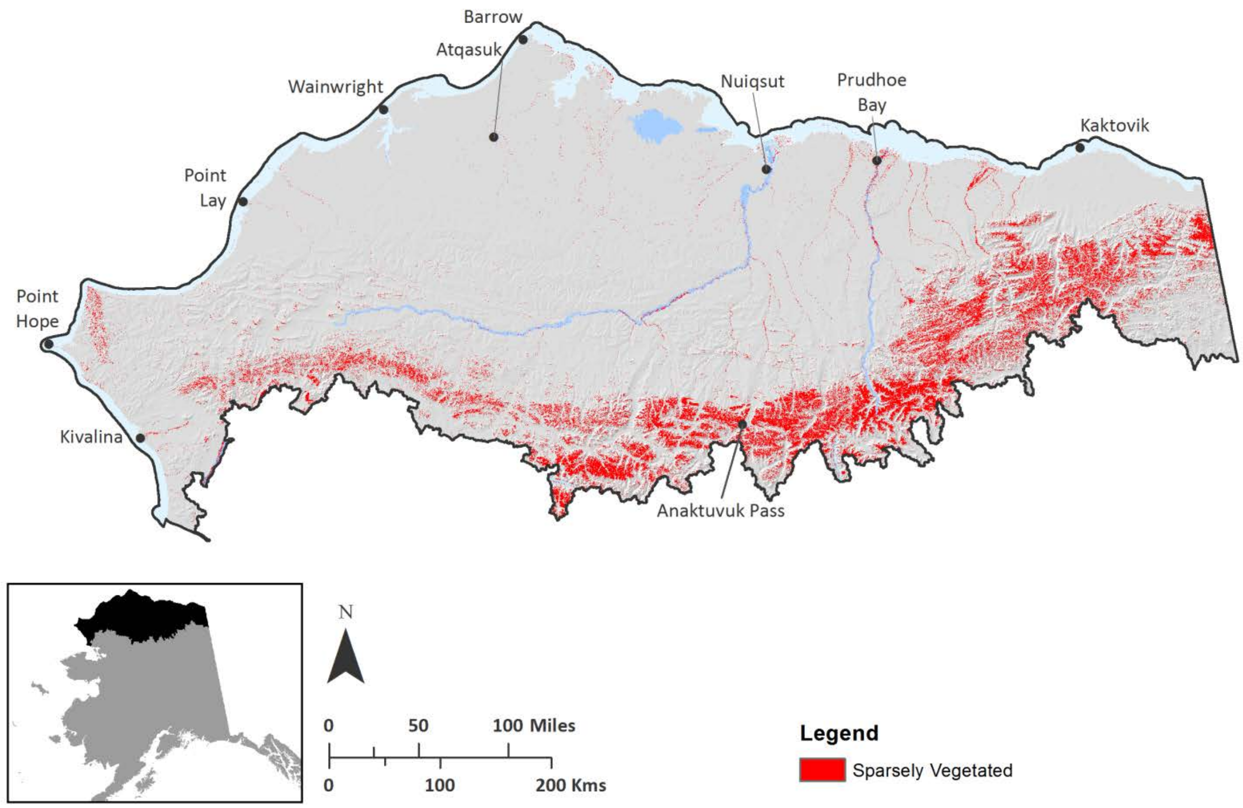

Figure H-36. Distribution of the sparsely vegetated landcover class in the North Slope study area.

Mesic sedge-dwarf shrub tundra (Figure H-32) and tussock shrub tundra (Figure H-29) provide moderate quality winter forage. Fruticose lichens occur in these landcover classes but not typically at high cover values. *Carex aquatilis*, *C. microchaeta*, *C. bigelowii* ssp. *lugens*, mosses, and evergreen shrubs are common at these sites.

7.4. Abiotic Change Agent Analysis

Date of Thaw

The phenology, nutrient content, and abundance of plant forage throughout the short summer growing season are critical to replenishing energy and protein lost during winter. Warming temperatures will increase the likelihood of advanced spring thaw, expediting snowmelt and vegetation emergence, thereby potentially increasing forage abundance at the time of calving.

We intersected the calving range map for each of the four north slope caribou herds with modeled outputs for date of thaw (DOT), using DOT as a proxy for onset of snowmelt. DOT refers to the projected date on which the running mean temperature crosses the freezing point in spring. It can be expected to correlate with the condition of ice on rivers, streams, and wetlands, and could have implications for timing of changes in vegetation phenology, as described above. Modeled results indicate that by 2060, DOT is expected to occur between 1 to 5 days earlier across the North Slope study area. For the three herds that calve on the Arctic Coastal Plain, DOT is only expected to be shifted by 1 to 2 days, while in the southwestern part of the study area, within the calving range of the Western Arctic Herd, DOT may shift from 3 to 5 days earlier (Figure H-37).

Minimal changes in DOT are not expected to be drastic enough to be an issue for caribou, who are very plastic in their response to change, but it is unknown whether this result can be generalized. Potential for trophic mismatch in relation to an earlier growing season is discussed below under growing season length.

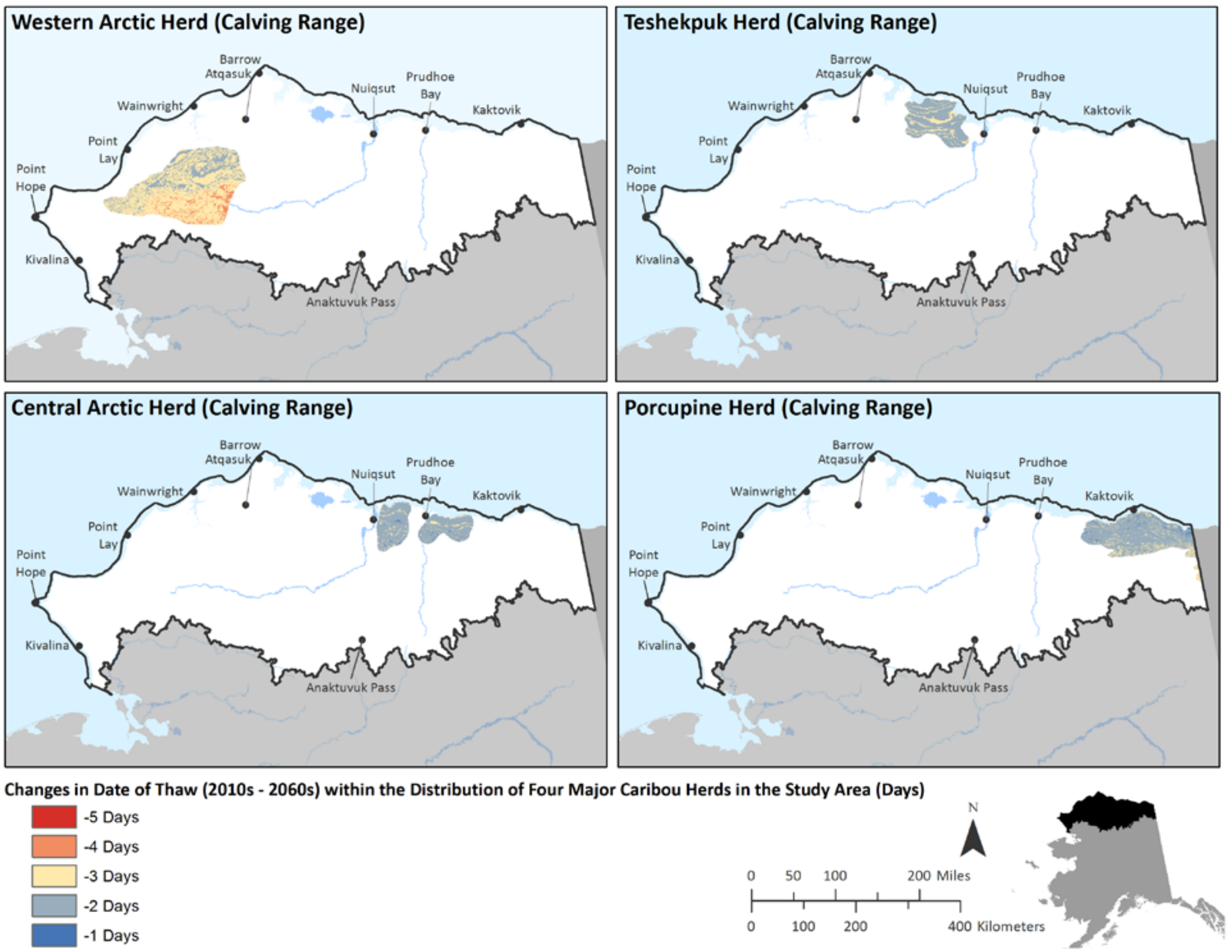

Figure H-37. Change in date of thaw from 2010s to 2060s within caribou calving habitat for the Western Arctic, Teshekpuk, Central Arctic, and Porcupine herds.

Growing Season Length

Climate models (see Section C. Abiotic Change Agents) indicate that warm season length (number of days between DOT and DOF) is projected to increase, on average, anywhere from 10 to 16 days across the North Slope study area, with the smallest increases seen in more southern and inland communities. A longer growing season may benefit caribou on their calving and summer ranges by promoting early onset of vegetation green-up, an increase in nutrient value of summer caribou forage, and an increase in the duration of time for which summer forage is available. If an earlier availability of nutrients coincides with peak lactation, calf survival will likely increase (Griffith et al. 2002). Increases in growing season length are projected be the most pronounced within the summer range of the Western Arctic and Teshekpuk herds, where growing season in coastal areas is expected to increase by 10 to 14 days by 2060 (Figure H-38).

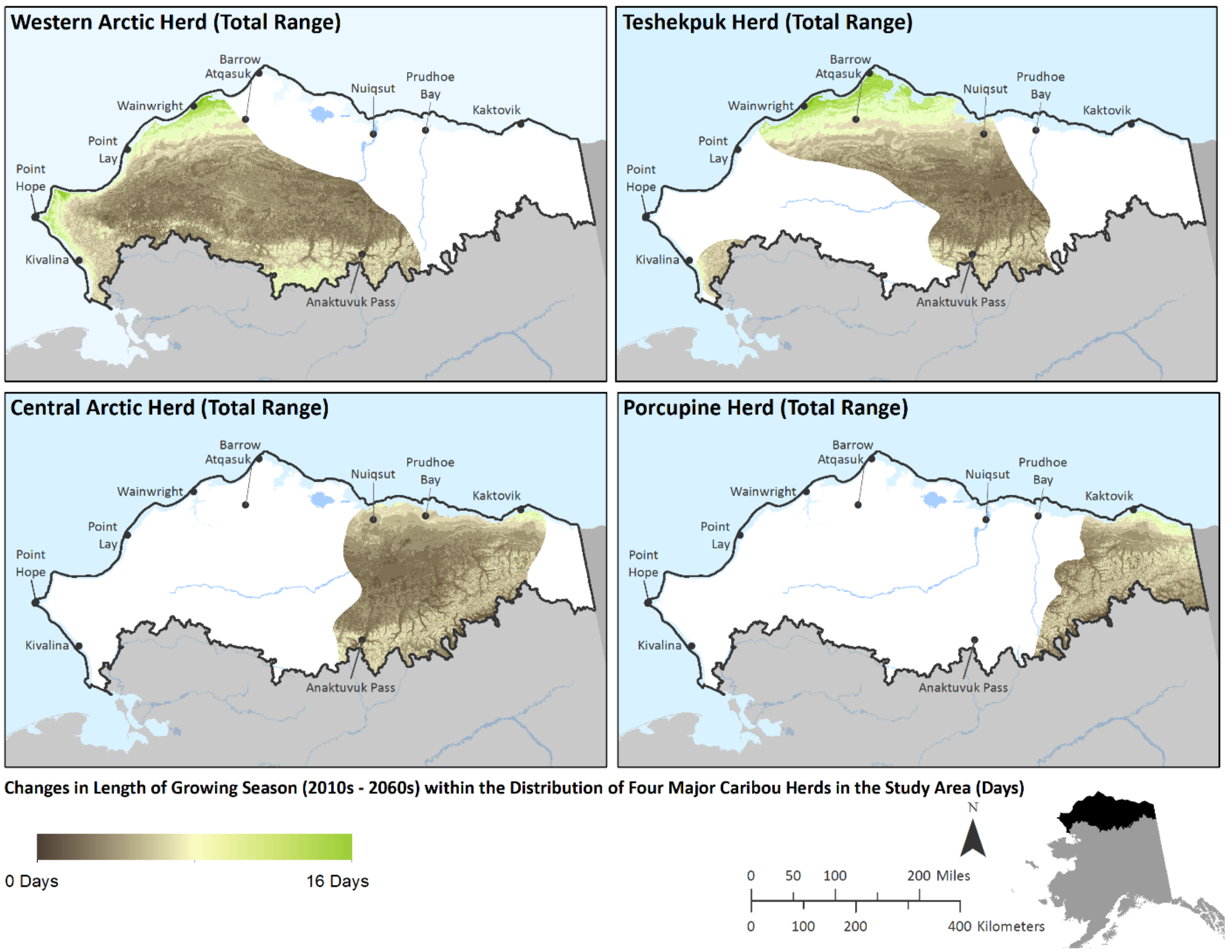

Figure H-38. Change in length of growing season from 2010s to 2060s for Western Arctic, Teshekpuk, Central Arctic, and Porcupine herds in the North Slope study area.

An increased length of growing season in the Arctic, and the corresponding earlier start of the growing season, may cause a trophic mismatch for caribou: the timing of caribou life cycle may lose synchronicity with peak resource availability, meaning that calves are born after most of the food has emerged, thereby reducing calf survival. In Greenland, an advance in onset of calving lagged behind an advance in onset of growing season, suggesting the possibility that eventually calves would be born after the peak nutrient content of forage (Post and Forchhammer 2008). However, the evidence from Greenland also suggests the possibility that caribou life cycles may adjust to take advantage of an increased length of growing season. Caribou would need to migrate and give birth earlier to capitalize on this pulse, but it is unknown whether they can adapt by advancing rut and changing the timing of migration (Reid et al.

2013). If life cycles adjust to changes in plant phenology, then the increase in length of growing season may increase caribou population sizes or individual fitness.

Snow Day Fraction

Warmer temperatures in winter will likely result in an increase in freeze-thaw cycles and the number of rain-on-snow (icing) events, as suggested by changing snow day fractions for fall and winter months (see Section C. Abiotic Change Agents). We used snow-day fraction as a proxy for rain on snow events. 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. Results indicate that throughout the annual range of the four caribou herds, 90% of precipitation is currently likely to fall as snow for all months from October to April. By 2060, conditions in December to April are still expected to be completely snow-dominated area-wide, however, marked changes are expected in the fall. Most notably, occasional October rainfall (≥ 15%) is expected across almost all of the Arctic coast and even in November, precipitation may arrive as rain more than 10% of the time around Kivalina and Point Hope. Icing in these areas could be potentially problematic for the Teshekpuk herd, whose winter range includes a small area adjacent to Kivalina and across the North Slope from Wainwright to Nuiqsut.

Denser, harder snow and the formation of a hard crust on top of the snow as a result of freeze thaw cycles may restrict accessibility to forage lichens and increase energetic costs (Putkonen and Roe 2003). Icing on the ground or snowpack following winter rain or melting has been correlated with starvation induced die-offs of Peary caribou and population declines in Svalbard and Wrangel Island reindeer (Reid et al 2013). Since lichens are a critical component of winter diet, a reduction in lichen abundance and thus a deterioration of winter range can lead to shifts in winter distribution (Joly et al 2010).

Wildfire

Wildfire has the potential to severely degrade winter caribou forage within the study area by removing lichens and rapidly restructuring vegetation communities in favor of graminoid and dwarf shrub plant species. Currently, the frequency and extent of wildfire in tundra is low (Joly et al. 2009). While the frequency and severity of wildfire is predicted to increase in the future across the North Slope study area, most of the region is likely to remain relatively free of fire, although sporadic tundra fires may occur in all sub-regions (see Section C. Abiotic Change Agents).

Increased summer temperatures and decreased summer precipitation as projected for the future (see Section C. Abiotic Change Agents) may cause a reduction in the quality of winter caribou forage on the North Slope. Warming and drying will likely make current lichen habitat less productive while simultaneously increasing competition from vascular plants, especially low and tall shrubs. Additional factors, such as snow entrapment and increased litter, related to expansion of low and tall shrub are also likely to contribute to the reduction of future lichen cover (Joly et al. 2009).

The population size of caribou herds inversely affects the carrying capacity of each herd's winter range. Lichen cover declined on unburned areas of the winter range of the Western Arctic Herd between 1981 and 2005 while caribou population increased to approximately 490,000 animals (Joly et al. 2007b).

Recovery of lichen cover after periods of heavy grazing can take few to many decades depending on local site conditions (Joly et al. 2009).

In Northeast Alaska, within the range of the Porcupine Caribou Herd, the predicted change in area of lichen-producing tundra by the 2060s ranges from an increase of several percent to a decrease of several percent, depending on the Global Circulation Model (GCM) selected. South of the study area boundary, but in habitats still used by the Porcupine Caribou Herd, declines of up to 21% in area of lichen-producing spruce forest are possible (Gustine et al. 2014). While wildfire may negatively influence caribou habitat for the Porcupine Herd, the primary reduction of that habitat will occur in spruce forests south of the North Slope study area.

Similarly, in Northwest Alaska, within the range of the Western Arctic Caribou Herd, declines of 5% to 10% in potential high quality winter range are predicted to occur by 2099, though it is important to note that these results include both tundra and spruce forest habitats and areas not included in the North Slope study area (Joly et al. 2012). Winter forage for the Teshekpuk Lake herd and Central Arctic herd are not likely to be largely impacted by wildfire in the future because these herds do not rely on spruce forest south of the Brooks Range.

7.5. Limitations

The methods selected for the analysis of spatial extent of preferred caribou forage are consistent with the goals and limitations of an REA. However, more refined methods that include the generation of new datasets through modeling could produce more detailed results on a per herd basis. For example, Wilson et al. (2012) developed models that looked at summer resource selection for the Teshekpuk herd using the following variables: vegetation type, phenology / forage biomass, terrain ruggedness based on elevation, distance to coast, and precipitation. A similar modeling exercise was performed to determine critical winter habitat for four ungulate species in British Columbia (Safford et al. 2004). Modeling resource selection or critical habitat is beyond the scope of the REA but would provide a useful tool for future studies investigating the distribution of preferred caribou forage.

Plant community composition and phenology of important forage species vary within the landcover classes selected for the NSSI landcover map. Snow accumulation, microclimate, drainage, soil characteristics, and topographic relief all affect caribou forage quality within each landcover class. Varied topography and the resulting varied snow melt are especially important regarding the quality of calving range because these factors prolong the period of emergence of *Eriophorum* inflorescences across a broader temporal scale than on flat terrain (Nellemann and Thomsen 1994). Microsite characteristics such as snow depth are currently difficult to assess but terrain ruggedness should be taken into account in more focused studies of caribou calving forage quality.

The ability of caribou to access winter forage is determined largely by snow depth and the frequency of rain on snow events (Joly et al. 2009). While the probability of rain on snow events is represented by snow day fraction, snow depth cannot be adequately represented because drivers of snow depth include many variables beyond amount of snow fall. This means that, while good quality winter forage may exist in some areas, high amounts of snow accumulation may make forage in those areas inaccessible for caribou.

Lake margins and riparian corridors are preferred habitats for caribou in summer. These habitats may not be adequately represented in the NSSI Landcover Map because they often occur with widths less than 30 m, therefore not filling a 30x30 m grid cell for vegetation classification. There also likely exists more tidal marsh vegetation than is classified as such in the NSSI landcover map because tidal marshes are often not wide enough to fill the 30 x 30 m grid cell mapping resolution.

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8. Lapland longspur (Calcarius lapponicus)

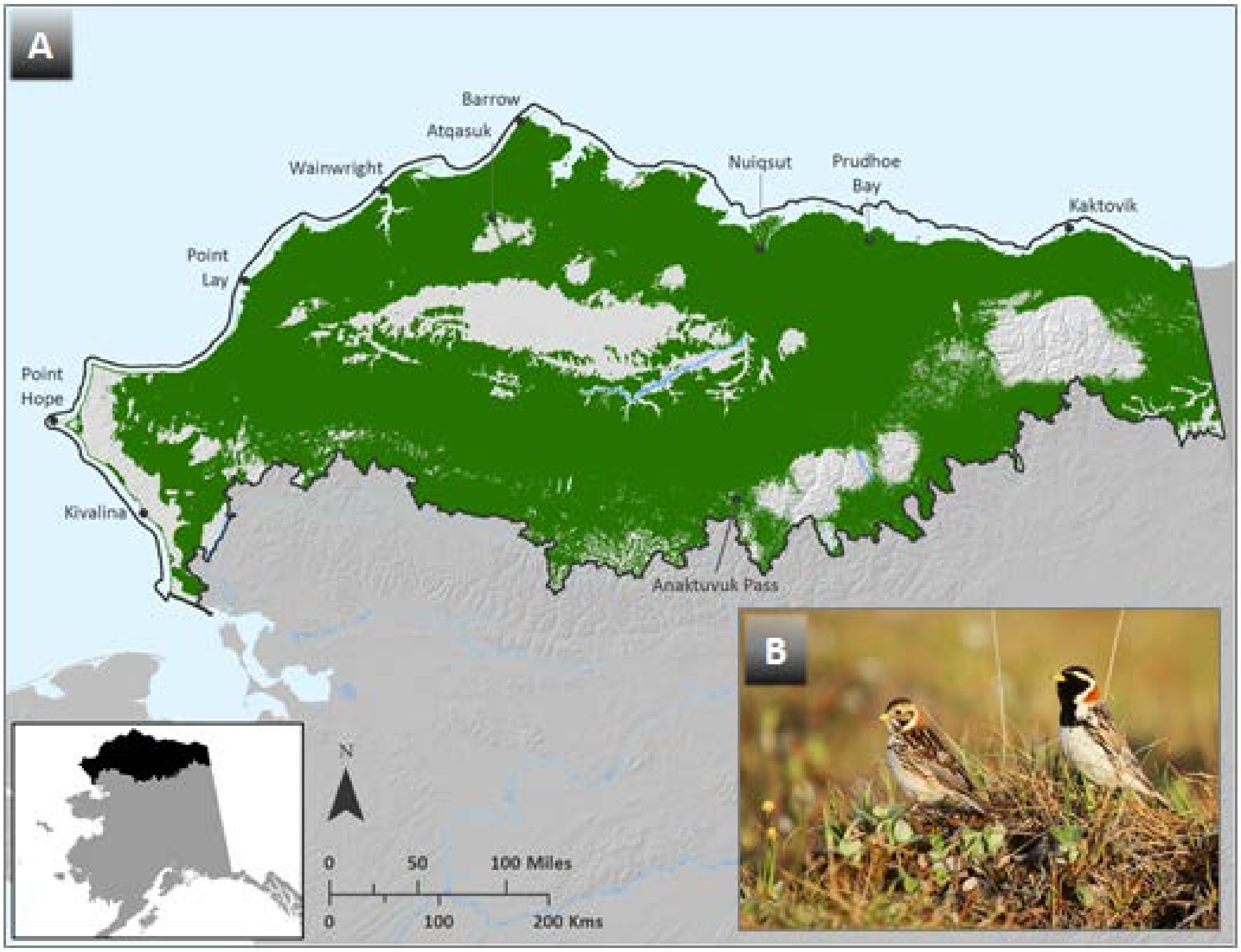

Figure H-39. Current modeled distribution of Lapland longspur (*Calcarius lapponicus*) in the North Slope study area (A) and Lapland longspur male and female at nest (B).

8.1. Introduction

The Lapland longspur (*Calcarius lapponicus*) is a migratory species that summers in circumpolar Arctic and subarctic regions, and winters further south in the temperate zones of Japan, Korea, China, central Eurasia and the North Seacoasts, and across continental North America. In Alaska, the Lapland longspur breeds from the Aleutian and Bering Sea Islands, through western Alaska and north across the Arctic. The Lapland longspur is the most abundant passerine breeder on the North Slope of Alaska with high nesting densities found throughout the Arctic Coastal Plain, but also nests in alpine habitats in the interior Brooks Range (Custer and Pitelka 1977, Liebezeit et al. 2011). Nest sites are often in dry/moist tundra near tussocks, and less frequently in wetter tundra habitats (Hussell and Montgomerie 2002). In the interior Brooks Range, nest sites are also found in alpine habitats.

Birds arrive at breeding sites on the north coast of Alaska during the third week of May (reviewed in Hussell and Montgomerie 2002) and nesting occurs in early June directly after snowmelt allowing for young to achieve independence prior to the end of insect emergence (particularly adult crane flies). Average clutch size is approximately 5 eggs and adults feed larval insects to their young (Custer and Pitelka 1977). Severe spring weather can decrease reproductive success (Wingfield and Hunt 2002).

Seeds, especially on exposed grasses, are a major component of Lapland longspur diets when snow still covers the ground. After snowmelt, Lapland longspurs primarily consume larval dipteran flies until July when adult dipteran flies emerge. During the breeding season, they typically forage in a wide range of habitats on a variety of invertebrates but also consume seeds and other vegetative matter (Hussell and Montgomerie 2002). Preferred foraging habitat often consists of drier upland sites but they will also forage in wet tundra. In August, saw-fly larvae are the most important food source (Custer and Pitelka 1978).

The Lapland longspur is considered a keystone species of arctic ecosystems because of its relation to vegetation stratigraphy, its abundance reflecting the height, nature and extent of willow scrub, and because of its dependence on the phenology and abundance of invertebrate prey and the effects that they have on prey and predator populations (avian and mammalian carnivores) (Christensen et al. 2013). This species is common throughout the Arctic wherever suitable habitat exists; thus, its disappearance from key areas would likely have ecosystem consequences, both as a consumer of arthropods and prey to generalist predators such as Arctic foxes, but also as prey to specialist predators, such as peregrine falcons (*Falco peregrinus*), where declines could have local consequences (ATBMP 2013).

8.2. Conceptual Model

The conceptual model below (Figure H-40) is based on literature review and describes the relationship between the various change agents and natural drivers for the Lapland longspur. The boxes and arrows represent the state of knowledge about the Lapland longspur and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and the Lapland longspur. Change agents selected for this REA and considered in this analysis include: climate change, fire, invasive species, and human use.

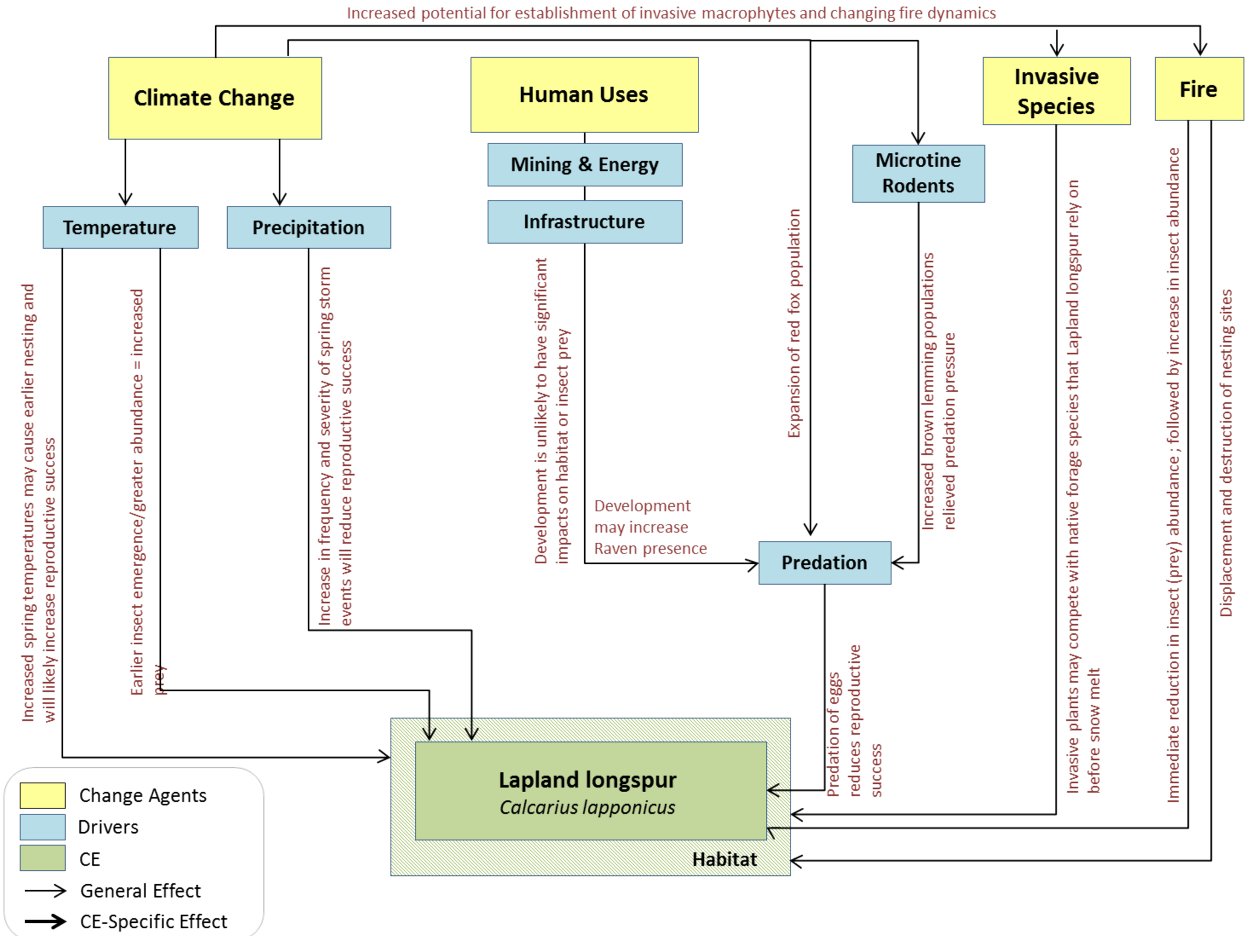

Figure H-40. Conceptual model for the Lapland longspur.

8.3. Attributes and Indicators

Attributes and indicators helped to define the relationships between conservation elements and change agents, and, where possible, the thresholds associated with these relationships. Based on the assessment of available indicators, spatial data used to assess the status of the Lapland longspur included: date of thaw, summer temperature, spring precipitation, and landscape condition (Table H-24).

Table H-24. Attributes and indicators for the Lapland longspur.

CA or Driver	Ecological Attribute	Indicator (unit of measure)	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Habitat availability[18]	Date of thaw (proxy for timing of snowmelt)	Onset of nesting is timed with snowmelt.	Later than average			Earlier than average.
	Food availability[19]	Mean temperature between DOT and DOF	Insect (primary prey) emergence and abundance are directly influenced by mean ambient temperature and number of frost-free days.	Below average			Above average
		Growing season length (#of days between DOT and DOF)		Below average			Above average
Fire	Prey availability; breeding habitat[20]	Fire return interval/relative flammability	Population reduced immediately after fire due to reduced insect (prey) abundance, displacement, damaged/burnt nest sites. Following a fire, new vegetation and insect abundance can increase bird diversity and abundance.	High fire return interval			Moderate fire return interval
Anthropogenic	Habitat quality / reproductive success[21]	Landscape condition model	Risk of predation on passerine bird nests increases within 5 km of human infrastructure. Ravens, a common predator associated with human infrastructure, have a foraging range of 5-7 km.	Human development < 5 km from nesting habitat	Human development 5 - 10 km from nesting habitat		Human development sites > 10 km from nesting habitat

[18] Based on Custer and Pitelka 1977 and Liebezeit et al. 2012.
[19] Based on Bolduc et al. 2013.
[20] Based on Wright 1981, Luensmann 2010, and Liebezeit et al. 2012.
[21] Based on Cannings and Hammerson 2004, Liebezeit et al. 2009, and Støen et al. 2010.

8.4. Distribution Model

We used predictive models generated by the Alaska Gap Analysis Project (AKGAP) to describe the distribution of the Lapland longspur across the North Slope study area (see Section H.1.1 for details relating to AKGAP models). A total of 4,329 occurrence records obtained from the AKGAP occurrence database and the BISON database were used to evaluate the model and generate a classification success statistic (Table H-25).

Lapland longspur are widely distributed throughout the entire study are in appropriate habitat (Figure H-39). Modeled outputs covered > 90% of the species range across the North Slope. Classification success values for the Lapland longspur AKGAP distribution model were 0.95%, indicating high model quality.

Table H-25. Datasets used for the Lapland longspur.

Dataset Name	Data source
Gap Analysis distribution model for the Lapland longspur	Alaska Gap Analysis Project, AKNHP
Gap Analysis terrestrial vertebrate occurrence geodatabase database records for Lapland longspur *	Alaska Gap Analysis Project, AKNHP
BISON occurrence records for Lapland longspur	BISON (http://bison.usgs.ornl.gov/#home)

*Sources for Gap Analysis Vertebrate Occurrence records for Arctic fox are a compilation of museum records and field survey data obtained from various agencies and researchers. A full bibliography of all data sources for this species is included in the North Slope Data Discovery Memo.

8.5. Abiotic Change Agents Analysis

We explored the relationship between Lapland longspur and three climatic change agents: date of thaw (DOT), growing season length, and mean summer temperature (JJA) at three time steps (current, near-term, and long-term). Current research indicates that years of late snowmelt could result in delayed breeding and that insect emergence and abundance are directly influenced by mean ambient temperature and number of frost-free days. We also compared the distribution of Lapland longspur to projected relative flammability to assess the effect that fire could have on habitat and forage availability.

Date of Thaw

The onset of nesting for Lapland longspur is timed with snowmelt (Custer and Pitelka 1977). Warmer spring temperatures can expedite snowmelt and create snow-free areas earlier, which could result in earlier nesting dates. The timing of insect emergence is also closely related to the timing of snowmelt, and might advance with warmer spring temperatures (Tulp and Schekkerman 2008). Earlier nesting dates may result in increased reproductive success for Lapland longspur (Liebezeit et al. 2012), as long as the shift in breeding season remains matched to the emergence of surface active insects.

We intersected the distribution map for Lapland longspur with modeled outputs for date of thaw (DOT), using DOT as a proxy for onset of snowmelt. DOT refers to the projected date on which the running mean temperature crosses the freezing point in spring. It can be expected to correlate with the condition of ice on rivers, streams, and wetlands, and could have implications for timing of breeding, breeding success, and changes in vegetation phenology. Modeled results indicate that by 2060, DOT is expected to occur between 1 to 6 days earlier within the current distribution of the Lapland longspur (Figure H-41). In areas of higher nesting densities like the Arctic Coastal Plain, DOT is only expected to be shifted by 1 to 2 days, while in the southern part of the study area, especially in the area adjacent to and west of Anaktuvuk Pass, DOT may be shifted from 4 to 6 days (Figure H-41).

Minimal changes in DOT are not expected to be drastic enough to be an issue for the Lapland longspur. The Lapland Longspur, appears to have adjusted nest initiation in response to climate warming over the last 10 years (J. Liebezeit and S. Zack, unpublished data in Liebezeit et al. 2012), but it is unknown whether this result can be generalized. Discussion of the potential for trophic mismatch in relation to earlier insect emergence is included with the discussion of growing season length and summer temperature, below.

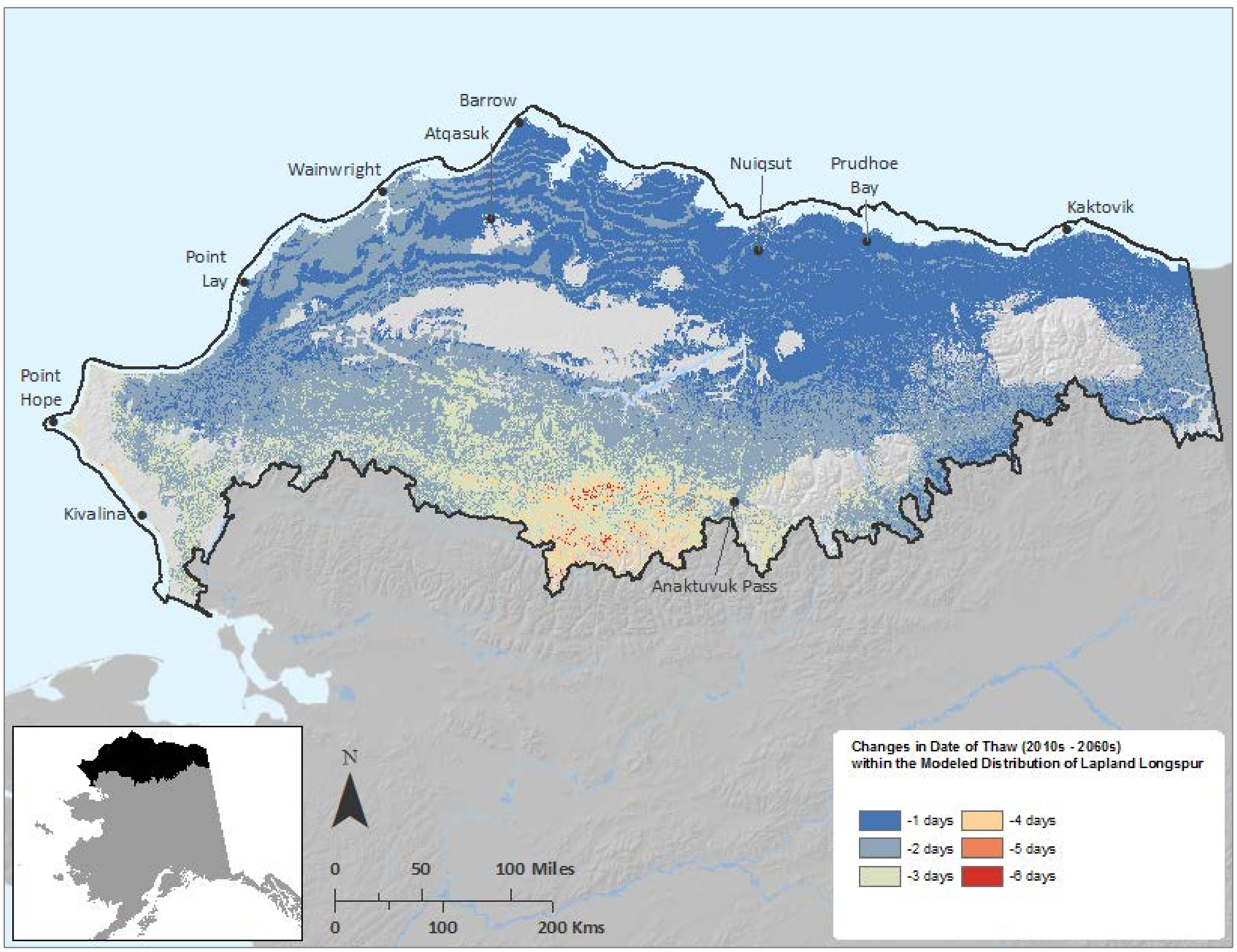

Figure H-41. Modeled decrease in date of thaw (DOT) between 2010s and 2060s within the current distribution of the Lapland longspur.

Length of Growing Season and Summer Temperature

Passerine breeding activity in the Arctic is closely linked with emergence of invertebrate prey (Fox et al. 1987), as described above. In addition to the timing of snowmelt, arthropod presence and abundance is directly influenced by mean ambient temperature and frost-free days (Bolduc et al. 2013). Because arthropods are highly sensitive to climate variation, climate change could affect prey abundance and/or shift the emergence date of insects. A longer growing season combined with warmer ambient temperatures could potentially result in increased insect abundance and more varied insect community composition (Danks 1992, Kittel et al. 2011), which could potentially benefit Lapland longspur by providing more abundant food sources.

Between the current (2010) and the near-term (2020), 100% of the area within the distribution of the Lapland longspur is expected to experience an increase of 0 - 1.3 °C in July temperature (Table H-26). By 2060, significant July temperature increases of > 1.3 °C are projected to occur in over half (57%) the species range (Table H-26). Geographically, warming will be more pronounced in the inland part of the Lapland longspurs distribution, with less change along the coast – similar to results for changes in DOT.

Table H-26. Predicted change over the near-term (2020) and long-term (2060) in abiotic change agents, mean July temperature and length of growing season, within the distribution of the Lapland longspur in the North Slope study area.

Lapland longspur	July Temperature		Length of Growing Season			
	0 - 1.3 °C	> 1.3 °C	< 0 Days	0 - 6 Days	7 - 14 Days	> 14 Days
Near-Term Future	100%	-	100%	-	-	-
Long-Term Future	43%	57%	-	-	98%	2%

Climate models (see Section C. Abiotic Change Agents) indicate that warm season length (number of days between DOT and DOF) is projected to increase, on average, anywhere from 10 to 16 days across the North Slope study area, with the smallest increases seen in more southern and inland communities. For the Lapland longspur, almost 98% of their current distribution is expected to see an increase of between one and two weeks in the growing season, and 2% will see an increase of greater than two weeks (Table H-26). Geographically, increases of > 14 days are only projected for the most northern part of the species range in the coastal margins between Wainwright and Barrow (Figure H-42).

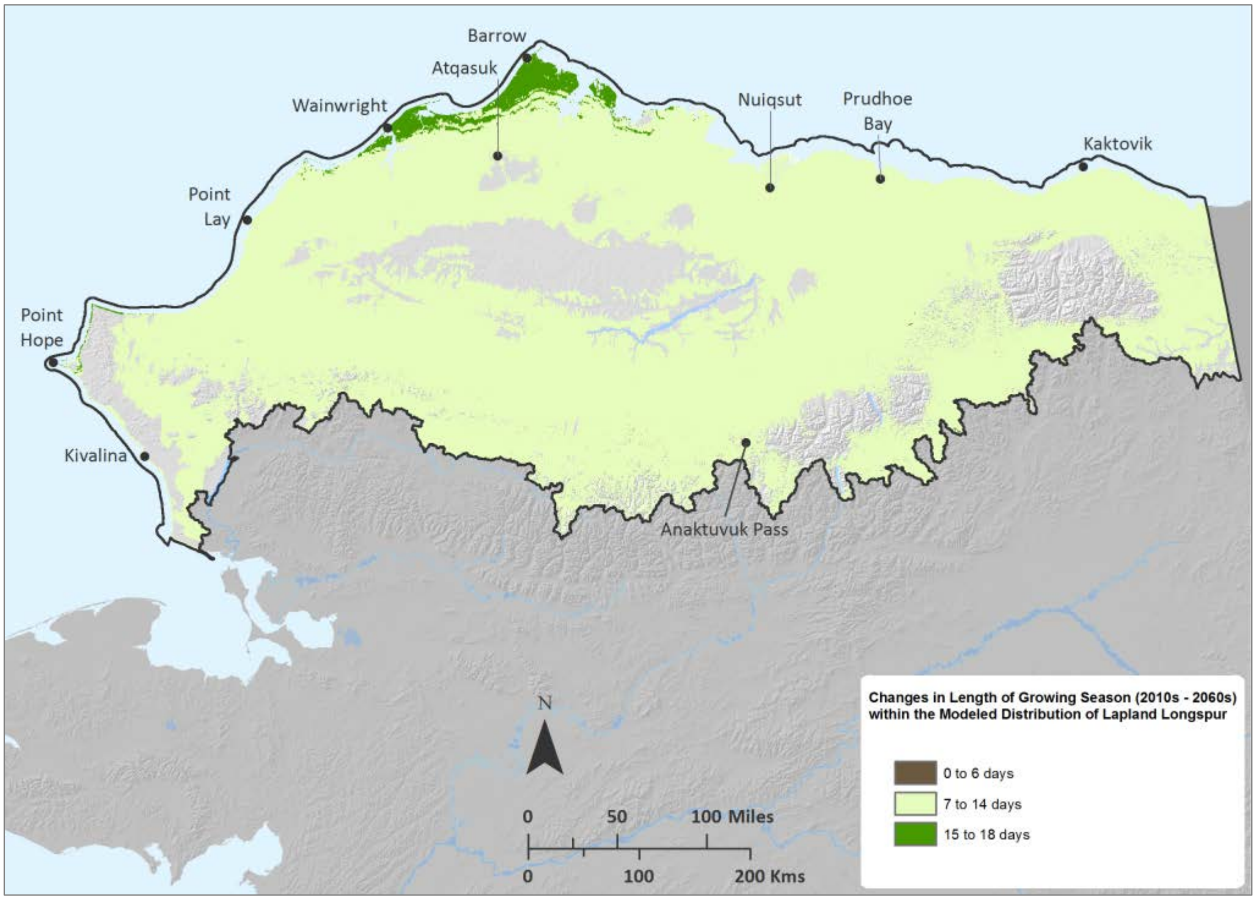

Figure H-42. Predicted change in length of growing season from 2010s to 2060s within the modeled distribution of the Lapland longspur.

A longer growing season, combined with warmer ambient temperatures could be beneficial to Lapland longspur nestling success. Longspurs may actually benefit from a warmer physiographical thermal niche, particularly during the nestling stage when thermo-regulatory capacity is compromised and cold snaps early in the breeding season can be frequent and potentially lethal (Barry 1962 in Liebezeit et al. 2012).

As the timing of seasonal events changes under the influence of climate change, corresponding adjustment in the timing of crucial life-history events for birds (e.g., breeding, migration) becomes an important issue. Although a longer growing season combined with warmer ambient temperatures could result in insect prey increases, shifts in the timing of insect emergence brought on by an earlier growing season could also be potentially deleterious to Lapland longspur survival if the insect outbreaks are not synchronous with migration and breeding events. Some evidence indicates that Lapland Longspurs are able to track phenological changes associated with a warming climate at least in terms of nest initiation (J. Liebezeit and S. Zack, unpublished data) suggesting they may be able to compensate for a warming climate, at least in terms of nest timing. However, their ability to cope with decoupling of nest initiation and other events is unknown (Liebezeit et al. 2012). At present, we lack information on changes in the timing of arrival of Lapland longspur to make determinations as to whether earlier insect emergence would result in a trophic mismatch.

Fire

Lapland longspurs are the dominant nesting bird within sedge tussock-shrub tundra, which covers more area than any other plant community in northwestern Alaska (Wright 1981). Historically, fire in sedge tussock-shrub tundra has resulted in a reduction of breeding Lapland longspurs the following year (Wright 1981). The following activities were indicated as factors and mechanisms for reduced bird abundance immediately following a fire: direct burning deterred settling of birds; males established larger breeding territories post fire; reduction of prey abundance; and elimination of nest sites from direct burning (Wright 1981). However, long-term post-fire effects are not reported.

Fire frequency across the North Slope study area is predicted to increase by the 2060s. However, 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 (see Section C. Abiotic Change Agents). Recent 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). The ALFRESCO model (described under the CA Fire Section) 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. ALFRESCO outputs of projected vegetation change indicate that shrub habitats will increase by 2060 throughout much of the study area, with highest increases in the Brooks Range Ecoregion (Figure H-43). During the past 25 years (1988-2012), passerines associated with shrub habitats have increased across the tundra on the Seward Peninsula (McNew et al. 2013). It seems likely that increases in shrub habitats would be beneficial to Lapland longspur, although broad-scale expansion of shrub communities at the expense of wet sedge tundra and moist sedge-shrub tundra on the Coastal Plain could reduce preferred breeding habitat (Martin et al. 2009).

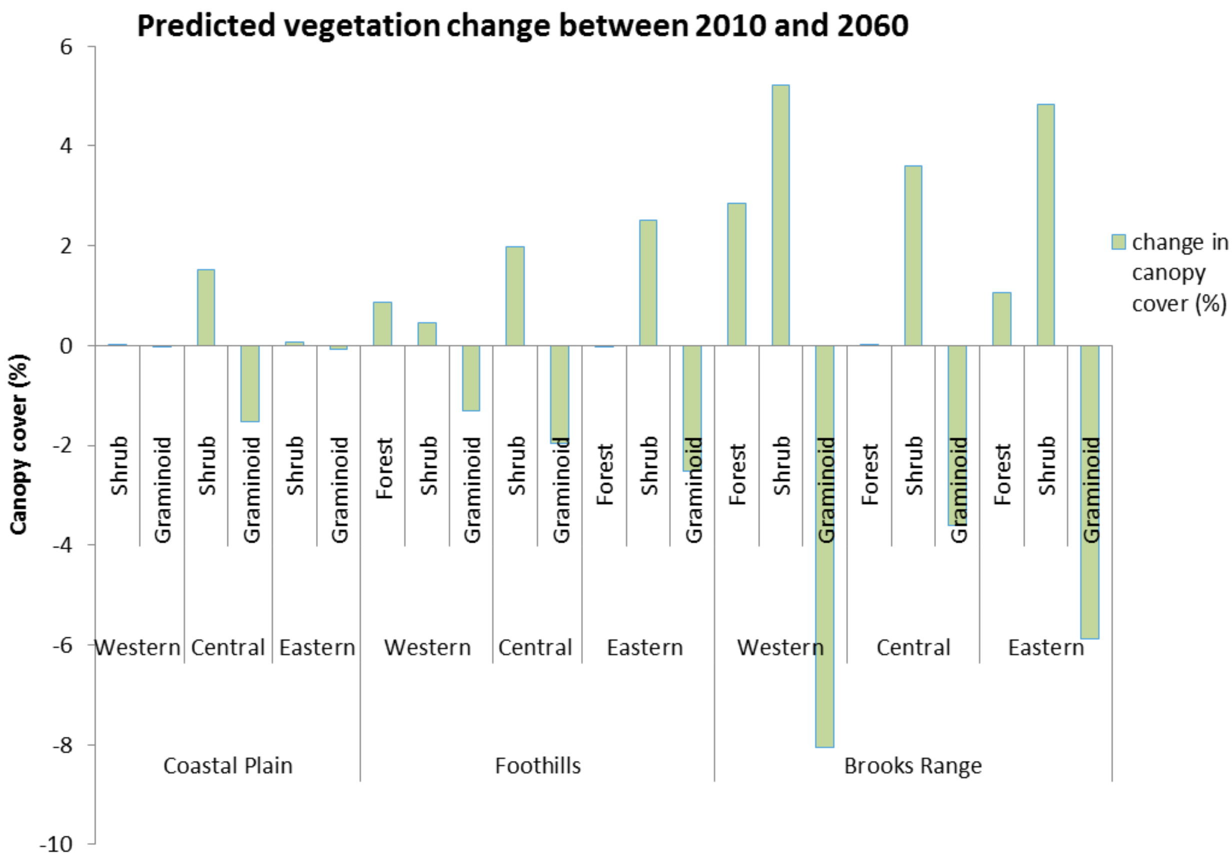

Figure H-43. Projected vegetation change (based on ALFRESCO modelling) by ecological sub-region in the North Slope study area.

Climate Summary

Overall, our assessment of abiotic climatic variables suggests that Lapland Longspurs could benefit and possibly increase under the current predictions of climate change during the 50-year timeframe of this assessment. Potential benefits include increased habitat due to climate-driven shrubification (both post-fire and without fire); decreased cold-related mortality early in the breeding season, due to warmer air temperatures; and more abundant and varied food sources, due to a longer and warmer growing season (Table H-27).

Table H-27. Summary of abiotic change agents used in the assessment for Lapland longspur and projected effects.

Indicator	Short-term (2020) trend	Long-term (2060) trend	Impact to	Effect
Date of thaw	No change	earlier	Earlier nesting, increased insect prey, increased reproductive success, potential for trophic mismatch	+
Growing season length	No change	+	Increases in insect prey, improved nestling success, potential for trophic mismatch	+/-
Summer temperature	Non-significant	+	Increases in insect prey	+
Fire	-	+	Short-term habitat loss, potential long-term gains	+/-

8.6. Current Status and Future Landscape Condition

The intersection of the Lapland longspur distribution map with the Landscape Condition Model indicates that the majority of habitat in the North Slope study area is classified as being in very high (intact) condition under all scenarios (Figure H-44). Potential threats as a result of increased development related to oil and gas infrastructure include potential increases in predation by ravens, as ravens are known to prey on Lapland longspur nestlings (Fox et al. 1987; Støen et al. 2010). Some evidence has suggested that ravens and foxes become more numerous in areas of human development because of the presence of additional food sources and artificial nesting/denning sites (Day 1998). While recent improvements to waste handling procedures associated with oil field infrastructure have likely dampened this effect in oil fields (Liebezeit et al. 2009), this may still be a concern in areas of other development.

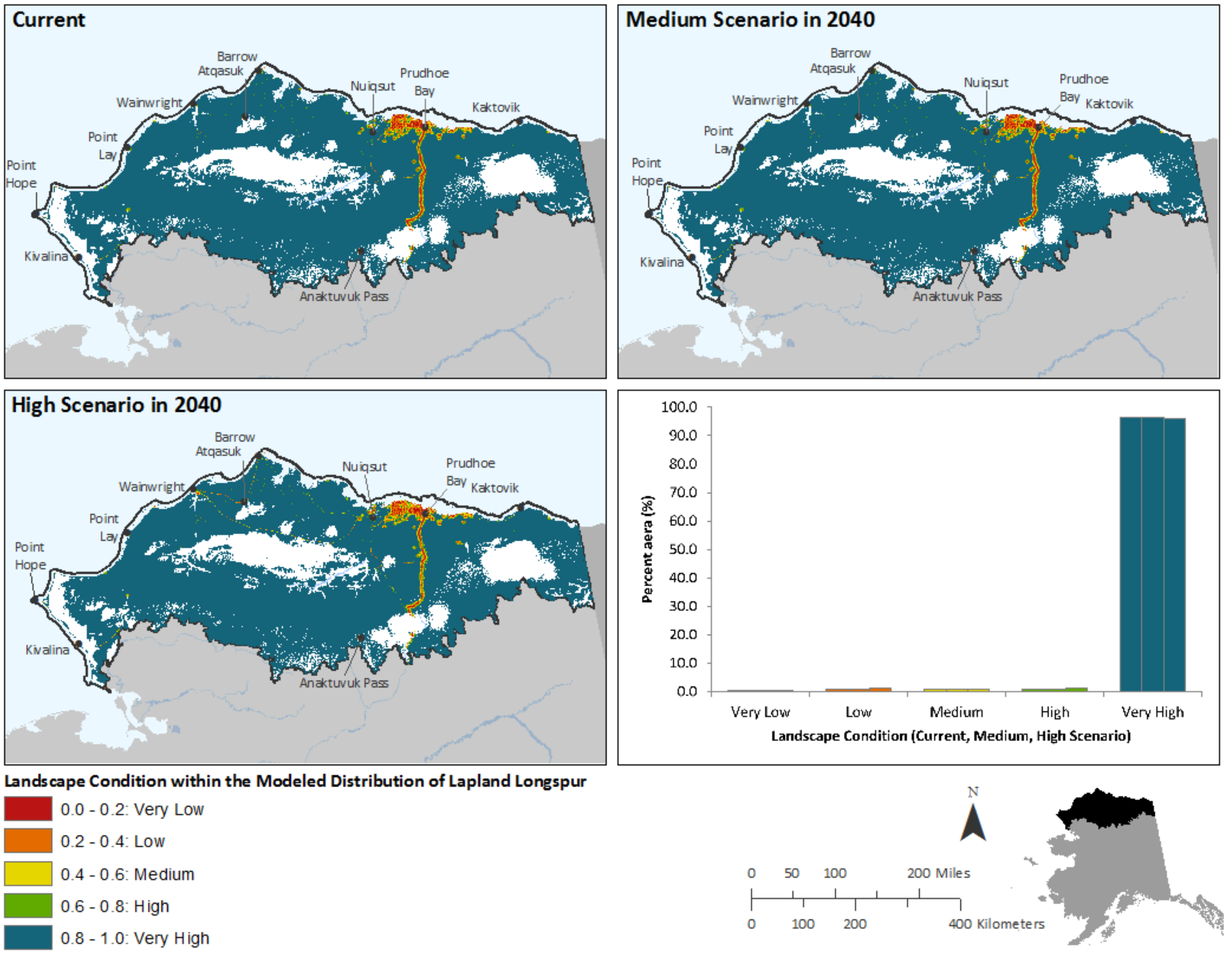

Figure H-44. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current distribution of Lapland longspur in the North Slope study area.

Currently, the degree of nest predation varies greatly from year to year. In years of low lemming abundance, predation by avian and mammalian predators on Lapland longspur increases, resulting in reduced reproductive success (Custer and Pitelka 1977). Breeding pairs that lose nests to predators rarely re-nest in the same season (Wingfield and Hunt 2002).

8.7. Limitations and Data Gaps

We lacked a suitable spatial layer to explore the relationship between spring storm events and Lapland longspur distribution. In West Greenland, Fox et al. (1987) reported that Lapland Bunting clutch size was depressed in years of climatic severity. Additionally, extreme weather events may change the activity patterns and availability of surface-active insects. A decrease in insect prey abundance during the Lapland longspurs reproductive period could have negative consequences.

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9. Baseline Data for Landbirds

MQ TF 1	What are the baseline data for the species composition, number of individuals, vegetation type used, and change in number/species composition of landbirds and their habitat over time?

9.1. Introduction

The avifauna of arctic Alaska is dominated numerically by waterfowl and shorebirds for which there are numerous long-term region-wide datasets available to assess species composition, distribution, trends and habitat use. However, this is not the case for landbirds, whose distributions are often more dispersed than waterbirds and shorebirds, and survey data tend to be more localized and disparate. This management question required that we obtain and assemble baseline information from historical and contemporaneous avian surveys to produce a spatial data layer that identified the distribution and species composition of landbirds (passerines) across the North Slope study area. Because many of these studies utilized diverse survey methods, study areas, and target taxa, they were not directly comparable and did not allow us to assess changes in the number/species composition and habitats over time, as this would have required substantial effort to standardize the data and produce relative abundance or density estimates, which was beyond the scope of the REA. During the North Slope REA Methods Workshop, the AMT agreed that a compilation of existing occurrence data sources and production of an associated spatial data layer would fulfill the requirements for this MQ.

9.2. Methods

We gathered baseline data from numerous and disparate avian breeding surveys across the North Slope, many that utilized different observers, survey methods, and objectives. We then summarized the data into a common format, attributed with 39 common fields, and housed this information in a project specific geodatabase. We produced a spatial data layer depicting species distribution and species composition. We then compared avian distribution information to an existing map of vegetative classes and identified those vegetation types (NSSI landcover classes) that have been surveyed for passerines with the most frequency during the time period of the data collection. The general methods for developing spatial products for landbird distribution are shown In the process model below (Figure H-45).

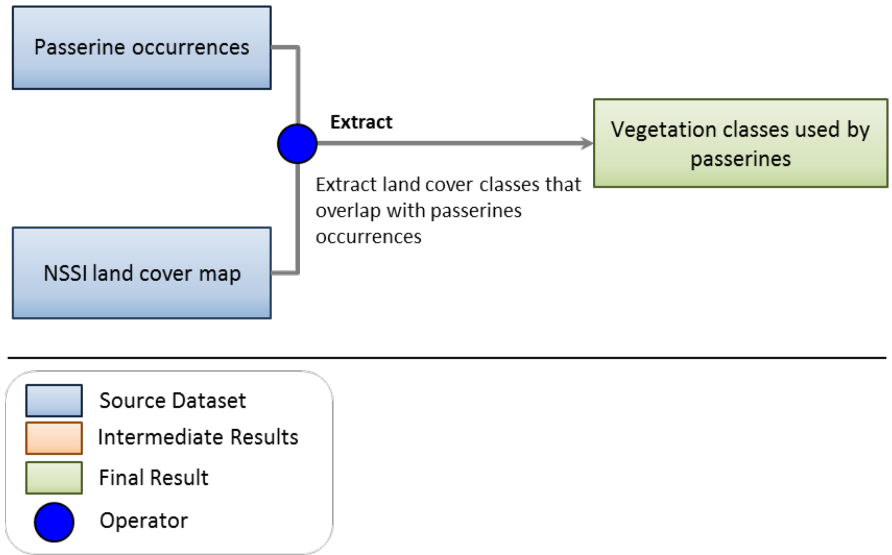

Figure H-45. Process model for MQ TF 1.

Table H-28. Data sources included in the development of the baseline landbird database for the North Slope REA.

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9.3. Results

All occurrence data used to answer this question were obtained from the Alaska Gap Analysis Project. This included 14,508 occurrence records for 59 species from 40 unique data sources, spanning the time period 1948 to 2009 (Table H-28). Although the data spanned the time period 1948 to 2009, the majority of data (90%) were collected between 1990 and 2009. Although many avian surveys have occurred in the North Slope study area prior to 1990, the goal of this assessment was to obtain as much high quality information as was possible within the constraints of project resources. As such, we sought out digital datasets that were easy to manipulate and reproduce spatially. Much survey data collected prior to 1990 exist primarily in project reports and were not generally available in digital format.

Geographically, passerine survey data were available from throughout the North Slope study area (Figure H-46). The majority of surveys occured along roads, in riparian areas, or adjacent to population centers of Barrow, Nuiqsit, and Prudhoe Bay, likley due to ease of accessibility. Survey data from the Brooks Foothills ecoregion was the most limited in scope.

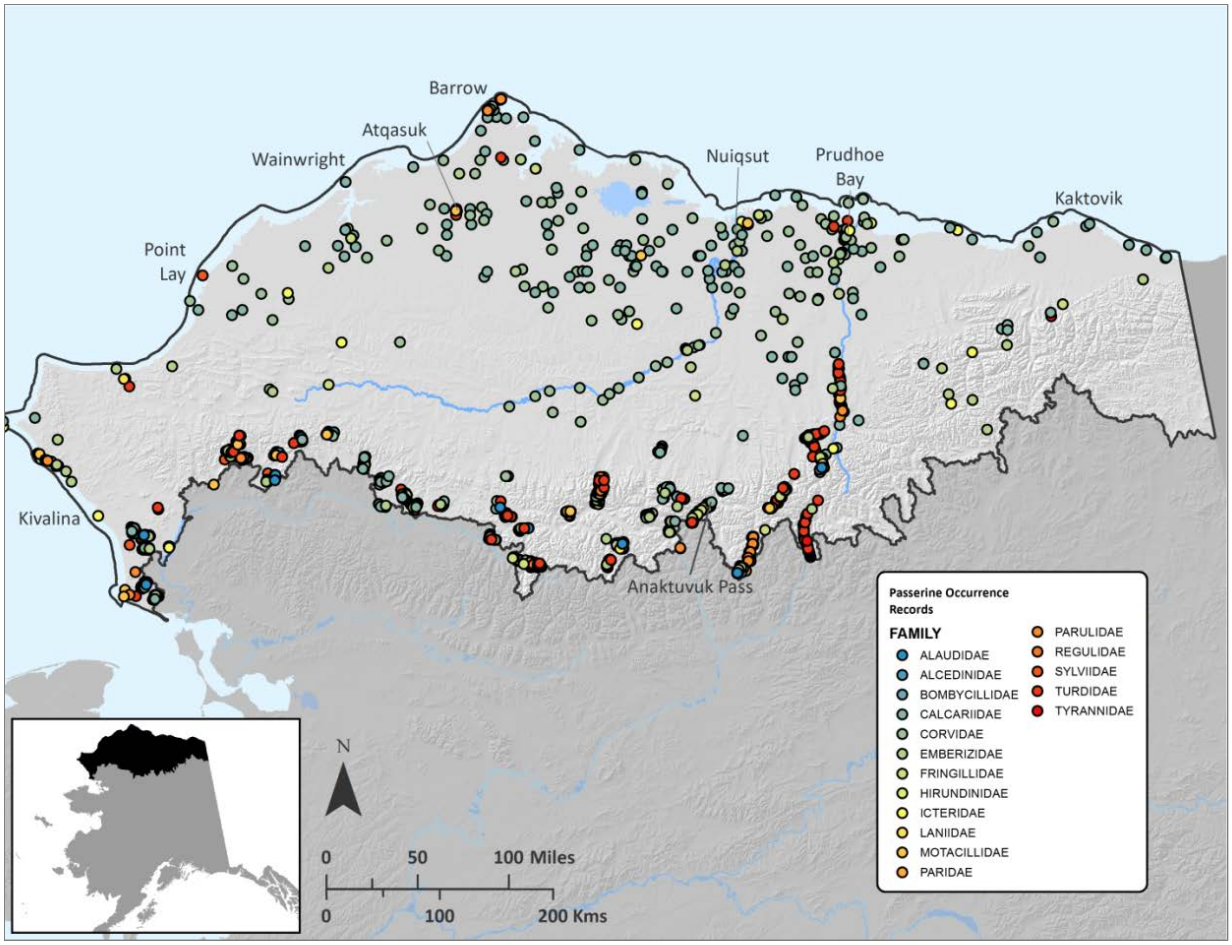

Figure H-46. Location of baseline passerine survey data for the time period 1948-2009. This dataset includes 14,508 occurrence records for 59 passerine species from 4**0** unique data sources.

Species composition

Because of the complexity involved with standardization of so many disparate datasets, we did not calculate relative abundance or provide density estimates for each species. Instead, we calculated species composition based solely on the total number of detections across all studies.

A total of 59 species from 17 families were detected in all surveys combined (Table H-29). Lapland longspur, savannah sparrow, American tree sparrow, and white-crowned sparrow were the most commonly detected species, all having > 1500 detections (Figure H-47). Common redpoll and American robin had between 100 and 1500 detections. Twenty-two of the 59 species had fewer than 20 detections (denoted by * in Table H-29). These species are likely uncommon to rare on the North Slope or detection probability may be low.

Table H-29. Passerine species composition by family (in bold) for all survey data combined for the time period 1948 – 2009. An asterisk* denotes species with fewer than 20 detections.

ALAUDIDAE
Horned lark
ALCEDINIDAE
Belted kingfisher*
BOMBYCILLIDAE
Bohemian waxwing*
CALCARIIDAE
Lapland longspur
Smith’s longspur
Snow bunting
CORVIDAE
Blackbilled magpie*
Common raven
Gray jay
Northwestern crow*
EMBERIZIDAE
American tree sparrow
Dark-eyed junco
Fox sparrow
Golden-crowned sparrow
Lincolns sparrow
Savannah sparrow
White-crowned sparrow
FRINGILLIDAE
Common redpoll
Gray-crowned rosyfinch
Hoary redpoll
Pine grosbeak*
Pine siskin*
White-winged crossbill
HIRUNDINIDAE
Bank swallow*
Barn swallow*
Cliff swallow*
Tree swallow*
Violet-green swallow*
ICTERIDAE
Brown-headed cowbird*
Red-winged blackbird*
Rusty blackbird
LANIIDAE
Northern shrike*
MOTACILLIDAE
American pipit
Eastern yellow wagtail
Red-throated pipit*
PARIDAE
Black-capped chickadee*
Boreal chickadee
Gray-headed chickadee*
PARULIDAE
Blackpoll warbler
Northern waterthrush
Orange-crowned warbler
Townsends warbler*
Wilsons warbler
Yellow warbler
Yellow-rumped warbler
REGULIDAE
Ruby-crowned kinglet
SYLVIIDAE
Arctic warbler
TURDIDAE
American robin
Bluethroat
Gray-cheeked thrush
Hermit thrush*
Mountain bluebird*
Northern wheatear
Swainson’s thrush
Townsends solitaire*
Varied thrush
TYRANNIDAE
Alder flycatcher
Olive-sided flycatcher
Says phoebe*

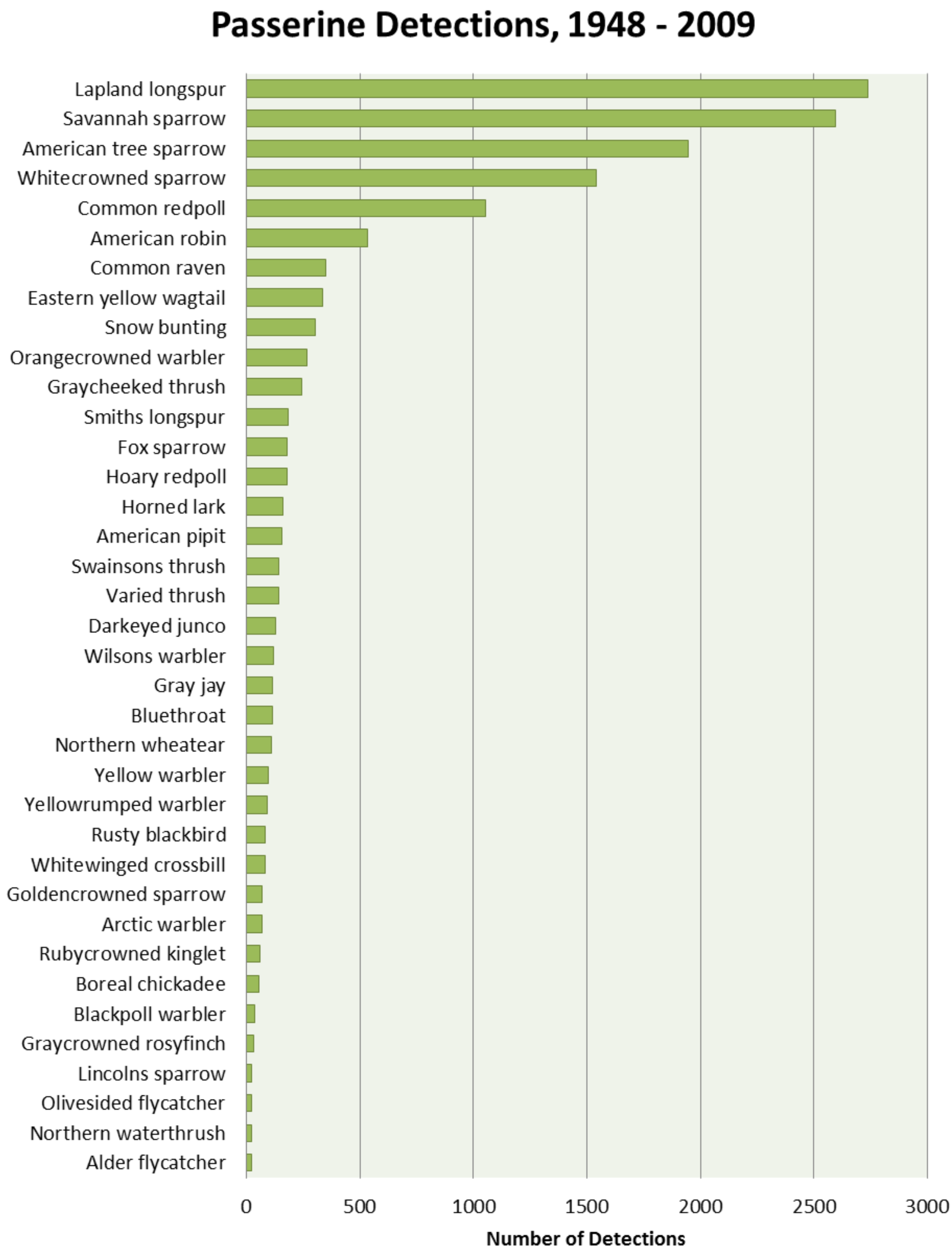

Figure H-47. Species composition and number of detections by species for all survey locations combined, 1948 – 2009.

Vegetation type used

Habitat information associated with the avian occurrence data was inconsistent, as many different techniques and multiple vegetation classification systems were used to quantify habitats in the various surveys. As a mechanism to assess "vegetation type used" by each of the passerine species in a systematic way, we intersected the passerine occurrence data layer with the NSSI landcover map and summarized landcover classes by avian occurrence. Shrub habitats, including tussock shrub tundra, mesic sedge-dwarf shrub tundra, birch ericaceous low shrub, and low and tall willow habitats had the greatest number of landbird occurrences associated with them (Figure H-48), which is consistent with general knowledge of passerine habitat use on the north slope (Martin et al. 2009).

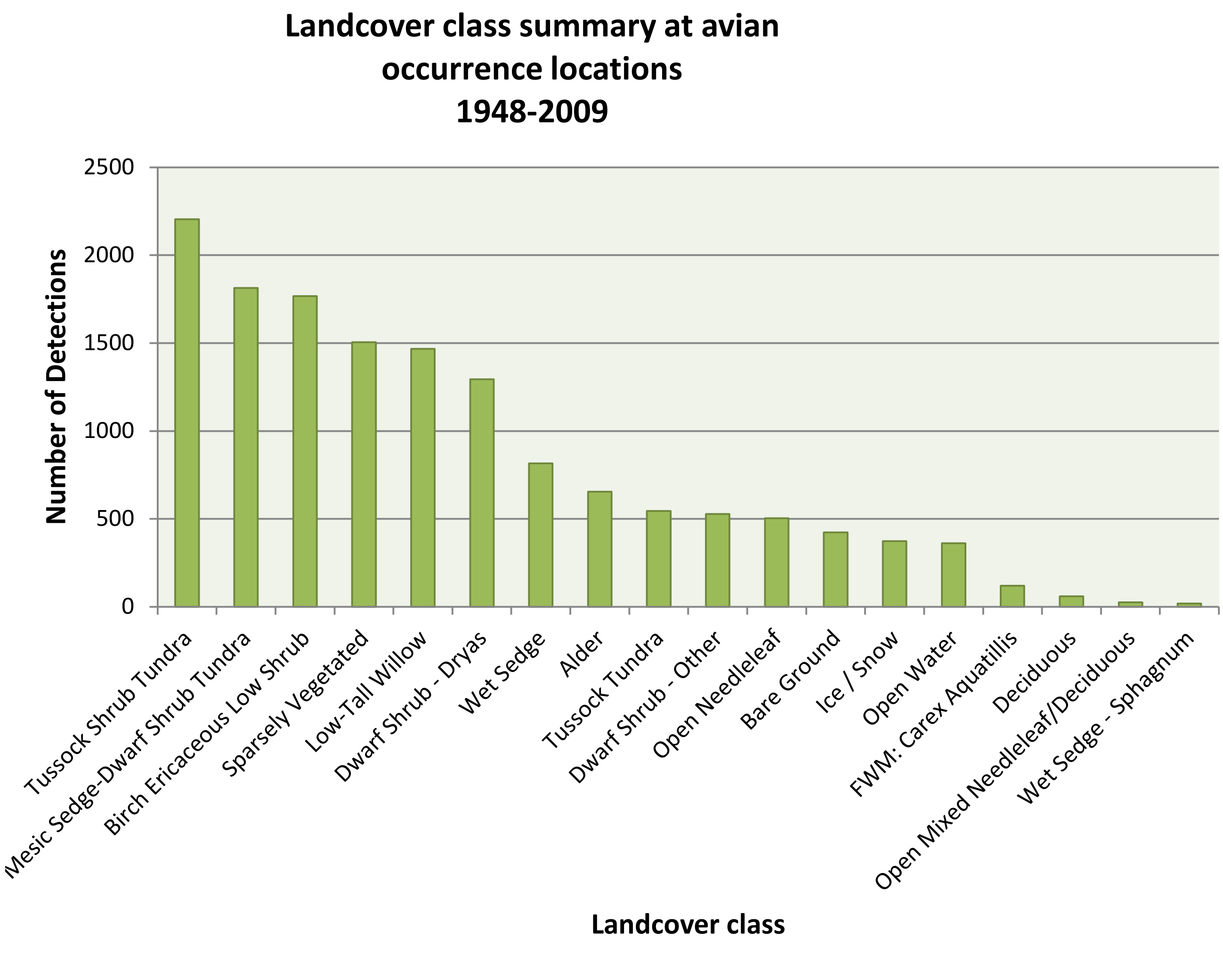

Figure H-48. NSSI landcover class summary at avian occurrence locations.

ALFRESCO outputs of projected vegetation change indicate that shrub habitats will increase by 2060 throughout much of the North Slope study area, with highest increases in the Brooks Range Ecoregion. During the past 25 years (1988-2012), passerines associated with shrub habitats have increased across the tundra on the Seward Peninsula (McNew et al. 2013). It seems likely that increases in shrub habitats would be beneficial to passerines on the North Slope as well, although broad-scale expansion of shrub communities at the expense of wet sedge tundra and moist sedge-shrub tundra on the Coastal Plain could reduce preferred breeding habitat for some species (Martin et al. 2009).

9.4. Limitations

The data presented here provide a baseline of information on passerine distribution and species composition on the North Slope, but are likely far from complete. As described above, much of the avian survey data collected prior to 1990 exists primarily in project reports and was not available in digital format for this analysis. This is an obvious limitation in using this data to address changes in species composition over time, as it is highly biased toward more contemporary conditions.

Datasets that were not available in digital format but would have greatly imporived this assessment include:

- Andersson, M. 1973. Birds of Nuvagapak Point, northeastern Alaska. Arctic 26:186-197.
- Cade, T. J. and C. M. White. 1973. Breeding of Say's phoebe in Alaska. Condor 75:360-361.
- Sage, B.L. 1974. Ecological Distribution of Birds in the Atigun and Sagavanirktok River Valleys, Arctic Alaska. Can. Field-Nat. 88: 281-291.
- Swem, T.R., C.M. White, and R.H. Ritchie. 1992. Comments on the status of certain birds on the North Slope of Alaska. Northwestern Naturalist 73:84-87.
- Tulp, I. and H. Schekkerman. 2008. Has prey availability for Arctic birds advanced with climate change? Hindcasting the abundance of tundra arthropods using weather and seasonal variation. Arctic 61(1):48-60.

Additionally, spatial data from the Alaska Landbird Monitoring Survey (http://alaska.usgs.gov/science/biology/bpif/monitor/alms.php) was not included in our mapping for sensitivity reasons, which would have filled in many gaps in areas not accessible by river or road.

9.5. Literature Cited

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McNew, L., C. Handel, J. Pearce, A. R. DeGange, L. Holland-Bartels, and M. Whalen. 2013. Changing Arctic ecosystems--the role of ecosystem changes across the Boreal-Arctic transition zone on the distribution and abundance of wildlife populations. USGS Fact Sheet. Obtained online at: https://pubs.er.usgs.gov/publication/fs20133054. Accessed 15October 2014.

10. Willow Ptarmigan (*Lagopus lagopus*)

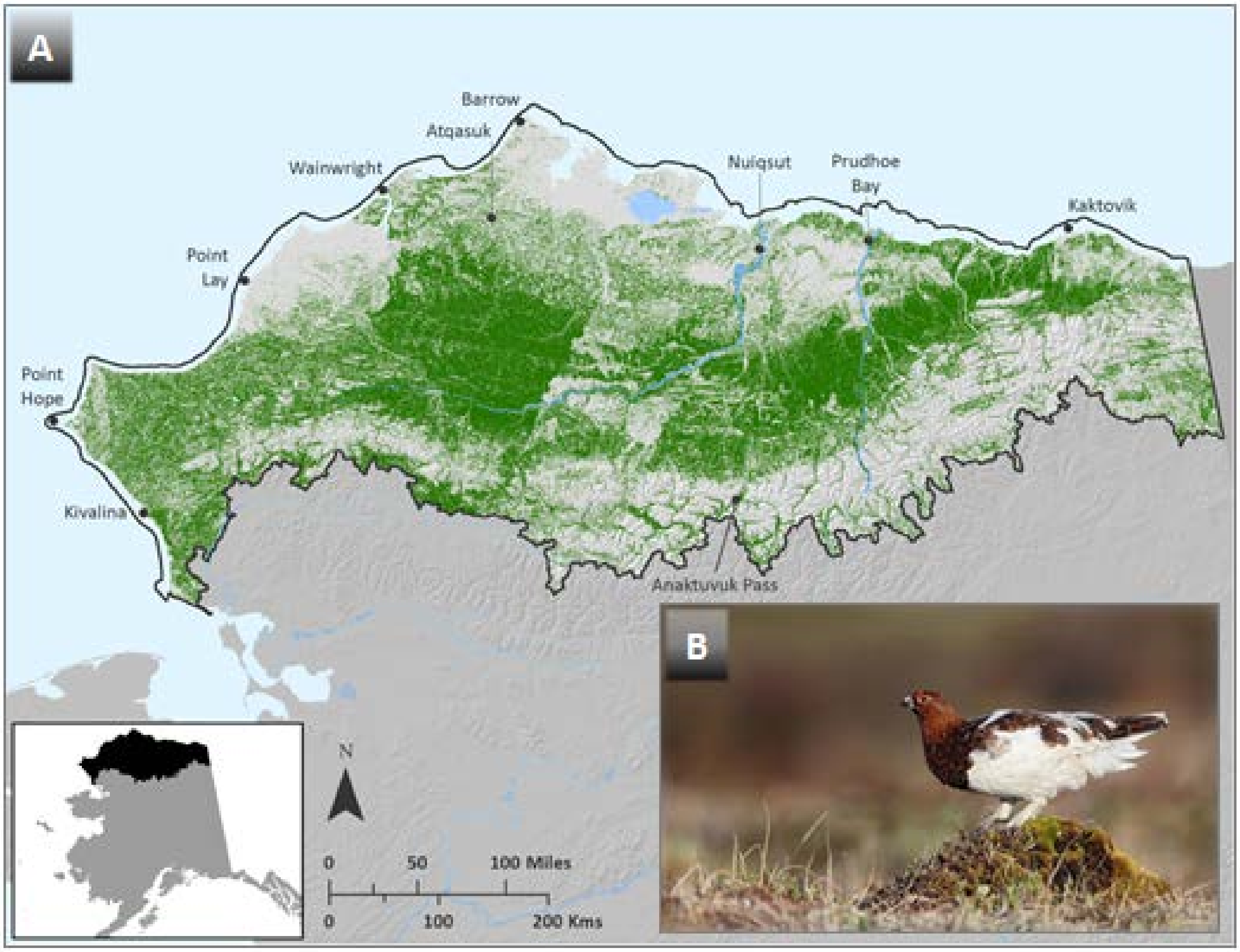

Figure H-49. Current modeled distribution of willow ptarmigan (*Lagopus lagopus*) in the North Slope study area (A) and willow ptarmigan (B).

10.1. Introduction

Willow ptarmigan (*Lagopus lagopus*) occupy the boreal and arctic northern hemisphere, and are one of the few bird species that remain in the Arctic year-round. In Alaska and northern Canada, willow ptarmigan are common in areas with patches of dense vegetation, especially where willow (*Salix*) or birch (*Betula*) shrubs are abundant. They are also found in sedge-willow (*Carex-Salix*) marshes, in meadows, along road and forest edges, and on open tundra. Unlike Rock Ptarmigan (*L. muta*), the species avoids dry, rocky areas. After chicks hatch, birds move to wetter areas, such as marshes and along streams (Hannon et al. 1998).

Ptarmigan nest on the ground after snow melt in willow and alder brush along major river corridors (Irving et al. 1967). Average clutch size is 6–10 eggs and chicks hatch in late June to early July. In the Yukon Territory, willow ptarmigan populations fluctuate in regular ten year patterns, although population cycles have recently been disrupted (Mossop 2011).

Willow ptarmigan forage changes throughout the year. In late September, willow ptarmigan in Arctic Alaska form flocks and migrate south to mountain passes in the Brooks Range or the boreal forest of the southern Brooks Range where they primarily forage on willow buds and twigs for the winter. In April and May, ptarmigan return to Arctic nesting grounds (Irving et al. 1967, Tape et al. 2010). When they arrive at breeding grounds in spring, snow still covers the ground restricting access to forage. Thus, they are forced to feed almost exclusively on taller shrub species, particularly *Salix alaxensis* (which constitutes up to 80% of their diet) (Tape et al. 2010). This level of intensive browsing reduces the number of catkins on tall, but not short willows, because the short shrubs are still buried by snow (Tape at al. 2010). Browsing of this severity slows the growth of willow shrubs and could affect shrub architecture to such an extent as to retard the greening trend or alter the snow regime—these direct effects and feedbacks are only recently being explored (Tape et al. 2010, Christie et al. 2014).

In June, prior to nesting, males spend much of their time defending nesting territories while females spend more time foraging. Willow catkins often remain the primary forage at this time of year. In July, adult ptarmigan forage on young willow leaves and maturing seeds. In August, *Arctous* berries become important in addition to willow leaves. Chicks feed on a variety of flowers, fruits, seeds, insects, and willow leaves (Williams et al. 1980).

Willow ptarmigan were selected as a Terrestrial Fine-Filter CE for this assessment because they are an important prey species for gyrfalcon (*Falco rusticolus*) and are considered a keystone species for tundra environments (Mossop 2011); they are an important subsistence resource, especially in the spring; and because of the marked impact they can have on shrub structure and productivity.

10.2. Conceptual Model

The conceptual model below (Figure H-50) is based on literature review and describes the relationship between the various change agents and natural drivers for the willow ptarmigan. The boxes and arrows represent the state of knowledge about the willow ptarmigan and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and the willow ptarmigan. Change agents selected for this REA and considered in this analysis include: climate change, fire, invasive species, and human use.

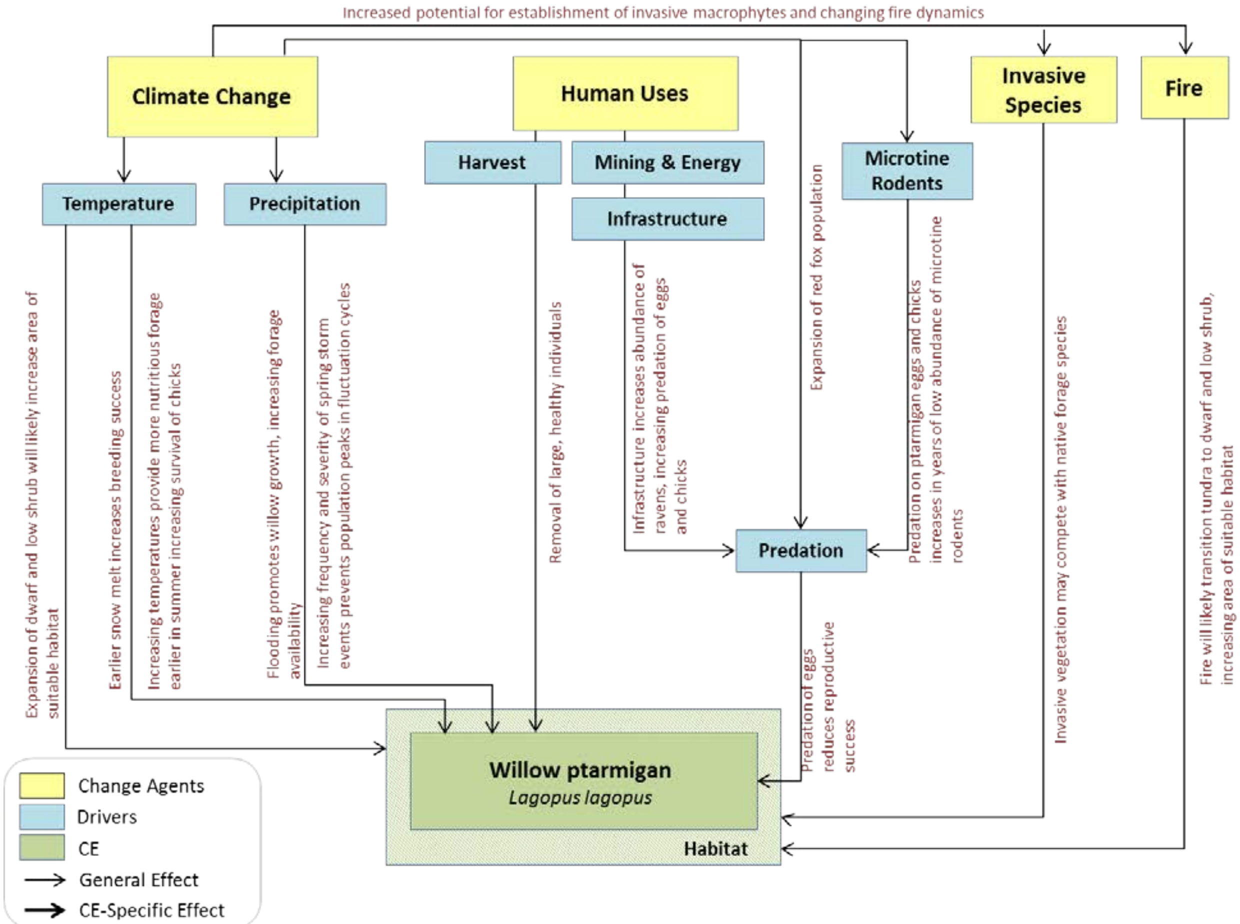

Figure H-50. Conceptual model for the willow ptarmigan.

10.3. Attributes and Indicators

Based on the assessment of available indicators, spatial data used to assess the status of the willow ptarmigan included: date of thaw (DOT), mean May temperature, June precipitation, mean July temperature, growing season length, fire return interval /ALFRESCO, and landscape condition (Table H-30).

Table H-30. Attributes and indicators for the willow ptarmigan.

CA or Driver	Ecological Attribute	Indicator (unit of measure)	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Habitat availability[22]	Date of thaw (timing of snowmelt)	Earlier snowmelt can increase consistency of breeding success. Ptarmigan begin breeding shortly after snow cover declines to 50%.	Later than average			Earlier than average
	Reproductive success[23]	May temperature	Earlier clutches are typically larger than clutches laid later in the spring. Earlier egg laying has been correlated with warmer temperatures the month prior to breeding.	Below average		Above average	Average
	Reproductive success[24]	June precipitation	Increased precipitation during incubation can decrease chick production/survival (clutch initiation begins late May/early June and chicks hatch late June).	Above average		Below average	Average
	Forage availability[25]	Summer temperature	Increased temperatures can provide more nutritious forage.	Below average		Average	Above average
Fire	Habitat availability	Fire frequency/ALFRESCO	Fire will likely transition tundra to dwarf and low shrub, increasing area of suitable habitat and forage.	Low return interval	Avg. return interval	High return interval	Moderate return interval

[22] Based on Cotter 1999, Martin and Weibe 2004, and Wilson 2008.
[23] Based on Wilson 2008 and Wilson and Martin 2010.
[24] Based on Steen et al. 1988 and Hannon et al. 1998 (a review of incubation timing from late May through late June).
[25] Based on Williams et al. 1980.

CA or Driver	Ecological Attribute	Indicator (unit of measure)	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Anthropogenic	Habitat quality / reproductive success[26]	Landscape condition model	Risk of predation by raven and red fox increases within 5 km of infrastructure.	< 5km	5 - 7 km	> 7 km from	> 10 km

[26] Based on Støen et al. 2010.

10.4. Distribution Model

We used predictive models generated by the Alaska Gap Analysis Project (AKGAP) to describe the distribution of the willow ptarmigan across the North Slope study area (see Section H.1.1 for details relating to AKGAP models). Willow ptarmigan are widely distributed across the North Slope in all three ecoregions (Figure H-49). Preferred habitats appear to be the more abundant inland, with the exception of the western part of the study area. In the southern part of the study area, ptarmigan distribution appears to be more tightly constrained to riparian areas.

A total of 2,827 occurrence records for the willow ptarmigan were obtained from various sources (Table H-31). Occurrence/survey data available to test the models were largely restricted to the Arctic Coastal Plain and Dalton Highway corridor (Figure H-51). Because so many of the records were densely clustered, we randomly selected 30% (n = 940) of the records for model evaluation. Classification success (CS) values for the willow ptarmigan AKGAP distribution model were 0.95, indicating high model quality.

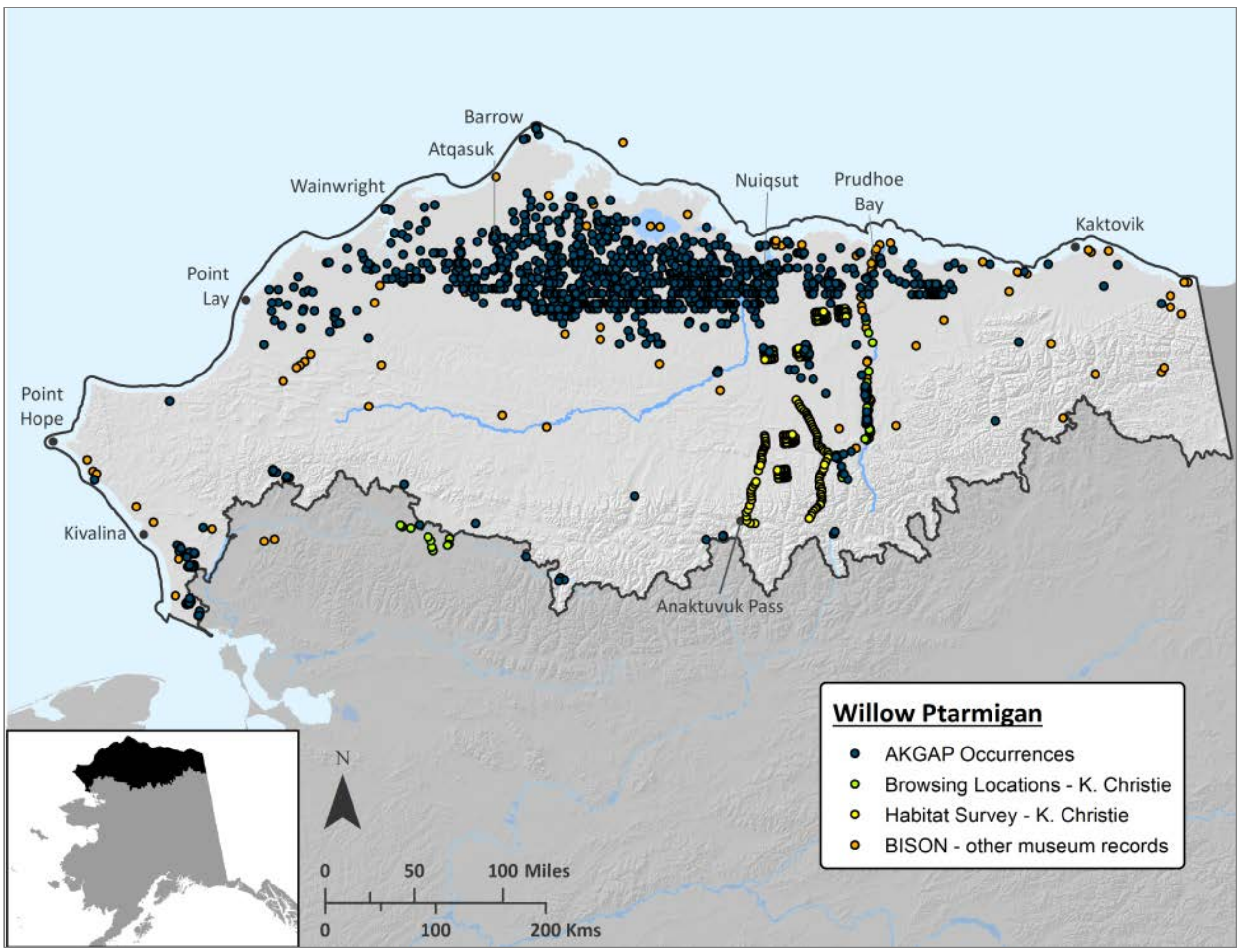

Figure H-51. Distribution of occurrence records for the willow ptarmigan in the North Slope study area.

Table H-31. Datasets used for willow ptarmigan.

Dataset Name	Data source
Gap Analysis distribution model for the willow ptarmigan	Alaska Gap Analysis Project, AKNHP
Gap Analysis terrestrial vertebrate occurrence geodatabase database records for willow ptarmigan *	Alaska Gap Analysis Project, AKNHP
BISON occurrence records for willow ptarmigan	BISON (http://bison.usgs.ornl.gov/#home)
Willow ptarmigan habitat survey, central Brooks Range	Katie Christie, UAF
Willow ptarmigan browsing study locations, Dalton Highway and Noatak River	Katie Christie, UAF

10.5. Abiotic Change Agents Analysis

We explored the relationship between willow ptarmigan and five climatic change agents: mean May temperature, date of thaw (DOT), June precipitation, mean July temperature, and growing season length at three time steps (current, near-term, and long-term). Current research indicates that warmer springs and earlier onset of snowmelt may improve breeding success (larger clutches and earlier date of first egg), while increases in precipitation during incubation (early summer) may be detrimental to chick growth and survival. Warmer summer temperatures and a longer growing season are expected to be beneficial to ptarmigan via more abundant forage and a longer period to successfully fledge young. We also explored the potential for expansion of favored dwarf and low shrub habitats through comparison with ALFRESCO model outputs.

Spring Temperature and Date of Thaw

Willow ptarmigan appear to adjust their lay dates according to snow cover, which varies annually and is dependent on spring ambient temperatures (Wilson 2008). A recent studies of rock ptarmigan (*L. muta*) and white-tailed ptarmigan (*L. leucura*) in the Yukon Territory reported that onset of egg-laying occurred earlier when spring temperatures in the month prior to breeding were warmer (Wilson and Martin 2010). Ptarmigan begin breeding shortly after snow cover declines to 50% (Hannon et al. 2008). The timing of snowmelt was correlated with the timing of egg laying in willow ptarmigan in Norway (Myrberget 1986). Females may be encouraged to lay eggs earlier if warmer temperatures advance snowmelt, which could results in increases in nesting habitat, and stimulate vegetative growth (Wilson and Martin 2010). In years with cold springs and late snowmelt, egg-laying is delayed (Hannon et al. 1988). Despite strong resilience in fecundity parameters, when snowmelt is extremely delayed, breeding success is greatly reduced (Martin and Weibe 2004).

Clutch initiation for willow ptarmigan begins in late May/early June and chicks generally hatch in late June (Hannon et al 1998). We compared the distribution of willow ptarmigan to May temperature and suggested that warmer spring weather could result in advances in snowmelt, which would encourage birds to lay earlier. This would have a positive effect on chick production, since earlier clutches have been shown to be larger than clutches laid later in the spring (Wilson 2008). We also intersected the distribution map for willow ptarmigan with modeled outputs for date of thaw (DOT), the day on which the running mean temperature is projected to cross the freezing point, using DOT as a proxy for onset of snowmelt. DOT can be expected to correlate, in general, with spring temperatures, and would also have implications for timing of egg laying in ptarmigan.

Modeled May temperature is expected to increase by 0.6 to 1.4 °C throughout the range of the willow ptarmigan by 2060 (Figure H-52a). May temperature increases in the near term, however, are likely to be minor, but by 2060, modeled temperature increases are significant in some areas (see Section C. Abiotic Change Agents). Significant increases of > 0.8 °C in May temperature are predicted for inland areas in the western half of the North Slope. Modeled DOT is expected to occur between 1 to 3 days earlier throughout the current distribution of the willow ptarmigan by 2060 (Figure H-52b). Currently, mean DOT within the range of willow ptarmigan occurs between May 17 and May 21. The warming trend predicted for May temperature across the North Slope, and the associated slight advance in DOT, suggests that future conditions may be advantageous for ptarmigan productivity, especially for birds nesting in the central and western Brooks Range.

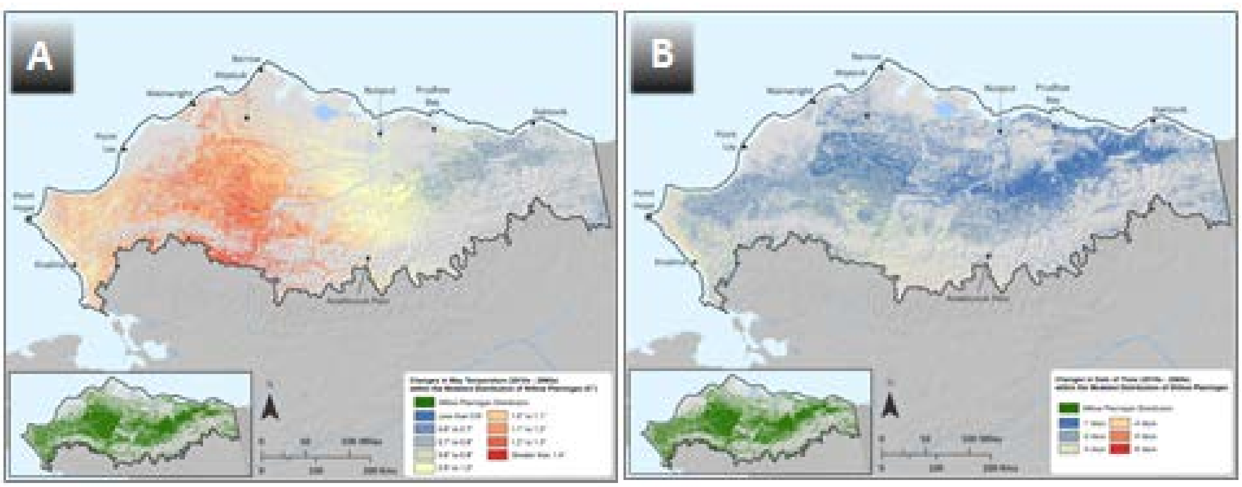

Figure H-52. Modeled change in May temperature (A) and date of thaw (B) from the 2010s to the 2060s within the current distribution of the willow ptarmigan.

Spring precipitation

Weather conditions during incubation may affect willow ptarmigan chick production both directly and indirectly. Chick production has been negatively correlated with both cold spring temperatures (discussed above) and the number of spring rain events prior to hatching (Wilson et al. 2008, Steen et al. 1988). Frequent precipitation and low air temperature during incubation may affect the hen's energy balance (Gabrielsen and Unander 1987) and also cause poor incubation conditions and weaker chicks (Steen et al. 1988). After hatching, poor weather conditions may affect chick survival indirectly by limiting access to food, since chicks are reluctant to feed in wet vegetation (Erikstad and Anderson 1983). We compared the distribution of willow ptarmigan with June precipitation and considered that wetter than average conditions would have a negative effect during incubation and on post-breeding success.

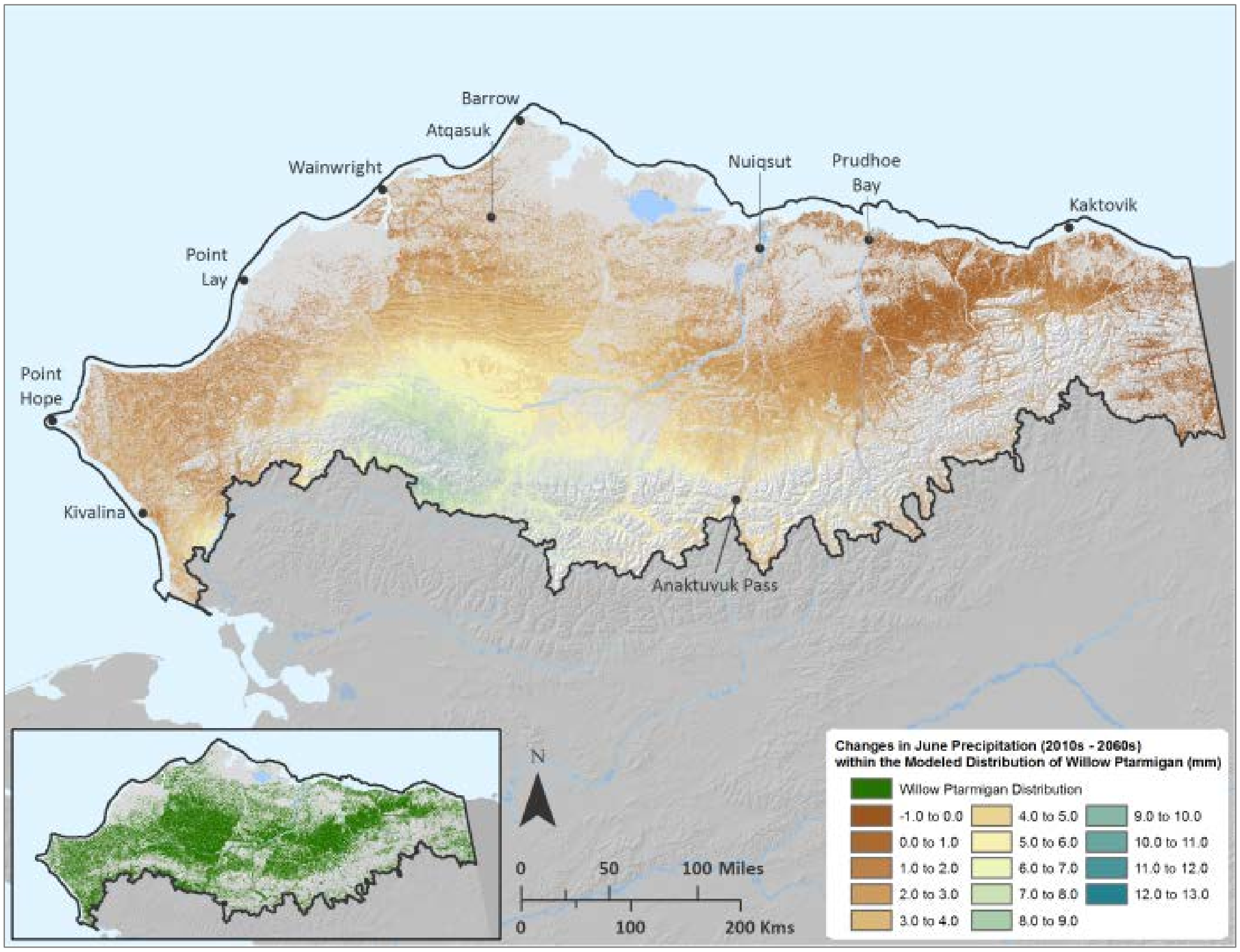

Figure H-53. Modeled change in June precipitation from the 2010s to the 2060s within the current distribution of the willow ptarmigan.

By 2060, slight to moderate increases of 1 to 9 mm in June precipitation are projected within the range of willow ptarmigan (Figure H-53). Significant increases (> 6.2 mm) in June precipitation are only projected to occur in the central and western Brooks Range, where ptarmigan distribution is largely limited to riparian areas. Little to no change is expected in more northerly inland areas, to the east, or along the coast.

Annual temperature and growing season length

Increases in ambient temperature and a longer growing season in the Arctic will result in increased photosynthetic activity and growth of willows and other shrubs (Christies et al. 2014). During the summer, expansion of dwarf and low shrub vegetation communities will likely increase the area of suitable breeding habitat available to willow ptarmigan. Additionally, increased temperatures can provide more nutritious forage, such as inflorescences of *Bistorta vivipara*, for ptarmigan chicks earlier in summer (Williams et al. 1980).

Timing of reproductive events within the breeding season may affect individual fitness and the number of young produced in the population. Birds that breed in northern environments are considered to be constrained by the time available to reproduce successfully (Hannon et al. 1988). A longer breeding season will promote a longer breeding window and allow young more time to forage before fall migration.

We compared the distribution of willow ptarmigan with mean July temperature (warmest month) and growing season length (estimated number of days with mean temperatures above freezing) and suggested that ptarmigan would benefit under warmer conditions through availability to more abundant or higher quality forage, and a longer growing season would allow for additional time to successfully fledge young. Modeled results indicate that between the current (2010) and the near term (2020), 100% of the area within the distribution of the willow ptarmigan will experience a non-significant increase of 0 - 1.3 °C in July temperature (Table H-32). By the 2060s, significant July temperature increases of > 1.3 °C are projected to occur in over 64% of the species range. By 2060, growing season increases of 7 to 14 days are projected to occur in 99% of the species range (Table H-32).

Table H-32. Predicted change over the near-term (2020) and long-term (2060) in abiotic change agents, mean July temperature and length of growing season, within the distribution of the Lapland longspur within the North Slope study area.

Willow ptarmigan	Δ July Temperature		Δ Length of Growing Season		
	0 - 1.3°C	> 1.3°C	0 - 6 Days	7 - 14 Days	> 14 Days
Near Term	100%	-	100%	-	-
Long Term	36%	64%	-	99%	1%

Fire – ALRESCO model

In the winter and spring when snow cover is extensive, willow ptarmigan on the North Slope of Alaska depend primarily on one willow species, *Salix alaxensis*, for food and cover (Christie et al. 2014). Any changes in the distribution of this one plant species could have a significant impact on willow ptarmigan. Fire will likely transition the tundra to dwarf and low shrub, potentially increasing the area of suitable habitat and forage for willow ptarmigan.

Fire frequency across the North Slope study area is predicted to increase. However, most of the region is likely to remain relatively free of fire although sporadic tundra fires may occur in all sub-regions (see Section C). Thus, changes in fire frequency will likely not have much of a direct impact on willow shrubs favored by willow ptarmigan. However, recent 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). The ALFRESCO model (described in the CA Fire Section) 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.

ALFRESCO outputs of projected vegetation change indicate that shrub habitats will increase by 2060 throughout much of the study area, with highest increases in the Brooks Range Ecoregion (Figure H-54).

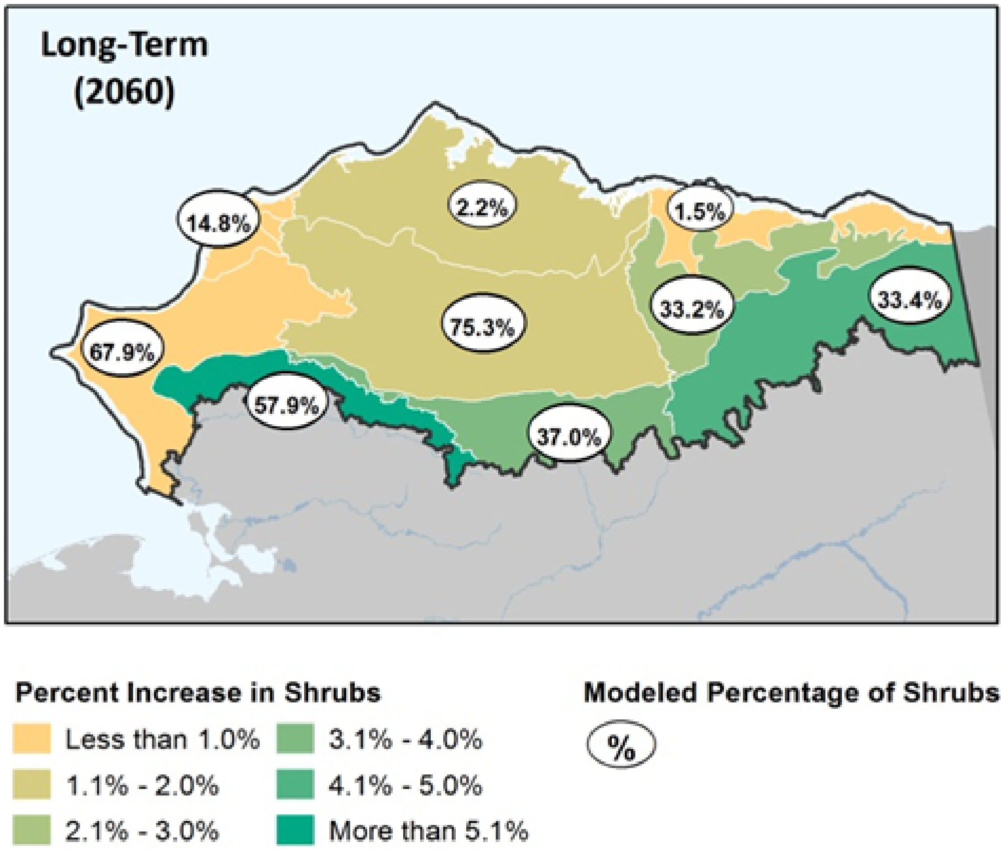

Figure H-54. Projected long-term (2060) change in shrub tundra by ecological sub-region (adapted from Fresco et al. 2014, this study).

With shrub expansion projected for the North Slope, it could provide expanded breeding habitat opportunities for this species. Willow ptarmigan are such extensive browsers on willow shrubs that they are able to influence their architecture, growth and reproduction. Furthermore, this species is capable of altering forage plants in such a way that it creates a broomed structure, which increases the quantity and availability of their own food source (Christie et al. 2014). Increased bud production, in combination with broomed architecture, may be beneficial for future ptarmigan browsing because the two processes result in higher concentrations of buds within easy reach of ptarmigan, thereby increasing the carrying capacity of their own habitat. It should also be noted, however, that spruce and deciduous forests are projected to expand into shrub-dominated areas. If this occurs, willow ptarmigan habitat will likely be reduced (Liebezeit et al. 2012).

Climate Summary

Overall, our assessment of abiotic climate variables suggests that willow ptarmigan will likely benefit from expected changes in environmental conditions (Table H-33), and that they have enough flexibility in life history to allow them to remain stable with regard to climate change, at least within the timeframe of this assessment. This species has such a marked impact on shrub structure and productivity that browsing by these herbivores needs to be considered in future models of shrub expansion in the Arctic.

Table H-33. Summary of abiotic CAs used in the core analysis assessment for willow ptarmigan and projected effects.

Indicator	Short-term (2020) trend	Long-term (2060) trend	Impact to	Effect
Spring temperature	+ or -	+	chick production	+
Date of thaw	+	+	chick production	+
Spring precipitation	+	+	chick survival	-
Annual temperature	+	+	forage availability	+
Growing season length	+	+	fledgling survival	+
Fire/ALFRESCO	n/a	+	habitat (shrub) expansion	+ or -

10.6. Current Status and Future Landscape Condition

The majority of current willow ptarmigan habitat is in areas with very high (intact) landscape condition (Figure H-55). Future scenarios of landscape condition do not indicate any significant changes in both medium and high scenarios.

Predation is the largest direct cause of nest failure for willow ptarmigan (Wilson 2008). Potential threats as a result of increased development related to oil and gas infrastructure include potential increases in predation by ravens, as ravens are known to prey on willow ptarmigan eggs and chicks. Some evidence has suggested that ravens become more numerous in areas of human development because of the presence of additional food sources and artificial nesting/denning sites. While recent improvements to waste handling procedures associated with oil field infrastructure have likely dampened this effect in oil fields (Liebezeit et al. 2009), this may still be a concern in areas of other development. Increased raven abundance could potentially reduce the reproductive success of willow ptarmigan (Støen et al. 2010).

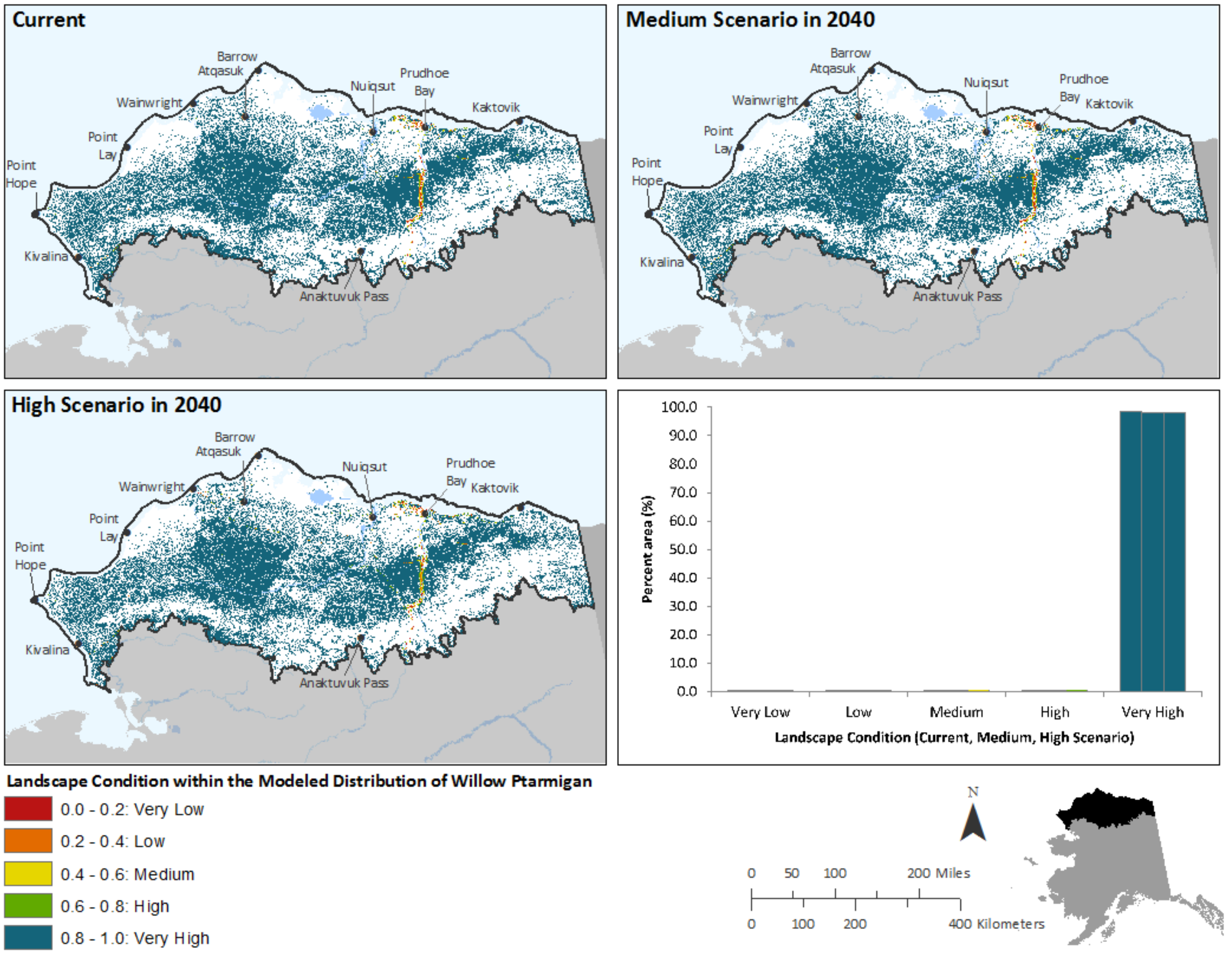

Figure H-55. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current distribution of Willow Ptarmigan in the North Slope study area.

10.7. Limitations and Data Gaps

The presence of large flocks of ptarmigan, combined with their exclusive preference for willow buds in the spring when first arriving at Arctic breeding grounds, results in substantial influence on the growth and architecture of willows that exceed snow level (Christie et al. 2011). After several years or ptarmigan browsing, willows become “hedged” just above average snow level, providing optimal food accessibility for future average snow years. In years of higher than average snowfall, willows may become buried and protected from browsing, whereas in years of lower than average snowfall, more willow branches are available for browsing. Food availability for ptarmigan is therefore strongly related to snow conditions in a given year (Christie et al. 2014). We lacked a suitable snow-depth layer for the REA that precluded examining the relationship of snow and its role in conjunction with ptarmigan herbivory.

Since limited spatial data were available on fire, most potential changes related to ptarmigan habitat were qualitatively described based on literature review and ALFRESCO model outputs.

10.8. Literature Cited

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11. Greater White-fronted Goose (*Anser albifrons*)

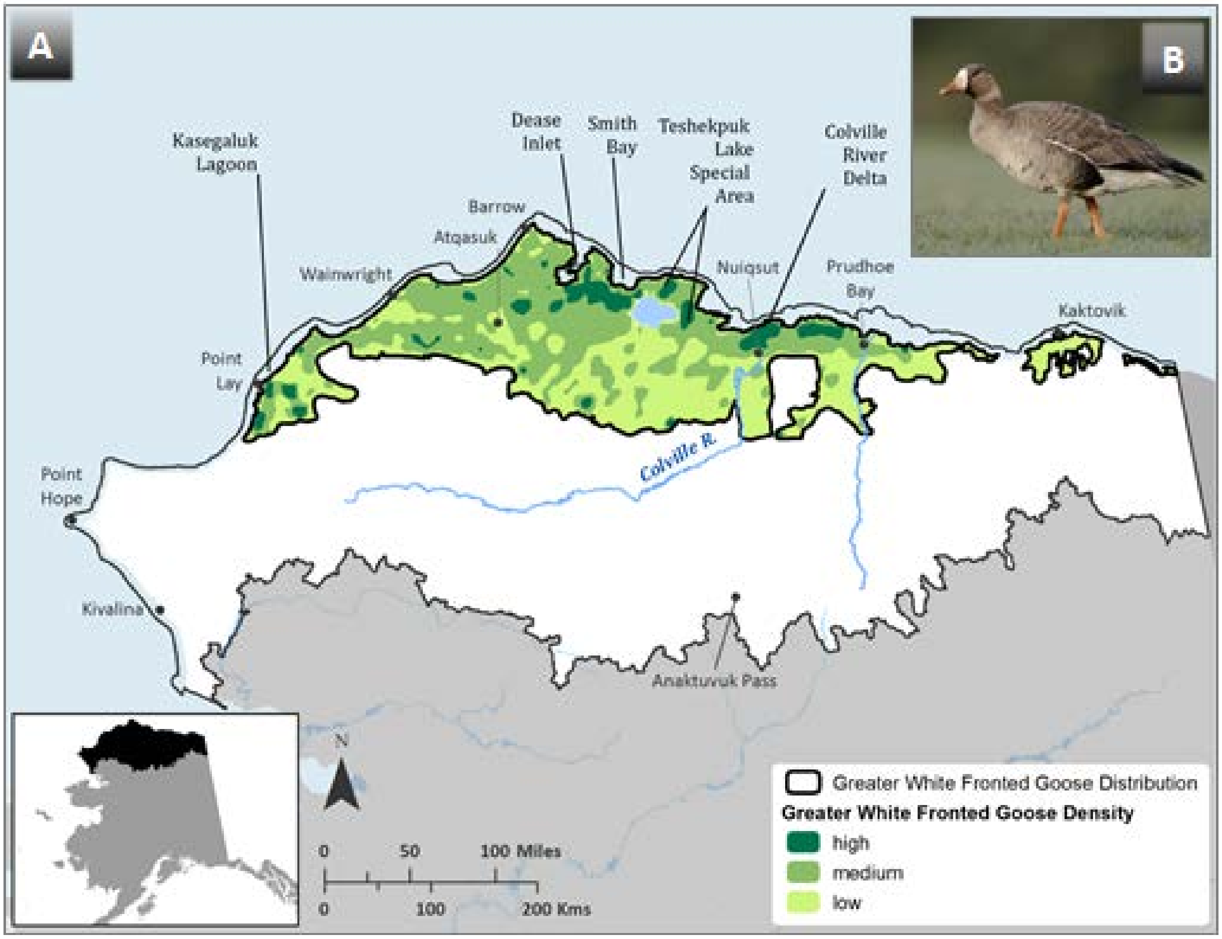

Figure H-56. Current modeled distribution of greater white-fronted goose (*Anser albifrons*) in the North Slope study area from density estimates provided by Platte, unpubl. data (A) and greater white-fronted goose (B).

11.1. Introduction

The greater white-fronted goose (*Anser albifrons*) has a nearly circumpolar distribution and is highly valued for sport hunting and as a subsistence food. In western North America, summer breeding occurs in arctic and boreal habitats from eastern Hudson Bay to western Alaska. Geese that breed in tundra habitats differ from those that breed in boreal habitats, and interchange between the two groups is small (Marks 2013). Geese that spend summers in the arctic of Alaska and Canada, winter in Texas, Louisiana, and Mexico. Individuals live up to 26 years with late maturation and produce a small number of offspring per year compared to other geese (Schoen and Senner 2002).

Between 2005 and 2009, the breeding population of greater white-fronted geese in the northern Arctic Coastal Plain grew rapidly but appeared to have leveled off in 2010-2011 (Larned et al. 2012). In 2012, population estimates were much higher than any previous year recorded, with population estimates as high as 329,792. In 2013, indices were again similar to the preceding five years and in 2014 indices were the lowest since 2007 (Marks and Fisher 2014).

Within the North Slope study area, greater white-fronted geese nest primarily within a strip that extends to approximately 30 km from the coast (King 1970). White-fronted geese have been noted on their Alaska Beaufort Sea breeding grounds from the second or third week of May to the first week of June (Johnson and Herter 1987). Arrival is about two to three weeks before incubation, during which time they feed intensively. Primary forage consists of *Arctophila fulva* shoots and *Triglochin palustris* bulbs (Budeau et al. 1991). Breeding pairs occupy much of the central Coastal Plain in open tundra with nest sites in dense grass, sedges, and shrubs, and commonly on slough banks, lake shores, pingos, and polygon ridges within 400 m of water (Rothe et al. 1983, Ely and Dzubin 1994).

Molting typically begins in early July. Geese select areas near lakes or river deltas that provide forage access and predator escape during this time. During the molting period, many geese aggregate around Teshekpuk Lake where their primary forage consists of *Arctophila fulva* and *Carex* species.

11.2. Conceptual Model

The conceptual model below (Figure H-57) is based on literature review and describes the relationship between the various change agents and natural drivers for the greater white-fronted goose. The boxes and arrows represent the state of knowledge about the greater white-fronted goose and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and the greater white-fronted goose. Change agents selected for this REA and considered in this analysis include: climate change, fire, invasive species, and human use.

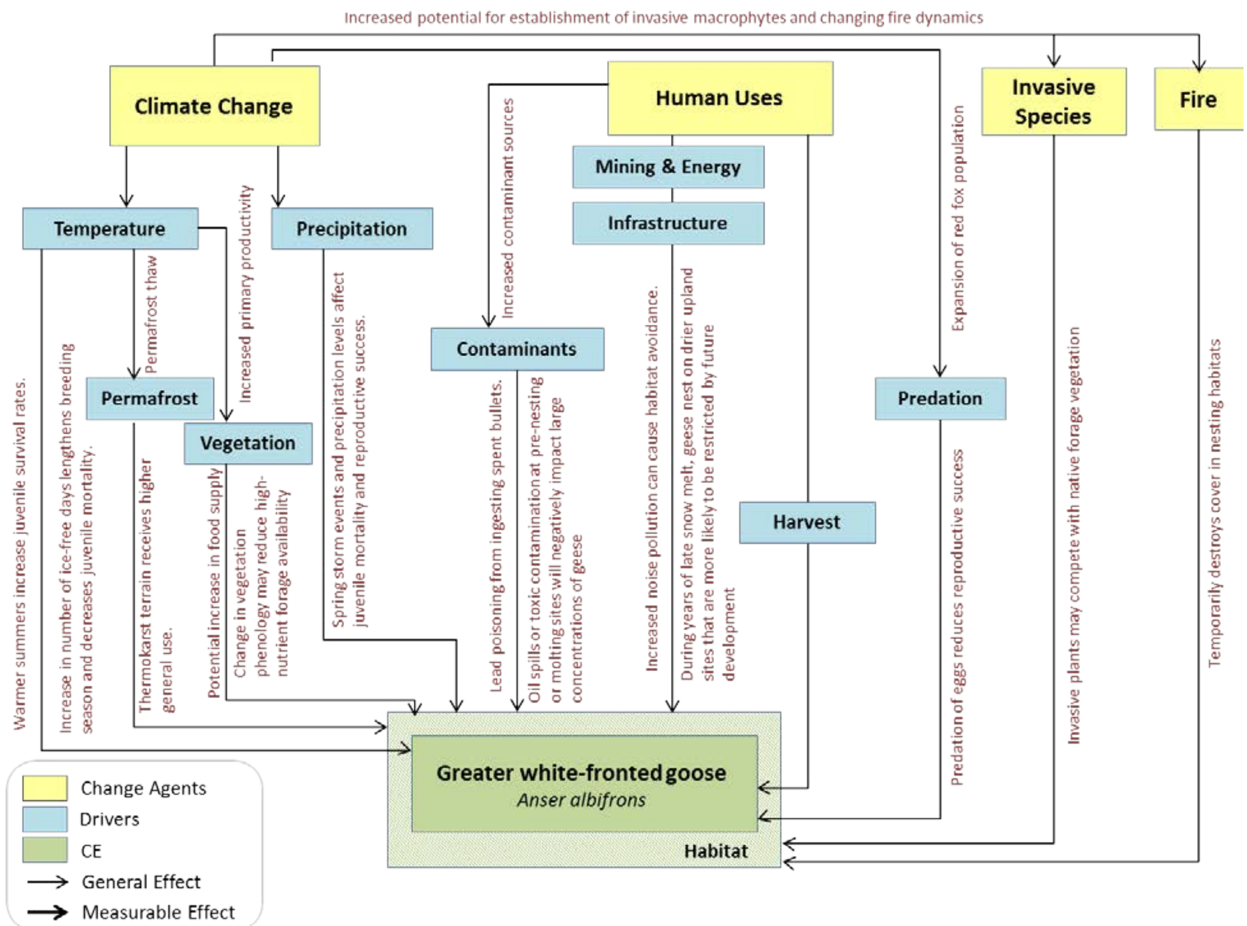

Figure H-57. Conceptual model for greater white-fronted goose.

11.3. Attributes and Indicators

Based on the assessment of available indicators, spatial data used to assess the status of the greater white-fronted goose included: date of thaw, summer temperature, spring precipitation, permafrost predisposition, and landscape condition (Table H-34).

Table H-34. Attributes and indicators for the greater white-fronted goose.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Food and habitat availability[27]	Date of thaw	Later than average snowmelt can result in delayed breeding; change in vegetation phenology may reduce availability of high-quality forage.	Later than average		Average	Earlier than average
	Reproductive success[28]	Spring precipitation - March, April, May	Increased precipitation results in decreased reproductive success.	Above average		Average	Below average
	Food availability[29]	Mean Summer Temperature - June, July, August	Warmer than average summers result in increased juvenile survival rates and increased forage production (biomass), but diminished forage quality.	Cooler than average		Average	Warmer than average
	Habitat quality[30]	Thermokarst predisposition	Habitat heterogeneity characteristic of thermokarst terrain receives higher general use by geese during the breeding season.	< 50%	50-75%	> 75%	> 90%
Fire	Habitat quality[31]	Fire return interval	Increased fire may temporarily reduce breeding habitat quality by destroying cover in nesting habitats.	High return interval			Low return interval

[27] Based on Ely and Dzubin 1994 and USFWS 2008.
[28] Based on Boyd and Fox 2008.
[29] Based on Boyd and Fox 2008 and Martin et al. 2009.
[30] Based on Martin et al. 2009.
[31] Based on Hoffpauier 1968.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Anthropogenic	Habitat quality[32]	Landscape condition model	White-fronts are sensitive to machine noise (within 5km of nesting) which can result in habitat avoidance. Aircraft disturbance can lead to habitat avoidance at breeding/nesting sites.	< 5km		> 5km	
	Predation pressure[33]	Landscape condition model	Risk of nest predation (by Arctic fox for example) increases within 5km of human infrastructure.	< 5km		> 5km	
	Habitat quality/reproductive success[34]	Landscape condition model	Geese have a foraging range of 3-10km during nesting. Contaminant leaks within this vicinity could have a negative effect on individual health and reproductive success.	< 3km		>10km	
	Habitat quality[35]	Subsistence use area	Lead poisoning from ingesting spent shotgun pellets.	High	Medium	Low	Zero

[32] Based on Barry and Spencer 1976 in Ely and Dzubin 1994, and Derksen et al. 1979.
[33] Based on Liebezeit et al. 2009.
[34] Based on Schoen and Senner 2002.
[35] Based on Frierabend 1983.

11.4. Distribution Model

We used predictive models generated by the Alaska Gap Analysis Project (AKGAP) to describe the distribution of the greater white-fronted goose across the North Slope study area (see Section H.1.1 for details relating to AKGAP models). We also obtained a breeding density distribution map for the greater white-fronted geese for the Arctic Coastal Plain from the USFWS (Platte, unpubl. data). For a final distribution model, we clipped the AKGAP model to the extent of the density distribution map, as it more closely defined the distribution of the greater white-fronted goose in the North Slope study area (Figure H-56). The clipped AKGAP model was then used for intersections with the CAs as part of the core analysis.

During the breeding season, greater white-fronted geese are distributed across the entire Arctic Coastal Plain, with densities being the highest within 30 km of the coast. Areas of high breeding density include the Colville River Delta, Teshekpuk Lake Special Area, Dease Inlet and Smith Bay, west of Atqasuk, and Kasegaluk Lagoon (Schoen and Senner 2002) (Figure H-56).

A total of 31,636 occurrence records for the greater white-fronted goose were obtained from various sources (Table H-35). Occurrence records were densely clustered on the Arctic Coastal Plain, so we subsampled them to obtain an accuracy assessment data set of 1,081 records. Classification success (CS) values for the greater white-fronted goose AKGAP distribution model were 0.95%, indicating high model quality.

Table H-35. Datasets used for greater white-fronted goose.

Dataset Name	Data source
Gap Analysis distribution model for the greater white-fronted goose	Alaska Gap Analysis Project, AKNHP
Gap Analysis terrestrial vertebrate occurrence geodatabase database records for greater white-fronted goose *	Alaska Gap Analysis Project, AKNHP
Greater white-fronted goose density map for the Arctic Coastal Plain	Migratory Bird Management, USFWS

*Sources for Gap Analysis Vertebrate Occurrence records for greater white-fronted goose are comprised of field survey data obtained from various agencies and researchers. A full bibliography of all data sources for this species is included in the North Slope Data Discovery Memo.

11.5. Abiotic Change Agents Analysis

We explored the relationship between the greater white-fronted goose and four climatic change agents: date of thaw, summer temperature, spring precipitation, and thermokarst predisposition at three time steps (current, near-term, and long-term). Earlier snowmelt as a result of warming temperatures could be beneficial to breeding geese by extending breeding season length, while changes in vegetation phenology could reduce availability of high-quality forage; we also speculated that warmer than average summer temperatures could affect juvenile survival rates as a result of a trophic mismatch; that higher than average spring precipitation could negatively affect reproductive success; and that expansion of thermokarst terrain could result in increases in higher quality habitats.

Date of Thaw and Summer Temperature

We intersected the distribution map for greater white-fronted goose with modeled outputs for date of thaw (DOT), as DOT can be expected to correlate in general with the condition of ice on rivers, streams, and wetlands, and could have implications for timing of breeding, breeding success, and changes in vegetation phenology. Results of our analysis indicate within the current North Slope breeding distribution of greater white-fronted goose, projected changes in DOT between present day and 2060 will be minimal (Figure H-58). In areas of highest geese densities, near the coastal communities of Nuiqsut, Prudhoe Bay, and Point Lay, DOT is only expected to occur 2 to 3 days earlier than current conditions (see Section C. Abiotic Change Agents).

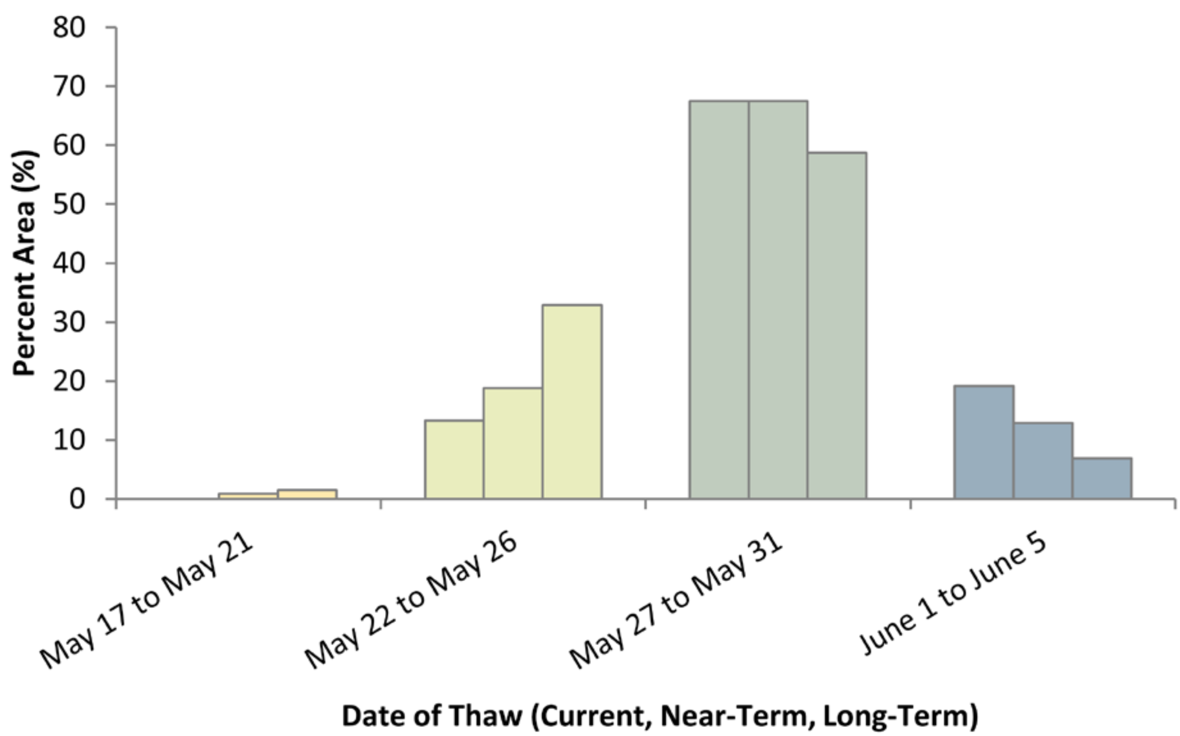

Figure H-58. Current, near-term future, and long-term future (left to right bars within clusters, respectively) date of thaw within the current modeled distribution of the greater white-fronted goose.

Warming temperatures will alter the overall phenology of the North Slope study area, including earlier snowmelt and plant growth (Sparks and Menzel 2002, Stone et al. 2002). An increase in the number of ice-free days and earlier spring thaw could result in earlier goose arrival and lengthened breeding season duration, potentially decreasing juvenile mortality rates (Sargeant and Raveling 1992, Ely and Dzubin 1994, Boyd and Fox 2008).

Increased primary production from earlier spring thaw and warmer temperatures will benefit geese as long as the shift in breeding season remains matched to the emergence of forage vegetation (USFWS 2008). Preliminary studies near Teshekpuk Lake (Schmutz et al. unpublished in Martin et al. 2009) suggest that warmer temperatures during the growing season result in greater plant biomass but diminished forage quality. For herbivorous geese such as white-fronts, forage quality rather than quantity is thought to be limiting and can affect gosling growth rates and survival. There is evidence suggesting that gosling size in years of higher spring temperature may be attributed to a mismatch between hatching dates of goslings and timing of peak forage quality (Martin et al. 2009).

To assess potential changes in growing season temperatures in relation to goose forage quality and abundance, we intersected the distribution map for greater white-fronted goose with modeled outputs for mean summer (June, July, August) temperature. Possible significant summer warming is expected by the 2060s for the North Slope study area, with the greatest changes expected in the inland part of the North Slope and less change along coastal areas (see Section C) favored by white-fronted geese. Similar to results for DOT, summer temperatures within the range of the greater white-fronted goose show only slight increases by 2060, but generally by not more than 0.8°C, and near-term summer warming is non-significant (Figure H-59).

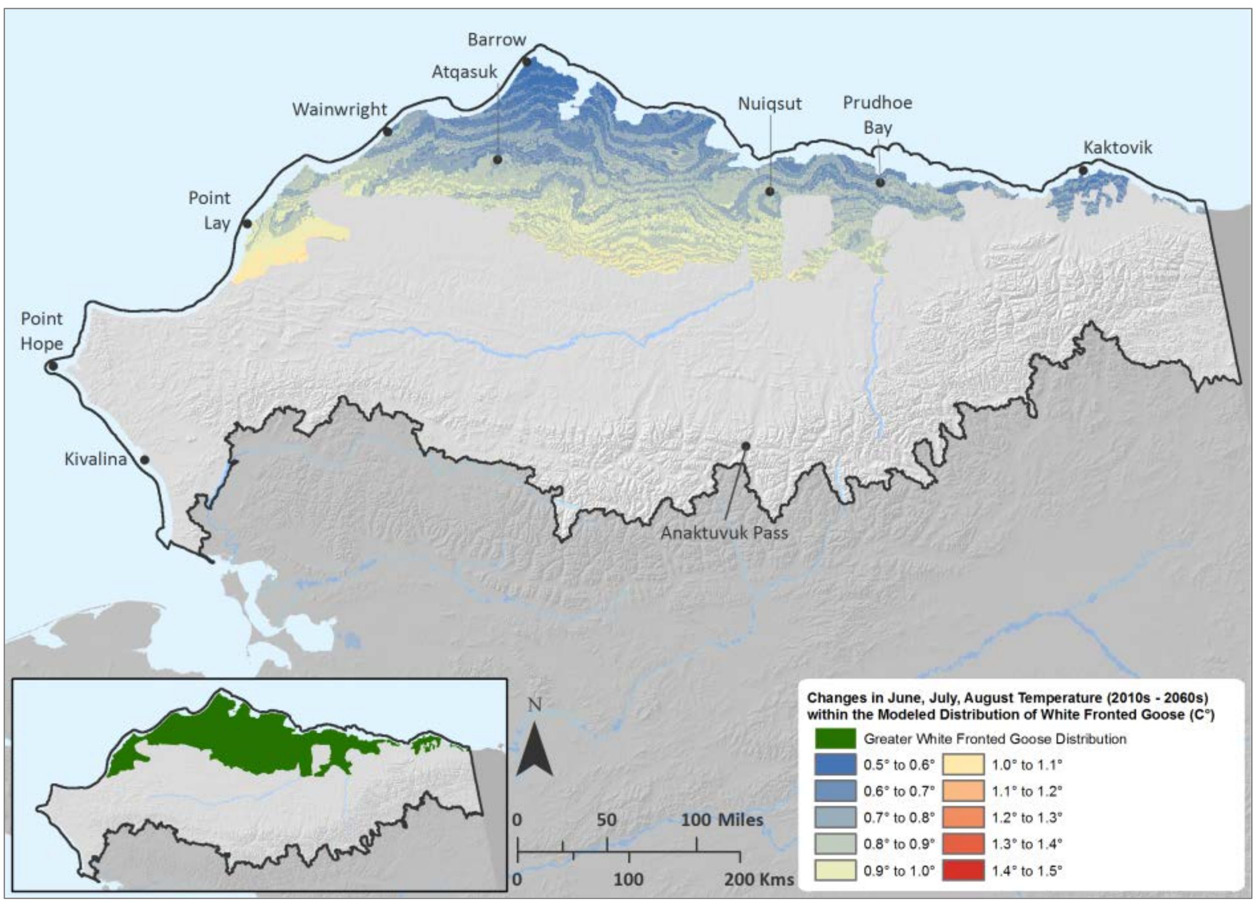

Figure H-59. Change in summer temperature (JJA) within the current modeled distribution of the greater white-fronted goose.

The timing of nesting for this species has advanced by 10 days since the 1970s, likely in response to increasing spring and summer temperatures (D. Ward, pers. comm. *in* Liebezeit et al. 2012). The slight increases projected in DOT and summer temperature for the North Slope study area will likely have little impact on this species breeding on the Arctic Coastal Plain. Because this species experiences much warmer conditions at interior Alaska breeding sites, they should be able to adapt physiologically to a warmer arctic environment. However, it is unknown if they can synchronize timing to changing schedules of other species and processes they depend on (e.g. timing of spring green up) (Liebezeit et al. 2012).

Spring Precipitation

Increases in spring precipitation as a result of climate change could lead to greater likelihood of flooding events. Flooding has been associated with greater white-fronted goose nest failure. On the Yukon-Kuskokwim Delta in 1978, 13 of 25 white-fronted goose nests flooded were destroyed, while only 3 out of 19 nests that had not been flooded were destroyed (Ely and Raveling 1984).

The overall pattern of change in summer precipitation across the North Slope study area shows greater increases to the south and east, and little or no change to the west, particularly on the coast. Results of our analysis indicate that within the range of the greater white-fronted goose there will be little change in spring precipitation between current conditions and 2060 (Figure H-60).

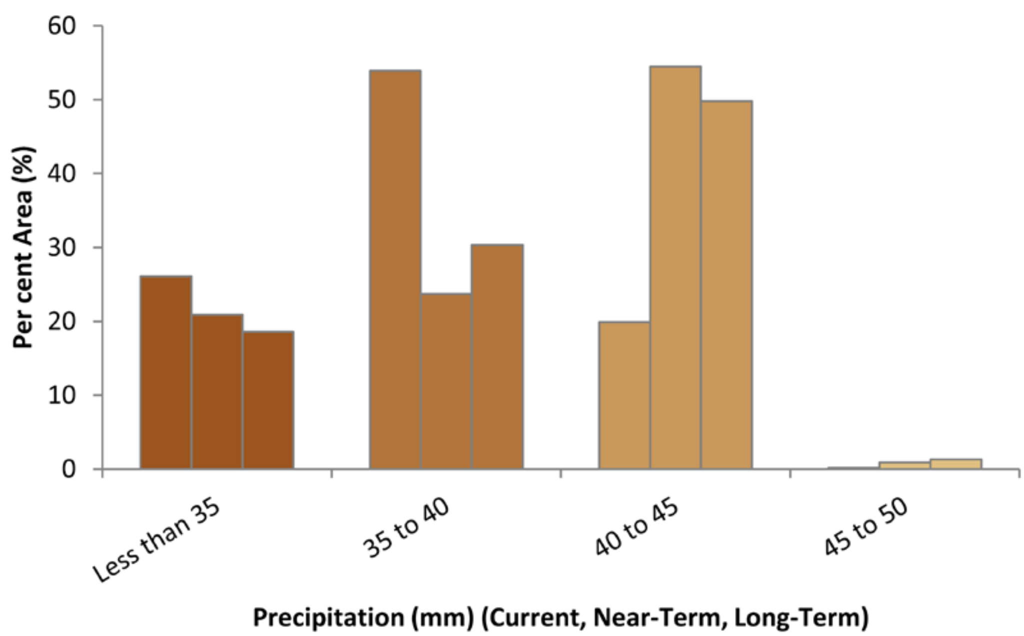

Figure H-60. Change in precipitation (mm) within the current modeled distribution of the greater white-fronted goose at current (left bars), near-term (2020; center bars), and long-term (2060; right bars) time steps.

Thermokarst Predisposition

Climate-mediated disturbance processes, such as thermokarst, could both create and destroy nesting and foraging habitats through both ice wedge degradation and draining of thaw lakes (Martin et al.

2009). Loss of productivity in drying polygon centers as a result of permafrost degradation could be compensated for by increased productivity of expanding thermokarst pits (Martin et al. 2009). Habitat heterogeneity characteristic of thermokarst terrain has been linked to higher general use by some waterfowl such as greater white-fronted goose (Troy 1991).

The thermokarst predisposition module developed for the North Slope determines how much area is predisposed to thermokarst disturbance, based on the occurrence and the ice content of permafrost, histels, and local drainage conditions (Zhang et al. 2014). We compared areas of thermokarst disposition to the current distribution of greater white-fronted goose to explore the association that increases in thermokarst terrain as a result of permafrost thaw could result in additional preferable habitat for geese and other waterfowl species.

With the exception of one small cluster, all mapped high density goose nesting areas are underlain by areas with 95% thermokarst predisposition, while medium density polygons are within both predisposed and non-predisposed areas (Figure H-61). However, since these areas are not likely to undergo a great deal of permafrost thaw in either the near term or long term, thermokarst effects may be limited.

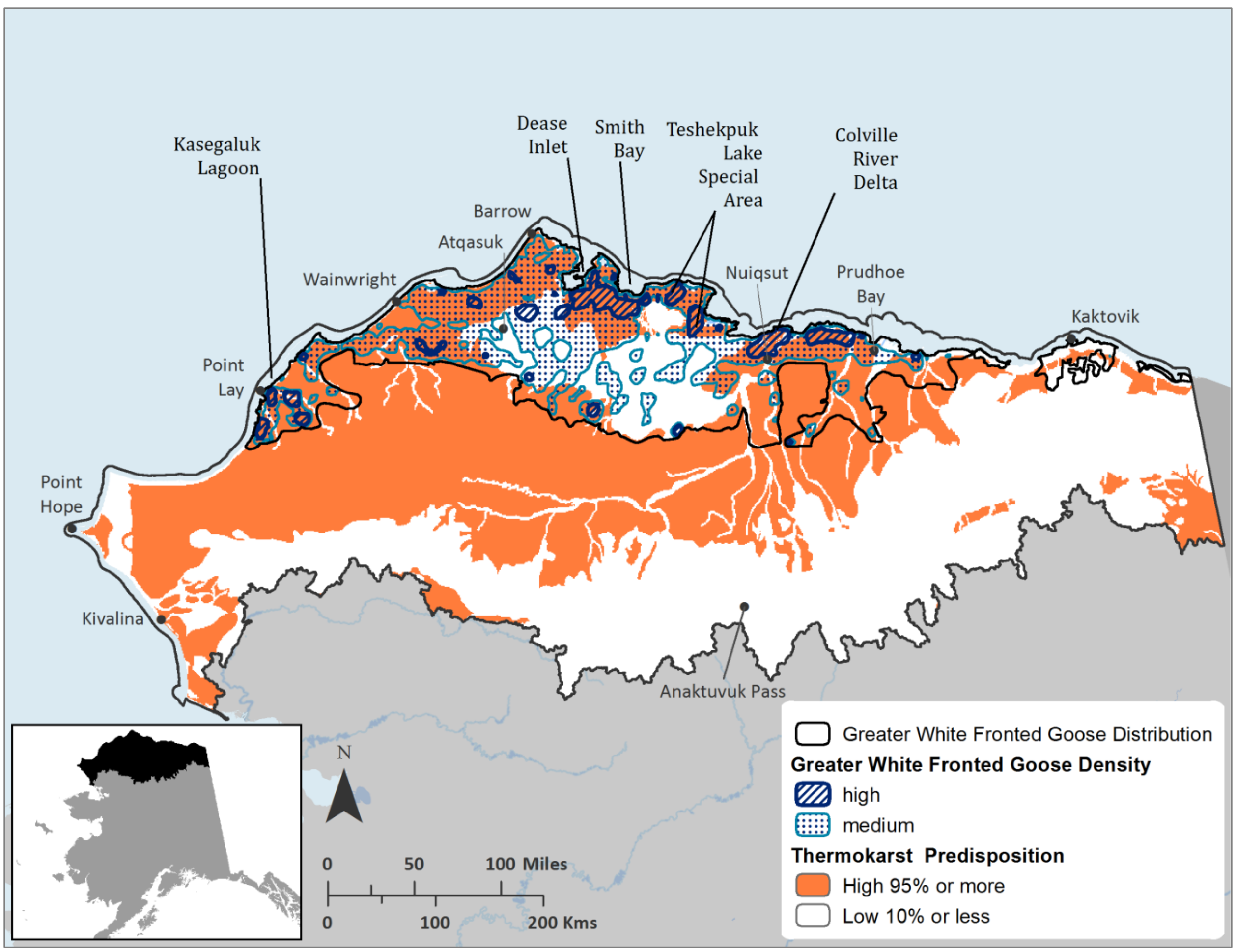

Figure H-61. Distribution of greater white-fronted goose intersected with modeled distribution of thermokarst predisposition in the North Slope study area.

Climate Summary

Overall, greater white-fronted geese appear to be prospering under recent climate-change-induced habitat modifications on both coastal and interior portions of the Arctic Coastal Plain. Population size of the greater white-fronted goose has increased seven-fold in northern Alaska since 1980 (Flint et al. 2008). Results of climatic comparisons here indicate that modeled changes in date of thaw, summer temperature, and spring precipitation will have minimal impacts on this species and that greater white-fronted geese will likely be adaptable enough to cope with the climate changes predicted to occur, at least during the timeline of this assessment (Table H-36).

Table H-36. Summary of abiotic change agents used in the assessment greater white-fronted goose and projected effects.

Indicator	Short-term (2020) trend	Long-term (2060) trend	Impact to	Effect
Date of thaw	Negligible	earlier	Earlier arrival and nesting, increased reproductive success, potential for trophic mismatch	+/-
Summer temperature	+	+	Earlier arrival and nesting, potential for trophic mismatch	+/-
Spring precipitation	No change	Negligible	Increases in flooding events and nest failure	?
Thermokarst predisposition	-	+	Potential gain in habitat availability	+

11.6. Current Status and Future Landscape Condition

The majority of current greater white-fronted goose habitat is in areas with very high (intact) landscape condition (Figure H-62). However, very low condition is indicated in high density nesting areas around Prudhoe Bay and Nuiqsut. Future scenarios of landscape condition do not indicate any significant changes in both medium and high scenarios.

Greater white-fronted geese are loyal to breeding and molting sites, which may hinder a population's ability to relocate if breeding or molting sites are negatively impacted or destroyed by development. 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 snowmelt, geese nest on drier upland sites (Ely and Raveling 1984) that are more likely to be restricted by future development. Greater white-fronted geese 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.

All-weather roads (necessitated by a warming climate and shortened ice road season) associated with energy extraction activities could impact greater white-fronted geese, especially near important molting areas around Teshekpuk Lake (Liebezeit et al. 2012).

Jaegers (*Stercorarius* spp.), large gulls (*Larus* spp.), and ravens (*Corvus corax*) prey upon nests of greater white-fronted geese. Gyrfalcon (*Falco rusticolus*), mink (*Mustela vison*) and large carnivorous mammals predate both eggs and geese (Schoen and Senner 2002). Arctic foxes are present in high densities in the northern portion of the NPRA (Bart et al. 2013) and exert high predation pressure on tundra nests during nesting season, including those of the greater white-fronted goose (Stickney 1991). Some evidence has suggested that predators such as ravens and Arctic fox become more numerous in areas of human development because of the presence of additional food sources and artificial nesting/denning sites. While recent improvements to waste handling procedures associated with oil field infrastructure have likely dampened this effect in oil fields (Liebezeit et al. 2009), this may still be a concern in areas of other development. Furthermore, predation by red foxes (*Vulpes vulpes*) may increase if the climate becomes more suitable for the expansion of the red fox population (Liebezeit et al. 2012).

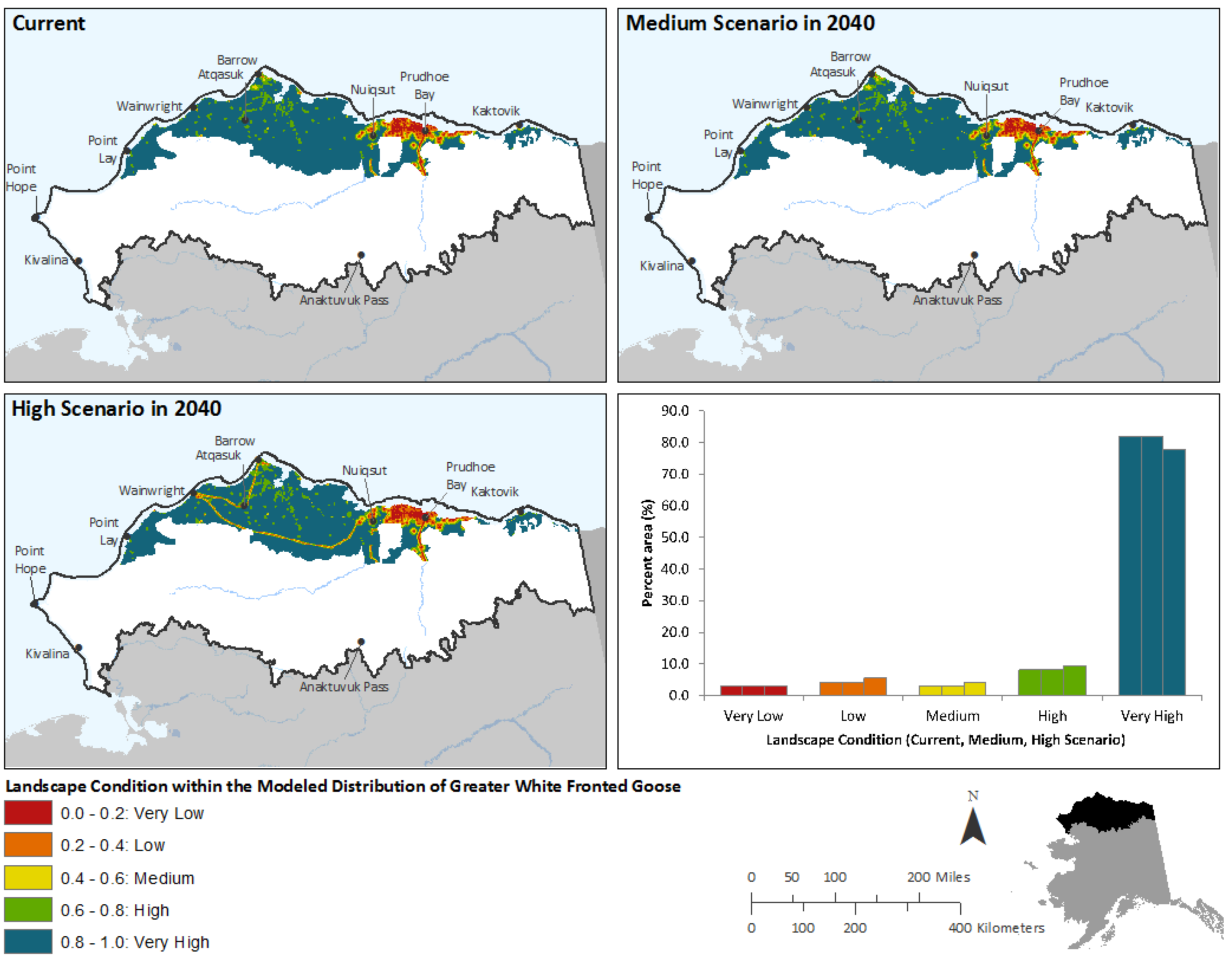

Figure H-62. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current distribution of greater white-fronted goose in the North Slope study area.

Greater white-fronted geese are harvested by subsistence users on the North Slope. Because greater white-fronted geese arrive relatively early in spring compared to other geese, they may receive greater subsistence hunting pressure prior to breeding. Roads associated with energy extraction activities could provide increased accessibility to goose nesting areas, thereby increasing potential for greater hunting pressure.

11.7. Limitations and Data Gaps

We did not directly explore the relationship between coastal erosion and salinization and the potential affects to post-breeding aggregations foraging/molting habitats, as this was beyond the scope of this assessment. However, MQ TF 4 does provide an overview of expected changes to habitat as a result of coastal erosion and salinization and could be referred to for comparison.

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12. Raptor Concentration Areas

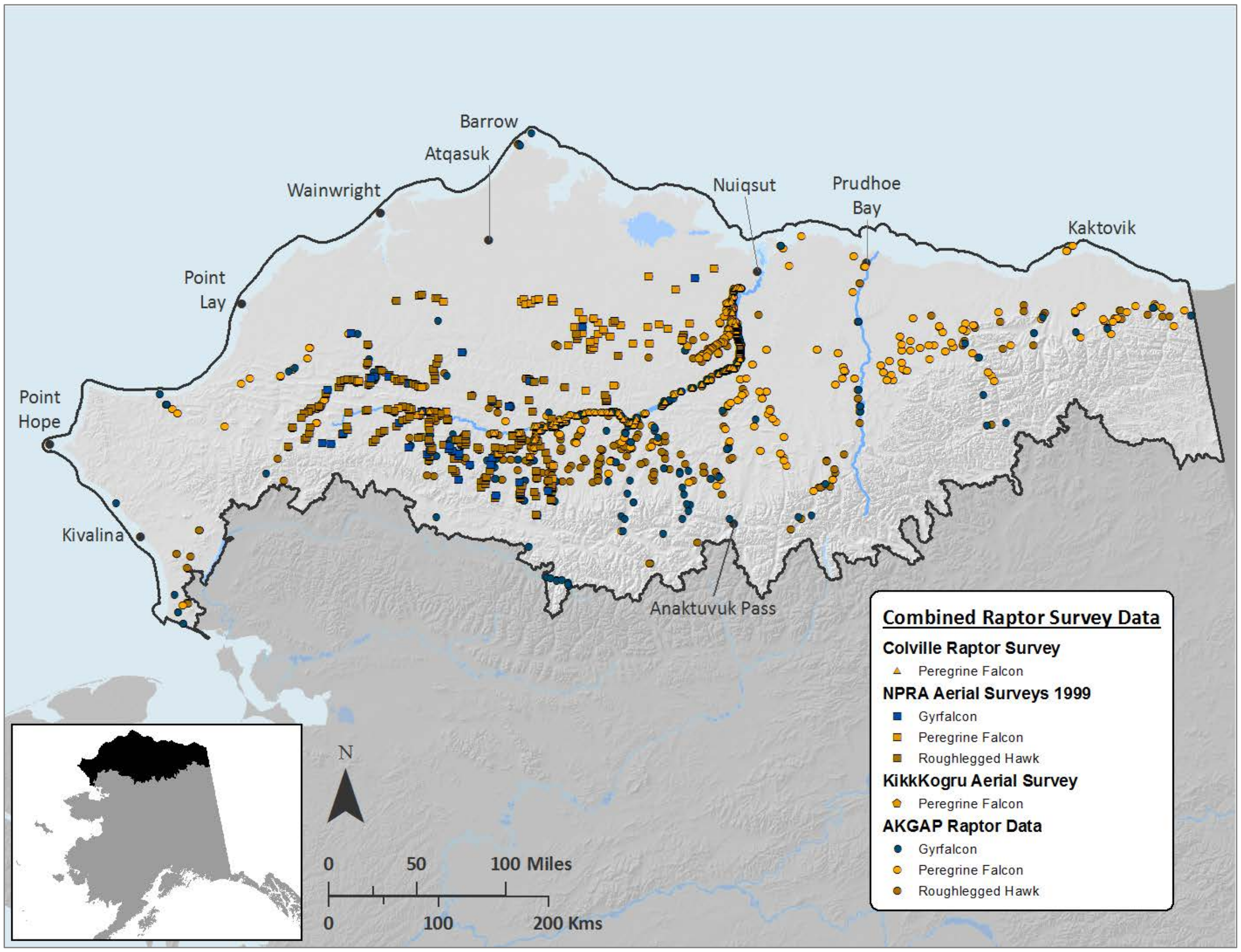

Figure H-63. Documented occurrences for peregrine falcon, gyrfalcon, and rough-legged hawk in the North Slope study area.

12.1. Introduction

Species selected to represent the "Raptor Concentration Areas" assemblage for the North Slope study area include gyrfalcon (*Falco rusticolus*), peregrine falcon (*Falco peregrinus tundrius*), and rough-legged hawk (*Buteo lagopus*). These three species share similar habitats in arctic Alaska, but differ in seasonal distribution and prey preferences. Primary habitats include cliffs in riparian areas along river drainages and major tributaries, shale banks, mud or sand banks, scree and talus slopes, and steep escarpment faces. This species assemblage was nominated as a Terrestrial Fine-Filter CE because of the role raptors play as top trophic-level predators and that changes in their status could be indicative of large-scale ecosystem changes.

The gyrfalcon is the largest falcon species, the most northern diurnal raptor, and an arctic specialist. It is migratory with a circumpolar distribution, including summer breeding sites in Alaska. Gyrfalcons are most common on the arctic slope east of the Sagavanirktok River and west of the Anaktuvuk River, with relatively low numbers along the Sagavanirktok River. The Colville River and adjacent drainages support a substantial proportion of the North Slope population (Johnson and Herter 1989). Gyrfalcons are also common east of the Canning River in the Arctic National Wildlife Refuge. Individuals are typically present on their breeding grounds from March to September (see Booms et al. 2008 for review); however, there is evidence for winter occupation of nest sites in Alaska (Cade 1960) and other northern regions (Platt 1976, Kuyt 1980, Norment 1985). Current population on the North Slope (*tundrius* subspecies) is estimated at 250 breeding pairs (USFWS 2001). This species nests primarily on precipitous cliff faces and typically utilizes nests built by other species (particularly common raven, golden eagle, and rough-legged hawk) (Booms et al. 2008). They lay one clutch (averaging 3.7 eggs; Booms et al. 2008) per year which is incubated for approximately 35 days (Platt 1977). Pairs may not breed every year, depending on prey availability (Cade 1960, Nielsen and Cade 1990). Ptarmigan are the preferred prey species, but they will also take birds ranging in size from passerines to geese (Poole and Boag 1988, Booms et al. 2008). Foraging range during breeding is approximately 12–15 km from the nest site (Palmer 1988).

The peregrine falcon ranges throughout much of the world as either a seasonal migrant or resident. Peregrine falcons that breed in arctic Alaska spend winters in Central and South America (Liebezeit et al. 2012). The principle nesting area in the North Slope study area occurs along the Colville River drainage (including major tributaries such as the Etivluk, Oolamnagavik, Killik, and Chandler rivers) and the Sagavanirktok River (APFRT 1982). Individuals are typically present on their breeding grounds from mid-April/mid-May to mid/late-August (APFRT 1982). They lay one clutch (averaging 3 eggs) per year (Cade et al. 1968, Wright and Bente 2001), which is incubated for 33 to 35 days (White et al. 2002). Peregrine falcons prey primarily on bird species including passerines, shorebirds, and ducks (Mindell and Craighead 1981, *reviewed in* White et al. 2002). Foraging range during breeding is approximately 8 km (Brown and Amadon 1968).

The rough-legged hawk is a migratory species that breeds in the circumpolar arctic and subarctic, and winters in the temperate northern hemisphere. It is the most abundant and wide-spread cliff-nesting raptor in the North Slope study area (Ritchie et al. 2003). Distribution and densities are enhanced during years of high microtine populations and appear to be limited to the north by lack of preferred nesting sites (Zarn 1975). They lay one clutch (averaging 3–4 eggs) per year (Swem 1996, Kessel 1989), which is incubated for a minimum of 32 days (Parmelee et al. 1967, Cramp and Simmons 1980). On the coastal plain of Alaska, they typically forage for small mammal prey in open tundra and low-brush habitats (e.g. river floodplains) (Bechard and Swem 2002). Foraging range during breeding is approximately 3–7 km (Cannings 2002).

The diversity of food habits vary annually for the three raptor species. Annual fluctuations in the population sizes of gyrfalcon and rough-legged hawk in Arctic Alaska are linked to the abundance of primary prey species (ptarmigan and lemmings, respectively), which are residents of the arctic environment (Mindell et al. 1987). Synchronous population cycles have been documented between willow ptarmigan (*L. lagopus*) and gyrfalcon, although the regularity of willow ptarmigan cycles may be faltering (Mossop 2011). Peregrine falcon populations appear to be more stable from year to year, likely because peregrines primarily consume migratory bird species, whose populations are less affected by local conditions, and therefore less volatile than populations of resident species (Mindell et al. 1987).

12.2. Conceptual Model

The conceptual model below (Figure H-64) is based on literature review and describes the relationship between the various change agents and natural drivers for the three raptor species included in this assemblage; peregrine falcon, gyrfalcon, and rough-legged hawk. The boxes and arrows represent the state of knowledge about the raptor assemblage and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and the raptor assemblage. Change agents selected for this REA and considered in this analysis include: climate change, fire, invasive species, and land use change (i.e. human development).

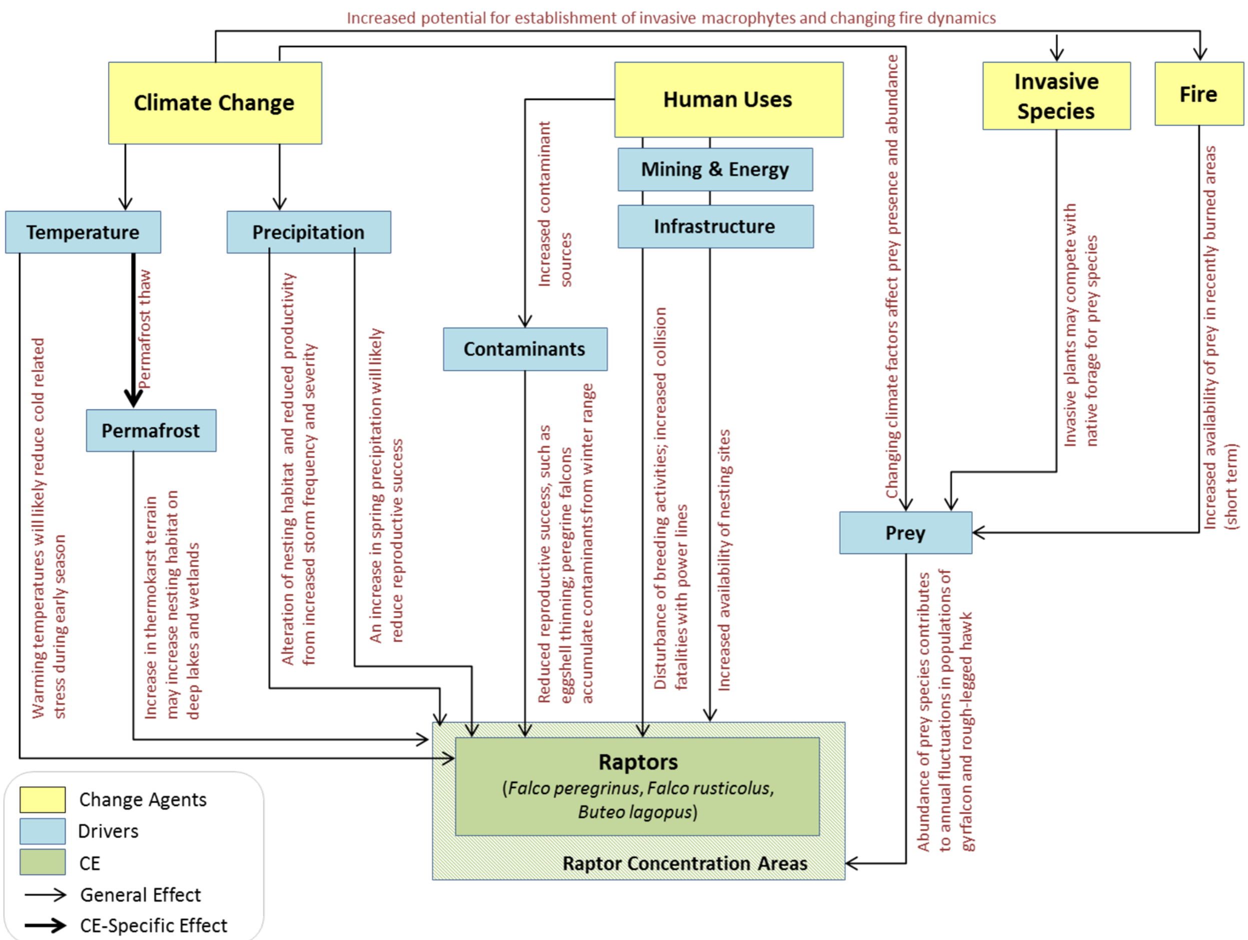

Figure H-64. Conceptual model for raptor concentration areas.

12.3. Attributes and Indicators

Attributes and indicators helped to define the relationships between conservation elements and change agents, and, where possible, the thresholds associated with these relationships. Based on the assessment of available indicators, spatial data used to assess the status of raptor concentration areas included: mean summer temperature, growing season length, spring precipitation, and landscape condition (Table H-37).

Table H-37. Attributes and indicators for raptor concentration areas.

CA or Driver	Ecological Attribute	Indicator (unit of measure)	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Prey availability[36]	Mean Temperature - June, July, August	Warmer temperatures associated with increases in prey availability, chick survival and reproductive success.	Below average		Average	Above average
	Prey availability[36]	Growing season length		Below average		Average	Above average
	Habitat availability[37]	Spring precipitation - March, April, May	Cold, wet springs can increase nestling mortality.		Above average	Average	
Anthropogenic	Habitat condition[38]	Landscape condition model (human footprint)	Disturbance at breeding sites may lead to abandonment and nest failure.	0-3 km	3 - 6 km	6 - 10 km	> 10 km

[36] Based on Cade et al. 1971, Bale et al. 2002, Liebezeit et al. 2012, and Bolduc et al. 2013.
[37] Based on Cade et al. 1971, Liebezeit et al. 2012.
[38] Based on Brown and Amadon 1968, Palmer 1988, Cannings 2002, and Oregon Department of Transportation 2007.

12.4. Distribution Model

For most of the Terrestrial Fine-Filter CEs, we used predictive models generated by the Alaska Gap Analysis Project (AKGAP) to describe the species distribution across the North Slope study area. However, the AKGAP distribution models for raptors were of generally of poor quality, as cliff nesting features were not mapped well in the land cover base maps used to generate the distribution models (Gotthardt et al. 2014). Therefore, we opted not to include them in this analysis. Instead, we compiled 5,166 existing occurrence records for peregrine falcon (n = 2752), gyrfalcon (n = 413), and rough-legged hawk (n = 2001) for the North Slope study area from a variety of data sources (Table H-38; Figure H-63). We standardized the data into a common format, projected it in ArcGIS, and buffered records that were clustered along river drainages and major tributaries. We selected a 5 km buffer distance based on previous work by Audubon Alaska, who identified important raptor habitat within a 5 km swath along the Lower Colville River (Alaska Audubon 2008). The bare rock cliffs along these rivers are critical habitat for nesting. The riparian areas along the rivers, including the gravel bars and shrubs within the river bottoms, are important raptor hunting habitat, as are the lakes and ponds and adjacent tundra.

Table H-38. Datasets used for raptor concentration areas.

Dataset Name	Data source
Alaska Gap Analysis terrestrial vertebrate occurrence database - peregrine falcon, gyrfalcon, and rough-legged hawk*	Alaska Gap Analysis Project, AKNHP
Peregrine falcon surveys in interior and northern Alaska, 1990	Bureau of Ocean Energy Management
Site occupancy of cliff nesting raptors in Arctic NWR	USFWS, Arctic NWR
Peregrine falcon locations in NPR-A	BLM, NPRA EIS

*23 unique datasets are included in the Alaska Gap Analysis occurrence database. A full list of citations is provided in the North Slope Data Discovery Memo.

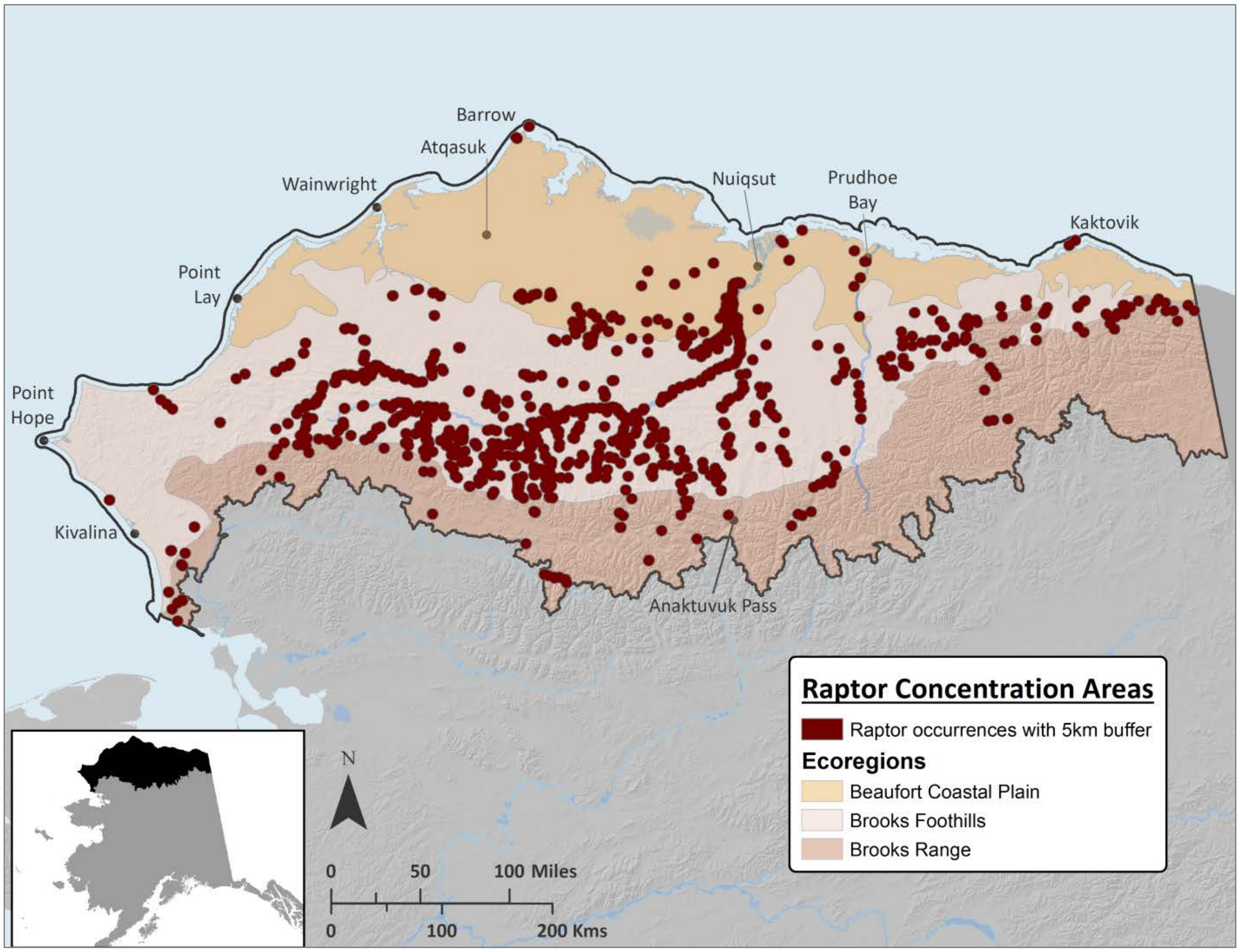

Figure H-65. Current distribution of raptor concentration areas in the North Slope study area.

Figure H-65 depicts important nesting concentration areas for the three raptor species included in this assemblage. Nesting sites, and therefore raptors, are most common in the Brooks Foothills, with less suitable habitat in the Brooks Range and the Beaufort Coastal Plain. Raptors nesting in the Brooks Range are primarily gyrfalcons. Gyrfalcons are rare to uncommon along the Beaufort Coastal Plain.

12.5. Abiotic Change Agents Analysis

We explored the relationship between arctic raptors and three abiotic climatic change agents: summer temperature, growing season length, and spring precipitation at three time steps (current, near-term, and long-term). We hypothesized that warmer than average summer temperatures and a longer growing season would be beneficial for raptors, by reducing cold related stress during early season, and potentially resulting in increases in prey availability, chick survival and reproductive success, while wetter than average springs (increase in frequency and severity of spring storms) could reduce raptor reproductive success.

Temperature and Growing Season Length

The results of our analysis indicate that within the current modeled distribution of raptor concentration areas, both summer temperature and growing season will increase by 2060. Summer temperatures increases will be significant, by as much as 1.3 °C, with the warmest temperatures occurring in the Brooks Foothills (Figure H-66). Growing season length (estimated days with mean temperatures above freezing) across the North Slope study area is currently between 110 to 130 days, but by 2060 will increase by 7 to 14 days throughout the entire raptor concentration area range (Figure H-67).

Warmer temperatures may be favorable for some arctic nesting raptors, as they are expected to result in increased insect abundance and more varied insect community composition (Danks 1992), providing energy dense diets for insectivorous passerines, which are primary prey items for peregrine falcon (Bale et al. 2002, Bolduc et al. 2013). Warming temperatures may also reduce cold related stress during early season nesting (Cade et al. 1971, Liebezeit et al. 2012, Ontario Peregrine Falcon Recovery Team 2010).

A longer growing season should promote a longer breeding window and allow fledglings more time to forage before fall migration (Kittel et al. 2010). This could be especially beneficial to gyrfalcon, which has the longest reproductive cycle of the three raptors (ca. 160-180 days from establishment of nesting territory to independently fledging young) and is the first raptor to arrive on arctic breeding grounds in the spring (Cade 2011). Breeding is currently timed so that young nestlings fledge during the period of peak availability of young, inexperienced prey (especially ptarmigan). In addition, a longer growing season may allow for earlier arrival of prey species (Murphy-Klassen et al. 2005) providing raptors with more abundant prey resources in the spring. It is unclear how raptor breeding phenology will be influenced by a lengthening Arctic summer, but it could be advantageous in spring and autumn by allowing for new trophic relationships (Cade 2011).

Currently, gyrfalcons are the most common raptor nesting in the Brooks Range and uncommon to rare along the Coastal Plain, where the current length of growing season may limit their ability to be successful reproductively. A longer growing season could allow gyrfalcons to expand their range northward, allowing for increased competitive interactions with peregrine falcons and rough-legged hawks. However, recent modeling efforts indicate that the future gyrfalcon range in Alaska could decrease substantially (Booms et al. 2011).

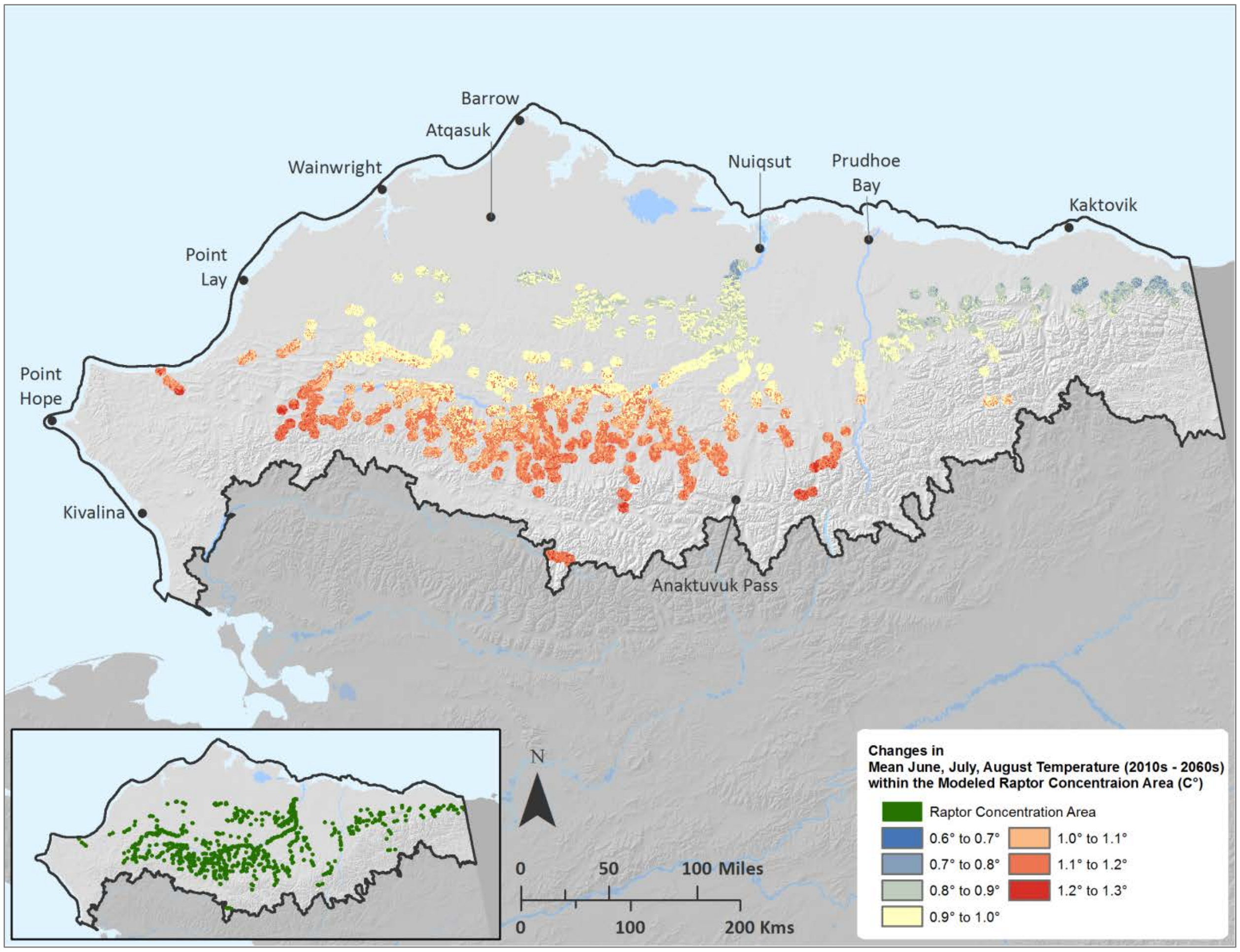

Figure H-66. Changes in mean summer (June, July, and August) temperature (2010s to 2060s) within the modeled raptor concentration area in the North Slope study area.

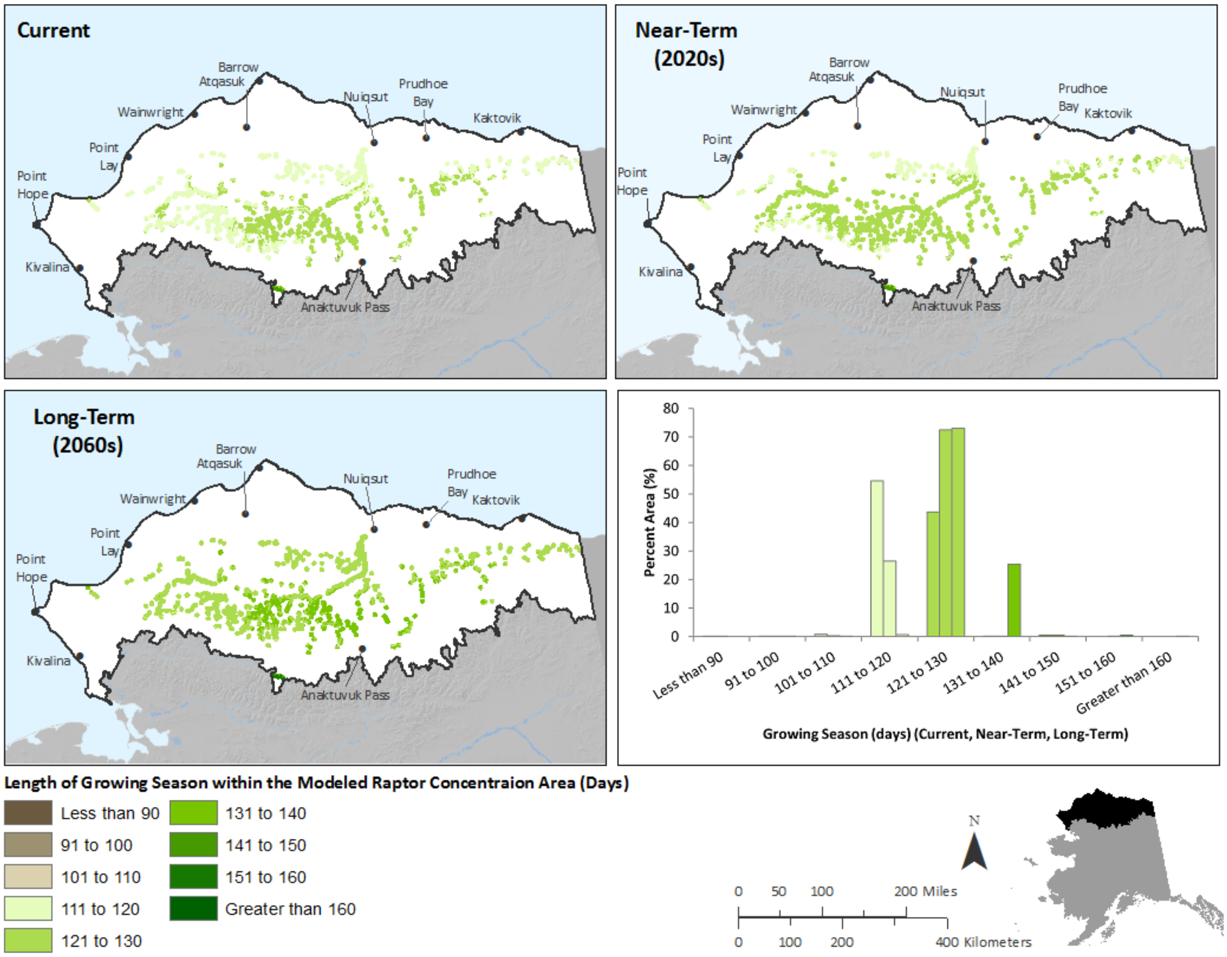

Figure H-67. Length of growing season at current, near-term future (2020s), and long-term future (2060s) time intervals within the modeled raptor concentration area in the North Slope study area.

Spring precipitation

An increase in the frequency and severity of erratic weather events has the potential to cause heavy rains that may negatively affect raptor productivity during incubation and brood rearing (Cade et al. 1971, Liebezeit et al. 2012, Ontario Peregrine Falcon Recovery Team 2010). Recently, researchers in the Canadian Arctic have linked an increase in the frequency of heavy rain over the last three decades to the recent decline of peregrine falcon nestling survival rates, and subsequent decreases in annual breeding productivity (Anctil et al. 2013). This direct linkage between rainfall and survival in wild birds indicates that top level avian predators may be significantly impacted by changes in precipitation regimes (Anctil et al. 2013).

We used precipitation as a surrogate for "increased storminess" in our comparison with raptor concentration areas. Results indicate that total precipitation may increase slightly between current conditions and 2060, but geographic patterns of precipitation are likely to remain relatively unchanged across the raptor concentration area range (Figure H-68). While the potential for increased storminess during the arctic spring is highly uncertain, total precipitation models indicate that impacts to raptors will likely be minimal.

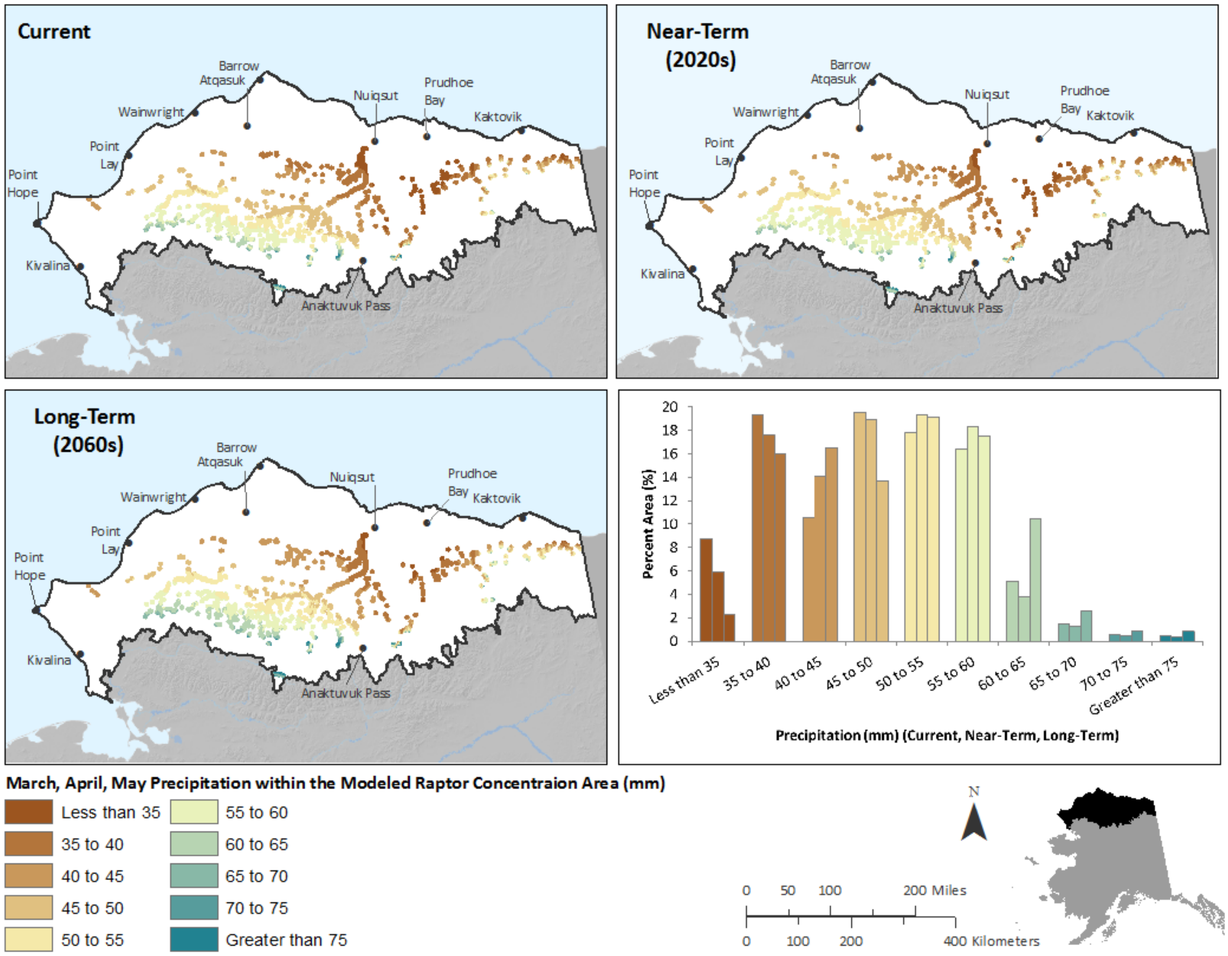

Figure H-68. Spring precipitation (March, April, and May) in mm within the modeled distribution of raptor concentration areas.

The 10-year population cycles of ptarmigan and hares and the 3-4 year cycles of microtine rodents are expected to exhibit lower peaks and less regularity under climate change. In the Yukon Territory, regular population cycles of willow ptarmigan (a major prey item for gyrfalcon) have faltered in recent years, likely a consequence of climatic changes (see Section H.8). Concurrent with observed changes in the population cycling of willow ptarmigan, the timing of gyrfalcon nesting has moved later in spring and fewer nest sites have been observed (Mossop 2011). The lack of recent peaks in ptarmigan population cycles, possibly caused by the increasing frequency and severity of spring storm events, has likely removed peaks in gyrfalcon reproduction that have historically boosted gyrfalcon populations during ptarmigan population troughs (Mossop 2011). Whether these population changes will persist and what they portend for predators needs study (Cade 2011).

Climate change, including warmer temperatures and increased precipitation, are expected to affect infectious disease prevalence and proliferation in arctic and subarctic regions (Kutz et al. 2009). An increased prevalence of disease may reduce these species' capacity to adapt to rapid climate change (Boom et al. 2011). For example, the northward expansion or ecological shift of diseases and parasites facilitated by warming climates (e.g., Hueffer et al. 2011) likely poses significant confounding risks to gyrfalcons in particular, which are known for their susceptibility to numerous diseases in lower latitudes (Booms et al. 2011).

Fire

The impact of fire and its potential increase in frequency and severity with a warming climate could affect raptor habitat. Although ALFRESCO predicts increased fire frequency in the foothills and Brooks Range sub-regions, and are where the majority of raptors are concentrated, total area burned is expected to remain relatively low and will likely not be a significant driver affecting raptor habitat.

Due to their high mobility, fire-related mortality of adult raptors is likely low. Nestling mortality is potentially higher because nestlings are unable to flee approaching fire (Luensmann 2010). Because these birds nest on cliff faces, rock outcrops, and similar sites, the potential for damage to nesting sites or nestling mortality is low but possible if vegetation on the nest ledge catches fire. Fire may threaten nests at the ground level amongst dense vegetation (Luensmann 2010).

Increased fire frequency may both create and destroy favorable hunting habitat (Racine and Jandt 2008). Bird diversity and small mammal populations will likely temporarily increase in recently burned areas, as these prey species are attracted to abundant new vegetative growth in the months following fire (Luensmann 2010, Liebezeit et al. 2012). In New Mexico and southern California, abundant prey species attracted golden eagles (*Aquila chrysaetos*) and peregrine falcons to recently burned areas (Lehman and Allendorf 1989).

Climate Summary

Of the three raptor species considered in this assessment, gyrfalcon are considered to be quite vulnerable to climate change due to factors mostly related to their narrow ecological niche that includes a specialized diet (ptarmigan) and nesting requirements, while rough-legged hawk and peregrine falcon are more likely be able to adjust to associated habitat changes predicted to occur on the North Slope over the time period of this assessment (Liebezeit et al. 2012). Overall, raptors could benefit from warmer temperatures by reducing cold related stress during nesting; a longer growing season provides a longer time period to fledge young; projected changes in spring precipitation related to decreases in nestling survival are expected to be negligible, as will affects from fire on nesting habitat (Table H-39).

Table H-39. Summary of abiotic change agents used in the assessment of raptor concentration areas and projected effects.

Indicator	Short-term (2020) trend	Long-term (2060) trend	Impact to	Effect
Summer temperature	+	+	Earlier food for prey, reduced cold related stress	+
Growing season length	+	+	Longer breeding window, more abundant spring prey	+
Spring precipitation	No change	Negligible	Decreases in nestling survival rates; decreases in annual breeding productivity	-
Fire	Negligible	Negligible	Loss of ground level nests; short-term increases in prey species	?

12.6. Current Status and Future Landscape Condition

The majority of current raptor concentration distribution locations are in areas with very high (intact) landscape condition (Figure H-69). Future projections of landscape condition suggest very little change in landscape condition in the vicinity of riparian corridors and areas occupied by these species.

Although landscape condition appears to be high in the general vicinity of nesting concentrations, these birds are highly sensitive and vulnerable to disturbance, especially at the nest site. Nest habitat is limited, so disturbed birds are unable to simply move elsewhere. Development will bring a general increase of human activities, including aircraft traffic, which will create additional disturbance to the birds. Threats associated with development as a result of oil and gas activities could include direct loss of habitat from the development footprint, including roads, pipelines, drilling pads, and residential facilities. Human activity (including noise, recreational activities, and vehicle traffic) and development near nesting sites can deter and disturb breeding activities, cause nest abandonment, and destroy potential nesting habitat (Oregon Department of Transportation 2007), although studies are not conclusive (Ritchie et al. 1997, Palmer et al. 2003). Peregrine falcons have shown greater negative response to animate (human) than to inanimate (aircraft) activity, and more to boats than to airplane (Windoor 1977, Nordmeyer 1999). Aircraft have been shown to disturb peregrines at distances less than 150 m during the fledgling period (Windoor 1977). Human presence has elicited higher levels of disturbance as far as 150 m from a cliff base (Windoor 1977).

Recreational users use boats for access and floating rivers in the area. Since the river is the agent of erosion which creates the cliffs so critical to the nesting raptors, recreational floaters pass directly under almost all nests. Increased recreational activity could disturb nesting birds. The Colville River is used for travel between subsistence hunting and fishing opportunities. Umiat is a camp along the Colville which supports oil and mineral exploration activities. It also serves as a landing field and refueling stop for aircraft (Alaska Audubon 2008). The high scenario LCM indicates potential for a pipeline connecting

Umiat to other oil and gas infrastructure, which could have negative implications for birds nesting in this area.

The Bureau of Land Management requires that permitted activities across the entire National Petroleum Reserve-Alaska adhere to a series of restrictions and required conduct around potential raptor nesting habitats, all of which are designed to minimize disturbance and nest abandonment (Audubon Alaska 2008). Recreational boating, wildlife viewing, and wilderness tours are all activities now conducted within the Colville corridor. Since the 1950s, the Colville River corridor has been used as a research area for monitoring Peregrine Falcons (Alaska Audubon 2008).

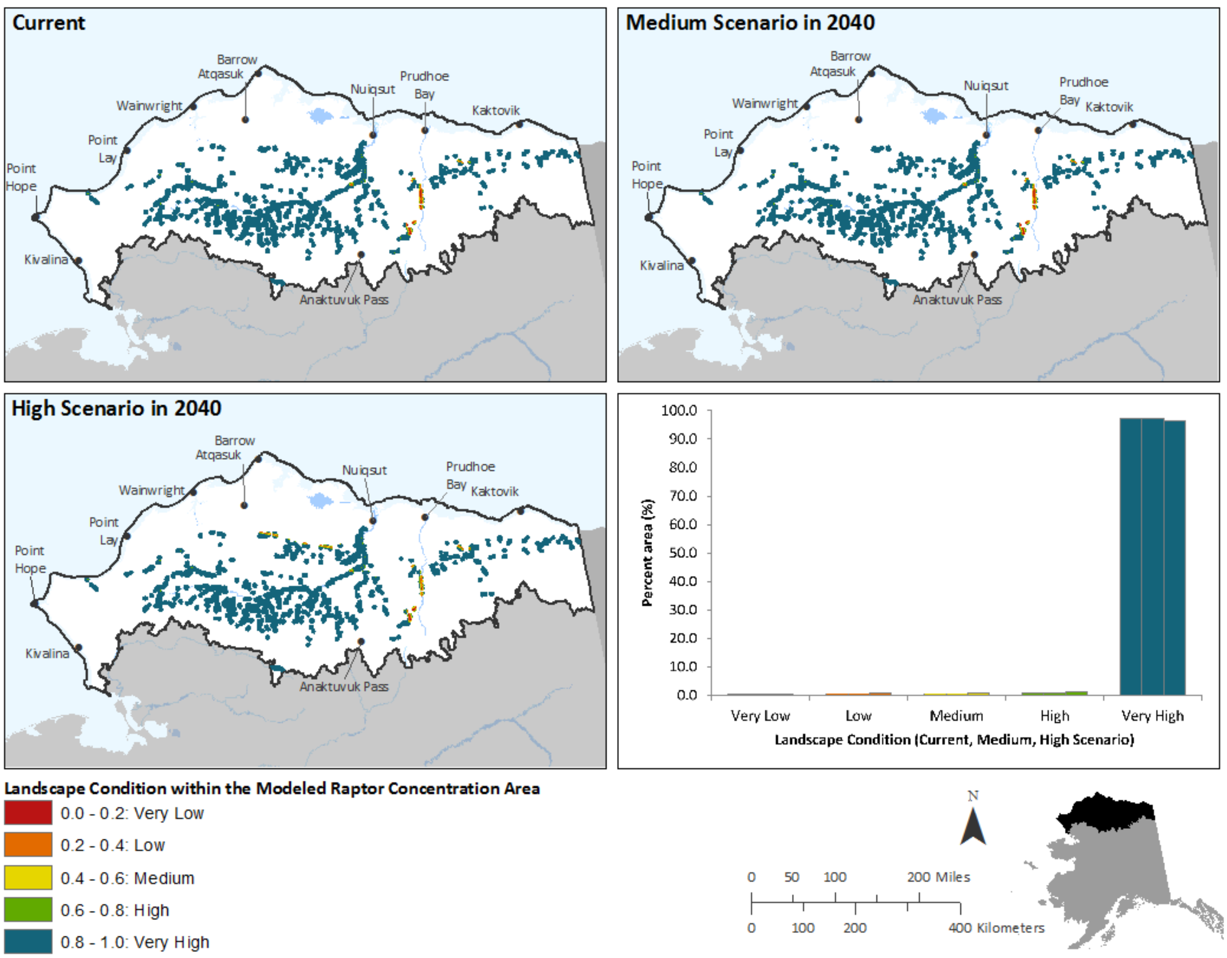

Figure H-69. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current raptor concentration areas in the North Slope study area.

Disturbances that may have contributed to the peregrine falcon decline which resulted in their listing status in 1970 include destruction of wetlands, construction of roads and other structures, poaching, removal of eggs and nestlings from nests, disturbance from recreational activities, and climate change (Kiff 1988). Because peregrine falcons use a wide range of habitats and landscapes, the effects of habitat degradation are difficult to assess. The greatest effects are likely due to losses of nesting sites, which may be limited.

Frequent interruptions during nesting can lengthen the incubation period and delay hatching (White et al. 2002). The timing of disturbance at nest sites also seems to be critical to nesting success (Ratcliffe 1993). Nesting peregrine falcons are intolerant of excessive human disturbance; they may abandon a nest site during courtship and move to another ledge or cliff. Breeding pairs may attempt to continue nesting if eggs or nestlings are being brooded, but often, the nest is deserted (Ratcliffe 1993). Peregrine falcon young can perish in harsh environments if the parents, panicked by disturbance, are away from the nest for long periods (White 1969). Ellis (1982) recommended that recreational activities and human development be minimized whenever peregrine falcons occupy an area, and concluded that protecting nesting sites from human disturbance is critical for peregrine falcon conservation (Stephenson and Calcarone 1999).

12.7. Limitations and Data Gaps

We did not address the potential impacts to raptor concentration areas as a result of fire frequency. Although ALFRESCO predicts increased fire frequency in the foothills and Brooks Range sub-regions, total area burned is expected to remain relatively low and will likely not be a significant driver affecting raptor habitat. Furthermore, we did not explore the relationship of raptor habitat with permafrost and thermokarst disposition. Thermokarst, through both ice wedge degradation and draining of thaw lakes (Martin et al. 2009) could both create and reduce nesting sites on deep lakes and wetland foraging sites. However, we felt we lacked suitable raptor distribution models to explore these potential relationships.

Although we sought to compile a comprehensive raptor dataset for the North Slope study area for this analysis, it is likely that there are numerous data sets that are lacking from this synthesis of observations that we were simply unaware of. We developed a database structure for this project that includes 5,166 records, which can easily be added to and updated over time as new information becomes available.

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I. Aquatic Coarse-Filter Conservation Elements

Leah Kenney, Dustin Merrigan, and Marcus Geist

Alaska Natural Heritage Program, University of Alaska Anchorage, 3211 Providence Drive, Anchorage, Alaska 99508

Summary

Section I. *Aquatic Coarse-Filter Conservation Elements* provides the detailed descriptions, methods, datasets, results, and limitations for the assessments of three habitats considered to be of high ecological importance in the region and potential impacts of CAs on these habitats.

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1. Summary of Aquatic Habitats (Coarse-Filter Conservation Elements)

Aquatic Coarse-Filter CEs are regionally important and characterize habitats that encompass many of the dominant ecological processes and patterns of the North Slope study area. Together the Coarse-Filter CEs address the habitat requirements of most native species. Four habitats (Table I-1) were selected as Coarse-Filter CEs: large streams, small streams, deep connected lakes, and shallow connected lakes. Stream distributions were mapped using data obtained from the National Hydrography Datasets (NHD; see Methods below). Deep and shallow connected lakes were mapped based on the NHD and additional datasets that had lake depth information (see Methods below).

Table I-1. Aquatic Coarse-Filter CEs selected for the North Slope REA.

Aquatic Coarse-Filter CEs	Ecological Importance
Large streams	High stream connectivity in the spring, source of freshwater and silt to river deltas; important spawning, rearing, and overwintering habitat; migration corridor habitat
Small streams	High stream connectivity in the spring; fish rearing and potentially spawning and overwintering
Deep connected lakes	Important breeding habitat for aquatic insects, fish, and waterbirds, and provide important overwintering habitat for fish
Shallow connected lakes	Summer foraging habitat for fish

The Coarse-Filter CEs section is organized by first describing the methods used to develop the distribution models for all the CEs. We then describe the characteristics, spatial distribution, and relationship of Aquatic Coarse-Filter CEs to the current and 2040 medium and high scenario landscape condition, as well as selected climate and CA variables understood to be critical.

2. Methods

For each Aquatic Coarse-Filter CE we developed distribution maps based on data obtained from the NHD and additional datasets (Table I-2). The NHD is a digital representation of the stream network and lakes shown on USGS topographic maps, which was created from historic aerial photos and is the best available spatial data of aquatic resources for the study area. However, the NHD has several limitations:

- The NHD underrepresents small streams because they are often masked by vegetation cover and not visible on aerial photography
- The NHD is outdated (most topographic maps were created in the 50's and 60's) and stream locations and lake areas have likely changed due to natural hydrologic disturbances and climate change
- Both stream order and stream gradient are needed to map aquatic habitats; the NHD is not attributed with stream order and does not align with valley bottoms in the Digital Elevation Model (DEM) so stream gradient cannot be calculated accurately

Additionally, the best available DEM for the study area is the National Elevation Dataset (60 m pixels). Due to the limitations of the NHD, aquatic habitats must be mapped by creating a stream network from the DEM, which has its own set of drawbacks:

- Utilizing a coarse DEM to map streams results in a gross oversimplification of the stream network length and complexity
- The DEM does not match the NHD, which is the best available representation of what exists on the ground
- When creating a stream network from a DEM, a decision must be made regarding the size of the watershed required to initiate a first order stream; there is no available data relating area to perennial flow initiation for the study area and due to the diversity of topographic, geologic, and permafrost characteristics across the North Slope study area, this relationship is expected to vary

In addition to the limitations of the data available for mapping aquatic habitats, it was beyond the scope of this project to create an aquatic habitat classification relating aquatic habitat types to physical, chemical, and biological conditions for the North Slope study area. Thus, for large and small streams, we developed distribution maps that were drawn directly from the NHD without additional processing or attribution. For deep and shallow connected lakes we used additional datasets (Table I-2) to identify shallow lakes (<1.6m) and deep lakes (>1.6m). However, not all lakes within the North Slope study area had lake depth data.

Table I-2. Source datasets for the distribution of Aquatic Coarse-Filter CEs.

Dataset Name	Data source
National Hydrography Dataset Waterbodies	USGS
National Hydrography Dataset Flowlines	USGS
Bathymetry of Alaskan Arctic lakes	BLM
SAR derived lake depths	GINA

Conceptual Models

These analyses are further aided by the development of CE-specific conceptual models. The CE-specific conceptual models represent a general review of the relationship between the CE, CAs and natural drivers.

Attributes and Indicators

Attributes and indicators helped to define the relationships between Conservation Elements (CEs) and Change Agents (CAs), and, where possible, the thresholds associated with these relationships. For each Coarse-Filter CE, we identified a number of attributes derived through the conceptual model, and assigned indicators to them based on available spatial data layers. Whenever possible, thresholds derived from the literature were set to categorize the data into standard reporting categories (i.e. indicator ratings).

Although numerous attributes and indicators affecting Aquatic Coarse-Filter CEs were identified during early phases of this REA (see results Table I-5), limited information exists for specific threshold effects of attributes and indicators for Coarse-Filter CEs. For example, currently there are no climate change predictions specific to aquatic habitats, such as changes to water temperature or hydrologic regime. Thus, not all of the attributes and indicators identified from the literature were included in this analysis because appropriate geospatial data were not available. Further information on the data gaps for each CE and their indicators are discussed briefly below and in Section K-1.1 and K-1.11.

Core Analysis

For each Aquatic Coarse-Filter CE, we assessed the current (2010), medium development scenario (2040), and high development scenario (2040) status. See Section F-2 for information on how status was calculated. For each Aquatic Coarse-Filter CE, we extracted and overlaid current CE distributions with the current, near-term (2020s), and long-term (2060s) status of relevant CA variables (Table I-3). The relevant CA variables are those considered to be most critical in structuring the Coarse-Filter CEs and include: temperature, change in length of growing season, areas of thermokarst, and permafrost. Distribution maps, conceptual models, and core analyses are presented for each Aquatic Coarse-Filter CE sections.

Table I-3. Source datasets for Core Analysis.

Dataset Name	Data source
Mean July temperature difference from 2010s-2020s and 2010s-2060s	SNAP, UAF
Change in length of growing season from 2010s-2020s and 2010s-2060s	SNAP, UAF
Areas of thermokarst from 2010s-2020s and 2010s-2060s	IEM Project, Genet, H., UAF
Change in mean annual ground temperature at one meter (MAGT) from 2010s-2020s and 2010s-2060s	GIPL and SNAP, UAF
Change in active layer thickness (ALT) from 2010s-2020s and 2010s-2060s	GIPL and SNAP, UAF

Management Questions (MQs)

There was one management question specific to Aquatic Coarse-Filter CEs that related to potential impacts of water withdrawal for oil and gas activities (MQ AC 1). We do not have the data available to answer this question spatially, thus we provided a literature review of the potential impacts that oil and gas activities could have on aquatic habitats within the North Slope study area. This MQ is addressed at the end of the Aquatic Coarse-Filter CE section.

3. Distribution on Public and Private Lands

We used the relative proportion Aquatic Coarse-Filter CE distribution falling within agency boundaries as a proxy for relative amount of management responsibility. The distribution of lakes in relation to areas managed both publicly and privately within the study area reflect the overall ratio of land ownership in the REA, with the highest percentages of species distributions occurring on BLM land (Table I-4).

Table I-4. Percentage of all lakes, deep lakes, shallow lakes, all streams, large streams, and small streams on public and private lands in the North Slope study area.

Land Owner	Aquatic Coarse-Filter (%)					
	All Lakes	Deep Lakes	Shallow Lakes	All Streams	Large Streams	Small Streams
Bureau of Land Management	75.03	83.28	61.26	46.44	38.00	47.55
Fish and Wildlife Service	1.33	0.79	2.26	16.19	15.41	16.29
Military	0.05	0.03	0.13	0.02	0.04	0.02
National Park Service	2.16	0.01	0.06	9.46	14.19	8.84
Native Patent or IC	7.48	5.74	8.66	9.13	13.34	8.58
Native Selected	0.27	0.17	0.16	0.62	0.77	0.59
Private	0.00	0.00	0.00	0.00	0.00	0.00
State Patent or TA	13.57	9.91	27.43	17.08	16.74	17.13
State Selected	0.11	0.07	0.05	1.06	1.51	1.00

4. Large Streams (Rivers) and Small Streams

Within the study area, small and large stream ecosystems provide important habitat for aquatic insects, fish, and waterbirds. Large streams (Figure I-1), referred to as rivers below, are those with sufficient depth to allow for deep pool areas, which provide overwintering habitat. Small streams are generally slow moving and freeze completely during the winter. However, some small streams (Figure I-2) may provide overwinter habitat in the form of springs and deep pools.

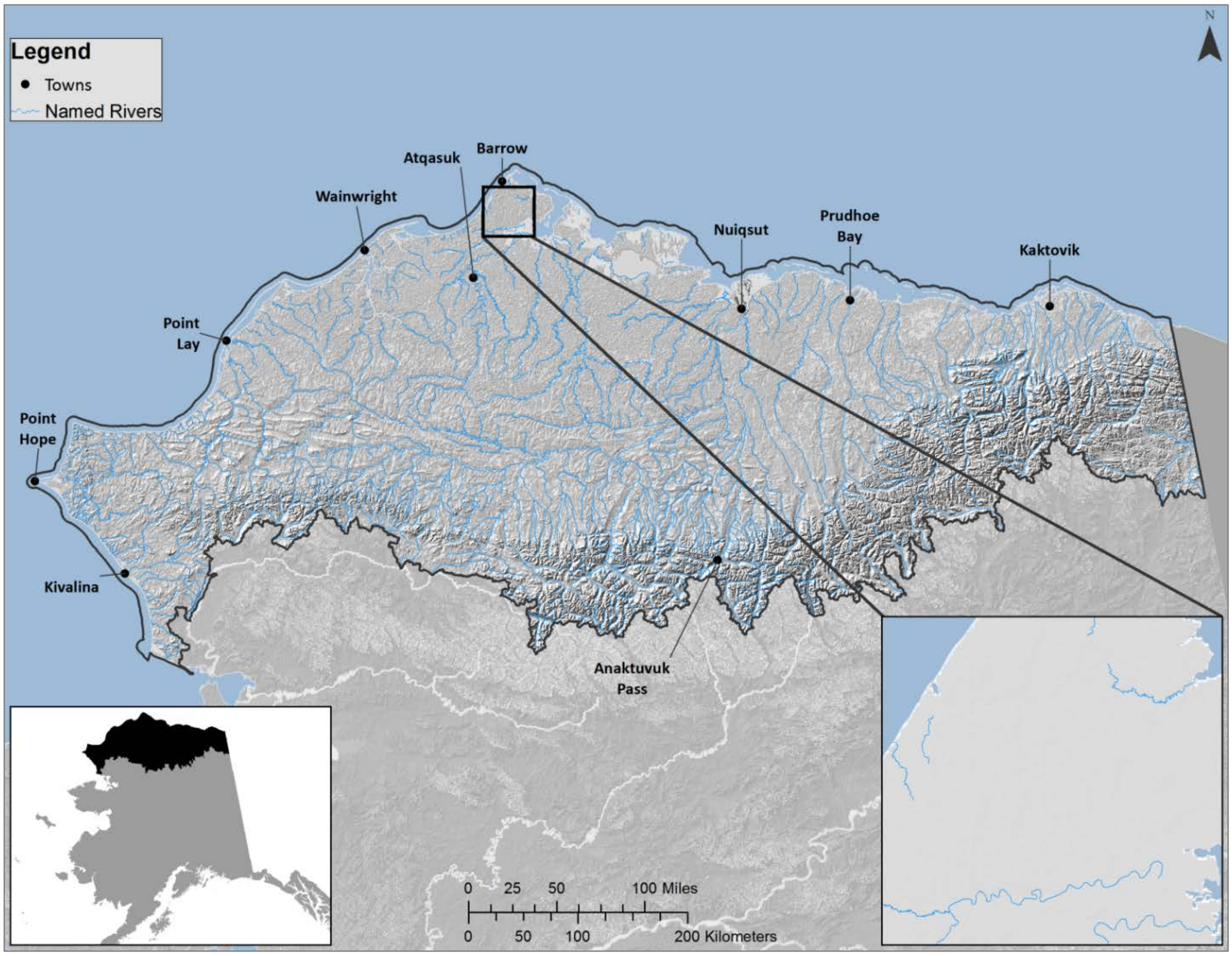

Figure I-1. Distribution of large rivers within the North Slope study area.

Stream and river ecosystems support extensive spawning and rearing habitat for numerous fish species in the study area. Streams and rivers also provide important habitat for aquatic invertebrates. Additionally, rivers and small streams provide important transportation and recreational uses for local residents. Rivers are typically less productive than smaller streams due to warmer temperatures in smaller tributaries (Hobbie 1995). Consequently, smaller streams are often preferred summer feeding habitat for many fish species and aquatic insects.

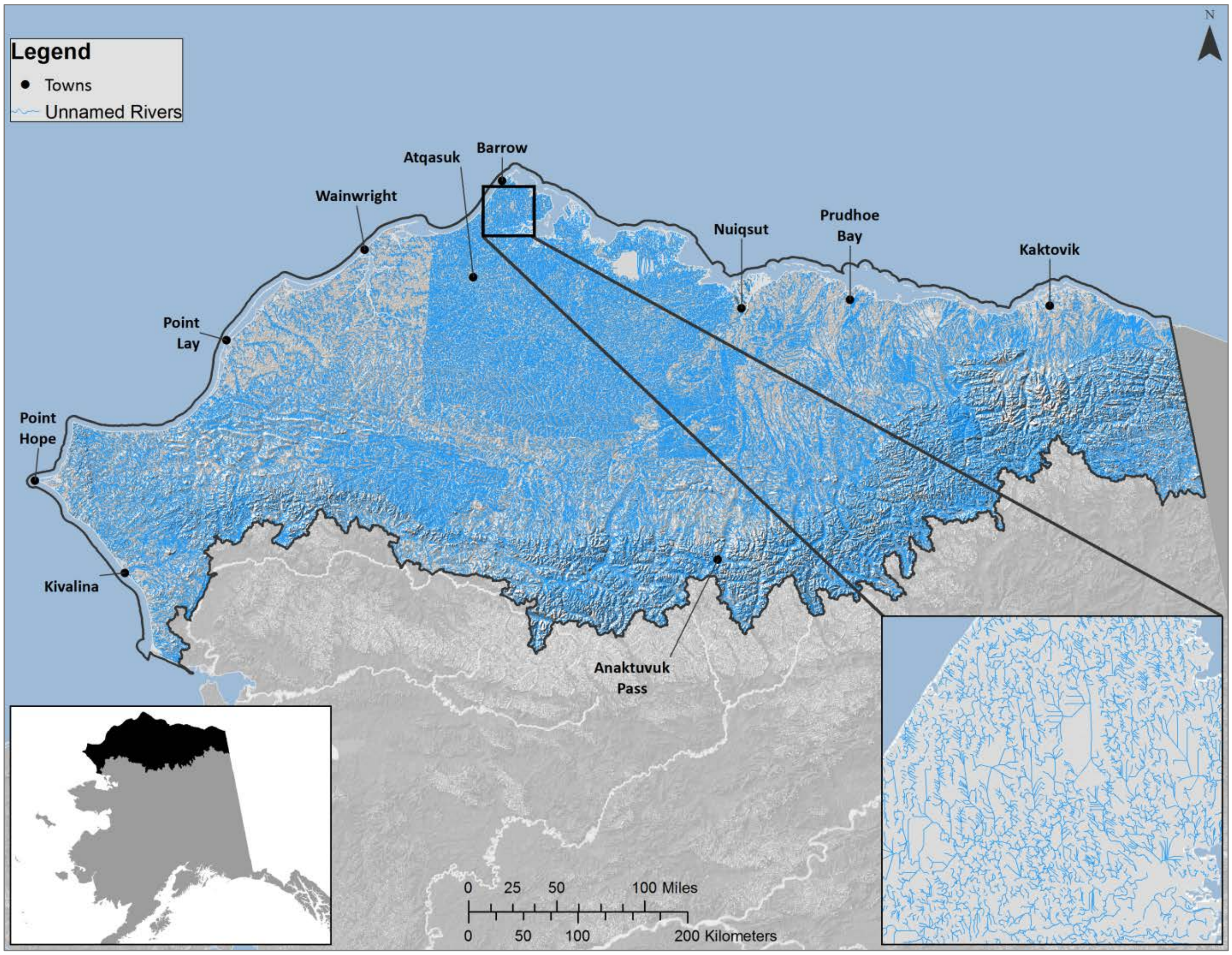

Figure I-2. Distribution of small streams throughout the North Slope study area.

4.1. Conceptual Model

The conceptual models below (Figure I-3 and Figure I-4) are based on a review of the literature and describe the relationship between the various CAs and natural drivers for rivers and small streams. The boxes and arrows represent the state of knowledge about streams and the relationship to each attribute.

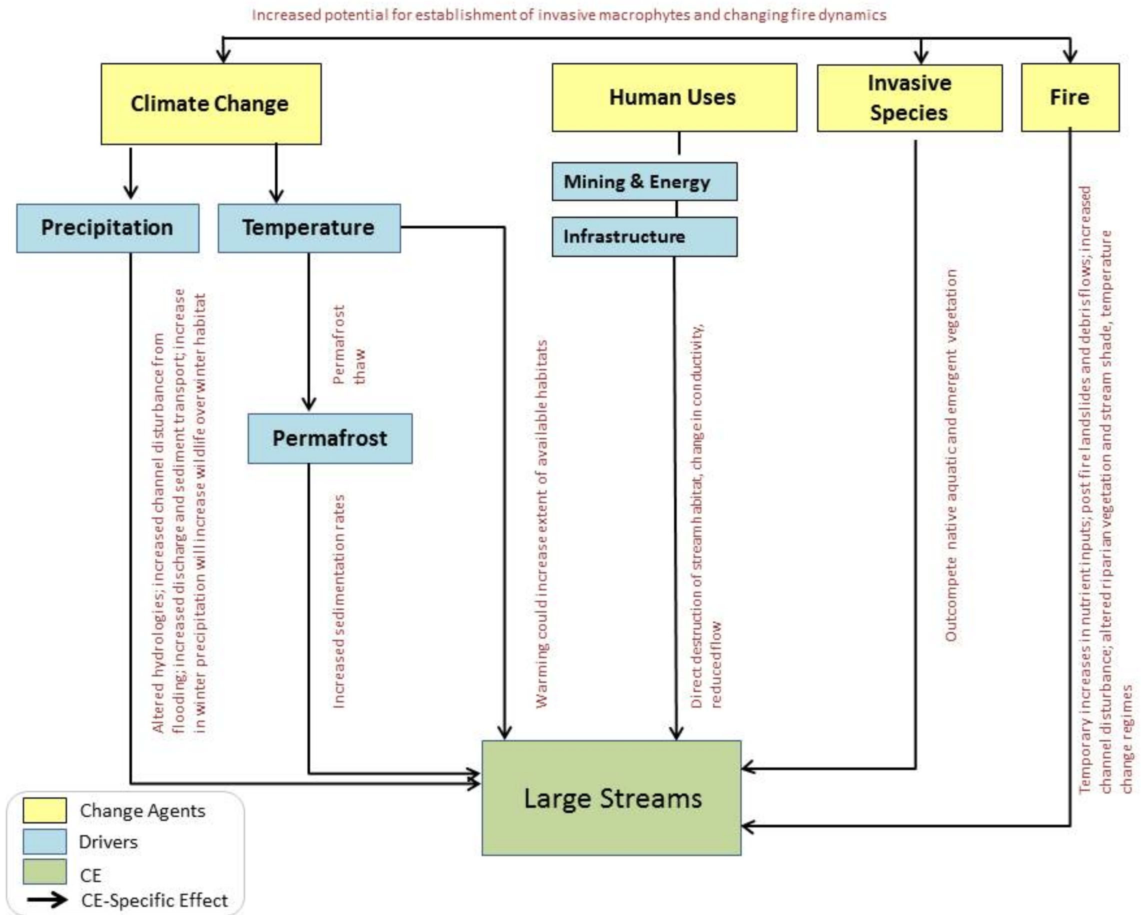

Figure I-3. Principal interactions among population drivers and CAs for large streams, rivers, within the North Slope study area.

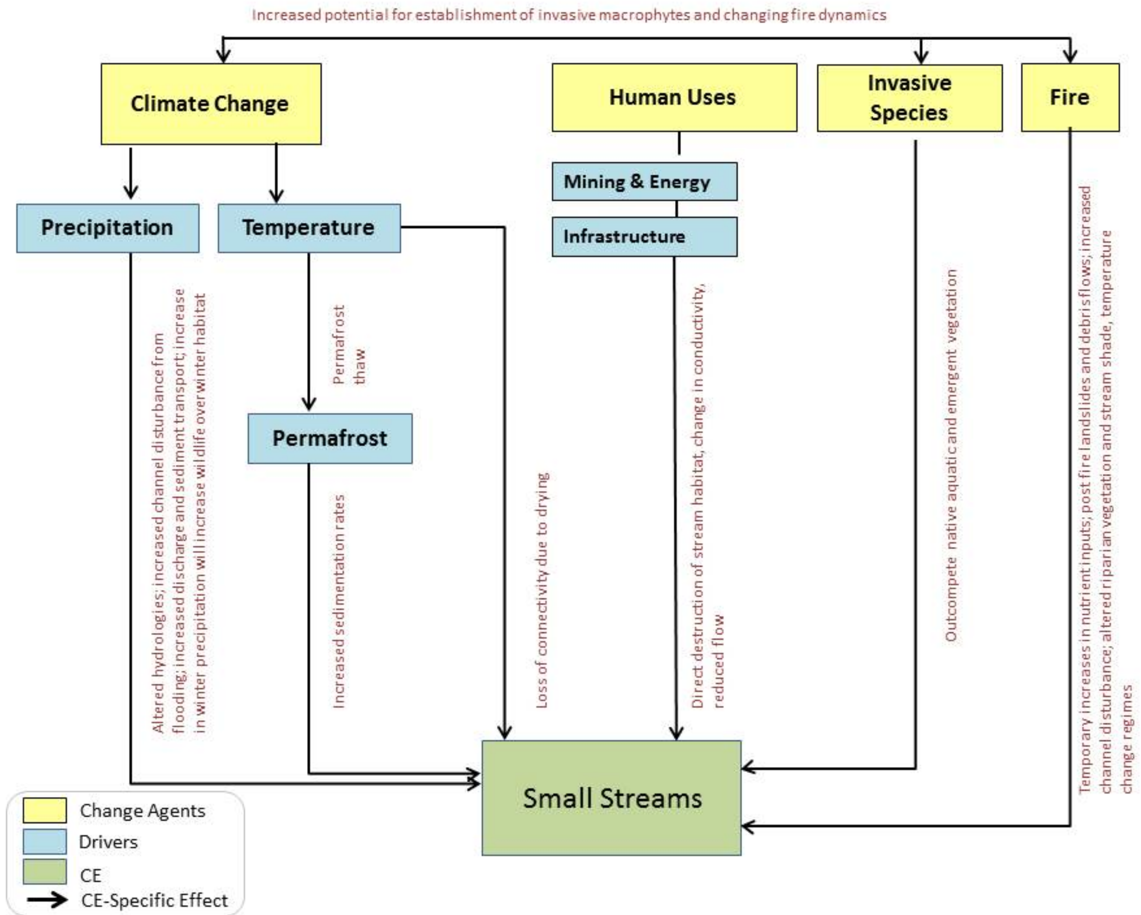

Figure I-4. Principal interactions among population drivers and CAs for small streams within the North Slope study area.

4.2. Attributes and Indicators

Relevant attributes and indicators that can be used to assess the status of the small streams and rivers are: winter precipitation, summer temperature, frost-free days/season length, mean annual ground temperature, fire frequency, contaminated sites, habitat fragmentation, and riparian invasive species (Table I-5).

Table I-5. Attributes and Indicators for small streams and rivers.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	**Fair**	**Good**	**Very Good**
Climate	Winter precipitation[1]	Dec-Feb total precipitation	Habitat	Less precipitation			More precipitation
	Winter precipitation[2]	Dec-Feb total precipitation	Habitat	More precipitation			Less precipitation
	Summer temperature[3]	June-August mean monthly air temperature	Habitat				
	Frost-free days/Season length[4]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Habitat				
Climate	Change in mean annual ground temperature at one meter (MAGT)[5]	Permafrost thaw	Habitat	From below -1m to above +1m			No Change

[1] Specific thresholds are unknown; Increased winter precipitation could increase available overwintering habitat for fish (by increasing the volume of water).
[2] Specific thresholds are unknown; Increased precipitation could result in increased run-off and sedimentation negatively impacting stream habitat.
[3] Specific thresholds are unknown; Low flow periods due to warmer, dryer air temperatures.
[4] Reist et al. 2006; General thresholds; Earlier ice-break up could change timing of processes that affect stream morphology (e.g., channel enlargement and scour of habitat).
[5] GIPL model, Lloyd et al. 2003; Brabets and Walvoord 2009; General thresholds; Changes in groundwater flow and stream discharge.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Fire	Fire frequency[6]	Fire return interval	Habitat	High return interval			Low return interval
	Fire frequency[7]	Fire return interval	Habitat	Low return interval			High return interval
Anthropogenic development	Contaminated sites[8]	Water quality	Habitat				
	Habitat fragmentation[9]	Road development	Habitat	Numerous intersections with streams			No intersection with streams
Invasive species	Riparian invasive species[10]	Out-compete native aquatic species	Habitat				

[6] Davis et al. 2013; Thresholds are general based on this study; Fires strip stabilizing vegetation from the landscape and increase erosion and runoff, resulting in higher sediment inputs to streams.

[7] Davis et al. 2013; Thresholds are general based on this study; Fire increases nutrient inputs.

[8] Thresholds will depend on specific contaminants at a site and proximity to streams; Oil contamination.

[9] Thresholds will depend on specific proximity of fish habitat to a site; Disrupt fish migratory movements; Stranding events.

[10] Specific thresholds are unknown; Small streams with slow moving waters would be most susceptible to invasion of *Elodea* spp.

4.3. Abiotic Change Agent Analysis

Climate

Future precipitation scenarios show a relatively high degree of uncertainty due to the inherent temporal and spatial variability of precipitation (see Section C). However, model results suggest increased summer rainfall and increased winter snowfall. An increase in precipitation during summer could be accompanied by increased flooding, sedimentation, and erosion which could have negative impacts for stream and river ecosystems of this region. Increased precipitation coupled with permafrost thaw may increase groundwater flows, which provide important overwintering habitats for Arctic grayling and Dolly Varden (Reist et al. 2006a).

Increases in summer air temperature will likely lead to increased stream and lake temperatures. Warmer water temperatures may result in range contractions for arctic fishes who are distributed wholly or primarily in northern areas and adapted to relatively colder waters, < 10˚ C (Reist et al. 2006a). Coldwater fishes with wide thermal tolerances (e.g. northern pike) will extend their ranges northward, while the effects of increased temperatures on coldwater species with more narrow thermal tolerances (e.g. lake trout) may be negative (Reist et al. 2006a). Furthermore, the effect of warmer summer temperatures on evaporation and evapotranspiration combined with permafrost thaw will result in lower stream flows (Prowse et al. 2006), which have been shown to negatively affect growth in adult Arctic grayling and positively affect growth in young-of-the-year (Reist et al. 2006b). Fish metabolic demands increase under warmer temperatures and populations that are currently food limited will require increased food resources to maintain current growth rates (Reist et al. 2006b). Increased nutrients from permafrost thaw and a longer ice-free season may result in increased freshwater productivity to match fish growth requirements (Reist et al. 2006b).

Permafrost

Permafrost thaw and thermokarst erosion have been shown to enhance groundwater discharge to streamflow within other parts of Alaska (Brabets and Walvoord 2009). Changes in groundwater flow, especially during spring and winter, could alter the timing and extent of ice cover and alter stream habitats. These changes to stream habitats will likely impact aquatic organisms (e.g., fish migrations) by changing stream velocities, water temperatures, concentrations of suspended sediments, and cause erosion (Prowse 2001). Small streams are especially dependent on perennial stream flow and because of this permafrost thaw and an increase in depth of the active layer could alter stream hydrology, increase channel disturbance from flooding, and increase discharge and sediment transport (Dingman 1973). Fish spawning areas might be especially susceptible to the effects of permafrost thaw as scouring of eggs and destruction of spawning habitat are likely. However, studies within the North Slope have found a link between permafrost thaw and increases in nutrients such as nitrogen and phosphorous which could have positive impacts for aquatic organisms (Reist et al. 2006b, Bowden et al. 2008).

The numbers of ice free days – estimated based on when the mean running water temperature is predicted to cross the 0°C point in the spring and fall -- is expected to change by only 2-3 days in the near-term (2020s). In the long-term (2060s) however, the number of ice free days is expected to increase by anywhere from 10-16 days, depending on sub-region (See Section C: Table C-9). Ice breakup is a major driver of important events that supply riparian habitats with the essential influx of sediment, nutrients, and water. Ice break up is also critical to morphological changes such as channel enlargement, scouring of substrate habitat, and the successional processes of riparian vegetation. The timing of fish movements from winter habitats to summer spawning and foraging habitats are largely dictated by ice break up in the spring. With a projected increase in the number of ice fee days, the timing of fish migrations may occur earlier in the season (Figure I-5). Likewise, fish movements from summer to overwintering habitats may shift to later in the year to correspond with the time that aquatic habitats become ice-free.

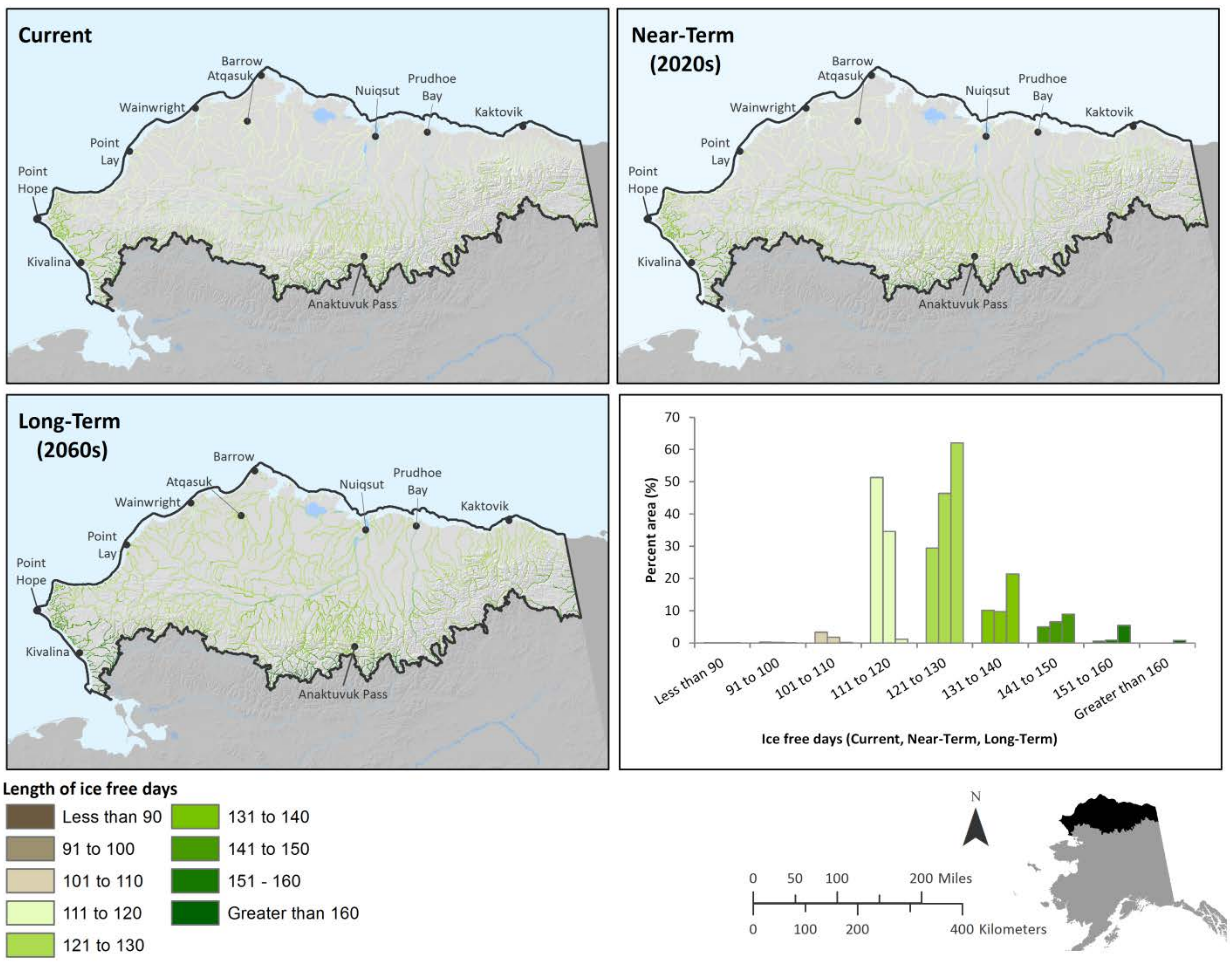

Figure I-5. Length of ice free days at current, near-term future (2020s), and long-term future (2060s) time intervals within the distribution of named rivers in the North Slope study area.

Fire

Changes in wildfire frequency, extent, and severity could have important compounding effects on stream and river ecosystems. Increased wildfire activity could result in warmer stream temperatures, altered stream hydrology, increased landslides, and altered channel disturbances. Additionally, fires that burn across small streams may cause fish mortalities from excessive temperatures, although these effects are often short-term (Hitt 2003). Fires also alter riparian vegetation and stream shade (Pettitt and Naiman 2007), resulting in more chronic thermal effects within streams.

4.4. Invasive Species

Invasive plant species have the potential to outcompete native aquatic and emergent vegetation. However, few invasive plant species have been documented within the study area and no aquatic species have been documented (see Section D. Biotic Change Agents). *Elodea* spp. is an invasive aquatic plant that has recently been documented in southcentral Alaska and Chena Slough, near Fairbanks. *Elodea* spp invade and outcompete other aquatic plant species in slow moving streams or small, shallow lakes and ponds. Thus, small streams with slow moving waters would be most susceptible to invasion of *Elodea* spp., but many other variables such as proximity to roads and transportation hubs are important indicators to the likelihood of *Elodea* spp. colonizing stream habitats within the study area.

4.5. Current Status and Future Landscape Condition

Construction or development along stream margins will likely alter stream and lake connectivity, remove or impair riparian vegetation and function, and increase sedimentation to important aquatic habitats. Similarly, removal of vegetation along streams banks for construction or infrastructure development may alter stream thermal regimes (Moore et al. 2005). These activities could have cascading negative effects on stream resources and aquatic organisms within the study area.

4.6. Applications

The stream and river distribution maps provide managers and researchers with baseline distribution information within the North Slope study area. Because streams and rivers are ubiquitous and abundant throughout the study area it is hard to discern specific stream systems using the map scale provided in Figure I-1 and Figure I-2. However, the original GIS data layers for all maps are available as a final product and will be served on-line. This will allow specific areas of interest to be seen at a finer scale to better evaluate the distribution of these resources.

4.7. Limitations

The lack of an aquatic habitat classification for the study area represents a huge data gap that could be preventing more effective management of aquatic habitat resources. This is especially important given the spatial inaccuracies and limited attribute information in the NHD necessary to map aquatic habitats. Even an updated NHD (e.g., NHD Plus) and an updated digital elevation model with finer resolution (i.e., <60m) would significantly increase our ability to more accurately and reliably map stream locations, calculate stream gradient, and estimate stream flow and velocity. Additionally, information on stream connectivity would greatly enhance our understanding of potential fish migration corridors and provide further information on the importance of stream connectivity in the functioning of downstream waters.

Limited information exists for specific threshold effects of CA attributes and indicators (Table I-5). For example, there currently are no climate change predictions thresholds for specific to aquatic habitats, such as changes to water temperature or hydrologic regime. Water temperature plays a vital role in fish reproduction and survival. Many fish species are sensitive to even slight increases in temperature, thus baseline water temperature data is essential to better understand current conditions and to help managers develop long-term monitoring strategies to understand the potential impacts of future increases in temperature.

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5. Deep and Shallow Lakes

There are thousands of lakes (Figure I-6) within the North Slope study area that range from small shallow (generally <1.6m deep) to large deep lakes such as Teshekpuk Lake. Most lake bottoms are composed of fine substrates throughout the study area though lakes within the Brooks Range are composed more commonly of gravel bottoms. Many lake connections are ephemeral especially during open water season (at break up and through the summer).

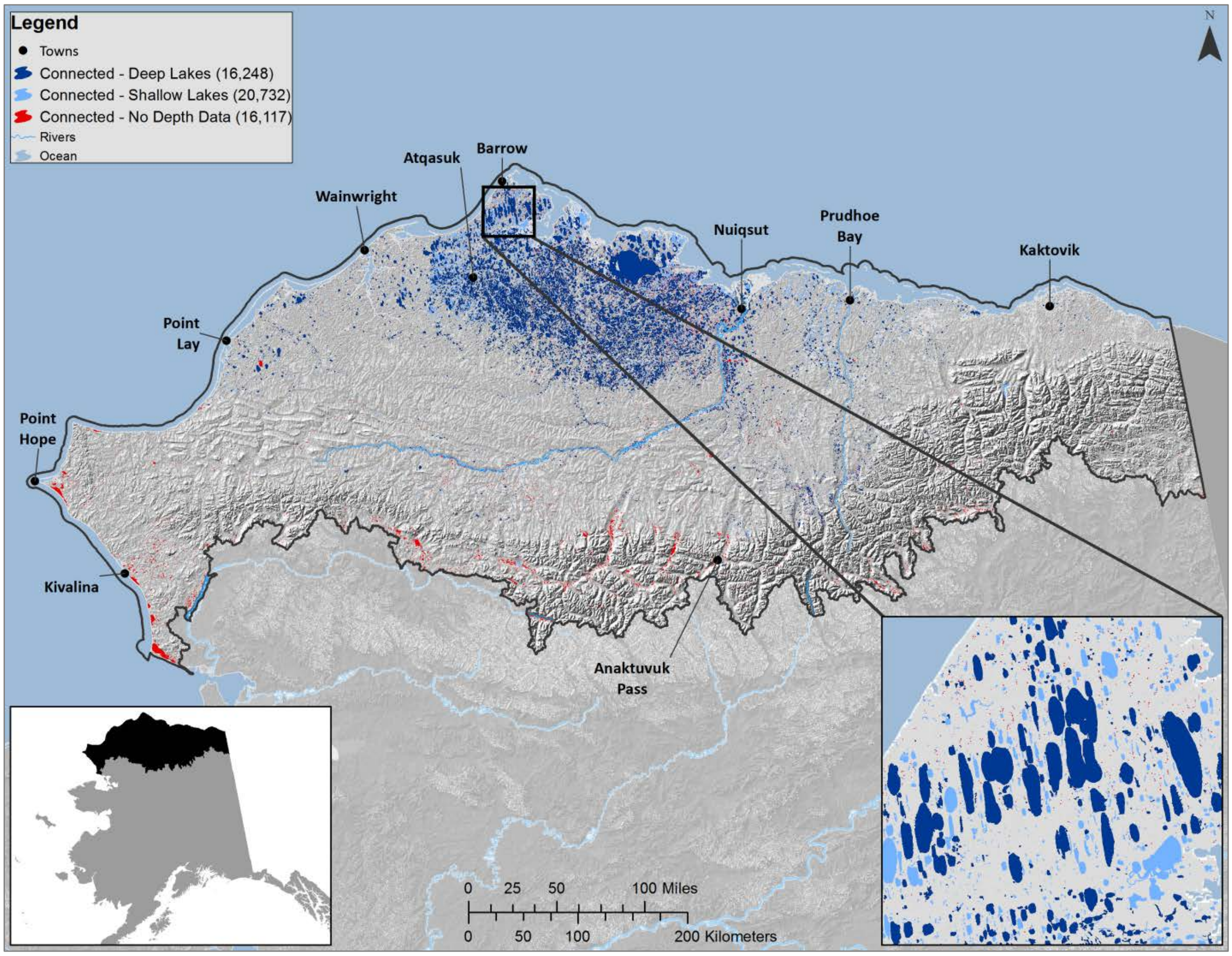

Figure I-6. Distribution of all connected lakes within the North Slope study area.

Deep and shallow connected lakes throughout the study area support a rich biodiversity of aquatic organisms and represent important foraging and breeding habitat for aquatic insects, fish, waterfowl and shorebirds. Additionally, lake ecosystems provide important recreational and personal uses for local residents (e.g., subsistence harvest of fish and wildlife).

5.1. Deep Connected Lakes

Deep connected lakes (Figure I-7) are generally greater than 1.6m depth (Mellor 1982, Jeffries et al. 1996, Grunblatt and Atwood 2013) and characterized by low temperatures, low prey densities, short open water periods, and limited overwintering habitat. Because of their depth and perennial flow, it is less likely that deep connected lakes freeze completely during winter, therefore providing important winter refuge for fish and other aquatic organisms.

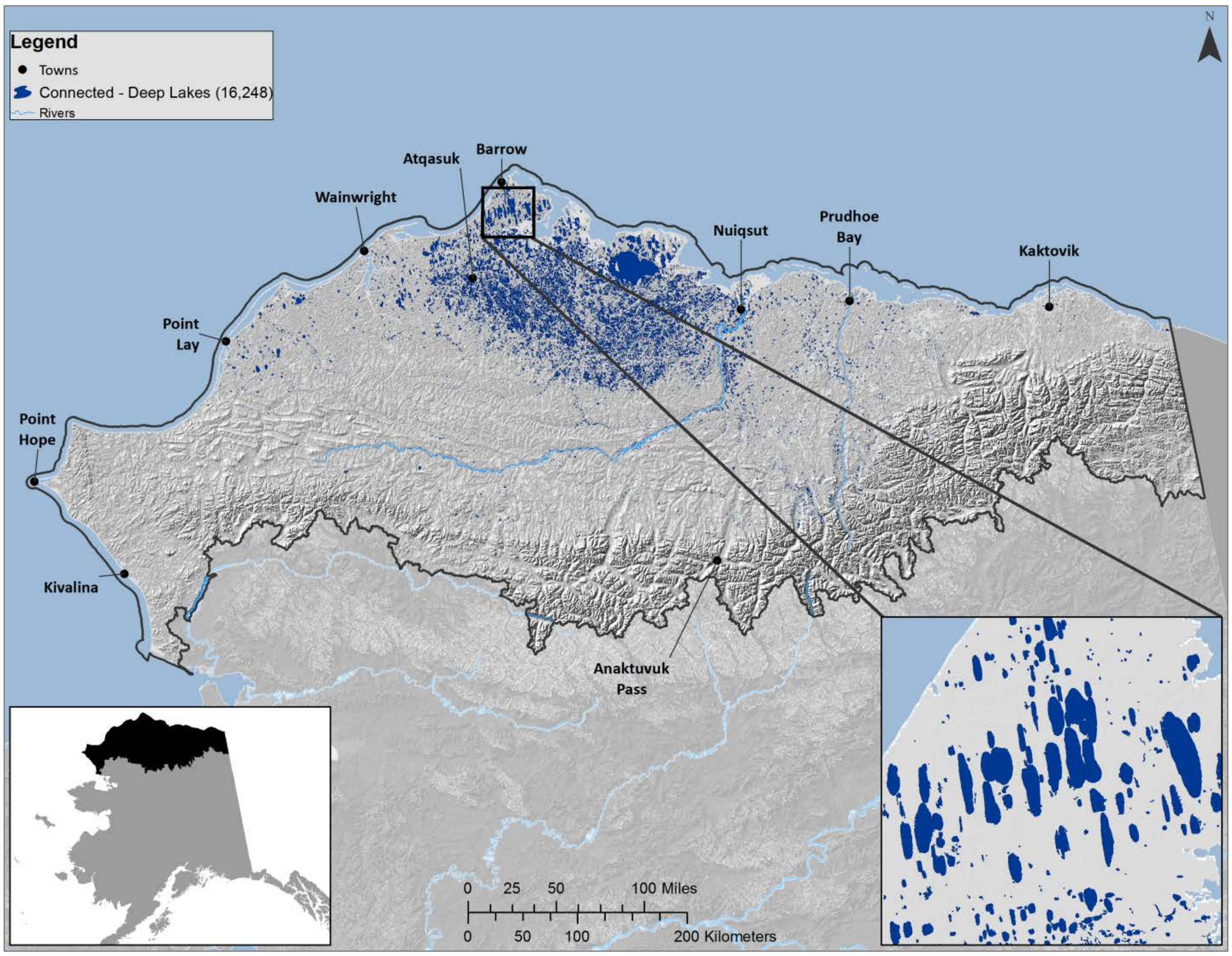

Figure I-7. Distribution of deep (>1.6m depth) lakes within the North Slope study area.

5.2. Shallow Connected Lakes

Shallow lakes (Figure I-8) are ubiquitous in the study area and represent approximately 40% of the landscape (Sellmann et al. 1975, Hinkel et al. 2005). Shallow lakes typically freeze to the bottom and only contain liquid water during the summer months (Kozlenko and Jeffries 2000). Shallow lakes do not provide fish overwintering habitat; however, they are used by fish for foraging habitats during the open water season. Most shallow lakes are dependent on surface runoff for recharge and are subject to substantial evaporative loss during summer (Miller et al. 1980). Lake connections can vary greatly and change throughout the open-water season, with ephemeral connections commonly occurring during high flows in the spring.

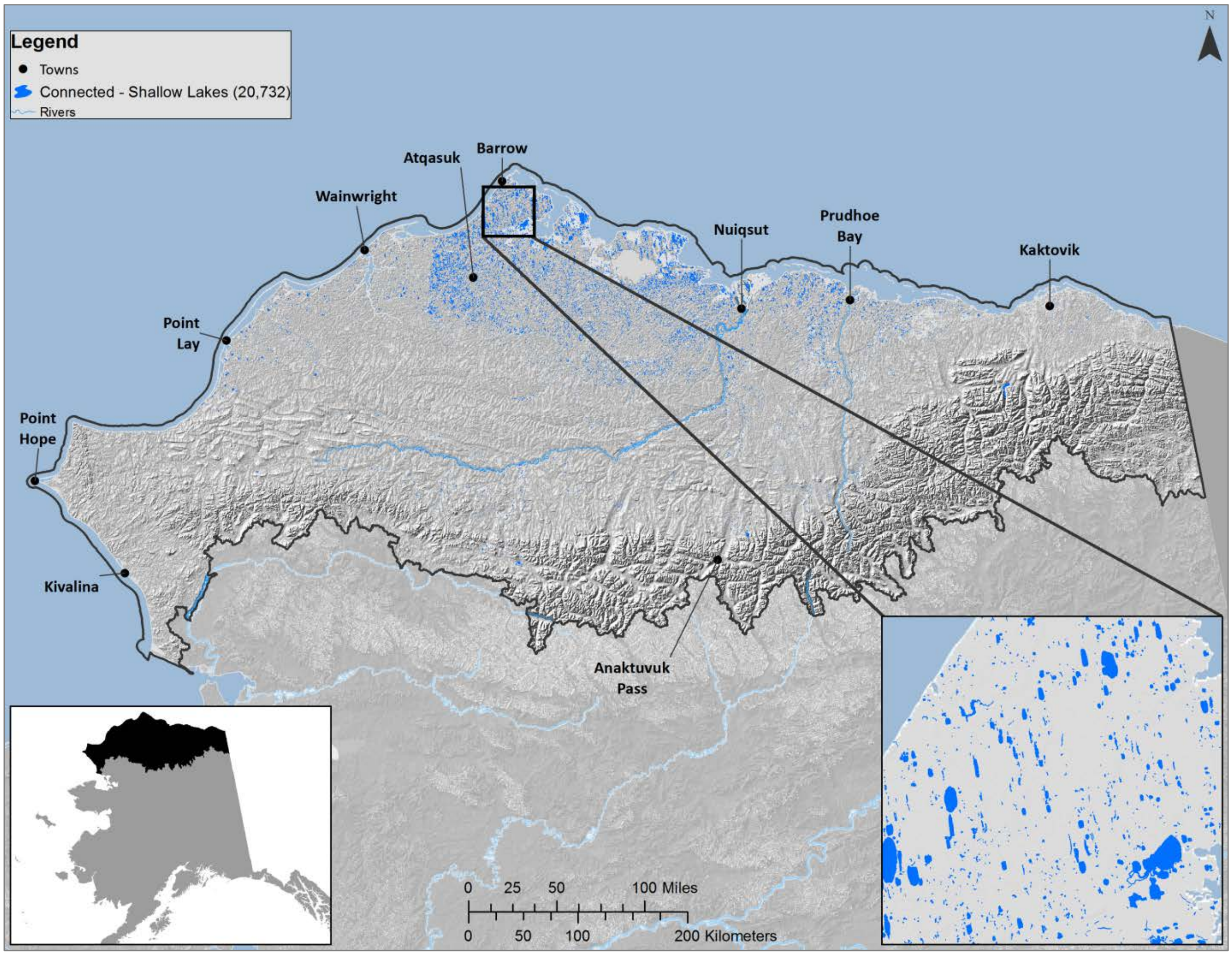

Figure I-8. Distribution of shallow (<1.6m depth) lakes within the North Slope study area.

5.3. Conceptual Model

The conceptual models below (Figure I-9 and Figure I-10) are based on a review of the literature and describe the relationships between the various CAs and natural drivers for deep connected lakes and shallow connected lakes. The boxes and arrows represent the state of knowledge about lakes and the relationship to each attribute.

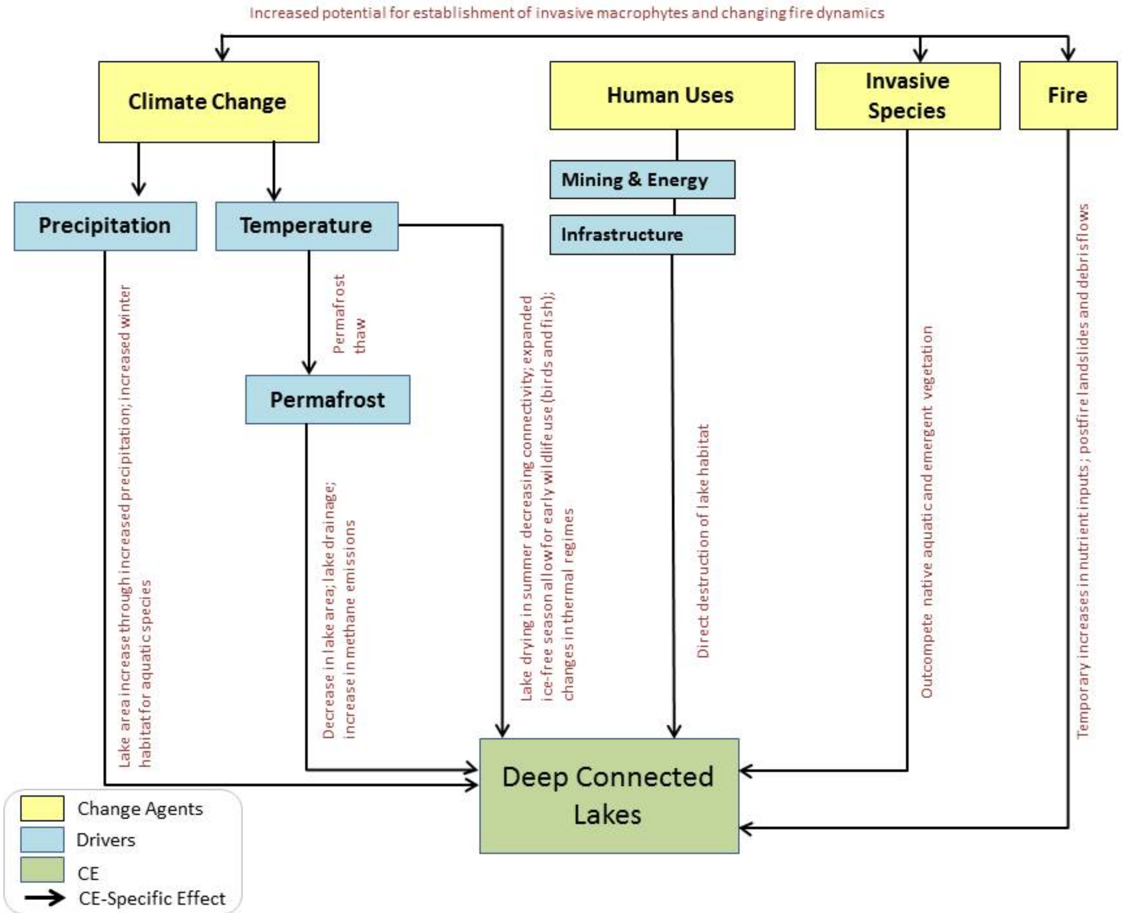

Figure I-9. Principal interactions among population drivers and CAs for deep connected lakes within the North Slope study area.

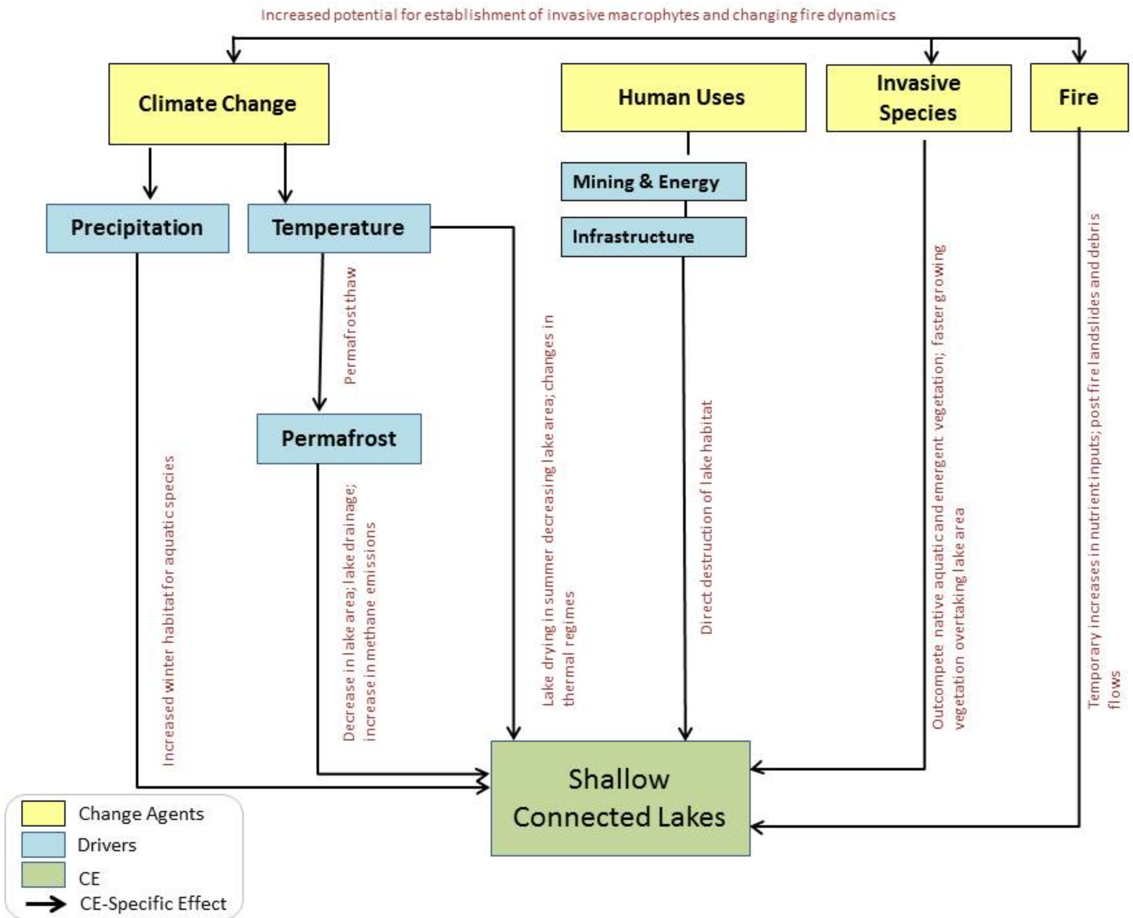

Figure I-10. Principal interactions among population drivers and CAs for shallow connected lakes within the North Slope study area.

5.4. Attributes and Indicators

Spatial data, most of which are available from this assessment, can be used to assess the status of deep and shallow connected lakes and include: winter precipitation, summer temperature, rain on snow events, mean annual ground temperature, fire frequency, contaminated sites, oil and gas activities, and riparian invasive species (Table I-6).

Table I-6. Attributes and Indicators for connected lakes.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[11]	Dec-Feb total precipitation	Habitat	Less precipitation			More precipitation
	Winter precipitation[12]	Dec-Feb total precipitation	Habitat	More precipitation			Less precipitation
	Summer temperature[13]	June-August mean monthly air temperature	Habitat				
	Rain on snow events[14]	Dec-Feb	Habitat	Snow fraction below 80% for more than one winter month	Snow fraction below 80% for one winter month	Snow fraction below 90% for one winter month	Snow fraction over 90% for all winter months
	Change in mean annual ground temperature at one meter (MAGT)[15]	Permafrost thaw	Habitat	From below -1m to above +1m			No Change

[11] Specific thresholds are unknown. Increased winter precipitation could increase available overwintering habitat for fish (by increasing the volume of water).
[12] Specific thresholds are unknown. Increased precipitation could result in increased run-off and sedimentation negatively impacting lake habitat.
[13] Specific thresholds are unknown. Lake drying due to warmer, dryer air temperatures, increased evapotranspiration which could lead to reduced run off.
[14] Based on Hansen et al. 2011;-thresholds are general.
[15] Based on GIPL model, Lloyd et al. 2003; Brabets and Walvoord 2009; thresholds are-general. Changes in groundwater contribution to baseline and seasonal flow.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Fire	Fire frequency[16]	Fire return interval	Habitat	High return interval			Low return interval
	Fire frequency[17]	Fire return interval	Habitat	Low return interval			High return interval
Anthropogenic development	Contaminated sites[18]	Water quality	Habitat				
	Oil and gas activities[19]	Water withdrawal	Habitat	Lakes used by fish			Lakes not used by fish
Invasive species	Riparian invasive species[20]	Out-compete native aquatic species	Habitat				

[16] Based on Davis et al. 2013; thresholds are general. Fires strip stabilizing vegetation from the landscape and increase erosion and runoff, resulting in higher sediment inputs to lakes.

[17] Based on Davis et al. 2013; thresholds are general. Fire increases nutrient inputs.

[18] Thresholds will depend on specific contaminants at a site and proximity to streams. Oil contamination that can alter groundwater interactions and negatively impact habitat for aquatic species.

[19] Based on BLM 2006;-thresholds are general. Effect water quality, reduce spawning habitat for burbot and reduce overwintering and foraging habitat for all other Coarse-Filter CEs.

[20] Specific thresholds are unknown. Shallow connected lakes would be most susceptible to invasion of *Elodea* spp.

5.5. Abiotic Change Agent Analysis

Climate

With warmer air temperatures, lake ice will freeze later and melt sooner, thereby lengthening the ice-free season. Warmer temperatures combined with increased snow cover are expected to have a significant impact on the annual heat budget of arctic lakes (Schindler and Smol 2006). Increased snow cover will insulate lakes and result in thinner ice. Reduced ice cover will create new habitat, especially in lakes that are frozen most of the year. Thinner lake ice will melt faster in spring, which could lead to earlier spring ice breakup and increased water temperature. Earlier ice breakup could result in channel blockage for lakes with connected streams. Changes in the freeze-thaw cycle that affect lake connectivity could alter migration movements of fish species such as broad whitefish that move into deeper connected lakes in the winter and migrate to shallower lakes for feeding and spawning in the summer.

Warmer temperatures coupled with increased evapotranspiration, especially later in the summer and early fall, could cause a drying effect and potentially decrease connectivity between streams and lakes. A lack of connectivity between inlet and outlet streams would limit access to important spawning areas, affect the amount of available overwintering habitat, and potentially disrupt the timing of annual migrations for fish species. However, the impact of temperature and evapotranspiration on loss of lake connectivity is influenced by other factors including overall lake size and lake depth.

Drier and warmer summer temperatures could reduce lake recharge because more water would be absorbed into soil. Snow melt during the spring is the primary source of water and nutrient recharge to both deep and shallow connected lakes in the study area. With increased temperatures, additional snow melt in lakes within areas that have thicker permafrost could result in increased lake area. These changes however, would be temporary if temperatures continue to rise.

Although specific effects of climate change on water temperature are not clear, the warming trend will likely result in both positive and negative impacts on aquatic biota and lake habitats. Increased water temperatures (Figure I-11) could increase primary productivity which could in turn improve the quality of fish feeding habitat by changing the abundance of prey species (Reist et al. 2006b). Water temperature is also critical in determining timing of different life history stages of fish. For instance, increased water temperatures could decrease the amount of time required for egg development and fish rearing and overall fish age at maturity. Increased temperatures within lake habitats could also impact timing of fish migrations, prevalence of disease, and long-term survival of fish, especially more cold-tolerant species such as Arctic grayling and burbot.

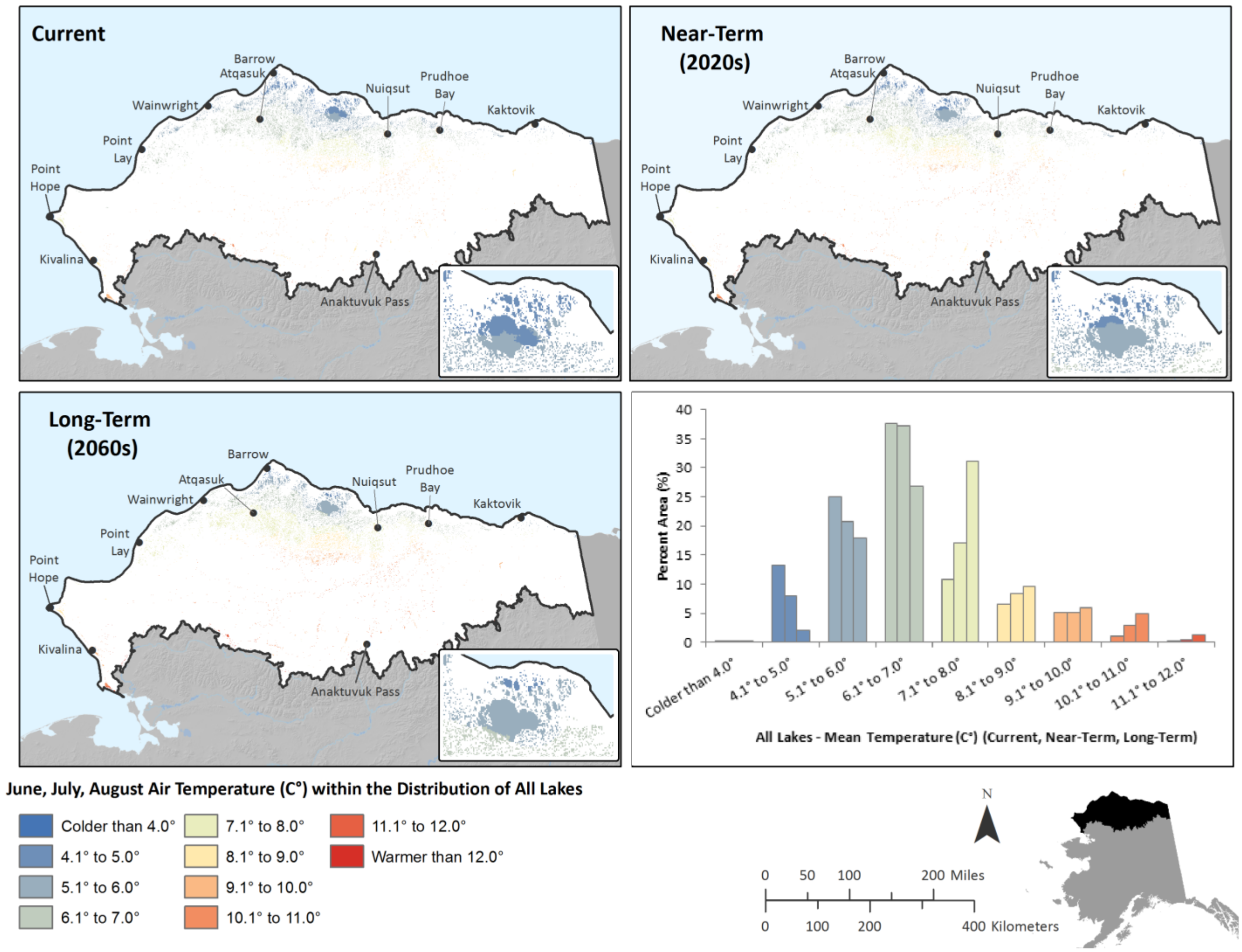

Figure I-11. Distribution of lakes and modeled increase in July temperature change from 2010 - 2060 within the North Slope study area.

Permafrost

Loss of permafrost, particularly when coupled with thermokarst-prone conditions and increased evaporation, increases the potential for lakes to shrink or dry out (especially shallow lakes) in the study area (Roach et al. 2013). Thawing of permafrost has also been linked to increases in substrate permeability and increased drainage for all lakes (Roach et al. 2013). New drainage networks could form if surrounding ice wedges degrade. However, other studies have documented an increase in lake area as a consequence of increased snow melt and more erosion due to permafrost thaw (Jones et al. 2011, Plug and West 2009, and Turner et al. 2014). Thus, lakes may drain entirely with permafrost melting, or lake levels may rise with increased inflow. Lastly, thawing permafrost could temporarily increase nutrient loading to lakes and increase primary productivity (Hobbie et al. 1995). This would benefit numerous fish and wildlife species that forage in these lakes. In addition to direct effects on lake habits, thawing permafrost along lake margins could increase the amount of methane released from lakes to the atmosphere (Walter et al. 2007).

Overlaying lake distribution and thermokarst predisposition (as defined by soil type, ice richness, and topographic variables) yields a complex picture of possible hydrologic change (Figure I-12). Most of the area with the greatest potential for thermokarst has permafrost with a mean annual ground temperature colder than -6.0°C. This suggests total thaw and collapse would be unlikely in either the near or long term. Although the interior of the Coastal Plain has cold and stable permafrost, lakes in this thermokarst-prone area suggests new drainage patterns are likely to emerge with small shifts in Active Layer Thickness (ALT). Thermokarst slumping is most likely to occur at a micro rather than macro scale, with localized drying of better-drained areas, and perhaps wetter conditions in others. Around the edges of lakes, loss of frozen soil may lead to slumping. However, potential thermokarst risk is low in areas near Point Hope and Kivalina where the mean annual group temperature is already increasing (suggesting continued permafrost loss) suggesting little risk of hydrologic change due to thermokarsts in those areas.

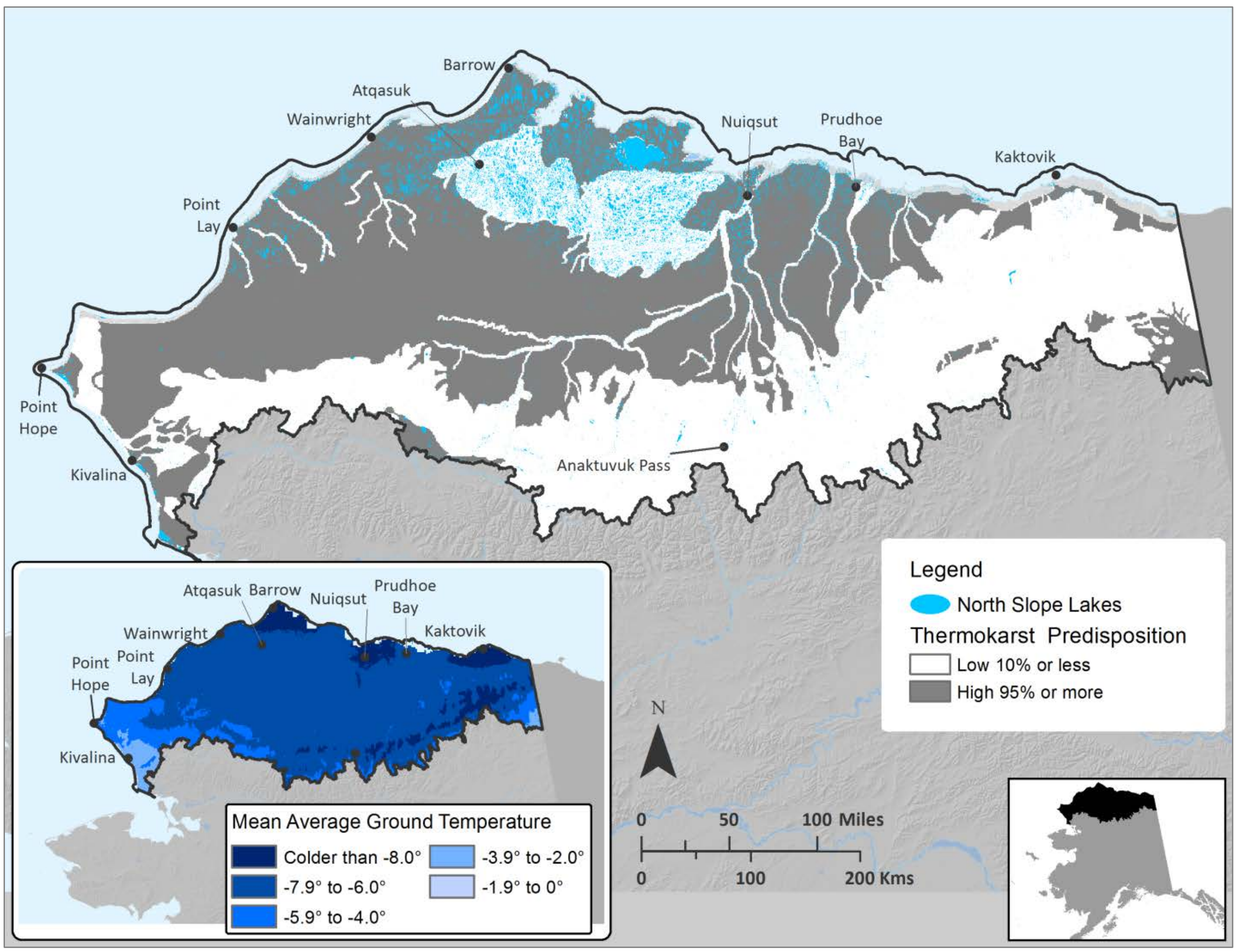

Figure I-12. Relationship between the current distribution of lakes and thermokarst potential.

Fire

Increased wildfire activity could result in increased landslides and debris flows along lake edges and shorelines. Increases in nutrient inputs could temporarily benefit aquatic organisms (e.g., juvenile fish and aquatic insects).

5.6. Invasive Species

Invasive plant species have the potential to outcompete native aquatic and emergent vegetation. However, few invasive plant species have been documented within the study area and no invasive aquatic species have yet been documented in the region (See Section D). *Elodea* spp. is an invasive aquatic plant that has recently been documented in south central Alaska and Chena Slough, near Fairbanks. *Elodea* spp. generally invade and outcompete other aquatic plant species in slow moving streams or small, shallow lakes and ponds. Thus, shallow connected lakes may be more susceptible to potential *Elodea* spp. invasions than deep connected lakes.

5.7. Current Status and Future Landscape Condition

Construction or development, especially oil and gas operations near deep connected lakes could increase sedimentation to lakes. Run-off from unpaved roads can result in sedimentation to lakes increasing turbidity and impacting water quality for aquatic organisms and human use. Oil and gas activities near streams that are connected to lake systems could also have negative impacts on the water quality of connected lakes. Changes in water quantity caused by withdrawals during exploration are typically from deep lakes during winter, while water withdrawals during operations and for domestic uses would also occur during the open-water season. Winter withdrawal from lakes for the creation of roads and other infrastructure has the potential to negatively impact overwintering fish populations by disrupting connectivity to other waterbodies and/or reducing lake area. Increased development, especially the construction of new roads can also facilitate the dispersal of invasive species into lakes. Increased road access for communities may increase fishing pressure and possibly negatively impact water quality of lakes.

Different from other REAs in Alaska, we worked closely with the NSSI Scenarios project to incorporate future human footprint estimates from their scenario exercises (see Section E). Instead of near and long-term futures, we use the “Medium” and “High” oil and gas scenarios generated as part of that effort. Due to the limited scope of the scenarios project, and the anticipated lack of population change in the villages, our future human footprint is largely driven by changes in oil and gas infrastructure. Future oil and gas infrastructure associated with the Medium Scenario develops part of the Greater Moose’s Tooth region of NPR-A, and further expands the development currently at Point Thompson. The Liberty drilling pads are expanded, and there is a new pipeline built connecting offshore activities to the Point Thompson region in the Medium Scenario as well. Additionally, we included the road and relocation of Kivalina in the Medium Scenario. The High Scenario included all the same development of the Medium Scenario, but expanded the Greater Moose’s Tooth development to include a pipeline connecting development on Smith Bay, develops a pipeline and road from the potential Chukchi Sea facilities, and develops a pipeline connecting Umiat to other oil and gas infrastructure. Although offshore activities are included in the NSSI scenarios, we did not include those developments given our terrestrial focus. 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 Scenario, the results should be considered representative of potential changes to overall landscape condition. Shallow, deep, and all lakes status under the current, medium and high development show similar results (Table I-7, Figure I-13, Figure I-14,and Figure I-15), that is, the condition is quite high. However, it is important to note that although shallow lakes are considered to have very high condition in general they differ by almost 10% between the shallow and deep lakes for the high development scenario and are potentially more at risk by development than the deep lakes (89.6% and 97.4% respectively).

Table I-7. Landscape condition displayed as percent total area within the distribution of shallow, deep, and all lakes.

Aquatic Coarse-Filter CE		**Landscape Condition (% Area)**				
		Very Low	**Low**	**Medium**	**High**	**Very High**
All Lakes	Current	0.31	0.78	0.98	1.19	96.74
	Medium Scenario	0.31	0.79	1.01	1.23	96.66
	High Scenario	0.31	0.98	1.28	1.54	95.89
Shallow Lakes	Current	0.77	2.30	3.09	3.13	90.71
	Medium Scenario	0.77	2.31	3.16	3.20	90.56
	High Scenario	0.77	2.60	3.45	3.50	89.68
Deep Lakes	Current	0.20	0.40	0.45	0.69	98.26
	Medium Scenario	0.20	0.40	0.47	0.72	98.21
	High Scenario	0.20	0.58	0.75	1.04	97.43

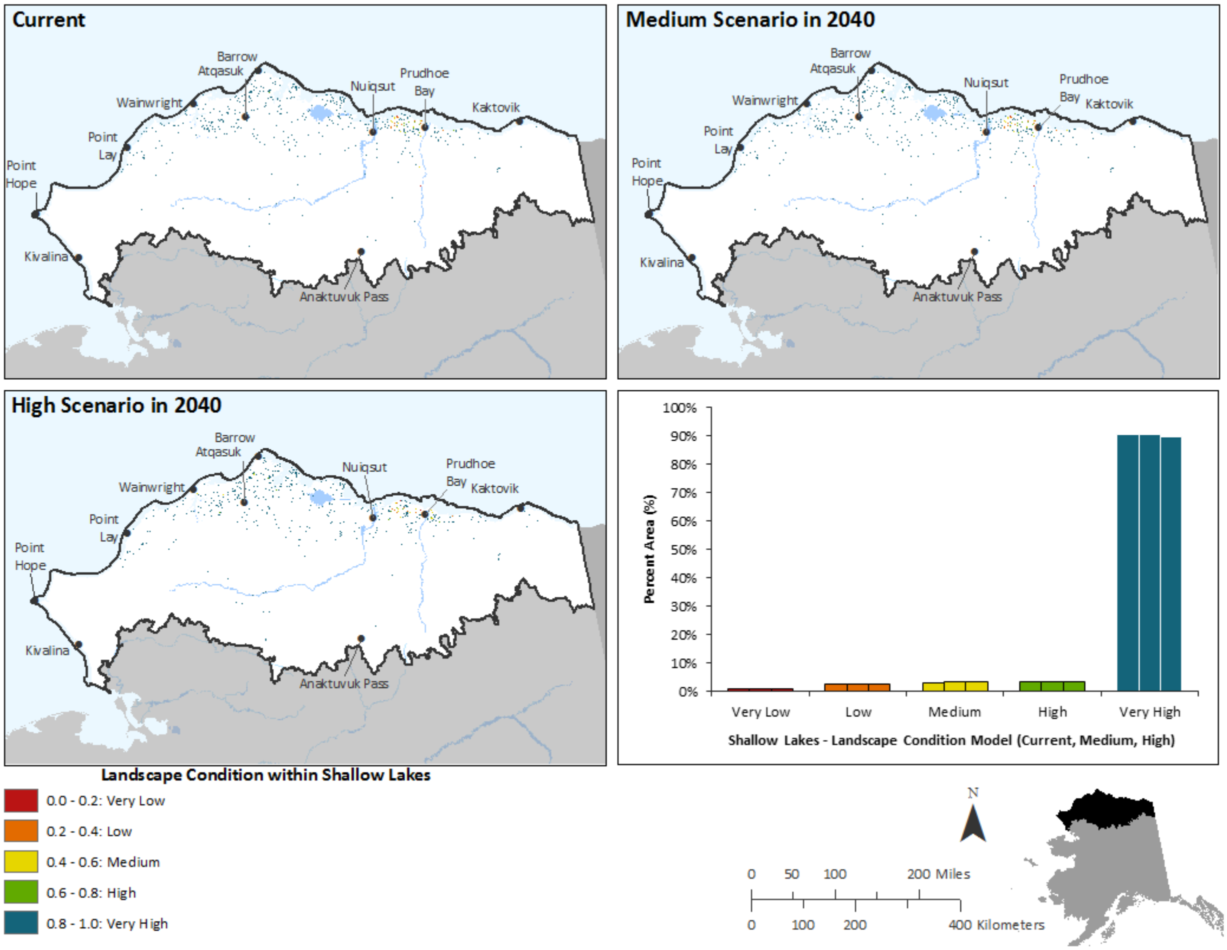

Figure I-13. Current, medium scenario (2040), and high scenario (2040) future landscape condition (summarized at the 5th level HUC) within current shallow lakes habitat in the North Slope study area.

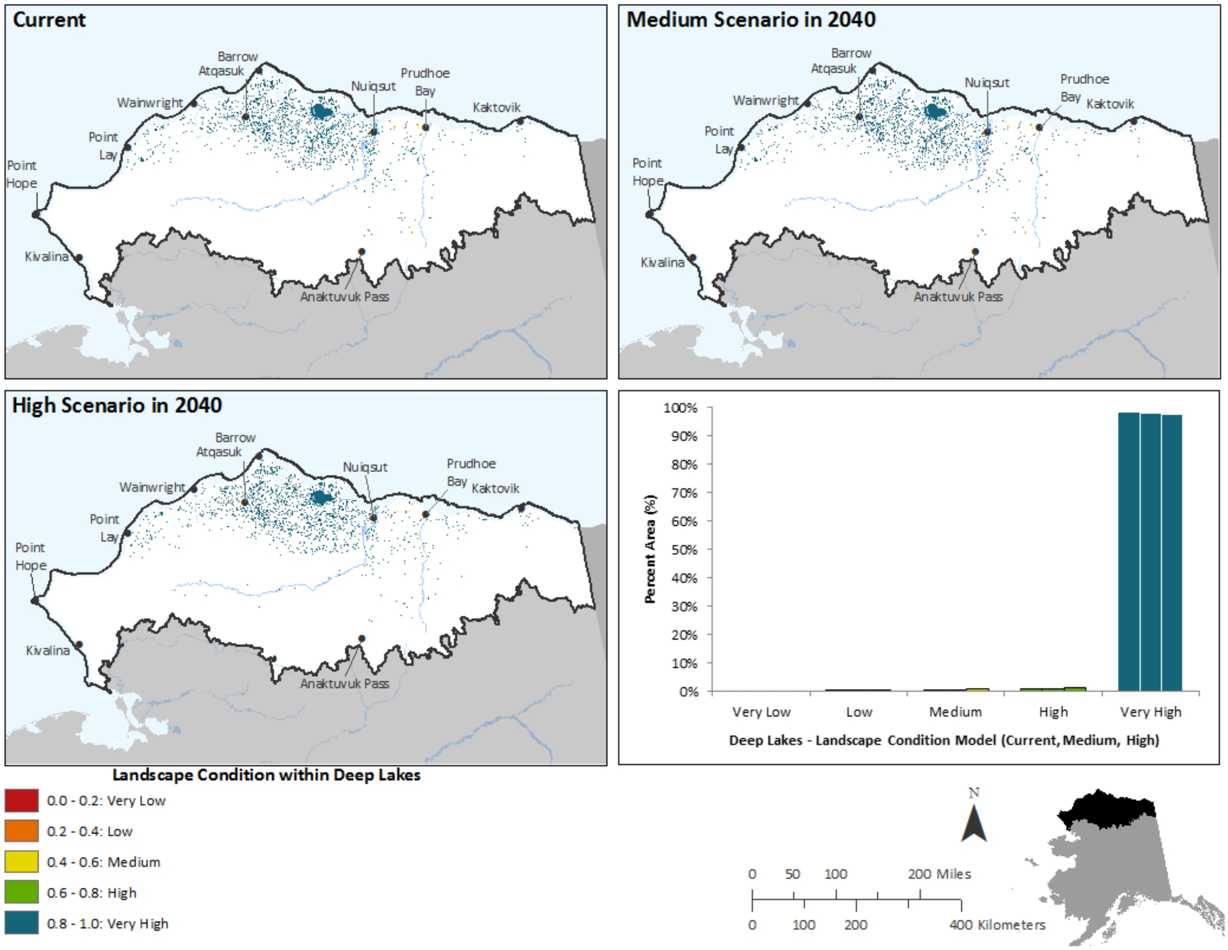

Figure I-14. Current, medium scenario (2040), and high scenario (2040) future landscape condition (summarized at the 5th level HUC) within current deep lakes habitat in the North Slope study area.

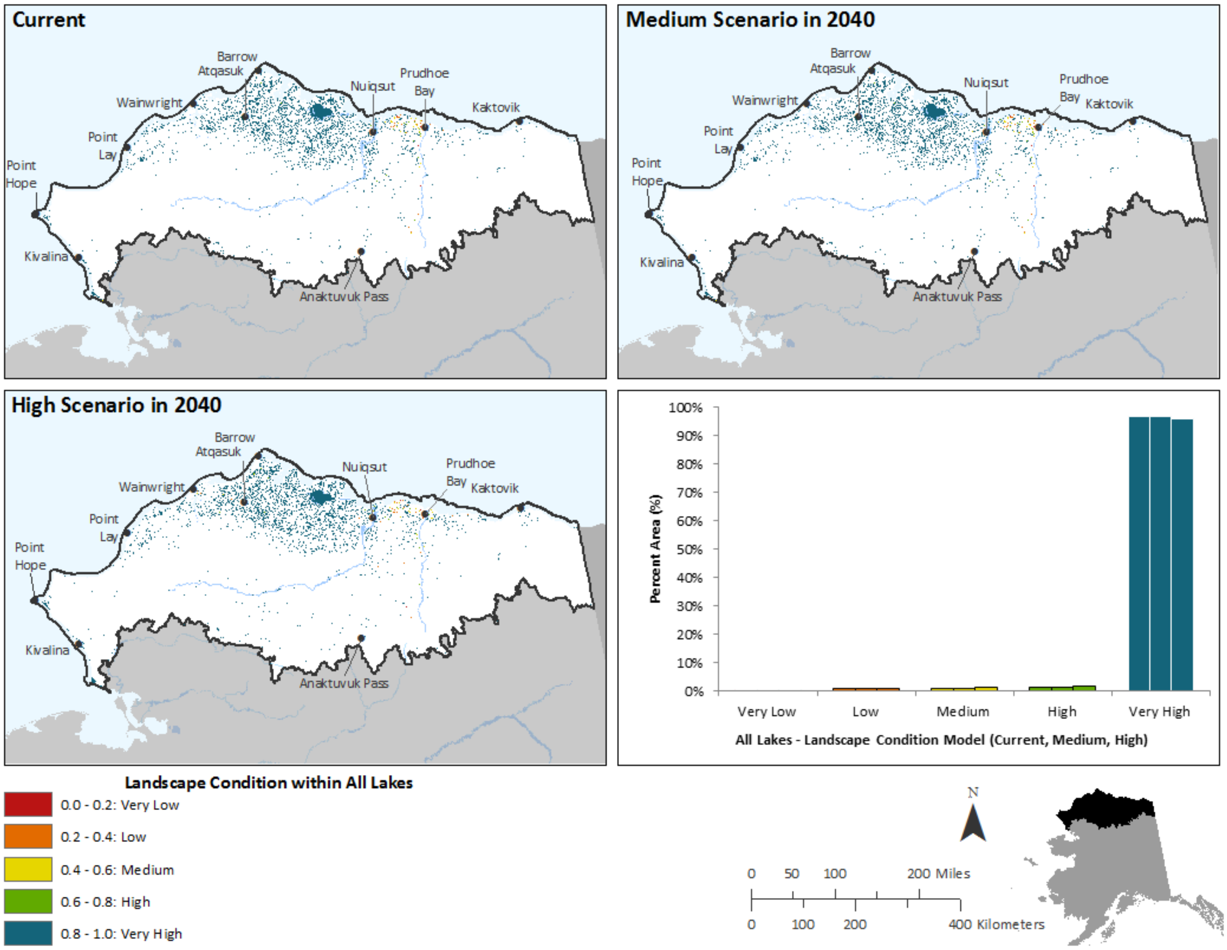

Figure I-15. Current, medium scenario (2040), and high scenario (2040) future landscape condition (summarized at the 5th level HUC) within current distribution of all lakes in the North Slope study area.

5.8. Applications

Lake distribution maps provide baseline information within the North Slope study area. Because lakes are abundant throughout the study area it is hard to discern specific lakes using the map scale provided (Figure I-6). However, the original GIS data layers for all maps are available as a final product and will be served on-line. This will allow specific areas of interest to be seen at a finer scale to better evaluate the distribution of these resources.

5.9. Limitations

The lack of an aquatic habitat classification for the study area represents a huge data gap that could be preventing more effective management of aquatic habitat resources. This is especially important given the spatial inaccuracies and limited attribute information in the NHD necessary to map aquatic habitats. The NHD is outdated (most topographic maps were created in the 50's and 60's) and lake areas have likely changed due to natural hydrologic disturbances and climate change. Limited information also exists for specific threshold effects of CA attributes and indicators Table I-5). For example, there currently are no climate change predictions thresholds for specific to aquatic habitats, such as changes to water temperature or hydrologic regime.

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6. Water Withdrawal from Lakes

MQ AC 1	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 habitat?

6.1. Introduction

Lakes within the North Slope study area are an important resource that support year-round oil and gas activities. Water withdrawal activities related to winter operations (e.g., building ice roads) usually takes place beginning in December or January, or when the tundra is sufficiently frozen (Hinzman et al. 2006). Year-round water withdrawals supply drilling operations, support camps, and facilities by providing potable water and dust control. Possible effects of water withdrawal include impacts to water quantity, quality, and direct impacts to aquatic biota.

We were not able to answer this question with spatial datasets due to the lack of available geospatial lake data. Data on lakes used for water withdrawal are available, as Meridian, Township and Range (MTRS) location references, but these data have not been provided with individual latitude and longitude locations. Moreover, this coarse location data is recorded for each permit in their respective permit, not in a central database available for this project. It was beyond the scope of this project to get these data entered into a digitally available format. Thus, we have identified this MQ as a **data gap**. Below we provide an overview of the potential affects that water withdrawal may have on aquatic habitats within the North Slope study area.

6.2. Water quantity

Lakes that do not freeze to the bottom in winter are an important source of water for ice road construction. Shallow lakes can also be used during the non-winter months for water withdrawal purposes. Ice roads are the main form of transportation in the winter and essential to oil and gas industrial activities. Lakes that do not freeze to the bottom provide critical habitat for overwintering fish and water withdrawals from these lakes could negatively impact fish populations. The BLM has developed requirements regarding the amount of water removed depending on lake characteristics, including depth and fish species present (NPRA Final Integrated Activity Plan/Environmental Impact Statement 2012). For example, lakes deeper than seven feet that contain sensitive fish species can only have 15% of the volume of water under the ice removed. Lakes between five and seven feet deep that have sensitive species will be considered on a case-by-case basis. Lakes that are greater than five feet deep with non-sensitive fish (ninespine stickleback and/or Alaska blackfish) can have up to 30% of the calculated volume of water removed. If there are no fish present in a lake, withdrawal cannot exceed 35% of the total volume of any lake.

Water withdrawals may have short- and long-term impacts on water quantity. For example, in the short-term winter water withdrawals can impact overwinter survival of fish populations by reducing the overall volume of water. In the long-term (2060), reduced water levels could affect invertebrates, aquatic vegetation, and waterfowl that rely on these lakes for nesting and feeding habitats. Additionally, longer-term effects of lake drawdown may impede the ability of fish to return to the same lake in subsequent years.

One of the biggest concerns with water withdrawal from lakes is that the lake might not receive sufficient water recharge during spring snow melt. However, studies focused on recharge of water withdrawal lakes found that spring snowmelt provided sufficient water to recharge lakes (Baker 2002, Miller 2005, Hinzman et al. 2006). Thus, current guidelines for water withdrawal may be protective enough such that water quantity of lakes, at least for winter water withdrawals are sufficient. However, further study at a broader scale is warranted to determine if this pattern is consistent across both deep and shallow lakes within the study area.

6.3. Water quality

Changes to water quality as a result of water withdrawal could include changes in temperature, dissolved oxygen, and other water quality variables (e.g., pH, turbidity, alkalinity, etc.). In particular, fish are sensitive to low oxygen concentrations and reduced water volume in lakes may lead to increased depletion of oxygen, especially during the winter. Numerous studies have measured the effects of water withdrawal on water quality and the majority of these studies found no difference between lakes used for water withdrawal and reference lakes (Miller 2005, Hinzman 2006, Baker 2002, Cott et al. 2008). Instead, lake variation (e.g., lake size, lake depth, physiochemical properties) and not water-withdrawal activities were the most important predictors of water quality changes (Cott et al. 2008, Baker 2002, Chambers et al. 2008).

Similarly, Miller (2005) and Hinzman (2006) found no difference between temperature changes and other water quality variables in lakes that were used for water withdrawal and control lakes. For example, dissolved oxygen levels in lakes were good throughout winter months regardless of water withdrawal (Miller 2005). Pumping from shallow lakes during the open-water season has not been studied as extensively as deep lakes in winter, but it’s likely to have a greater effect on water quality than pumping a comparable volume from deeper lakes.

Water withdrawals also have the potential to cause erosion and siltation which could increase turbidity and suspended solid concentrations in both lakes and streams. In addition, activities related to water withdrawal have the potential to affect surface water quality through accidental spills of fuel or lubricants.

6.4. Outflow/stream connectivity and down basin habitat

Understanding risks associated with water withdrawal on stream connectivity and down basin habitat is not well known. Withdrawal from lakes during the open-water season may alter stream connectivity to lakes. If water volume is reduced enough to affect outflow stream connectivity this could have impacts on fish migration corridors. As a result, fish may become stranded in disconnected habitats and unable to access preferred habitats for feeding or spawning, or return to preferred overwintering habitats. Water withdrawal could also affect the timing of stream flow, altering the velocity of streams and impacting both insect and fish populations (Spence et al. 1996). Because glacial systems are characterized by low flow in winter, stream connectivity may be especially vulnerable to impacts of water withdrawals in winter. However, most water withdrawal activities occur north of the Brooks Range where glacial habitats are more common.

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J. Aquatic Fine-Filter Conservation Elements

Leah Kenney

Alaska Natural Heritage Program, University of Alaska Anchorage, 3211 Providence Drive, Anchorage, Alaska 99508

Summary

Section J. *Aquatic Fine-Filter Conservation Elements* provides the detailed descriptions, conceptual models, and limitations for the assessments of five fish species considered to be of high ecological importance in the region.

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1. Summary of Aquatic Species (Fine-Filter Conservation Elements)

Five regionally important fish species were selected as Aquatic Fine-Filter Conservation Elements (CEs) to represent the variety of fish species of conservation concern and/or subsistence importance within the North Slope study area (Table J-1). For the purposes of the REA, chum salmon were selected as representatives of salmonids, and broad whitefish are treated as representative of whitefish species. Burbot represent a top-level predator with the potential for significant bioaccumulation of toxins. Dolly Varden are included to encompass higher elevation and steeper gradient stream habitats, as well as both anadromous and freshwater life history.

We identified the Fine-Filter CEs as a **data gap** during the data discovery phase of this project. Similar to previous REAs in Alaska (Seward Peninsula and Yukon-Kuskokwim REAs), aquatics data related to both Coarse-Filters CEs and Fine-Filters CEs have been very limited and have largely been identified as data gaps. The Fine-Filter CEs for the North Slope study area are especially data limited to the point that we were not able to accurately produce distribution models or maps for any of our Fine-Filter CEs.

Occurrence data do exist for these Fine-Filter CEs within the North Slope study area, however most of these data are presently available only in non-digitized format (e.g., hardcopies, inventory reports, unpublished data, etc.). Due to the lack of spatial data available, we collaborated with BLM Fisheries Biologists to assist with their efforts to enter these fish distribution datasets into the geodatabase RipFish that was developed and is maintained by BLM. Our contribution to this database serves as a final product for the Aquatic Fine-Filter CEs and will allow managers to readily have access to fish distribution data and conduct future spatial analyses. This database will further facilitate effective management decisions related to fish distributions and the potential effects that development and climate change may have on CEs in the North Slope study area.

Table J-1. Aquatic Fine-Filter Conservation Elements selected for the North Slope REA.

Aquatic Fine-Filter CEs	Ecological Importance
Arctic grayling (*Thymallus arcticus*)	Arctic grayling are resident fish distributed throughout the stream network and in lake habitats across the North Slope study area.
chum salmon (Oncorhynchus keta)	Chum salmon are representative of anadromous fish, and provide nutrient inputs to both aquatic and terrestrial ecosystems, providing a food resource for large predators and humans.
burbot (*lota lota*)	Burbot are long-lived resident fish that are mostly found in deep lakes. They eat other fish, making them susceptible to bioaccumulation of contaminants and potential indicators of change in the arctic. Burbot are used in localized subsistence fisheries.
broad whitefish (*Coregonus nasus)*	Broad whitefish are an important subsistence species for communities within the North Slope study area. In addition, they exhibit both anadromous and resident forms and utilize a diversity of lake and river habitats on the coastal plain for overwintering, rearing, and spawning.
Dolly Varden (Salvelinus malma)	Dolly Varden are utilized heavily by residents of Kaktovik and Kivalina and are well distributed throughout the stream network, especially in the eastern coastal plain and in the Brooks Range and Foothills ecoregions. They are both anadromous and freshwater resident within the North Slope study area.

1.1. Management Questions (MQs)

There were two management questions specific to Aquatic Fine-Filter CEs. The first MQ was focused on identifying baseline characteristics and trends in fish habitat, distribution, and movements (MQ AF 1). The second MQ related to the potential impacts that oil and gas infrastructure may have on fish habitat, distribution, and movements (MQ AC 2). We do not have the data available to answer these MQs spatially, thus we provided a literature review of baseline data and the potential impacts that oil and gas infrastructure could have on fish and their behavior and habitats within the North Slope study area. These MQs are addressed at the end of the Aquatic Fine-Filter CEs section.

1.2. Distribution Models and Conceptual Models Methods

As described above, fish species data for the North Slope study area are especially data limited to the point that we were not able to accurately produce distribution models for any of the selected fish species. However, we did collaborate with BLM Fisheries Biologists to enter fish distribution datasets into the BLM geodatabase "RipFish" by manually searching reports and entering in spatial data associated with the Aquatic Fine-Filter CEs. In addition to this, we also developed conceptual models for each fish species through an extensive literature review to describe the relationship between the various Change Agents (CAs) and natural drivers for all fish species and one model for all fish species in general. Conceptual models are box and arrow figures that represent the state of knowledge about fish and its relationships to each attribute. CAs and the environmental parameters that they affect, or drivers, have specific effects on particular fish species and general affects that will impact most fish species similarly. We also identified attributes and indicators (environmental predictors) to assist with evaluation of status for each CE. These define the relationships between CEs and CAs, and, where possible, the thresholds associated with these relationships. For each Fine-Filter CE we identified a number of attributes derived through the conceptual model, and assigned indicators to them based on available spatial data layers. Whenever possible, thresholds derived from the literature were set to categorize the data into standard reporting categories (i.e. indicator ratings).

1.3. Results

Conceptual Model

The conceptual model below (Figure J-1) is for fish species in general. The boxes and arrows represent the state of knowledge about fish and its relationships to each attribute. CAs and the environmental parameters that they affect, or drivers, have specific effects on particular fish species and general affects that will impact most fish species similarly. To differentiate clearly between specific and general impacts, we propose a base conceptual model that details the general interactions between CAs, drivers, and fish habitat as well as fish in general.

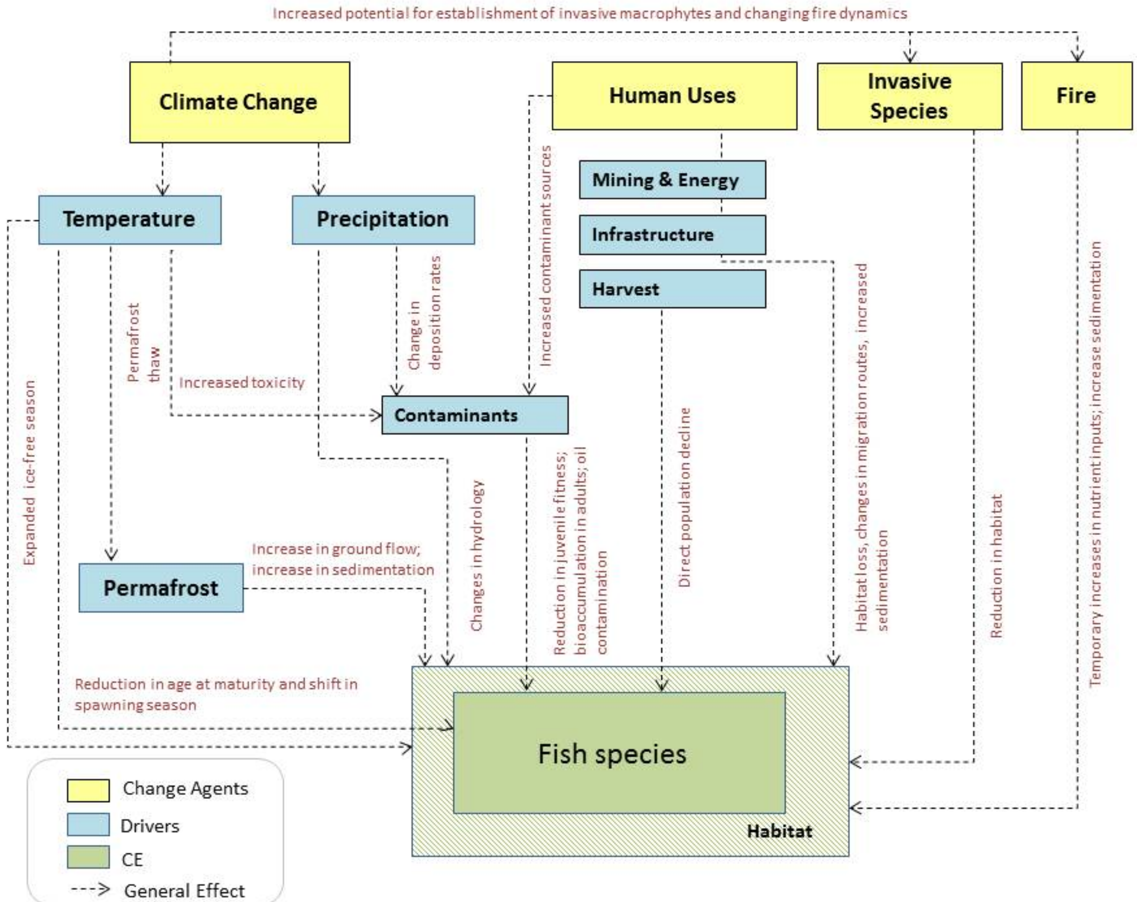

Figure J-1. Principal interactions among population drivers and Change Agents for fish species in the North Slope study area.

Attributes and Indicators

Key CA attribute and indicators for all fish species include: winter precipitation, summer temperature, frost-free days/season length, mean annual ground temperature, road development, habitat fragmentation, contaminated sites, and oil and gas activities (Table J-2).

Table J-2. Attributes and Indicators for all Fine-Filter fish species in the North Slope study area.

CA or Driver	Key Attribute	Indicator	Effect/ Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[1]	Dec-Feb total precipitation	Fish overwintering habitat	Less precipitation			More precipitation
	Winter precipitation[2]	Dec-Feb total precipitation	Fish overwintering habitat	More precipitation			Less precipitation
	Summer temperature[3]	Mean ambient air temperature (June-August)	Increased susceptibility to disease	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C
	Temperature[4]	Year-round temperature	Habitat Physiological stress	Water temperature increase of > 4°C	Water temperature increase of 2°C-4°C		No temperature increase

[1] Specific thresholds are unknown; Increased winter precipitation could increase available overwintering habitat (by increasing the volume of water).
[2] Specific thresholds are unknown; Increased precipitation could result in increased run-off and sedimentation negatively impacting habitat.
[3] Based on Zuray et al. 2012; Thresholds based on salmonid studies and may not apply to all CEs.
[4] Based on Reist et al. 2006, Schiedek et al. 2007; Increased water temperatures could preclude some species from preferred habitat; increase physiological stress.

CA or Driver	Key Attribute	Indicator	Effect/ Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	Temperature[5]	Year-round temperature	Contaminant exposure				
Climate	Frost-free days/Season length[6]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Increased juvenile growth rates			Increased number of frost-free days	
	Frost-free days/Season length[7]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Increase fish feeding time; shifts in time of spawning			Increased number of frost-free days	
	Change in mean annual ground temperature at one meter (MAGT)[8]	Permafrost thaw	Reduce habitat quality	From below -1m to above +1m			No Change

[5] AMAP 2002; Thresholds unknown; Increased water temperatures allow for certain contaminants to become more bioavailable.
[6] Reist et al. 2006; General thresholds; A longer ice-free season could improve the quality of feeding habitats with an increase in primary productivity due to longer periods of solar exposure.
[7] Reist et al. 2006; General thresholds; A longer ice-free season will decrease the amount of time that fish spend overwintering and increase the amount of time that fish can spend feeding; Spawning shifts to correspond with ice-free season.
[8] Lloyd et al 2003 (based on GIPL model); Bowden et al. 2008 (based on general effects); Increased stream turbidity from erosion and runoff may reduce primary production and aquatic invertebrate populations, lowering the quality of fish feeding habitat and reduce spawning habitat.

CA or Driver	Key Attribute	Indicator	Effect/ Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	Change in mean annual ground temperature at one meter (MAGT)[9]	Permafrost thaw	Improve habitat quality	From -1m to above +1m			No Change
Fire	Fire frequency[10]	Fire return interval	Feeding (summer) habitat	High return interval			Low return interval
Fire	Fire frequency[11]	Fire return interval	Feeding (summer) habitat	Low return interval		High return interval	
Anthropogenic development	Contaminated sites[12]	Water quality	Habitat				

[9] Lloyd et al 2003 (based on GIPL model); Bowden et al. 2008 (based on general effects). Permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations.

[10] Davis et al. 2013; Thresholds are general based on this study; Fires strip stabilizing vegetation from the landscape and increase erosion and runoff, resulting in higher sediment inputs to streams and lakes.

[11] Davis et al. 2013; Thresholds are general based on this study; Fire increases nutrient inputs.

[12] Thresholds will depend on specific contaminants at a site and proximity to waterbodies; Oil contamination.

CA or Driver	Key Attribute	Indicator	Effect/ Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	Road development[13]	Water quality	Habitat	Numerous intersections with streams and lakes			No intersection with streams and lakes
	Habitat fragmentation[14]	Road development	Habitat				
	Oil and gas activities[15]	Water withdrawal	Habitat	Lakes used by fish			Lakes not used by fish

[13] Thresholds will depend on specific proximity of fish habitat to a site; Turbidity, metals and hydrocarbon contamination, temperature changes.
[14] Thresholds will depend on specific proximity of fish habitat to a site; Disrupt fish migratory movements; stranding events.
[15] BLM 2006; General thresholds; Affect water quality, reduce spawning habitat for burbot and reduce overwintering and foraging habitat for all other Fine-Filter CEs.

Abiotic Change Agent Analysis

Climate

Although projected increases in air temperature are not always linearly correlated with increases in water temperature, the warming trend will result in two phenomena that have major impacts on fish habitat: increase in the duration of the ice-free season for lakes and rivers and permafrost thaw. Warmer air temperatures will increase the length of the ice-free season to a later freeze-up date and an earlier thaw date. A reduction in the length of the growing season (a proxy that directly relates to ice-free season) will decrease the amount of time that fish spend overwintering and increase the amount of time that fish can spend feeding (Reist et al. 2006). As a consequence, the age at maturity for fish will decrease because individuals will be able to feed more during any single year (Brown et al. 2012). Changes in water temperatures can also alter the timing of life history events, such as sexual maturation and timing of migration and spawning, and limit preferred habitats (Reist et al. 2006). Spawning will likely shift later in the year for autumn spawners and earlier in the year for spring spawners to correspond with the time that aquatic habitats become ice-free. Additionally, warmer water temperatures will have cascading effects on the susceptibility of fish to diseases and parasites (Zuray et al. 2012), increase the availability and effects of contaminants (Schiedek et al. 2007), and decrease biologically available dissolved oxygen (Ficke et al. 2007).

Increasing annual temperatures will cause a general trend of permafrost thaw at the landscape level, increasing the depth of the soil active layer and the mean annual ground temperature (see Section C). Deeper active layer and thermokarst could result in redistribution of water and new drainage networks and could also lead to increased erosion and sedimentation. Sedimentation of gravel-substrate in streams will reduce the quality of spawning habitat for species that rely on gravel substrate to hide their eggs (Brown et al. 2012). Additionally, increased stream turbidity from erosion and runoff may reduce primary production and aquatic invertebrate populations, lowering the quality of fish feeding habitat by reducing the abundance of prey species either directly or indirectly (Owens et al. 2005). On the other hand, permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations (Bowden et al. 2008). Increased nutrient input will improve the quality of fish feeding habitat with the direct or indirect increased abundance of prey species (Reist et al. 2006). Effects of permafrost thaw are likely to be localized, and could result in positive effects on some fish habitats, while incurring negative effects on other fish habitats.

A predicted increase in winter precipitation could potentially increase available overwintering habitat directly by increasing the volume of water and indirectly through the loss of snow insulation which would reduce ice thickness. Increased precipitation could also result in increased run-off and sedimentation to fish habitat.

The combination of climate CAs and their effects on fish CEs are complex and often interconnected. Consequently, the future long-term impacts to fish CEs and aquatic habitats remain unclear.

Fire

Fire removes stabilizing vegetation from the soil surface and can result in an increase in erosion and runoff, resulting in higher sediment inputs to streams and rivers. Increased runoff has the potential to decrease both primary productivity and aquatic invertebrate populations through increased turbidity. The increases in erosion and runoff in burned areas also increase nutrient inputs to aquatic habitats (Davis et al. 2013). These effects are temporary and are typically limited by the re-establishment of vegetation.

Contaminants

As water temperature increases, certain contaminants become more bioavailable (e.g., mercury) and exposure rates of contaminants in fish will likely increase. Mercury is a highly toxic metal that has negative impacts on the health of fish populations as well as wildlife and humans that consume fish. Microbial activity can convert inorganic mercury into its most toxic form, methlymercury (MeHg) (Benoit et al. 2003), where it is rapidly incorporated into the food web and biomagnifies from one trophic level to the next (Ochoa-acuña et al. 2002). Warming temperatures within the North Slope study area may further exacerbate mercury exposure in fish within this region by both releasing snowpack- and permafrost-entrained mercury, and by enhancing conditions that facilitate methylproduction (AMAP 2002).

Oil contamination is another contaminant of concern for fish species within the study area. Oil contamination has the largest impact on embryos because of their reduced capacity to leave the contaminated area (Short et al. 2003, Moles et al. 1979).

Current Status and Future Landscape Condition

Most development on the North Slope is related to oil and gas industries. Fish species on the North Slope can be affected by a number of factors related to development including: changes in water quality, construction of stream crossings, winter water withdrawals, and release of contaminants. Habitat alterations to stream flow or changes to underlying sediments caused by stream crossings can lead to changes in water temperature, turbidity, and dissolved ion concentrations, which in turn could have negative impacts on fish populations. Major construction, especially of roads will increase erosion and runoff leading to increased stream turbidity and sedimentation, and could introduce contaminates (e.g., vehicular leaks and spills) into fish habitats. Additionally, the construction of roads (both permanent and temporary) may channelize river systems and hinder fish migration routes between different habitats.

For example, in a recent study focused on the impacts of stream crossing structures in the North Slope oilfields near Prudhoe Bay indicated that 29% of the crossings evaluated restricted or completely blocked fish passage (Morris and Winters 2008).

Harvest

Many fish species are harvested for subsistence and sport use within the North Slope study area (See Section E. Anthropogenic Change Agents). While commercial fishing in the area is relatively small at present time, it has the potential to increase in the future.

Invasive Species

Invasive plant species have the potential to outcompete native aquatic and emergent vegetation. However, few invasive plant species are documented within the study area, none of which are aquatic species (See Section D. Biotic Change Agents). *Elodea* spp. is an invasive aquatic plant of concern that has recently been documented in south central Alaska and Chena Slough, near Fairbanks. *Elodea* spp. generally invade and outcompete other aquatic plant species in slow moving streams or small, shallow lakes and ponds.

1.4. Applications and Limitations

Understanding the response to climate-associated changes on fish species is difficult with inadequate distribution data. Our efforts to assist BLM with entering fish distribution data into the RipFish database have contributed greatly to our understanding of fish baseline data for the study area. However, information on feeding and overwintering areas, migrations and movements, and population level studies are lacking. Future research efforts should focus on obtaining these data for the study area.

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2. Dolly Varden (*Salvelinus malma*)

Dolly Varden occur in the study area as lake-resident, stream-resident, and anadromous populations; although, they are considered to be predominantly anadromous within the study area. Anadromous Dolly Varden are commonly harvested subsistence fisheries in the study area. Dolly Varden generally mature at five to nine years of age and can spawn multiple times throughout their lifetimes. Dolly Varden tagging studies have shown that overwintering and spawning habitats may change over time due to changes in channel morphology affecting groundwater inputs (Viavant 2004). Documented spawning habitats east of the Dalton Highway were in the upper reaches of watersheds and timing of spawning ranged from mid-August to late September (Viavant 2004). However, some Dolly Varden may overwinter in areas not connected to their natal streams (Crane et al. 2005). Major river drainages used by Dolly Varden for spawning, rearing, and overwintering habitat include the Colville, Kuparak, Canning, and Sagavanirktok (Scanlon 2012).

Dolly Varden habitats and life histories are based on descriptions in Morrow (1980). Dolly Varden use habitats associated with groundwater discharge for spawning, rearing, and overwintering. However, these habitats in the study area comprise a relatively small proportion of overall stream habitats and thus, are limiting to populations. Overwintering habitat is especially critical and limited to small streams with spring-fed areas. Spawning occurs from August through late September. Females lay eggs in small, dugout nests in stream gravel beds. Hatching of eggs generally occurs in March, and juvenile fish emerge from the gravel in late spring and after break-up, which generally begins in late May. Dolly Varden migrate to streams and river channels that were previously frozen, and to the nearshore coastal waters for feeding and rearing. Larger juvenile and adult fish consume salmon fry, salmon eggs, invertebrates, and small fish. Juveniles feed primarily on macroinvertebrates.

2.1. Conceptual Model

The conceptual model below (Figure J-2) is based on a review of the literature and describes the relationship between the various CAs and natural drivers for Dolly Varden. The boxes and arrows represent the state of knowledge about Dolly Varden and the relationship to each attribute.

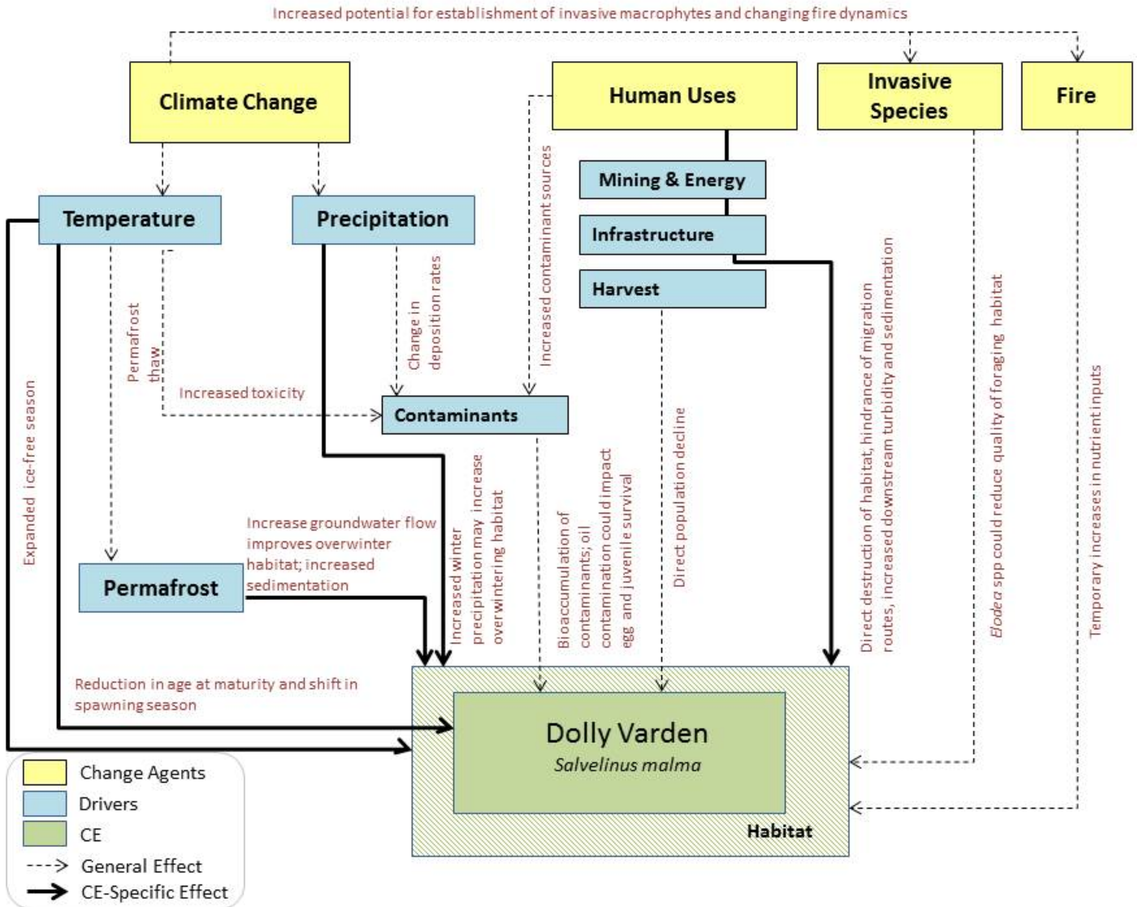

Figure J-2. Principal interactions among population drivers and CAs for Dolly Varden within the North Slope study area.

2.2. Attributes and Indicators

CA attribute and indicator data for Dolly Varden include: winter precipitation, summer temperature, frost-free days/season length, mean annual ground temperature, road development, habitat fragmentation, contaminated sites, and oil and gas activities (Table J-3).

Table J-3. Attributes and Indicators for Dolly Varden.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[16]	Dec-Feb total precipitation	Overwintering habitat	Less precipitation			More precipitation
	Winter precipitation[17]	Dec-Feb total precipitation	Overwintering habitat	More precipitation			Less precipitation
	Summer temperature[18]	June-August mean monthly air temperature	Summer habitat	Warmer air temperature			No change in air temperature
	Summer temperature[19]	June-August mean monthly air temperature	Parasite infections	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C
	Frost-free days/Season length[20]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Shift in spawning time			Increased number of frost-free days	

[16] Specific thresholds are unknown; Increased winter precipitation could increase available overwintering habitat (by increasing the volume of water).
[17] Specific thresholds are unknown; Increased precipitation could result in increased run-off and sedimentation negatively impacting habitat.
[18] Nolan et al. 2011; General thresholds; Decrease in glacial melt run-off as a result of warming climate glacier retreat.
[19] Zuray et al. 2012; Thresholds based on salmonid studies; Warmer waters may increase the prevalence of diseases and parasites.
[20] Specific thresholds are unknown; Spawning will shift later in the fall to correspond with the time that aquatic habitats become ice-free.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	Frost-free days/Season length[21]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Juvenile growth			Increased number of frost-free days	
	Change in mean annual ground temperature at one meter (MAGT)[22]	Permafrost thaw	Loss of habitat for lake resident populations				
	Change in mean annual ground temperature at one meter (MAGT)[23]	Permafrost thaw	Increased overwintering habitat				
	Change in mean annual ground temperature at one meter (MAGT)[24]	Permafrost thaw	Foraging habitat	From below -1m to above +1m			No Change

[21] Reist et al. 2006; general thresholds; The age at maturity for Dolly Varden will likely decrease because individuals will be able to feed more during any single year.
[22] Lloyd et al. 2003 (based on GIPL model); Lake drainage will result in loss of habitat or decline in lake area.
[23] Increased ground flows in winter as a consequence of permafrost thaw could improve overwintering habitat for Dolly Varden.
[24] GIPL model, Lloyd et al. 2003 (based on GPL model); Bowden et al. 2008 (based on general effects); Increased nutrient input with permafrost thaw will improve feeding habitat by increasing primary productivity.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Anthropogenic development	Road development[25]	Water quality	Habitat	Numerous intersections with streams and lakes			No intersection with habitats
	Habitat fragmentation[26]	Road development	Habitat	Numerous intersections with streams and lakes			No intersection with habitats
	Contaminated sites[27]	Water quality	Habitat				
	Oil and gas activities[28]	Water withdrawal	Habitat	Lakes used by Dolly Varden			Lakes not used by Dolly Varden

[25] Thresholds will depend on specific proximity of fish habitat to a site; Turbidity, metals and hydrocarbon contamination, temperature changes.
[26] Thresholds will depend on specific proximity of fish habitat to a site; Disrupt fish Dolly Varden movements; stranding events.
[27] Thresholds will depend on specific contaminants at a site and proximity to waterbodies; Oil contamination.
[28] BLM 2006; General thresholds; Effect water quality, reduce foraging and overwintering habitat.

2.3. Abiotic Change Agent Analysis

Climate

Increasing annual temperatures are predicted to increase permafrost thaw in the study area, increasing the depth of the soil active layer and the mean annual ground temperature (see Section C). As a consequence, there will likely be increased erosion and runoff into lakes and streams. Similarly, lake drainage, as a consequence of permafrost thaw, is likely to increase as the depth of the active layer increases. Increased lake drainage, will likely reduce available habitat for resident lake populations of Dolly Varden. On the other hand, permafrost thaw could increase groundwater flow in winter improving overwintering habitat and increasing overwintering survival for Dolly Varden. Permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations (Bowden et al. 2008). Increased nutrient input will improve the quality of fish feeding habitat with the direct or indirect increased abundance of prey species (Reist et al. 2006). Increased sedimentation in streams will reduce the quality of spawning habitat for Dolly Varden because they rely on gravel substrate to hide their eggs.

With projected increased temperatures, the duration of the ice-free season will likely increase which will improve the quality of feeding habitats as those habitats will remain ice-free for a longer period of time (Reist et al. 2006). Consequently, the age at maturity for Dolly Varden will likely decrease because individuals will be able to feed more during any single year. Spawning will shift later in the fall to correspond with the changes in the duration of the ice-free season. Warmer waters may also increase the prevalence of diseases and parasites (Reist et al. 2006).

Increased temperatures within the study area will have a significant impact on glacial stream systems. Glacial melt and runoff is an important source of late summer discharge to streams and rivers that provide sufficient flow allowing Dolly Varden to reach spawning and overwintering habitats (Nolan et al. 2011). With the loss of sufficient late summer discharge, overwintering habitat could become even more limited for Dolly Varden in streams directly influenced by glacier run-off (e.g., streams within the Brooks Range area). Furthermore, a decrease in discharge could negatively impact Dolly Varden that use glacial systems to complete their migrations from summer feeding areas to spawning and overwintering habitats.

A predicted increase in winter precipitation could potentially increase available overwintering habitat directly (by increasing the volume of water) and indirectly through the loss of snow insulation which would reduce ice thickness. Increased precipitation could also result in increased run-off and sedimentation to Dolly Varden habitat.

Contaminants

Melting glaciers can release contaminants that have accumulated from years of atmospheric deposition, including persistent organic pollutants and mercury, into streams and lakes where fish can readily absorb these pollutants (Blais et al. 2001). Dolly Varden commonly use glacial streams, especially in the Brooks Range area and therefore may be vulnerable to high exposure rates of contaminants as glaciers continue to melt. Furthermore, because Dolly Varden can be piscivorous during the juvenile and adult freshwater stages, they have the propensity to bioaccumulate and biomagnify organochlorine and heavy metal contaminants.

2.4. Current Status and Future Landscape Condition

Major construction, especially of roads will increase erosion and runoff leading to increased stream turbidity and sedimentation. Increased turbidity and sedimentation could have negative impacts on egg and juvenile survival. Road development at stream crossings could disrupt migratory pathways and alter access between key summering and wintering habitats. Much road development occurs during the winter which could have negative impacts on Dolly Varden overwintering habitat. Water removal and gravel extraction can have population-level effects on Dolly Varden due to the limited overwintering habitat on the North Slope.

Harvest

Dolly Varden are an important subsistence resource to North Slope residents (Craig 1989). Overwintering and spawning populations also provide for sport fisheries. Dolly Varden represents approximately 40% of the total subsistence harvest fisheries in Kaktovik (Pedersen 2005). Recent Dolly Varden subsistence harvests for the North Slope area range from approximately 4,000-10,000 (Scanlon 2012). Recent estimated annual sport harvests are around 1,000 for the entire North Slope, catches are around 5,000, and total effort is around 5,000 angler days (Scanlon 2012). Annual average sport harvest of Dolly Varden for 2001-2012 was 5,053 fish and annual sport catch averaged 18,000-20,000 (Scanlon 2012). Sport harvest of Dolly Varden on the North Slope is currently estimated to be within sustainable limits (Scanlon 2012).

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3. Broad whitefish (*Coregonus nasus*)

Broad whitefish are typically anadromous, although freshwater resident populations have been documented in lakes and streams within the study area. Broad whitefish mature between five to eight years of age, depending upon the population (Brown et al. 2012). Similarly, the longest lived broad whitefish range from 16 years in the mainstem Yukon River to one 35-year-old fish from the McKenzie River Delta (Brown et al. 2012). Spawning occurs in late fall to early winter in gravel stream beds (ADF&G 1986). After spawning, broad whitefish migrate downstream to overwinter under the ice in deep freshwater pools in rivers and lakes (Morris 2006). Migration to their summer feeding areas in salt water begins during spring break up. The diet of broad whitefish is composed of marine and freshwater invertebrates.

Studies have documented the importance of small drainages with lake connectivity for broad whitefish summer habitat on the North Slope (Morris 2006). Suitable overwintering habitat is one of the most severe constraints on broad whitefish populations and the use of ephemeral streams to move into lake habitats for overwintering is especially important (Morris 2006). Broad whitefish were documented using a diversity of habitats for overwintering in the Teshekpuk Lake area, such as the coalesced lakes at the headwaters of the Mayoriak River, in deep pools (> 15 feet) of the Mayoriak River, and the lower reaches of the Chipp River and its connected lakes (Morris 2006).

3.1. Conceptual Model

The conceptual model below (Figure J-3) is based on a review of the literature and describes the relationship between the various CAs and natural drivers for Dolly Varden. The boxes and arrows represent the state of knowledge about Dolly Varden and the relationship to each attribute.

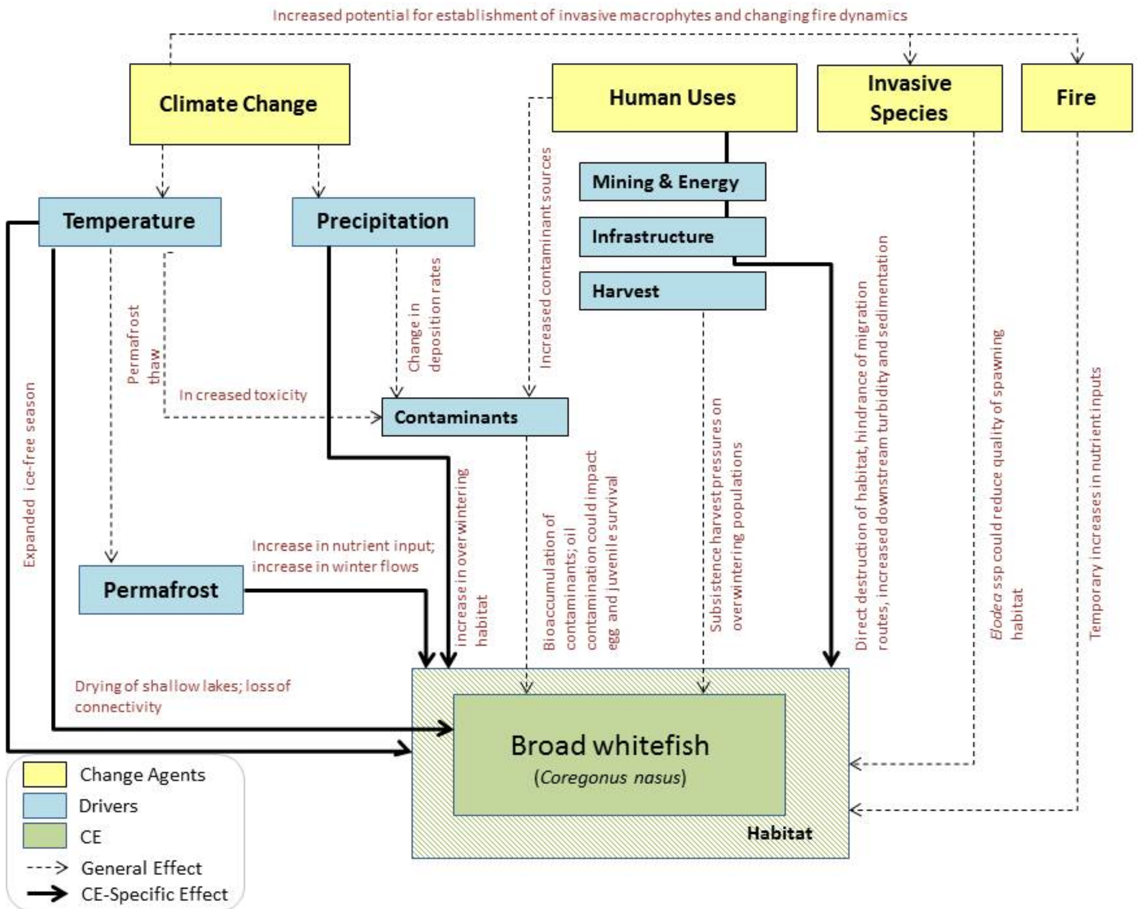

Figure J-3. Principal interactions among population drivers and CAs for Broad whitefish within the North Slope study area.

3.2. Attributes and Indicators

Key CA attribute and indicator data for broad whitefish include: winter precipitation, summer temperature, frost-free days/season length, mean annual ground temperature, road development, habitat fragmentation, oil and gas activities, and contaminated sites (Table J-4).

Table J-4. Attributes and indicators for Broad whitefish.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[29]	Dec-Feb total precipitation	Overwintering habitat	Less precipitation			More precipitation
	Winter precipitation[30]	Dec-Feb total precipitation	Overwintering habitat	More precipitation			Less precipitation
	Summer temperature[31]	June-August mean monthly air temperature	Summer habitat	Warmer temperature			No change in temperature
	Summer temperature[32]	June-August mean monthly air temperature	Parasite infections	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C
	Frost-free days/Season length[33]	Cumulative days with temps above 0 °C (Days between DOT	Egg development and shifts in spawning time			Increased number of frost-free	

[29] Specific thresholds are unknown; Increased winter precipitation could increase available overwintering (by increasing the volume of water).
[30] Specific thresholds are unknown; Increased precipitation could result in increased run-off and sedimentation negatively impacting habitat.
[31] Specific thresholds are unknown; Loss of lake connectivity; lake drying.
[32] Zuray et al. 2012; Thresholds based on salmonid studies; Warmer waters may also increase the prevalence of diseases and parasites.
[33] Specific thresholds are unknown; With an earlier breakup period, egg development time would likely be reduced and it's possible that spawning will shift to later in the fall.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
		and DOF)				days	
	Frost-free days/Season length[34]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Juvenile growth			Increased number of frost-free days	
	Change in mean annual ground temperature at one meter (MAGT)[35]	Permafrost thaw	Overwintering habitat			Increased rates of thaw	
	Change in mean annual ground temperature at one meter (MAGT)[36]	Permafrost thaw	Foraging habitat	From below -1m to above +1m			No Change

[34] Reist and Bond 1988; Reist 2006; General thresholds; The age at maturity for broad whitefish will likely decrease because individuals will be able to feed more during any single year.
[35] Specific thresholds are unknown; Increased ground flows in winter as a consequence of permafrost thaw could improve overwintering habitat.
[36] Lloyd et al. 2003 (based on GIPL model); Bowden et al. 2008 (based on general effects); Increased nutrient input with permafrost thaw will improve feeding habitat by increasing primary productivity.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Anthropogenic development	Road development[37]	Water quality	Habitat	Numerous intersections with habitats			No intersection with habitats
	Habitat fragmentation[38]	Road development	Habitat	Numerous intersections with habitats			No intersection with habitats
	Oil and gas activities[39]	Water withdrawal	Habitat disturbance or loss	Lakes used by broad whitefish			Lakes not used by broad whitefish
	Contaminated sites[40]	Water quality	Habitat				

[37] Thresholds will depend on specific proximity of fish habitat to a site; Turbidity, metals and hydrocarbon contamination, temperature changes.
[38] Morris and Winters 2008; Thresholds are general; Disrupt fish migratory movements; direct destruction of habitat, erosion, sedimentation.
[39] BLM 2006; Thresholds are general; Effect water quality, reduce spawning habitat and reduce overwintering habitat.
[40] Thresholds will depend on specific contaminants at a site and proximity to waterbodies; Oil contamination could reduce egg survival and spawning habitat.

3.3. Abiotic Change Agent Analysis

Climate

Broad whitefish rely on productive shallow lakes for summer foraging and ephemeral stream systems to move into lake habitats for overwintering (Morris 2006). With projected increases in temperature and permafrost thaw, the potential for drying of shallow lakes is a concern for populations of broad whitefish in the study area. A loss of connectivity to lakes could have negative consequences for broad whitefish populations. A loss of connectivity, or decline in lake area could affect migrations into summer feeding habitat (Morris 2006). Furthermore, shallow lakes that are commonly used as summer feeding habitats by broad whitefish are especially susceptible to increases in temperature and lake drying. Thus, broad whitefish that use these lakes could be exposed to lethal or near lethal temperatures during the summer and/or experience stranding events due to loss of connectivity from summer feeding habitats into overwintering habitats. If migratory corridors between highly productive foraging lakes and cooler river systems were reduced across the landscape due to warmer temperatures, lake-feeding broad whitefish could experience increased summer mortality.

With projected increased temperatures, the duration of the ice-free season will likely increase. A longer ice-free season could improve the quality of feeding habitats as those habitats will likely experience an increase in primary productivity due to longer periods of solar exposure (Reist et al. 2006). The open water period is the primary feeding time for broad whitefish (Reist and Bond 1988) thus, the age at maturity will likely decrease because individuals will be able to feed more during any single year. With an earlier breakup period, egg development time would likely be reduced and it's possible that spawning will shift to later in the fall to correspond with the time that water temperature approaches 0°C or the time that aquatic habitats become ice-free, respectively. However, warmer waters may also increase the prevalence of diseases and parasites (Reist et al. 2006).

Permafrost thaw will likely increase groundwater flows in winter improving overwintering habitat for broad whitefish which will likely increase overwintering survival, at least temporarily. Permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations (Bowden et al. 2008). Thus, increased nutrient input will improve the quality of fish feeding habitat with the direct or indirect increased abundance of prey species (Reist et al. 2006).

A predicted increase in winter precipitation could potentially increase available overwintering habitat directly by increasing the volume of water and indirectly through the loss of snow insulation which would reduce ice thickness. Increased precipitation could also result in increased run-off and sedimentation.

Contaminants

As water temperature increases, certain contaminants become more bioavailable (e.g., mercury) and thus, exposure rates of contaminants in fish will likely increase with a warming climate (AMAP 2002). Broad whitefish is an important subsistence fish to residents on the North Slope, and exposure to toxic pollutants could reduce the value of broad whitefish as a subsistence resource. Because broad whitefish consume mostly lower trophic level species such as invertebrates, they are less likely to contain high levels of contaminants, compared to piscivorous species such as Dolly Varden and chum salmon. However, broad whitefish are a long-lived species and have the potential to bioaccumulate contaminants over time. Thus, the effects of contaminants on individual fish over time and human exposure of contaminants through consumption of fish is a potential concern.

Oil field operations have the potential to introduce contaminants to aquatic habitats, including broad whitefish habitats within the North Slope study area. Whereas, some contaminants such as organochlorines (e.g., PCBs, DDT, and POPs) and mercury have both local and distant anthropogenic sources, petroleum products are directly related to local activities. Spilled petroleum products may arise from activities such as drilling and transportation of personnel and materials. Contaminants on roads from vehicle leakage may run off into drainages affecting water quality. Petroleum products may persist in aquatic environments for years after a spill or leak. Petroleum products can directly affect the health of fish by impacting their ability to adequately take up oxygen or through ingestion, which may compromise other physiological functions (Peterson et al. 2003). Oil contaminations can also severely impact egg, larvae, and juvenile survival because of their reduced capacity to leave the contaminated area (Brown et al. 2012).

3.4. Current Status and Future Landscape Condition

Road development for oil and gas exploration and water withdrawal are considered to be the most important development concerns within the North Slope study area. Major construction, especially of roads will increase erosion and runoff leading to increased stream turbidity and sedimentation. Increased turbidity and sedimentation could have negative impacts on egg and juvenile survival (Brown et al. 2012). Road development at stream crossings could disrupt migratory pathways and alter access between key summering and wintering habitats. Due to the use of small drainages, including ephemeral streams, any development that would impede fish passage within these small drainages, could have negative impacts on broad whitefish populations within the North Slope study area (Morris 2006). Broad whitefish are considered potentially sensitive to water withdrawal activities, especially during the winter when habitat is most limiting (BLM 2006). Bridges and culverts used for development of oil production could affect broad whitefish habitat directly by increasing sedimentation or altering migration routes.

In addition to direct environmental changes resulting from road construction, roads increase human access to previously remote areas, which facilitates increased recreational use of resources.

Harvest

Broad whitefish is one of the most heavily harvested subsistence fish species on the North Slope. Currently, no agency manages broad whitefish on the North Slope. The community of Nuiqsut operates subsistence fisheries year-round, although most fishing efforts occur in summer and fall. On the Colville Delta, reported summer harvests have ranged from 3,000-4,000 broad whitefish.

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Zuray, S., R. Kocan, and P. Hershberger. 2012. Synchronous cycling of Ichthyophoniasis with Chinook salmon density revealed during the annual Yukon River spawning migration. 28 Transactions of the American Fisheries Society 141: 615-623. DOI 10.1080/00028487.2012.683476.

5. Chum Salmon (*Oncorhynchus keta*)

Chum salmon are anadromous fish that spawn in summer and fall; juveniles migrate directly to the ocean where they spend two to four winters at sea. It is assumed that chum salmon that spawn in the Arctic spend most of their marine phase in the North Pacific, but may spend their first winter in the Beaufort Sea, offshore deep under pack ice (Irvine et al. 2009).

As adults, chum salmon almost always return to spawn in their natal stream to spawn in late summer or early fall (Morrow 1980). Embryos hatch after 3–4 months, depending on water temperature and remain in the gravel while continuing to absorb nutrients from the egg yolk for an additional 60–90 days before emerging (Morrow 1980). Fry emerge from the gravel during spring (April-May) and migrate to the ocean within days or a few weeks after hatching (Salo 1991). Juvenile chum salmon that hatch far upriver begin feeding on insect larvae while still moving toward the sea (Morrow 1980).

Spawning populations of chum salmon have been documented in the Colville River and elsewhere in the study area (Bendock 1979, Craig and Haldorson 1986), but it is unknown whether these spawning events sustain consistent runs of chum. There are several chum salmon spawning locations in the study area documented in the ADF&G Anadromous Waters Catalog: Noatak River, Kiyak Creek, Wulik River, Kivalina River, Pitmegea River, Kuchiak Creek, Kaolak River, an unnamed tributary to the Ketik River, Mikigealiak River, Kungok River, an unnamed tributary to the Kungok River, Kugrua River, Meade River, Colville River, and the Itkillik River (Johnson and Coleman 2014). Winter temperatures of Arctic marine waters are generally lethal for salmon (Irvine et al. 2009). Groundwater-fed streams are usually many degrees warmer than other streams in the study area, thus the eggs may be able to survive. The lower thermal temperature limit for chum salmon is 2.7 °C. (Azumaya et al. 2007). Typical Arctic stream temperatures average between 0 - 0.5°C in winter months, but pockets of groundwater provide shelter with temperatures between 2 - 5°C throughout winter months (Craig and Haldorson 1986). Warming conditions may be producing more suitable habitat for salmon in the Arctic.

5.1. Conceptual Model

The conceptual model below (Figure J-4) is based on a review of the literature and describes the relationship between the various CAs and natural drivers for chum salmon. The boxes and arrows represent the state of knowledge about chum salmon and the relationship to each attribute.

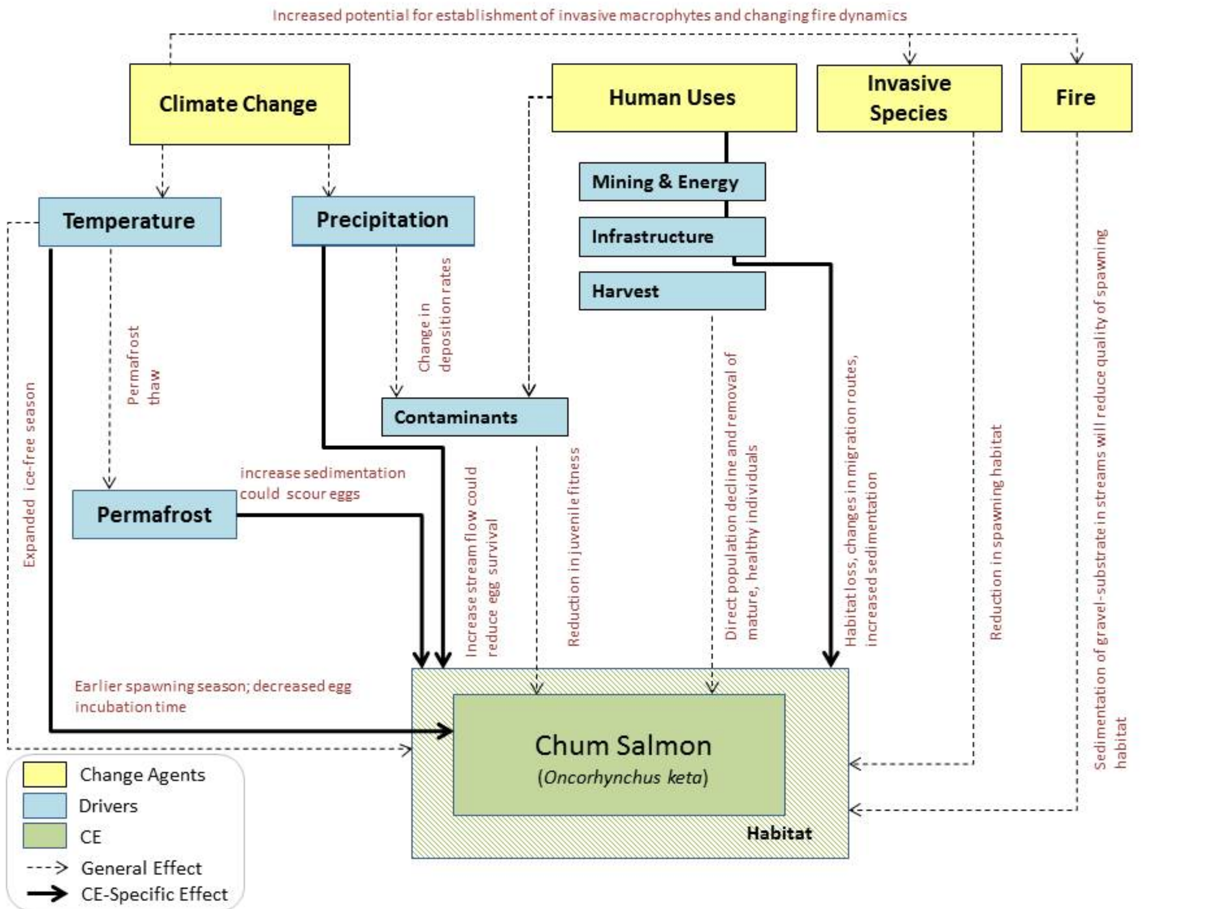

Figure J-4. Principal interactions among population drivers and CAs for Chum Salmon within the North Slope study area.

5.2. Attributes and Indicators

Key CA attribute and indicator data for chum salmon include: winter precipitation, fall temperature, mean annual ground temperature, summer temperature, road development, habitat fragmentation, and contaminated sites (Table J-4).

Table J-5. Attributes and Indicators for Chum Salmon.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[41]	Nov-Dec total precipitation	Spawning habitat	More precipitation			Less precipitation
	Fall temperature[42]	Mean ambient Fall air temperature (Sept-Dec)	Chum salmon embryonic development	Water temperature below 0°C	Water temperature between 0°C - 4.0°C	Water temperature around 4.0 °C	Water temperature between 4.0 °C - 10 4.0 °C
	Fall temperature[43]	Mean Sept air temperature	Pre-spawning mortality	Water temperature above 20°C	Water temperature above 15°C		
	Change in mean annual ground temperature at one meter (MAGT)[44]	Permafrost thaw	Spawning habitat	From below -1m to above +1m			No Change

[41] Lisle 1989; Thresholds general; Increased precipitation could result in increased run-off and scour redds.
[42] Morrow 1980; Raymond 1981; Beacham et al. 1988; Chum salmon need initial incubation temperatures of about 4.0 °C for successful early embryonic development; warmer water temperatures may reduce hatch time.
[43] Murphy 1985; Pre-spawning mortality related to increased temperatures.
[44] GIPL model, Lloyd et al. 2003 (based on GPL model); Lisle 1989 (based on general effects); Increased permafrost thaw could cause scour of salmon redd's.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	**Fair**	**Good**	**Very Good**
	Summer temperature[45]	June-August mean monthly air temperature	Parasite infections	Water temperature above 20°C	Water temperature above 15°C	Water temperature around 15°C	Water temperature below 15°C
Anthropogenic development	Road development[46]	Water quality	Spawning habitat	Numerous intersections with streams			No intersection with streams
	Habitat fragmentation[47]	Road development	Spawning habitat	Numerous intersections with streams			No intersection with streams
	Contaminated sites[48]	Water quality	Habitat				

[45] Zuray et al. 2012; Warmer waters may increase the prevalence of diseases and parasites.
[46] Thresholds will depend on specific proximity of fish habitat to a site; Turbidity, metals and hydrocarbon contamination, temperature changes from impoundment; overall effects on spawning habitat.
[47] Morris and Winters 2008; thresholds are general; Disrupt fish migratory movements; direct destruction of habitat, erosion, sedimentation.
[48] Thresholds will depend on specific contaminants at a site and proximity to waterbodies; Oil contamination could reduce egg survival and spawning habitat.

5.3. Abiotic Change Agent Analysis

Climate

Water flow through substrate, water temperature, and dissolved oxygen concentration (Maclean 2003) are important factors that influence redd site selection by chum salmon. Increased permafrost thaw and snow melt may increase the rate of stream discharge and the potential for scour and sedimentation of chum salmon redds (Lisle 1989). Increased precipitation (especially in winter) could have similar negative impacts on chum salmon spawning habitat by increasing the potential scouring of redds and erosion of streambanks. Time of fry emergence is related to water temperature during incubation (Salo 1991) and thus, changes during the early part of incubation can affect time of emergence. As water temperatures increase, egg incubation rates will increase and time to emergence and migration will decrease. Chum salmon may benefit from warmer water temperatures by creating a more stable water temperature for spawning (Maclean 2003). Chum salmon need initial incubation temperatures of about 4.0 °C for successful early embryonic development (Raymond 1981, Beacham et al. 1988). Warmer water temperatures in fall chum spawning sites may also be important in controlling the timing of their emergence in relation to the availability of their prey (Cushing 1990, Gotceitas et al. 1996). However, an increase in water temperatures coupled with low water flow could cause higher fish densities and depleted oxygen concentrations, resulting in high pre-spawning mortality (Murphy 1985).

5.4. Current Status and Future Landscape Condition

The majority of the chum salmon's life occurs in the marine environment, thus the largest impact of road development and oil and gas operations would affect spawning habitat since juveniles do not rear in streams. However, if adult chum salmon overwinter in freshwater habitats in the study area, then overwintering populations could be affected by winter development activities. Road construction has the potential to cause high sediment loads in streams (Beschta 1978). Similarly, stream culverts at road crossings may hinder migration routes (Morris and Winters 2008).

Harvest

Subsistence and sport harvest studies for chum salmon in the study area are limited. However, estimates of sport chum salmon harvest in Brooks Range drainages from 1994-2004 was less than 15 individuals for all years, except for 2000 when 763 individuals were reportedly harvested (Jennings et al. 2007). A recent study in Elsoon Lagoon documented the harvest of 483 chum salmon from the lagoon during 20 July – 31 August, 2008 (North Slope Borough et al. 2009).

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6. Arctic Grayling (*Thymallus arcticus*)

Arctic grayling are one of the most widespread fish species within the North Slope study area and are found exclusively in fresh water throughout the year. Arctic grayling are well adapted to the rigors of the arctic climate as they spend their entire life cycle within aquatic habitats on the North Slope. They can be migratory or relatively sedentary and remain in the same section of a stream year round (Morris 2003). Similar to most other arctic fishes, available overwintering habitat is critical to their survival and is considered to be the major limiting factor for populations of Arctic grayling. Their tolerance of low dissolved oxygen levels allows grayling to survive the long winters in areas where many other species would perish ("Arctic Grayling", para. 4). After spring break-up, Arctic grayling begin movements into streams and rivers that were previously frozen (Morris 2003). Glacial rivers in the Brooks Range area are important migration corridors to tundra streams where grayling spawn and rear (Tack 1980). Arctic grayling typically spawn in May and June in riffle areas of streams. After spawning, they move from smaller streams to the main streams and rivers where they spend the summer (Morrow 1980). Some Arctic grayling demonstrate strong site fidelity, returning every year to the same spawning and feeding areas (Morrow 1980). Juveniles emerge from the gravel in late June and early July and remain in the foothill streams throughout the summer. In late fall (before freeze-up), Arctic grayling move into overwintering areas in clear river channels associated with year round springs and deep pools (West et al. 1992). Arctic grayling are considered generalists, but primarily consume macroinvertebrates (Hobbie et al. 1995). They will also eat salmon eggs and out-migrating salmon smolts. Grayling mature between the age of six and nine years and can live for up to 30 years (ADF&G 2015).

Arctic grayling require colder water temperatures than most other fish with thermal maximum temperatures for adults around 20°-25°C (Stewart et al. 2007). For adults, temperatures above 15°C are considered to induce stress, and temperatures greater than 20°C cannot be tolerated for long without mortality. However, juveniles can tolerate warmer waters (between 10°- 20°C). Thus water temperature of summer rearing and feeding habitats is an important determinant of the summer distribution of Arctic grayling, such that larger grayling tend to be found in the cooler upper reaches of rivers, whereas smaller grayling tend to be located in warmer downstream reaches.

6.1. Conceptual Model

The conceptual model below (Figure J-5) is based on a review of the literature and describes the relationship between the various CAs and natural drivers for Arctic grayling. The boxes and arrows represent the state of knowledge about Arctic grayling and the relationship to each attribute.

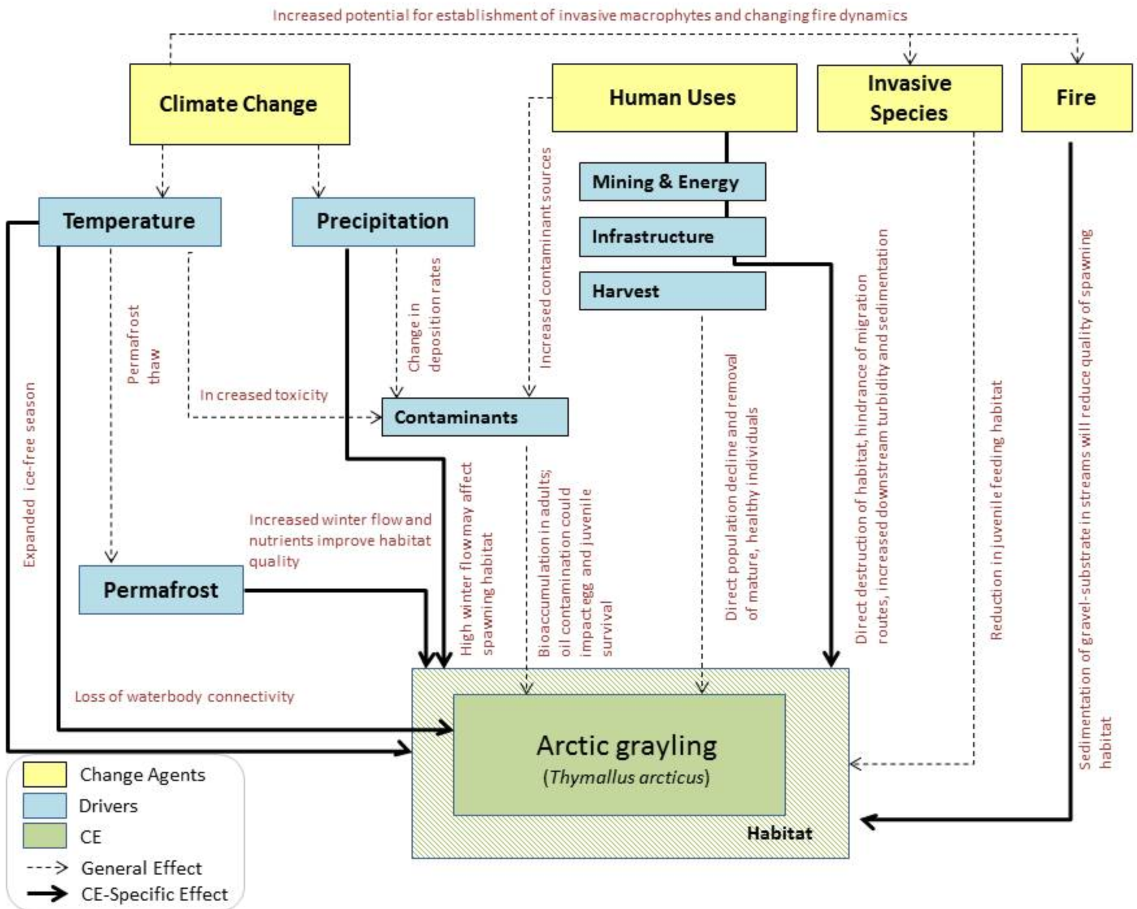

Figure J-5. Principal interactions among population drivers and CAs for Arctic grayling within the North Slope study area.

6.2. Attributes and Indicators

Key CA attribute and indicator data for Arctic grayling include: winter precipitation, summer temperature, frost-free days/season length, mean annual ground temperature, road development, habitat fragmentation, oil and gas activities, and contaminated sites (Table J-6).

Table J-6. Attributes and Indicators for Arctic grayling.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[49]	Dec-Feb total precipitation	Overwintering habitat	Less precipitation			More precipitation
	Winter precipitation[50]	Dec-Feb total precipitation	Overwintering habitat	More precipitation			Less precipitation
	Summer temperature[51]	June-August mean monthly air temperature	Adult survivorship	Water temperature between 20°C-25°C	Water temperature above 20°C		Water temperature below 15°C
	Summer temperature[52]	June-August mean monthly air temperature	Parasite infections	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C
	Frost-free days/Season length[53]	Cumulative days with temps above 0 °C (Days between DOT	Egg development and shifts in spawning time			Increased number of frost-free	

[49] Specific thresholds are unknown; Increased winter precipitation could increase available overwintering (by increasing the volume of water).
[50] Specific thresholds are unknown; Increased precipitation could result in increased run-off and sedimentation negatively impacting habitat.
[51] Stewart et al. 2007; Thermal stress.
[52] Zuray et al. 2012; Thresholds based on salmonid studies; Warmer waters may increase the prevalence of diseases and parasites.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
		and DOF)				days	
	Frost-free days/Season length[54]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Juvenile growth			Increased number of frost-free days	
	Change in mean annual ground temperature at one meter (MAGT)[55]	Permafrost thaw	Overwintering habitat			Increased rates of thaw	
	Change in mean annual ground temperature at one meter (MAGT)[56]	Permafrost thaw	Foraging habitat	From below -1m to above +1m			No Change
Anthropogenic development	Road development[57]	Water quality	Habitat	Numerous intersections with habitats			No intersection with habitats
	Habitat	Road development	Habitat	Numerous intersections			No intersection

[53] Specific thresholds are unknown; With an earlier breakup period, egg development time would likely be reduced and it's possible that spawning will shift to later in the fall.

[54] Reist and Bond 1988; Reist et al. 2006; General thresholds; The age at maturity for Arctic grayling will likely decrease because individuals will be able to feed more during any single year

[55] Specific thresholds are unknown; Increased ground flows in winter as a consequence of permafrost thaw could improve overwintering habitat.

[56] GIPL model, Lloyd et al. 2003 (based on GPL model); Bowden et al. 2008 (based on general effects); Increased nutrient input with permafrost thaw will improve feeding habitat by increasing primary productivity.

[57] Thresholds will depend on specific proximity of fish habitat to a site; Turbidity, metals and hydrocarbon contamination, temperature changes.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	fragmentation[58]			with habitats			with habitats
	Oil and gas activities[59]	Water withdrawal	Habitat disturbance or loss	Lakes used by Arctic grayling			Lakes not used by arctic grayling
	Contaminated sites[60]	Water quality	Habitat				

[58] Morris and Winters 2008; thresholds are general; Disrupt fish migratory movements; direct destruction of habitat, erosion, sedimentation.
[59] BLM 2006; Thresholds are general; Effect water quality, reduce spawning habitat and reduce overwintering habitat.
[60] Thresholds will depend on specific contaminants at a site and proximity to waterbodies; Oil contamination could reduce egg survival and spawning habitat.

6.3. Abiotic Change Agent Analysis

Climate

With projected increased temperatures, the duration of the ice-free season will likely increase (see Section C). A longer ice-free season could improve the quality of feeding habitats as those habitats will likely experience an increase in primary productivity due to longer periods of solar exposure (Reist et al. 2006). Permafrost thaw will likely increase groundwater flows in winter improving overwintering habitat for Arctic grayling which will likely increase overwintering survival, at least temporarily. Permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations (Bowden et al. 2008). Thus, increased nutrient input will improve the quality of fish feeding habitat with the direct or indirect increased abundance of prey species (Reist et al. 2006). A predicted increase in winter precipitation could potentially increase available overwintering habitat directly (by increasing the volume of water) and indirectly through the loss of snow insulation which would reduce ice thickness. Increased precipitation could also result in increased run-off and sedimentation.

Increased temperatures (coupled with increased evapotranspiration) may affect connectivity between stream and lake habitats and limit access to spawning and overwintering habitats (Reist et al. 2006). Warmer waters may also increase the prevalence of diseases and parasites (Reist et al. 2006).

Contaminants

As water temperature increases, certain contaminants become more bioavailable (e.g., mercury) and thus, exposure rates of contaminants in fish will likely increase with a warming climate (AMAP 2002). Similar to broad whitefish, Arctic grayling consume mostly lower trophic level species such as invertebrates, and are less likely to contain high levels of contaminants (e.g. heavy metals and organochlorines), compared to piscivorous species such as Dolly Varden and chum salmon. However, because Arctic grayling are a long-lived species they have the potential to bioaccumulate contaminants over time and may concentrate levels of contaminants. High contaminant levels are a concern for individual fish as well as wildlife and humans that consume them.

Oil field operations have the potential to introduce contaminants to aquatic habitats within the study area. Whereas, some contaminants such as organochlorines (e.g., PCBs, DDT, and POPs) and mercury have both local and distant anthropogenic sources, petroleum products are directly related to local activities. Spilled petroleum products may arise from activities such as drilling and transportation of personnel and materials. Contaminants on roads from vehicle leakage may runoff into drainages affecting water quality. Petroleum products may persist in aquatic environments for years after a spill or leak and can directly affect the health of fish by impacting their ability to adequately take up oxygen through ingestion, which may compromise other physiological functions (Peterson et al. 2003). Oil contamination has the largest impact on embryos because of their reduced capacity to leave the contaminated area (Short et al. 2003, Moles et al. 1979).

Bridges and culverts used for development of oil production could affect Arctic grayling habitat directly by increasing sedimentation or altering migration routes. Additionally, road development will provide access for humans to utilize streams or reaches previously inaccessible and this could potentially increase fishing pressure in local streams.

6.4. Current Status and Future Landscape Condition

Road development for oil and gas exploration and water withdrawal are considered to be some of the most important development concerns within the study area (see Section E). Oil exploration typically occurs during winter months which could have negative impacts on Arctic grayling overwintering populations. Arctic grayling are considered potentially sensitive to water withdrawal activities, especially during the winter when habitat is most limiting (BLM 2006). Road development at stream crossings could disrupt migratory pathways and alter access between key summering and wintering habitats. Due to the use of small drainages, including ephemeral streams, any development that would impede fish passage within these small drainages, could have negative impacts on Arctic grayling populations within the study area (Morris 2006). Furthermore, because Arctic grayling growth rates are low and recruitment is variable they may not respond to disturbance well (Buzby and Deegan 2000). In addition to direct environmental changes resulting from road construction, roads increase human access to previously remote areas, which facilitates increased recreational use of resources.

Harvest

Arctic grayling is an important subsistence species within the study area. Sport fishing effort is generally light, but variable, with most effort focused on streams and lakes along the Dalton Highway (Scanlon 2012). Estimated harvest of Arctic grayling within the North Slope was 2,204 in 2011 and the 10-year average was 3,028 (Scanlon 2012). Arctic grayling catch in 2011 was estimated around 12,000 fish (Scanlon 2012).

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7. Burbot (*Lota lota*)

Burbot are commonly found in well oxygenated streams and deep lakes (Morris 2003). Burbot are widespread in distribution throughout the study area, but their abundance is considered relatively low. The low abundance of burbot may be attributed to inefficient sampling gear and thus their distribution and abundance is likely underestimated for this area. Migratory patterns are not well known, but in general, burbot are rather sedentary fish except for movements between feeding and spawning areas (Morrow 1980). Burbot are unique in that they spawn under the ice, usually between January and February and fry hatch in March or April. During spawning, adults will gather in large groups and form a writhing mass with a few females at the center, surrounded by many males (Cahn 1936). Burbot mature in six to seven years and are a relatively long-lived species that can live up to 20 years (Morrow 1080). Optimal water temperature for burbot is reported at 15.6-18.3 °C (Scott and Crossman 1973). Juveniles feed on insects for the first few years, and then shift to a mostly piscivorous diet as adults (Morrow 1980). Although considered relatively sluggish in nature, burbot are voracious predators that feed at night. Similar to most other fish species on the North Slope, overwintering habitat is a major factor constraining burbot populations.

7.1. Conceptual Model

The conceptual model below (Figure J-6) is based on a review of the literature and describes the relationship between the various CAs and natural drivers for Burbot. The boxes and arrows represent the state of knowledge about Burbot and the relationship to each attribute.

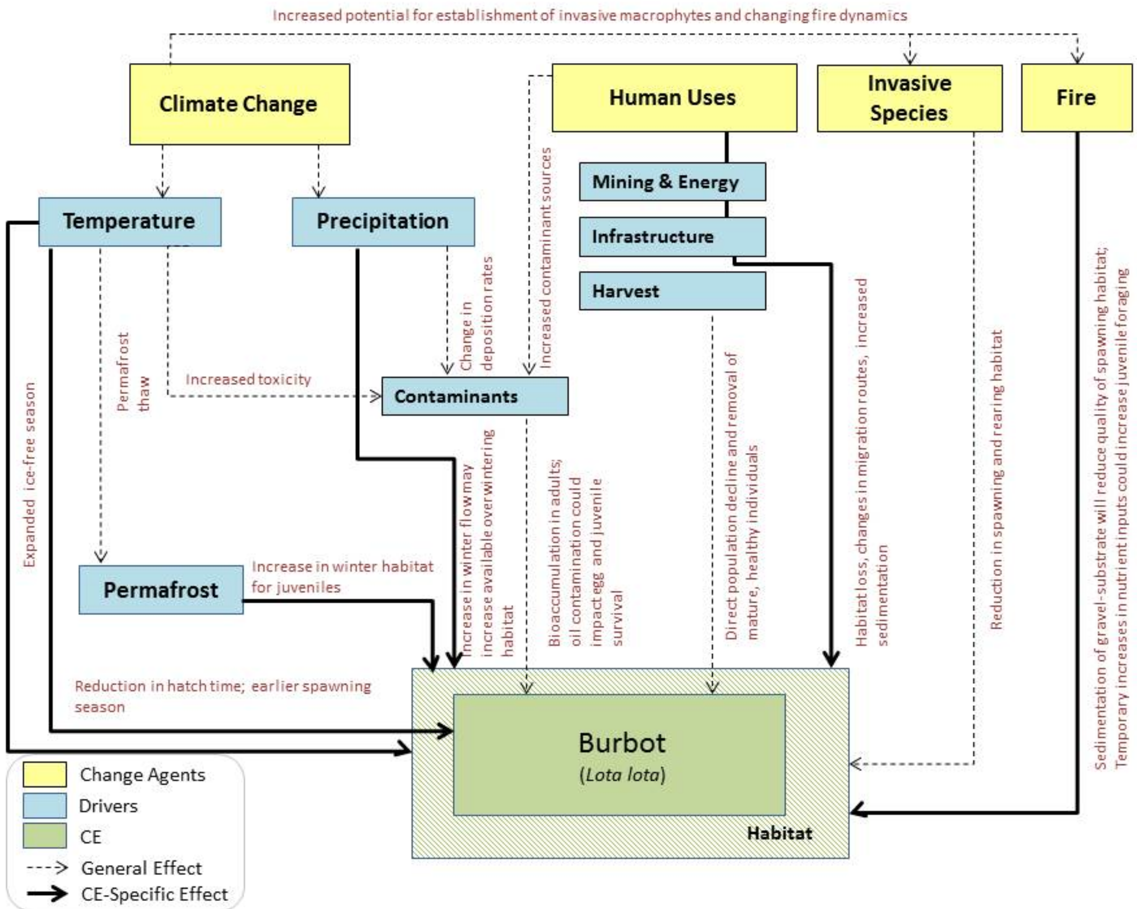

Figure J-6. Principal interactions among population drivers and CAs for Burbot within the North Slope study area.

7.2. Attributes and Indicators

Key CA attribute and indicator data for burbot include: winter precipitation, summer temperature, frost-free days/season length, mean annual ground temperature, road development, habitat fragmentation, oil and gas activities, and contaminated sites (Table J-4).

Table J-7. Attributes and Indicators for Burbot.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[61]	Dec-Feb total precipitation	Spawning habitat	Less precipitation			More precipitation
	Summer temperature[62]	June-August mean monthly air temperature	Summer habitat	Warming water temperatures			No change in water temperature
	Summer temperature[63]	June-August mean monthly air temperature	Parasite infections	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C
	Frost-free days/Season length[64]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Egg development and juvenile growth	Water temperature below 0°C	Water temperature below 3.6°C	Water temperature around 3.6°C	Water temperature above 3.6°C

[61] Specific thresholds are unknown; Increased winter precipitation could increase available overwintering (by increasing the volume of water).
[62] Specific thresholds are unknown; Loss of lake connectivity; lake drying.
[63] Zuray et al. 2012; Thresholds based on salmonid studies; Warmer waters may also increase the prevalence of diseases and parasites.
[64] McCrimmon 1959; Increased temperature may reduce hatching time and increase the amount of time that fish can spend feeding.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	Frost-free days/Season length[65]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Juvenile growth			Increased number of frost-free days	
	Change in mean annual ground temperature at one meter (MAGT)[66]	Permafrost thaw	Overwintering habitat			Increased rates of thaw	
	Change in mean annual ground temperature at one meter (MAGT)[67]	Permafrost thaw	Foraging habitat	From below -1m to above +1m			No Change
Anthropogenic development	Road development[68]	Water quality	Habitat	Numerous intersections with habitats			No intersection with habitats
	Habitat fragmentation[69]	Road development	Habitat	Numerous intersections with habitats			No intersection with habitats

[65] Reist and Bond 1988; Reist et al. 2006; General thresholds; The age at maturity for burbot will likely decrease because individuals will be able to feed more during any single year.

[66] Specific thresholds are unknown; Increased ground flows in winter as a consequence of permafrost thaw could improve overwintering habitat.

[67] GIPL model, Lloyd et al. 2003 (based on GPL model); Bowden et al. 2008 (based on general effects); Increased nutrient input with permafrost thaw will improve feeding habitat by increasing primary productivity.

[68] Thresholds will depend on specific proximity of fish habitat to a site; Turbidity, metals and hydrocarbon contamination, temperature changes.

[69] Morris and Winters 2008; Thresholds are general; Disrupt fish migratory movements; direct destruction of habitat, erosion, sedimentation.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	Oil and gas activities[70]	Water withdrawal	Habitat disturbance or loss	Lakes used by burbot			Lakes not used by burbot
	Contaminated sites[71]	Water quality	Habitat				

[70] BLM 2006; Thresholds are general; Effect water quality, reduce spawning habitat and reduce overwintering habitat.

[71] Thresholds will depend on specific contaminants at a site and proximity to waterbodies; Oil contamination could reduce egg survival and spawning habitat.

7.3. Abiotic Change Agent Analysis

Climate

Burbot are especially well adapted to cold water temperatures. An increase in water temperature as a result of climate change could negatively impact burbot populations (Jackson et al. 2008). Warmer air temperatures will increase the length of the ice-free season to a later freeze-up date and an earlier thaw date (see Section C). A lengthening of the duration of the ice free season could have an impact on the timing of spawning and egg hatching for burbot in the study area. Burbot eggs need approximately 71 days with temperatures between 0 °C-3.6 °C to hatch (McCrimmon 1959). Thus, an increase in temperature may reduce hatching time and increase the amount of time that fish can spend feeding. As a consequence, the age at maturity for burbot may decrease because individuals will be able to feed more during any single year. Changes in water temperatures can also alter the timing of life history events, such as sexual maturation and timing of migration and spawning (Reist et al. 2006). An increase in winter precipitation could potentially increase available overwintering habitat directly by increasing the volume of water and indirectly through the loss of snow insulation which would reduce ice thickness. Warmer waters may also increase the prevalence of diseases and parasites (Reist et al. 2006).

Contaminants

As water temperature increases, certain contaminants become more bioavailable (e.g., mercury) and exposure rates of contaminants in fish will likely increase. Studies in arctic Canada have documented high concentrations of mercury and polychlorinated biphenyl (PCB) in burbot (Carrie et al. 2010). Because these contaminants bioaccumulate and biomagnify they have the potential to accumulate levels that pose a direct health risk to humans and wildlife that consume them. Warming temperatures within the study area may further exacerbate contaminants exposure in burbot within this region by both releasing snowpack and permafrost-entrained mercury, and by enhancing conditions that facilitate methylmercury production (AMAP 2002). Future increases in mercury concentrations in aquatic habitat could pose a health risk to individual fish and potentially reduce the value of burbot as a subsistence resource.

Oil field operations have the potential to introduce contaminants to aquatic habitats within the study area. Whereas, some contaminants such as organochlorines (e.g., PCBs, dichlorodiphenyltrichloroethane metabolites (DDT), and persistent organic pollulants (POPs)) and mercury have both local and distant anthropogenic sources, petroleum products are directly related to local activities. Spilled petroleum products may arise from activities such as drilling and transportation of personnel and materials. Contaminants on roads from vehicle leakage may runoff into drainages affecting water quality. Petroleum products may persist in aquatic environments for years after a spill or leak and can directly affect the health of fish by impacting their ability to adequately take up oxygen through ingestion, which may compromise other physiological functions (Peterson et al. 2003). Oil contamination has the largest impact on embryos because of their reduced capacity to leave the contaminated area (Short et al. 2003, Moles et al. 1979).

7.4. Current Status and Future Landscape Condition

Most development in the study area is related to oil and gas industries (see Section E). Habitat alterations to stream flow or changes to underlying sediments caused by stream crossings can lead to changes in water temperature, turbidity, and dissolved ion concentrations, which in turn could have negative impacts on burbot populations. Major construction, especially of roads will increase erosion and runoff leading to increased stream turbidity and sedimentation, and could introduce contaminates into these habitats (e.g., vehicular leaks and spills). Because burbot spawn during the winter, water withdrawals from lakes could have negative impacts on spawning populations.

Harvest

Ice-fishing for burbot during winter is a popular fishing practice in the study area. Sport fisheries of burbot occur throughout the study area, but are relatively modest compared to other fish species. The largest fisheries occur in the Copper River area. Burbot sport fisheries increased from 1977-1983 by 30% annually (across the state) as a result of increased access to fishing sites and increased human population related to the construction of the Trans-Alaska Pipeline (Stapanian et al. 2010). Statewide harvest from 2002-2011 average 5,600 fish with no apparent trend during that time period. Little is known of the burbot subsistence fisheries on in the study area.

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8. Baseline Fish Information

MQ AF 1	What are the baseline characteristics and trends in fish habitat (lakes and streams), fish distribution, and fish movements?

8.1. Methods

We identified the Fine-Filter CEs (fish) as a **data gap** due to sparse fish occurrence data within the North Slope study area. Fish occurrence data have been collected within the study area, however most of these data are presently available only in non-digitized format (e.g., hardcopies, inventory reports, unpublished data, etc.). Due to the lack of spatial data available, we began collaboration with BLM fisheries biologists to assist with their efforts to enter these fish distribution datasets into the geodatabase RipFish that was developed and is maintained by BLM. Our contribution to this database serves as a final product for the Aquatic Fine-Filter CEs and will allow managers to readily have access to fish distribution data and conduct future spatial analyses. For this MQ we provide a literature review on fish movements and life history information for the Fine-Filter CEs.

8.2. Broad whitefish

Trends in Movements

Broad whitefish are typically anadromous, although freshwater resident populations have been documented in lakes and streams within the North Slope study area. Spawning occurs in late fall to early winter in gravel stream beds (ADF&G 1986). After spawning, broad whitefish migrate downstream to overwinter under the ice in lakes that are deep enough and do not freeze to the bottom, as well as rivers and streams with deep pools (Morris 2006).

Studies have documented the importance of small drainages with lake connectivity for broad whitefish summer habitat on the North Slope (Morris 2006). Suitable overwintering habitat is one of the most severe constraints on broad whitefish populations and the use of ephemeral streams to move into lake habitats for overwintering is especially important (Morris 2006). Broad whitefish have been documented using a diversity of habitats for overwintering in the Teshekpuk Lake area, such as the coalesced lakes at the headwaters of the Mayoriak River, in deep pools (> 15 feet) of the Mayoriak River, and the lower reaches of the Chipp River and its connected lakes (Morris 2006).

Broad whitefish telemetry studies within the Fish Creek drainage and Teshekpuk Lake area have provided insight into summer and winter habitat use as well as general movements within the study area (Morris 2006). Overall, habitat use and movement is highly variable and site fidelity appears to be low (Morris 2006). After ice break up in the spring (though some movements occur under the ice) broad whitefish move between lakes and river drainages and to coastal feeding areas (Craig 1984, Morris 2006). Due to the broad range of habitats used for spawning, foraging, and overwintering, Morris (2006) suggested this species is likely more resilient to localized disturbances.

See database RipFish with recently entered occurrence points (Figure J-7).

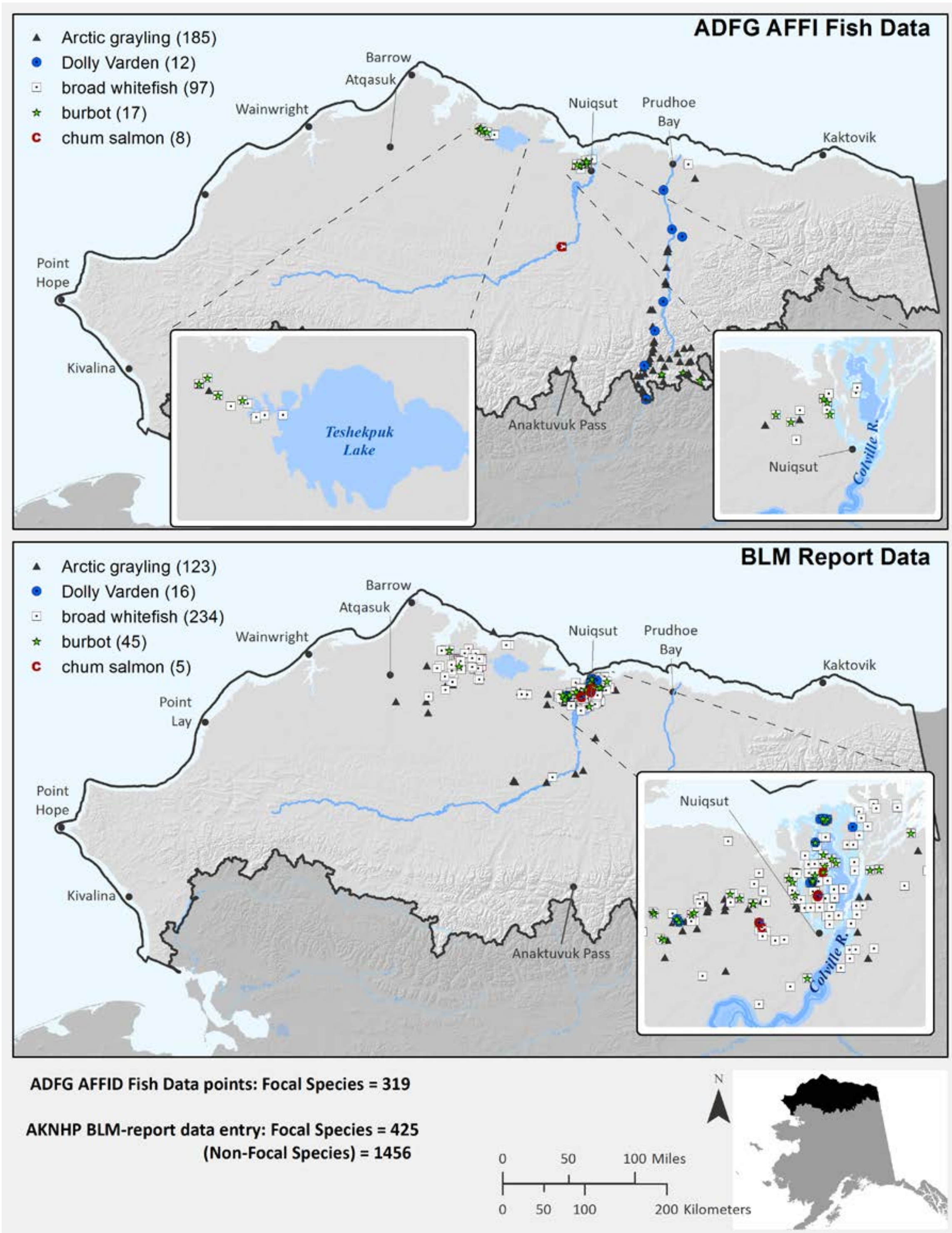

Figure J-7. Existing occurrence point data from AK Department of Fish and Game (ADF&G) Alaska Freshwater Fish Inventory (AFFI) and Bureau of Land Management (BLM) for all five fish species.

8.3. Dolly Varden

Trends in Movements

Dolly Varden occur in the study area as lake-resident, stream-resident, and anadromous populations although they are considered to be predominantly anadromous within the study area. Small streams (including headwater streams) and habitats associated with discharging groundwater are used by Dolly Varden for spawning, rearing, and overwintering. However, these habitats on the North Slope comprise a relatively small proportion of overall stream habitats and thus, are limiting to populations. Overwintering habitat is especially critical and limited to small streams with spring-fed areas.

Movements from winter to summer habitat are poorly studied, but it is assumed that Dolly Varden move away from overwintering areas after spring break-up. Dolly Varden tagging studies have shown that overwintering and spawning habitats may change over time due to changes in channel morphology affecting groundwater inputs (Viavant 2004). Dolly Varden may overwinter in areas not connected to their natal streams (Crane et al. 2005). Major river drainages used by Dolly Varden for spawning, rearing, and overwintering habitat include the Colville, Kuparak, Canning, and Sagavanirktok (Scanlon 2012). Radio telemetry studies within the Kagvik Creek found individual movements were minimal during the winter (Scanlon 2004). It is assumed that Dolly Varden make short distance movements during the winter when looking for better oxygenated waters (Scanlon 2004).

Younger individuals and resident forms will spend the summer foraging within freshwater habitats, whereas, anadromous adults will move to nearshore coastal waters for feeding (Viavant 2004, Scanlon 2004). Dolly Varden generally mature at five to nine years of age and can spawn multiple times throughout their lifetimes (ADF&G 1986). Anadromous adults migrate to the sea at maturity. See database RipFish with recently entered occurrence points (Figure J-7).

8.4. Arctic grayling

Trends in Movements

Arctic grayling are resident species found in freshwater habitats throughout the year within the study area. They can be migratory or relatively sedentary and remain in the same section of a stream year round. Similar to most other arctic fishes, available overwintering habitat is critical to their survival and is considered to be the major limiting factor for populations within the study area.

Their tolerance of low dissolved oxygen levels allows grayling to survive the long winters in areas where many other species would perish. Additionally, Arctic grayling require colder water temperatures than most other fish with thermal maximum temperatures for adults around 20–25 °C (Stewart et al. 2007). For adults, temperatures above 15 °C are considered to induce stress, and temperatures greater than 20 °C cannot be tolerated for long without mortality. However, juveniles can tolerate warmer waters (between 10–20 °C). Thus water temperature of summer rearing and feeding habitats is an important determinant of the summer distribution of Arctic grayling, such that larger grayling tend to be found in the cooler upper reaches of rivers, whereas smaller grayling tend to be located in warmer downstream reaches.

Some individuals have been documented traveling up to 100 miles from their summer feeding areas to overwintering habitat, while some individuals remain in the same stream year round (ADF&G 2015). Glacial rivers in the Brooks Range area are important migration corridors to tundra streams where grayling spawn and rear (Tack 1980). Arctic grayling migrate to their spawning areas in early spring. Some individuals demonstrate strong site fidelity, returning every year to the same spawning and feeding areas (Morrow 1980, Morris 2003). Spawning usually occurs in outlet streams of shallow lakes and inlet streams of deep lakes (Tack 1980). Arctic grayling usually begin their migration from spawning habitat to feeding habitats after spring break-up (Tack 1980). Migration to overwintering habitat begins in early fall before ice formation (ADF&G 2015, Tack 1980).

8.5. Chum salmon

Trends in Movements

Chum salmon are anadromous fish that spawn in summer or fall; juveniles migrate directly to the ocean where they spend two to four winters at sea. Very little is known about chum salmon distribution and movements within the study area. Spawning populations of chum salmon have been documented in the Colville River and elsewhere on the North Slope (Bendock 1979, Craig and Haldorson 1986), but it is unknown whether these spawning events sustain consistent runs of chum salmon.

In general, chum salmon almost always return to spawn in their natal stream in late summer or early fall (Morrow 1980). Embryos hatch after 3–4 months, depending on water temperature and remain in the gravel while continuing to absorb nutrients from the egg yolk for an additional 60–90 days before emerging (Morrow 1980). Fry emerge from the gravel during spring (April–May) and migrate to the ocean within days or a few weeks after hatching (Salo 1991).

Overwintering habits of chum salmon are also poorly studied within the North Slope study area, but it’s assumed that chum salmon spend their first winter in the Beaufort Sea, offshore deep under pack ice, and then migrate to the North Pacific for the remainder of their marine phase (Irvine et al. 2009). Winter temperatures of arctic marine waters are generally lethal for salmon. The lower thermal temperature limit for chum salmon is 2.7 °C (Azumaya et al. 2007). Typical arctic stream temperatures average between 0 and 0.5 °C in winter months, but pockets of groundwater provide shelter with temperatures between 2-5 °C throughout winter months (Craig and Haldorson 1986). Warming conditions may be producing more suitable habitat for salmon in the Arctic. See database RipFish with recently entered occurrence points (Figure J-7).

8.6. Burbot

Trends in Movements

Burbot are commonly found in well oxygenated streams and deep lakes (Morris 2003). Burbot are considered to be widespread in distribution throughout the study area, but at relatively low abundance. Migratory patterns are not well known, but in general, burbot are rather sedentary fish except for movements between feeding and spawning areas (Morrow 1980). Burbot are unique in that they spawn under the ice, usually between January and February and fry hatch in March or April. During spawning, adults will gather in large groups and form a writhing mass with a few females at the center, surrounded by many males (Cahn 1936). Burbot mature in six to seven years and are a relatively long-lived species that can live up to 20 years. Optimal water temperature for burbot is reported at 15.6–18.3°C (Scott and Crossman 1973). Juveniles feed on insects for the first few years, and then shift to a mostly piscivorous diet as adults (Morrow 1980). Although considered relatively sluggish in nature, burbot are voracious predators that feed at night.

Similar to most other fish species on the North Slope, overwintering habitat is a major factor constraining burbot populations. Overwintering areas have been documented in the Colville, the Sagavanirktok, and Kuparuk Rivers (Bendock 1980). Very little is known about burbot movements within the study area. However, Morris (2003) documented movements of up to 30km within the main channel habitats of Inigok Creek, Fish Creek, and Judy Creek. See database RipFish with recently entered occurrence points (Figure J-7).

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9. Effects of Oil and Gas on Fish

MQ AC 2	How does oil and gas infrastructure (e.g. roads, pads, pipeline), both permanent and temporary, affect fish habitat, fish distribution, and fish movements?

Oil and gas infrastructure includes the construction of roads, pads, and pipelines that have the potential to cause adverse effects to important fish habitat, to fish distributions, and to fish movements within the study area. Aquatic habitats within the study area provide important spawning, foraging, rearing, and overwintering habitat for both anadromous and freshwater fishes. Development within or near aquatic habitats may result in direct impacts to fish species and habitats at the development location, but also within surrounding areas and downstream from these activities.

9.1. Methods

We identified the Fine-Filter CEs (fish) as a **data gap** due to sparse fish occurrence data within the study area. Fish occurrence data have been collected, but most of these data are not electronically available. Consequently, we were not able to produce distribution maps for any of the fish species which precluded us from conducting spatial analysis related to this question. Instead, we provide a literature review of the potential impacts of oil and gas infrastructure on fish habitats, distribution, and movements. See Section E. for a thorough review of oil and gas development and associated infrastructure within the study area.

9.2. Results

Infrastructure and development for oil and gas activities, such as road construction (gravel and ice roads), pads, pipelines, and culverts, can have detrimental effects on fish spawning, rearing, and overwintering habitat. A number of factors related to development can have impacts on fish and their habitats including: direct habitat alterations, changes in water quality and quantity (e.g., from winter water withdrawals), and release of contaminants.

Road construction has the potential to cause direct destruction of habitat as well as high sediment loads in streams that can adversely affect fish embryo survival (Everest et al. 1987) and fry emergence and increased predation (Weaver and Fraley 1993). Similarly, stream culverts at road crossings may channelize river systems, impede fish passage, and alter migration routes to overwintering and feeding areas. For example, a recent study focused on the impacts of stream crossing structures near Prudhoe Bay found that 29% of the crossings evaluated restricted or completely blocked fish passage (Morris and Winters 2008). Additionally, habitat alterations to stream flow or changes to underlying sediments caused by stream crossings can lead to changes in water temperature, turbidity, and dissolved ion concentrations, which in turn could have negative impacts on fish populations (Hanley et al. 1983). Efforts to mitigate these impacts have been developed and include building bridges instead of culverts, or constructing culverts on smaller streams. Additionally, streams and rivers designated as Essential Fish Habitat (EFH) are provided regulatory protection under the Anadromous Fish Act. Similarly, pipelines cannot be built within 500 feet of fish-bearing waterbodies thus limiting more direct impacts from this type of infrastructure (BLM 2012).

Temporary infrastructure, including the building of ice roads has the potential to alter water quantities in streams and lakes and affect overall water quality. A review of the impacts of water withdrawal on fish habitat is discussed in Section I.

Removal of stream vegetation during construction or infrastructure development can have short-term affects by altering stream temperatures and affecting thermal regimes by increasing the amount of sunlight exposure (Beschta et al.1988, Moore et al. 2005). Similarly, contamination of fish habitats can have both short-term and long-term impacts, depending on the time of year and the type and extent of contamination. Road construction can result in the increase of erosion and runoff leading to increased stream turbidity and sedimentation. Furthermore, vehicular leaks and spills could introduce contaminates directly into fish habitats. Oil contamination has the largest impact on embryos because of their reduced capacity to leave the contaminated area (Short et al. 2003, Moles et al. 1979). Thus, spills that occur within spawning habitats could have the most detrimental effects on fish populations.

Populations of resident species such as burbot and grayling may experience the greatest impacts from oil and gas infrastructure given that they are dependent, year-round, on freshwater habitats within the study area. On the other hand, chum salmon and other anadromous species spend the majority of their life in the marine environment thus potential impacts are likely to be localized to spawning and the relatively short juvenile rearing period. Fish species that predominately use low-gradient streams, may be more susceptible to increased sedimentation (due to lower stream flow) related to road development activities than other species.

Gravel mined for road and pad development has evolved since the opening of the Prudhoe Bay Oilfield in 1968. Early practices included mining from river floodplains, but agencies discouraged this method by the mid-1970s when mining practices were modified to target uplands sites for multiple users (Mclean 1993). Many of these mine sites were converted to reservoirs and subsequent studies by U.S. Fish and Wildlife Service and Alaska Department of Fish & Game led to the finding that they were providing high quality habitat for fish and wildlife (Ott et al. 2014). New policies beginning in the late-80s allowed for gravel mining in floodplain habitats when the potential enhancement of fish and wildlife habitats could be shown (Mclean 1993).

Rehabilitation practices for gravel pits include connecting them to streams and rivers so that they can be recolonized and excavating along the shoreline to provide shallow littoral habitat for juveniles fish (Mclean 1993, Jorgenson and Joyce 1994). Monitoring of reclaimed gravel pits has shown that multiple species may use them in both summer and winter, depending upon the diversity of habitats present and the size of the stream to which it is connected (Jorgenson and Joyce 1994).

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K. Data Gaps and Omissions

E. Jamie Trammell[1], Tracey Gotthardt[1], Monica L. McTeague[1], Justin R. Fulkerson[1], Nancy Fresco[2], Tina Boucher[1], Leah Kenney[1], Diwakar Vadapalli[3], and Matthew L. Carlson[1]

[1]Alaska Natural Heritage Program, University of Alaska Anchorage, 3211 Providence Drive, Anchorage, Alaska 99501

[2]Scenarios Network for Alaska & Arctic Planning, 3352 College Road, Fairbanks AK 99709

[3]Institute of Social and Economic Research, University of Alaska Anchorage, 3211 Providence Drive, Anchorage, Alaska 99508

Summary

Section K. *Data Gaps and Omissions* details the compiled data gaps from all topics included in the REA and describes important omitted management questions.

Contents

Management Questions

Tables

1. Data Gaps

The data gaps summarized here are often related to the limitations described after the results for each CA, CE, or MQ in the previous sections. The summary below is intended to provide comprehensive documentation of all data gaps encountered throughout the REA process for the North Slope study area. Data gaps are organized by CA and then CE.

1.1. Data Gaps Summary

Significant data gaps limited the ability of our team to address the 20 selected Management Questions (MQs) based on the lack of available and reliable data for the entire study area. Below we summarize the key data gaps for each MQ that limited out ability to address the MQs spatially and identify which critical datasets would be required to address the MQ fully (Table K-1).

Table K-1. Key data gaps for the North Slope REA for each Management Question (MQ) and critical datasets that would be required to fully address the selected MQ.

MQ #	Management Question	Dataset Gap	Dataset Needed
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?	Not enough fire data in the region to make the model very robust.	Need more information on fire history.
AB 2	How will permafrost change spatially and temporally over the next two decades?	No data on fine-scale permafrost change; feedback from other CAs not accounted for in the model.	Higher resolution permafrost map; integrated permafrost model with other CAs to better assess temporal component
AP 1	What physical and perceptual limitations to access to subsistence resources by local residents are caused by oil/gas activities?	No surveys employed to specifically address this question	Structured surveys on an annual basis
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 ANWR, Gates, Noatak?	No air quality models created for the entire region	Long time monitoring of air quality in North Slope and other contributing areas

MQ #	Management Question	Dataset Gap	Dataset Needed
AC 1	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?	No water withdrawal maps are available. The lake distribution maps are uncertain and have a high degree of error.	Need water withdrawal maps for the region and need an update to the National Hydrography Dataset (NHD).
AC 2	How does oil and gas infrastructure (e.g. roads, pads, pipeline), both permanent and temporary, affect fish habitat, fish distribution, and fish movements?	Not enough fish occurrence data to develop fish distribution datasets.	Need more fish occurrence data in order to develop fish distribution models.
AF 1	What are baseline characteristics and trends in fish habitat (lakes and streams), fish distribution, and fish movements?	Not enough fish occurrence data to develop fish distribution datasets.	Need more fish occurrence data in order to develop fish distribution models.
AF 2	What are the measurable and perceived impacts of development on subsistence harvest of fish?	No surveys employed to specifically address this question	Structured surveys on an annual basis
AT 1	What parameters can help measure impacts from anthropogenic activities independently of natural cycles and vice versa?	No data that has been consistently collected to address this question	Consistent monitoring of both natural and human systems
AT 2	What potential impacts will oil/gas exploration and development have on CE habitat?	Magnitude of future oil and gas development unknown	More detailed estimate of oil and gas development footprint
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?	No systematic collection	Systematically collected contaminant data for all subsistence species

MQ #	Management Question	Dataset Gap	Dataset Needed
TC 1	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.)	Current extent, much less future extent, is poorly represented in publically available datasets.	Comprehensive infrastructure dataset available to the public
TC 2	What are the changes in habitat and vegetation related to changing permafrost conditions, and what will these changes mean to wildlife and habitats?	Mismatch of land cover datasets used by the different models. Mismatch of land cover used to model species and those used to map coarse-filter CEs.	Comprehensive, unified, hierarchical land cover dataset that is used across all modeling efforts.
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?	Lack of understanding of hydrologic conditions, no spatial data, no hydrologic models, and no hydroclimatic models.	Watershed-scale hydrologic models for the North Slope
TC 4	What are the expected changes to habitat as a result of coastal erosion and coastal salinization?	No comprehensive current shoreline and historic shoreline maps and no storm surge model.	Consistently developed current shoreline and historic shoreline maps and a storm surge model.
TC 5	How is climate change affecting the timing of snow melt and snow onset, spring breakup and green-up, and growing season length?	Temporal resolution of climate data is too coarse to precisely quantify these changes	Daily climate data, better snow models
TF 1	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?	No spatial data for land birds and their habitat over time.	Need spatial data on land birds and their habitat over time.

MQ #	Management Question	Dataset Gap	Dataset Needed
TF 2	What are caribou preferences for vegetation communities? Where do these vegetation communities exist?	No high resolution data (<30m) on lake margins, riparian corridors, and tidal marshes.	Need lake margin, riparian corridor, and tidal marsh vegetation maps at higher than 30m resolution.
TF 3	What are the measurable and perceived impacts of development on subsistence harvest of caribou?	No surveys employed to specifically address this question	Structured surveys on an annual basis
TF 4	What are caribou seasonal distribution and movement patterns and how are they related to season and weather?	No kernel density, whether seasonal or annual, were available for the Porcupine Herd. No raw telemetry data was received by AKNHP for the Western Arctic, Teshekpuk, and Central Arctic herds. No seasonal fall and spring ranges were available for the Teshekpuk Herd.	Radio-collar data would improve the accuracy and utility of the seasonal distributions and would enable mapping of ranges during migration seasons.

1.2. Data Gaps Related to Climate Change Modeling

Uncertainty relating to climate modeling, climate data, and the cliomes model are described in detail in Section C-1.5. This uncertainty led to some limitations in the temporal and spatial scale at which results could be analyzed and the conclusions that could be drawn from the data. In addition to the constraints imposed by these inherent uncertainties and limitations, there were also constraints to this analysis imposed by gaps for which no climate data was available. These gaps are summarized below.

- Available temperature data refers to air temperature only. Although spot data for water temperature from specific sites and locations are available, no systematic, consistent, complete, or gridded data are available. This limits the applicability of SNAP provided climate data to aquatic assessments.
- Although many of the weather phenomena that affect CEs are linked more closely to extreme events than to average conditions, no consistent gridded climate data were available at a temporal scale finer than the monthly data available from SNAP. Lack of daily data makes it difficult to project events such as extreme heat, extreme cold, flash floods, and rain-on-snow events.

- The available precipitation data do not differentiate between rain and snow; nor is any direct metric available for snow pack depth, rain on snow events, or other parameters that directly or indirectly impact certain CEs. We did estimate snow-day fraction and cumulative snowfall for the season, but this does not include compaction, sublimation, wind transport, etc., and thus provides only a very coarse and approximate surrogate for snow depth. We recognize that snow pack is very important to all species and suggest that this is a key data gap for the region.
- Long-term climate stations are extremely sparse in general in Alaska, and very few of these stations are located above 500 m elevation.
- Lack data on microclimates, driven (in part) by the lack of a high resolution DEM.
- Need more studies that explicitly address the climate variables that can be modeled and the response of species (especially CEs) to those variables.
- Lack of defined (or even hypothesized) thresholds for CEs in response to change agents.
- Time lags can be expected between changes in climate and associated changes in vegetation, but there is little data on the duration of these lags.
- The cliomes model only correlates climate envelopes to vegetation communities and therefore does not take into account ecological changes such as fire on the landscape.
- The cliomes model is linked only to climate, and not to physiographic features that also determine habitats and ecosystems.

1.3. Data Gaps Related to Permafrost

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.

- Limited number of field validation points.
- Lack of a regionally-defined permafrost model. Current model was developed statewide, which may oversimplify soil thermodynamics occurring on the North Slope.
- Lack of historical data on the vegetation response to changes in permafrost conditions.
- Soil thermal dynamics are complicated by feedback between fire, vegetation, and climate, and no data or models fully account for these feedbacks.
- 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 or the response of permafrost.
- The best available permafrost model provides outputs at 1 km resolution. Discontinuous permafrost can vary at scales much finer than this, due to variable slope and aspect, drainage patterns, etc.
- Thermokarst risk is based only on soil conditions and topography, and is not yet directly linked to permafrost data.
- The surface area over which the changes in active layer occur makes even small changes significant forces on the landscape, but these changes are hard to predict. The transition from

low-centered to high-centered polygons, for example, can be driven by a couple centimeter change in elevation.
- Little information is known about how water moves through the active layer and out into the ocean. Understanding the role of the active layer in maintaining or creating hydrologic connectivity is essential for understanding how vegetation could respond to changing permafrost conditions.

Management Questions

MQ AB 2	How will permafrost change spatially and temporally over the next two decades?

As noted above, readily available models do not capture fine-scale changes in permafrost, although these changes can be estimated, based on broader-scale warming of soils. Additionally, temporal changes may be altered by feedbacks not accounted for in the model. For example, fire is likely to accelerate thaw in burned areas, especially if the fire is high-intensity, and removes the insulating organic layer. The available model also does not fully account for localized changes along waterways or around lakes.

1.4. Data Gaps Related to Fire

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 must be considered more broadly, in terms of trends over time, rather than in terms of specific fire behavior at particular sites.

- No clear and consistent data are available regarding fire severity.
- No consistent data are available on changes in lightning strikes or other fire starts over time. The existing lightning strikes dataset does not serve our purposes because the frequency of lightning strikes recorded increases with advances in detection technology.
- Calibrating tundra fire frequency is extremely difficult, due to the rarity of such fires and thus the sparseness of available data.
- 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.
- ALFRESCO uses more general landcover definitions from those used elsewhere in this project, and these cannot be completely reconciled. An updated and broadly accepted vegetation or land cover map need to be developed for the region so future modeling efforts can use a consistent baseline.

Management Questions

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?

Because tundra fires are rare, and are projected to continue to be rare, and because occasional very large fires can create outliers in the data, assessing trends over time can be very difficult. In other words, changes in mean values are likely to be small compared to standard deviation or other measures of variability. Additional data on the nature and size of tundra fires in similar systems could help better parameterize the ALFRESCO model.

1.5. Data Gaps Related to Invasive Species

Uncertainty related to invasive species is described in detail in Section D-3.4. These uncertainties led to limitations in the scale at which results are meaningful and what conclusions could be drawn. These primary gaps are summarized below.

- Survey data for invasive species is lacking for many regions and concentrated in and adjacent to population centers. Therefore current distributions of non-native species are likely to represent a subset of the total area. Interpretations of current and future infestation vulnerabilities are likely to inflate the importance of roads and population centers.
- Future infestation vulnerabilities are based on development scenarios and climate change models that are inherently uncertain – caution should be exercised in interpretation of these outputs.
- Interactions among disturbances, climate change, and human activities are likely to be very important in invasive species establishment; however we have limited understanding of these indirect effects.
- Research specifically directed towards movements of invasive species in rural Alaska is very limited.
- Research on ecological impacts of invasive species on species and habitats of conservation concern (and specifically for CEs represented here) are largely absent in Alaska.

1.6. Data Gaps Related to Anthropogenic Change Agents

Quantifying the human component within an ecoregional context is particularly challenging and fraught with data gaps due to the transdisciplinary nature of the endeavor. Here are some of the key data gaps associated with this assessment:

- Social data not collected or reported at ecological scales or within ecological boundaries
- Road and other land use data not consistently created across jurisdictional boundaries, leading to spatial mismatches and uncertainty in accuracy and authority.

- Oil and gas infrastructure data is still largely proprietary, thus limiting the ability to comprehensively map human activity on the landscape.
- Subsistence data not consistently collected or mapped for all villages across the North Slope.
- No method for tracking food sharing across the ecoregion, limiting the ability to understand region-wide impacts of changes in subsistence species accessibility.

Management Questions

Multiple management questions concerning people's perception of environmental change were particularly challenging due to limited data availability. These data gaps stem partially from the difficulty in translating traditional ecological knowledge into western scientific concepts.

- Lack of targeted surveys to explore the perceived versus observed changes in caribou, fish and access to subsistence in general due to oil and gas development. Few studies that have explicitly studied the relative impact of human activities versus natural disturbances on key subsistence species.

1.7. Data Gaps Related to Landscape Condition Model (LCM)

Although the LCM utilizes our best available knowledge related to impacts of human land use on a landscape, there are some necessary generalizations made. Not all landscapes respond the same way to specific land uses (i.e. roads likely have a larger impact on wetlands than uplands), and thus the LCM serves as a relative measure of impact.

- Only a few publically available studies have assessed the impacts of current ice roads on various ecosystem functions, and the results are unclear.
- Snow and ice road data was not available for the entire ecoregion, nor is it something that was modeled into the future, thus limiting our ability to model LCM into the future.
- Accurately mapped local road data are poor, as many are missing from the Alaska Department of Transportation dataset, and could not be extracted from other datasets.
- Trail data are of poor quality and unreliable. Accurately mapped and attributed trail information is an important data gap identified in this analysis, and would allow for a more accurate estimate of landscape condition.
- Spatial data on gravel pits and mines were not available and were therefore not included in the LCM.

1.8. Data Gaps Related to Terrestrial Coarse-Filter Conservation Elements

Land cover and vegetation distributions are well mapped on the North Slope compared to other regions in the state. However, there are still some key data gaps that would improve this assessment if they were filled.

- Current barrier island distribution data are incomplete, therefore we used National Wetland Inventory (NWI) polygons.
- Current Tidal Marsh distribution are incomplete, therefore we used NWI polygons.
- The NSSI map does not include an accuracy assessment. Therefore we are unable to provide a level of confidence for the distribution of landcover classes used to generate the CEs.
- A mismatch of scale exists between SNAP products and vegetation mapping. Therefore intersections between products mapped at 30 m resolution and SNAP products can be misleading, especially for CEs with small or linear distributions.
- The ALFRESCO vegetation map is too generalized to be useful for CEs that include tundra landcover classes. A key data gap is a consistently used, multi-scaled map of vegetation and land cover for the region.
- Spatial data on gravel mines were not available and are considered a data gap; this layer was not included in the Landscape Condition Model or in the current footprint for oil and gas.

Management Questions

MQ TC 1	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.)

Few studies have been designed to address the cumulative impacts of oil and gas development on vegetation and hydrology. Furthermore, none have produced spatial data that was available for this analysis. Our best available information was that produced by the LCM, limiting our ability to accurately address this management question.

- No public spatial data on the impact of roads and pipelines on hydrology in the North Slope
- No public spatial data on the impact of roads and pipelines on vegetation in the North

MQ TC 4	What are the expected changes to habitat as a result of coastal erosion and coastal salinization?

We explored contrasting an older coastline map with a new coastline map to empirically determine which habitats had been lost or gained due to coastal erosion. However, the old coastline map was inaccurate and generating a new coastline is beyond the scope of this assessment. A storm surge model would be needed to evaluate the effects of coastal inundation.

- Lack of a consistently developed current and historic shoreline
- Lack of a storm surge model for the region

1.9. Data Gaps Related to Terrestrial Fine-Filter Conservation Elements

Publically available spatial information on species distributions has long been missing from Alaska. Fortunately, the AKGAP program has made a substantial dent in that data gap for the state. However, data at the regional scale is still often missing, and the need for more systematic surveys or non-game species is essential.

- The AKGAP distribution model for the Nearctic brown lemming was the best available model that we could obtain for this assessment, yet associated accuracy statistics were low. An improved distribution model, or alternative data to test the model are recognized as a priority.
- No suitable snow depth layer exists currently for the North Slope study area. A suitable snow-depth layer for the North Slope study area would allow for:
    - Better interpretation and prediction of snow characteristics in relation to sub-nivean and caribou habitat availability, and also ptarmigan herbivory.
    - Identification of where snow depth might preclude caribou travel or limit migration routes in early spring.
- We lacked a suitable spatial layer to explore the relationship between spring storm events and Lapland longspur distribution.
- Since limited spatial data were available on fire, most potential changes related to ptarmigan habitat were qualitatively described based on literature review and ALFRESCO model outputs.
- We felt we lacked suitable raptor distribution models to explore the potential relationships with permafrost and thermokarst disposition. Although we sought to compile a comprehensive raptor dataset for the REA it is likely that there are numerous data sets that are lacking from this synthesis of observations. We developed a database structure for this project that includes 5,166 records, which can easily be added to and updated over time as new information becomes available.

Management Questions

MQ TF 1	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?

- Data were not available spatially, but rather in tabular form. Spatial composition and population data is an important data gap.

MQ TF 2	What are caribou preferences for vegetation communities? Where do these vegetation communities exist?

- Lake margins and riparian corridors are preferred habitats for caribou in summer. These habitats may not be adequately represented in the NSSI Landcover Map because they often occur with widths less than 30 m, therefore not filling a 30 × 30 m grid cell for vegetation classification. There also likely exists more tidal marsh vegetation than is classified as such in the NSSI landcover map because tidal marshes are often not wide enough to fill the 30 × 30 m grid cell mapping resolution.

MQ TF 4	What are caribou seasonal distribution and movement patterns and how are they related to season and weather?

- The importance of habitat as represented by kernel density, whether seasonal or annual, for the Porcupine Herd was not obtained because of telemetry data for the Porcupine Herd is managed jointly between Alaska and Yukon. Although AKNHP formed a data sharing agreement with ADF&G within the timeframe of the REA, AKNHP did not receive any raw telemetry data. We were therefore unable to produce methodologically identical seasonal kernel densities for the Western Arctic, Teshekpuk, and Central Arctic herds. The lack of unified methodology between all herd ranges and seasons precludes detailed comparison between herds or seasons.
- Seasonal ranges for fall and spring migrations were only available for the Teshekpuk Herd, and therefore fall and spring ranges were not mapped for this assessment. Radio-collar data would improve the accuracy and utility of the seasonal distributions and would enable mapping of ranges during migration seasons.

1.10. Data Gaps Related to Aquatic Coarse-Filter Conservation Elements

Data gaps are particularly abundant for aquatic systems in the North Slope. From fundamental datasets like the NDH, to basic information about hydrologic regimes, systematic collection, synthesis and mapping of this data is absent.

- No existing aquatic habitat classification exists for the North Slope (or anywhere in the state).
- The National Hydrography Dataset (NHD) is very outdated (most topographic maps were created in the 50's and 60's) and stream locations and lake areas have likely changed due to natural hydrologic disturbances and climate change.
- Gauging stations are few and far between, limiting our ability to understand potential changes in hydrographs due to climate change.
- Little consensus exists on what constitutes a connected vs. disconnected lake in the North Slope, much less data to support those classifications.
- Water temperature data is few and far between and not systematically collected for regional-scale assessments of climate change.

Management Questions

MQ AC 1	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?)

Spatial data on water withdrawal is a big data gap limiting our ability to effectively address this question. Additionally, no systematic monitoring of water quality at sites with withdrawal is performed.

1.11. Data Gaps Related to Aquatic Fine-Filter Conservation Elements

We identified the Fine-Filter CEs as a data gap during the data discovery phase of this project. Similar to previous REAs in Alaska (Seward Peninsula and Yukon-Kuskokwim REAs), aquatics data related to both Coarse-Filters CEs and Fine-Filters CEs have been very limited and have largely been identified as data gaps. The Fine-Filter CEs for the NOS study area are especially data limited to the point that we were not able to accurately produce distribution models or maps for any of our Fine-Filter CEs.

Our efforts to assist BLM with entering fish distribution data into RipFish database have contributed greatly to our understanding of fish baseline data for the NOS study area. However, information on feeding and overwintering areas, migrations and movements, and population level studies are lacking. Future research efforts should focus on obtaining these data for the North Slope.

- Water temperature data for the NOS study area is lacking, and the impacts to fish that occupy the North Slope is largely unknown.
- Climate-linked aquatic models to predict future changes in water temperature are not available.
- Data related to long-term trends and temporal changes in fish populations are not available.

Management Questions

MQ AC 2	How does oil and gas infrastructure (e.g. roads, pads, pipeline), both permanent and temporary, affect fish habitat, fish distribution, and fish movements?
MQ AF 1	What are baseline characteristics and trends in fish habitat (lakes and streams), fish distribution, and fish movements?

Without fish distribution models, and given the limitations of the human footprint maps we developed, there are some fundamental data gaps in addressing these management questions.

- No fish distribution models
- Imperfect human footprint data
- Lack of consistent fish population monitoring
- Lack of temporal data on fish habitat, limited known about their current distribution, much less historical distribution.
- Lack of available data on fish movements.

2. Omitted Management Questions

A list of Management Questions (MQs) was initially generated by the UA Team after they scoured various documents, identifying management and research objectives for the North Slope. Additionally, the BLM Arctic Field Office identified MQs for the NPR-A in 2011, and also provided additional questions specifically for this effort. This produced a list of approximately 275 potential MQs. However, because the REA is rapid, the BLM has mandated that only 20 - 40 MQs be addressed through 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 ranking 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 for prioritization. We tallied the ranks and reordered the questions for another round of ranking. The second round yielded responses, which we again tallied and sorted accordingly. The questions were ranked a final time with a result of a clear set of 20 MQs that were considered the highest priority by the AMT and Technical Team (Section B - 2-3). We retained an additional 10 MQs that were ranked highly by the AMT, as additional questions to consider if we were forced to remove MQs due to data gaps (Table K-2). A complete list of original and omitted MQs ranked as high, medium, low, and out of scope is included as Table K-3, Table K-4, Table K-5, and Table K-6.

Table K-2. Second Tier MQs, based on the Delphi survey of MQs. Questions were subsequently weighted to reflect scores of high, moderate, and low priority ranks. The cumulative scores for these questions represent the next highest priority and were maintained as alternative MQs in the event data gaps prohibited addressing a top priority MQ during analysis.

MQ #	Management Question	CE	CA
TC 6	How will plant species composition shift in response to long-term climate change, and what are the implications for habitat structure and quality of the prevalent available forage (i.e., digestibility, nutrient content)?	Terrestrial- Coarse Filter	Abiotic
AA 1	Have environmental changes caused people to adjust their hunting/fishing/gathering and food handling practices?		Abiotic and Anthropogenic
TF 5	What is the seasonal variation in caribou food production and availability (i.e. likelihood of increased icing events) under changing climate conditions?	Terrestrial- Fine Filter	Abiotic
AP 3	What are the appropriate social and economic indicator data that should be gathered (e.g., for historic baseline and trend data)?		Anthropogenic
AF 3	What are the expected changes in fish distribution?	Aquatic- Fine Filter	Abiotic and Anthropogenic
TC 7	Will fire intensity and burn severity change; and if it does, what will be the impacts, for example on permafrost and the active layer, vegetation and herbivores?	Terrestrial- Coarse Filter	Abiotic
AP 4	How should we integrate local and traditional knowledge into social and economic investigations of North Slope people and communities?		Anthropogenic
AP 5	Where are the locations of soils suitable/unsuitable for infrastructure development?		Anthropogenic
AA 2	How will changes in permafrost condition manifest for winter tundra travel, does an increasing depth of the active layer impact seasonal tundra travel?		Abiotic and Anthropogenic
AA 3	What industry activities are seasonally-dependent and how is climate change affecting that? (includes ice roads, breakup flooding, etc.)		Abiotic and Anthropogenic

3. Highest Ranked Management Questions

Table K-3. Highest ranked MQs provided to AMT 1 Workshop for review. Organized by theme (listed alphabetically), showing source of the question, original question, and rewrite of question (if applicable)**.**

Theme	Source	Original Question	Rewritten Question
Air Quality	ArFO	How is oil and gas development on the North Slope impacting near- and far-field air quality?	
Air Quality	ArFO	How will oil and gas development in NPRA contribute to air quality in the future, with particular emphasis on communities and "sensitive class 2" areas such as ANWR, Gates, Noatak?	
Air Quality	ArFO	How will the evolving fire regime on the North Slope contribute to air quality in the future, with particular emphasis on communities and "sensitive class 2" areas such as ANWR, Gates, Noatak?	
Climate and Weather	Emerging Issues	How will changes in weather pattern/climate affect winter exploration seasons?	
Climate and Weather	WildREACH	How much change will occur in the timing of snow melt and snow onset?	
Climate and Weather	WildREACH	How will changes in precipitation, evapotranspiration, and active layer depth alter summer surface water availability in shallow-water and mesic/wet tundra habitats?	
Climate and Weather	WildREACH	How reliable are the projections for increasing precipitation and evapotranspiration?	
Climate and Weather	WildREACH	How will changes in precipitation, evapotranspiration, and active layer depth alter summer surface water availability in shallow-water and mesic/wet tundra habitats?	
Contaminants	Emerging Issues	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?	**Rewritten** to: Have contaminated sites been mapped and 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?

Theme	Source	Original Question	Rewritten Question
Cultural Resources	ArFO MQs, NPRA AIM	What are the effects of climate change on cultural and paleontological resources?	
Erosion	Emerging Issues	What are the expected changes to habitat as a result of erosion and related redistribution of both fresh and saline water?	**Rewritten** to: What are the expected changes to habitat as a result of coastal erosion?
Fire Regime	Emerging Issues	How will vegetation respond given projected fire and climate regimes?	
Fire Regime	Emerging Issues	What are the current links between climate and fire, fire and vegetation, vegetation and ungulates (especially caribou)?	
Fire Regime	Emerging Issues	Given future scenarios for climate, fire, and vegetation response, how are herbivores likely to respond?	
Fire Regime	Emerging Issues	How will key forage species for caribou and other ungulates be impacted by a changing fire regime, and will this alter habitat use and migration?	
Fire Regime	Emerging Issues, NPRA AIM	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 on the North Slope?	**Rewritten** to: 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?
Fire Regime	Emerging Issues	Will lightning activity change in terms of frequency, location, seasonal pattern?	
Fire Regime	Emerging Issues	Will fire intensity and burn severity change; and if it does, what will be the impacts, for example on permafrost and the active layer?	
Fire Regime	NPRA AIM	What changes in permafrost and vegetation will be driven by fire and how will these effect the communities that they support?	
Fire Regime	Emerging Issues, NPRA AIM	Is there/what is the current relationship between fire, vegetation succession, and landform on the North Slope?	
Fire Regime	NPRA AIM	How will permafrost thaw affect fire regime?	

Theme	Source	Original Question	Rewritten Question
Fire Regime	Emerging Issues	What is the role of fire in tundra surface stability – e.g., will increased albedo and removal of vegetation layer increase active layer thaw and thermokarsting?	
Fish	ArFO MQs	How does oil and gas infrastructure (e.g. roads, pads, pipeline), both permanent and temporary, affect fish habitat, fish distribution, and fish movements?	
Fish	ArFO MQs	What are baseline characteristics and trends in fish habitat (lakes and streams), fish distribution, and fish movements?	
Fish	ArFO MQs	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?	**Rewritten** to: How does water withdrawal from lakes affect down-basin stream habitat?
Invasive Species	NPRA AIM	What are the location, abundance, and trend of invasive species?	
Invasive Species	Emerging Issues	Are we likely to see new invasive species; which ones; by which pathway; how do we reduce/prevent invasion; how do we best detect and respond to invasion; and what will the effects of increased invasion be?	**Rewritten** to: 1. Which areas of the REA are more susceptible to invasive species establishment currently? 2. Which areas of the REA are more susceptible to invasive species establishment in the future? 3. Which CEs are most likely to be impacted by invasive species? 4. What are the potential ecological impacts of invasive species on CEs?
Invasive Species	NPRA AIM	What are the known and likely introduction vectors of invasive species and what is the current status of populations?	**Rewritten** to: What are the known and likely vectors for introduction of invasive species?
Migratory Birds	Emerging Issues	Is there sufficient data on rare species to credibly advise whether a specific management action is/isn't needed?	**Rewritten** to: Where are threatened/endangered/rare/sensitive species found?
Migratory Birds	ArFO MQs	What are the baseline data for the species composition, numbers of individuals, vegetation type used, and change in numbers/species composition of landbirds and their habitat over time?	
Migratory Birds	ArFO MQs	How has the abundance and distribution of yellow-billed loons changed over time in the NPR-A?	**Rewritten** to: How has the distribution of yellow-billed loons changed over time on their north slope breeding grounds?

Theme	Source	Original Question	Rewritten Question
Permafrost	Emerging Issues	What are the changes in habitat and vegetation related to changing permafrost conditions, and what will these changes mean to wildlife and habitats?	
Permafrost	Emerging Issues	NSSI agencies' immediate need is to be able to predict how permafrost will change temporally and spatially over the next one to two decades.	**Rewritten** to: How will permafrost change spatially and temporally over the next two decades?
Permafrost	Emerging Issues	How will changes in permafrost condition manifest for winter tundra travel, does an increasing depth of the active layer impact seasonal tundra travel?	
Permafrost	NPRA AIM	What are the changes in habitat and vegetation related to changing permafrost conditions, and what will these changes mean to wildlife and habitats?	
Permafrost	NPRA AIM	Is the permafrost-fire relationship driven by fire or the loss of permafrost?	
Social and Economic Structure	Emerging Issues	What may be the relevance of various existing management authorities (e.g., Executive Order 12898 [Environmental Justice], NEPA, and the OCS Lands Act) to considerations of the impacts of energy development or climate change on social and economic structure on the North Slope?	**Rewritten** to: What are the impacts of energy development on social and economic structure on the North Slope? This rewording is misrepresenting the original question. Recommend: "What are the different layers of regulatory control in North Slope with respect to energy development and their impact on social and economic structure in the North Slope?"
Social and Economic Structure	NPRA AIM	What are the cumulative effects of anthropogenic activities?	
Social and Economic Structure	Emerging Issues	What are the appropriate social and economic indicator data that should be gathered (e.g., for historic baseline and trend data)?	
Social and Economic Structure	Emerging Issues	How should we integrate local and traditional knowledge into social and economic investigations of North Slope people and communities?	
Social and Economic Structure	Future Needs	What are the effects of weather on construction season?	

Theme	Source	Original Question	Rewritten Question
Social and Economic Structure	Emerging Issues	What are industry activities in winter and spring (need to develop a database of industry activities for winter and spring)?	
Soils	NPRA AIM	Where are the locations of soils suitable for infrastructure development?	**Rewritten** to: Where are the locations of soils suitable/unsuitable for infrastructure development?
Subsistence	ArFO MQs	Is the harvest of caribou by residents of the NPRA and nearby communities affected by oil and gas activity in the NPR-A?	**Rewritten** to: What is the impact of development on subsistence harvest of caribou?
Subsistence	ArFO MQs	Is the harvest of fish by residents of the NPRA and nearby communities affected by oil and gas activity in the NPR-A?	**Rewritten** to: What is the impact of development on subsistence harvest of fish?
Subsistence	ArFO MQs	What physical and perceptual limitations to access to subsistence resources by local residents are caused by oil/gas activities?	
Subsistence	ArFO MQs	Have erosion and/or other environmental changes affected subsistence use areas and caused people to adjust their hunting/fishing/gathering practices?	
Terrestrial Wildlife	Emerging Issues	What parameters can help measure impacts from anthropogenic activities independently of natural cycles and vice versa?	
Terrestrial Wildlife	Emerging Issues	What is the winter ecology of caribou?	
Terrestrial Wildlife	Emerging Issues	What is the seasonal variation in caribou food production under changing climate conditions?	
Terrestrial Wildlife	Emerging Issues, NPRA AIM	How might changing fire regimes and fire response affect caribou distribution and the distribution of caribou food sources?	
Terrestrial Wildlife	ArFO MQs	What impacts will oil/gas exploration and development have on wildlife populations and how can we mitigate those impacts?	**Rewritten** to: What potential impacts will oil/gas exploration and development have on CE habitat?
Terrestrial Wildlife	ArFO MQs	What are their seasonal distribution and movement patterns?	

Theme	Source	Original Question	Rewritten Question
Terrestrial Wildlife	ArFO MQs, NPRA AIM	What are the status and trend of these communities?	**Rewritten** to: What are caribou preferences for vegetation communities? Where do these vegetation communities exist?
Terrestrial Wildlife	ArFO MQs	How are polar bears using the NPR-A today (pre-development) for natal denning and summer activity?	**Rewritten** to: Where is polar bear seasonal habitat?
Terrestrial Wildlife	Emerging Issues	What baseline measurements of caribou are needed but not yet documented?	
Terrestrial Wildlife	ArFO MQs	How are movement rates related to season and weather?	**Rewritten** to: How are movements related to season and weather?
Terrestrial Wildlife	ArFO MQs	How have types and levels of contaminants changed in the last 10 years for Colville River peregrine falcons?	**Rewritten** to: How have types and levels of contaminants changed in the last 10 years for peregrine falcons?
Terrestrial Wildlife	AK BLM State Office	How will introduction of a reindeer herding program affect caribou and vegetation?	
Vegetation	NPRA AIM	What are the condition and trend of vegetation (including rare) species and communities in natural and disturbed areas?	**Rewritten** to: Which rare species and vegetation communities are threatened by CAs?
Vegetation	NPRA AIM	What are the location, abundance, and pattern of vegetation (including rare) species and communities in natural and disturbed areas?	**Rewritten** to: Where are rare species and vegetation communities?
Vegetation	ArFO MQs	What are the impacts of oil/gas development (i.e. gravel pad and road construction; pipeline construction) on tundra vegetation? (Known impacts include burial, dust, saline runoff and altered soil moisture.)	
Vegetation	Emerging Issues	Will a changing fire regime play a role in vegetation change and should fire be used as an active tool for vegetation management?	**Rewritten** to: What is the impact of fire regime on vegetation
Vegetation	NPRA AIM	Where has disturbance occurred related to energy, fire, development, and insects and disease?	
Vegetation	WildREACH	How will plant species composition shift in response to long-term climate change, and what are the implications for habitat structure and quality of the prevalent available forage (i.e., digestibility, nutrient content)?	

Theme	Source	Original Question	Rewritten Question
Vegetation	Emerging Issues	Can we model the habitat effects of vegetation change (e.g., effect of vegetation change on habitat of yellow-billed loon, other species)?	
Vegetation	Emerging Issues	Can we (or do we need to) identify refugia for vegetation types and the bird species associated with them?	**Rewritten** to: Where are refugia for unique vegetation communities and the bird species associated with them?
Vegetation	Emerging Issues	Can we expect new ESA listings among North Slope plants species; which species are most likely?	**Rewritten** to: Where are rare (federally listed, BLM sensitive species) species found?
Vegetation	Emerging Issues	Do we have the baseline data needed to detect change?	
Vegetation	NPRA AIM	Do we have the baseline data needed to detect change?	
Vegetation	Combined-Emerging Issues and NPRA AIM	What should we expect in the way of range extensions? How will vegetation changes affect the food base for herbivorous species (especially caribou), and how will that in turn affect their numbers and use? How will vegetation change affect lichen fields and their recovery? How will shrub size and extent change?	**Rewritten** to: Where and how will shrub expansion impact caribou food availability?
Vegetation	NPRA AIM	What are the major vegetation successional pathways for the tundra vegetation classes, and how do the most common disturbance types affect those pathways?	

4. Medium Ranked Management Questions

Table K-4. Medium ranked MQs provided to AMT 1 Workshop for review. Organized by theme (listed alphabetically), showing source of the question, original question, and rewrite of question (if applicable)**.**

Theme	Source	Original Question	Rewritten Question	UA Rationale
Climate and Weather	Emerging Issues	How will changing weather conditions affect species movements, survival, and reproduction?		Needs clarification. Qualitative assessment + literature review.
Climate and Weather	WildREACH	How will the annual precipitation input on the Coastal Plain and Foothills be allocated between winter (snow pack) and summer?		Needs clarification. SNAP data and analysis
Climate and Weather	WildREACH	How will the frequency of rain-on-snow and severe winter storm events change?		Might be estimated based on temperature predictions, but no direct model available.
Contaminants	Emerging Issues	What is needed to understand contaminant risks and impacts on human health?	What is needed to understand the impacts of contaminants on human health?	Identifying the threshold of contaminants in relation to each CE, and addressing a data gap with respect to each source of contaminant.
Contaminants	Emerging Issues	What are contaminant risks associated with energy development and is the current level of contamination well documented?	What are contaminant risks associated with development?	Identifying the threshold of contaminants in relation to each CE, and addressing a data gap with respect to each source of contaminant.
Cultural Resources	ArFO MQs	What are the effects of oil and gas activities on cultural and paleontological resources in the NPR-A?	Where could oil and gas exploration and development overlap with known cultural and paleontological sites?	Identifying cultural and paleontological resources, and assessing the impacts of resource development activities, climate change, and recreation uses are within our expertise

Theme	Source	Original Question	Rewritten Question	UA Rationale
Cultural Resources	ArFO MQs	What are the impacts of recreational public travel through cultural and paleontological resource areas?		Identifying cultural and paleontological resources, and assessing the impacts of resource development activities, climate change, and recreation uses are within our expertise
Fire Regime	Emerging Issues	Will human safety conditions change if/when fire increases; how will this affect fire suppression decisions; and how will this affect communications with villages so that they are kept in touch on fire status?	How will altered fire regime affect communities, subsistence opportunities, infrastructure, and human safety?	ISER can provide location information on infrastructure and other anthropogenic uses.
Fire Regime	Emerging Issues	What is the role of fire in tundra surface stability – e.g., will increased albedo and removal of vegetation layer increase active layer thaw and thermokarsting?		This can be partially addressed independently using our fire and permafrost models
Invertebrates	WildREACH	How will warming and changing seasonality affect abundance and peak activity periods of biting insects, and what are the bioenergetic consequences for caribou in particular?	How will warming and changing seasonality affect abundance and peak activity periods of biting insects?	Literature review plus possible spatial data for current mosquito and fly harassment areas. Recent paper by Wilson et al. 2012 addresses some of the spatial aspects of this MQ - summer resource selection for the Teshekpuk herd
Invertebrates	WildREACH	How will warming and changing seasonality affect the prevalence of parasites and disease vectors (e.g., nematode parasites of muskoxen and Dall's sheep)?		Question cannot be answered with spatial data. We have a very similar question for YKL. Literature review only.

Theme	Source	Original Question	Rewritten Question	UA Rationale
Invertebrates	WildREACH	How does temperature affect growth and development of aquatic insects?		There are already several publications addressing this question - many from the Arctic. This can be answered in a literature review. Another AKNHP project is looking at this question across sites in coastal Alaska, but data are not yet ready for analysis.
Migratory Birds	Emerging Issues	How & where will oil spill risks to birds (from rig operation, loading/ transport, pipelines) be altered if additional energy development occurs?	What are the effects of potential energy development on migratory bird habitats?	Needs clarification. Requires information on important waterfowl areas. Other migratory species? Need clarification on species or species groups. Spatial data to map current distribution and link to habitats is likely available.
Migratory Birds	ArFO MQs	What are the possible impacts to other geese resulting from the increasing snow goose population in the NPR-A?	What are the possible impacts to other geese resulting from the increasing snow goose population	Reframe so this is a spatial assessment, not population level
Permafrost	NPRA AIM	Is the permafrost-fire relationship driven by fire or the loss of permafrost?		We can model both, but not simultaneously
Saltwater Intrusion	Emerging Issues	How will increasing salinity in near shore waters affect fish species? How will it affect fish in areas not currently saline (lower reaches of rivers, flood lakes, …)?		Near shore waters probably considered marine, this might be out of scope. But, can try to address effects of saltwater intrusion in coastal lakes and rivers on fish species using a literature review. Review would include tolerance of fish species.

Theme	Source	Original Question	Rewritten Question	UA Rationale
Sea Ice and Ocean Conditions	Emerging Issues	How will changes in sea ice affect the need for land-based infrastructure (e.g., barge landings)?		ISER can provide location information on infrastructure and other anthropogenic uses.
Sea Ice and Ocean Conditions	Emerging Issues	How will over land weather (precipitation, wind, snowfall) be affected by changing sea ice & how will it affect management decisions (off-road travel, water permits)?		We are limited in our ability to answer this by the assumptions built into the GCMs we will use in this REA
Social and Economic Structure	Emerging Issues	Need to understand the factors that affect these social indicators – i.e., need to know how to explain what drives cause and effect in observed changes in social indicators.		Needs clarification. Depends upon the indicators of interest, and how much cause and effect is desired. This needs to be focused, but seems to fit within the capabilities of ISER.
Social and Economic Structure	Emerging Issues	What are industry activities in winter and spring (need to develop a database of industry activities for winter and spring)?		The availability of data is unknown, but this would be within our capacity.
Subsistence	ArFO MQs	Has land use by local residents changed since the 105(c) studies were conducted in the late 1970s? If so, can changes be attributed to adaptations resulting from an increased presence of oil and gas exploration activity (or in the future: development activity)?		Needs clarification
Terrestrial Wildlife	Emerging Issues	What may be the effect of changes in caribou numbers and distribution on subsistence use?	What may be the effect of changes in caribou distribution on subsistence use?	This requires seasonal use data which may not be available, but if it is then this fits within our expertise.

Theme	Source	Original Question	Rewritten Question	UA Rationale
Terrestrial Wildlife	ArFO MQs	How do occupancy and productivity numbers for cliff-nesting raptors along the Colville River fluctuate in a pre-development environment?	What is the current distribution of cliff-nesting raptors along riparian corridors in pre-development areas?	
Terrestrial Wildlife	ArFO MQs, NPRA AIM	What habitats are most preferred by cliff-nesting raptors along the Colville River?	What habitats are most preferred by cliff-nesting raptors?	Combined with other question
Vegetation	Emerging Issues	What should we expect in the way of range extensions?		Needs clarification. This will be done, in part, during the core analysis. However, if there are specific species/communities that are of interest, then we need clarification.
Vegetation	Emerging Issues, NPRA AIM	How will vegetation changes affect the food base for herbivorous species (especially caribou), and how will that in turn affect their numbers and use?		We are addressing a similar question in the YKL REA, focused just on lichen, so this is within our capacity. Could be a core question if lichen becomes a CE.
Vegetation	Emerging Issues	How will vegetation change affect lichen fields and their recovery?		Could be core question if lichen is a CE. This is something within our capacity.
Vegetation	Emerging Issues, NPRA AIM	How will shrub size and extent change?		The first part of this question is out of scope for the REA, but the second part could be considered a core analysis if shrubs are chosen as a CE or CA.
Vegetation	Emerging Issues	For change detection, which species or habitat types should be measured and at what scale; which sites should be used and how do we ensure comparability?		This is within our expertise, but again would require major work effort. Part of it will be identified through the core analyses.

Theme	Source	Original Question	Rewritten Question	UA Rationale
Air Quality	Lon Kelly	How will oil and gas exploration and development, industry in northern Europe and Asia, research projects, changing climate, and environmental regulation impact air quality on the North Slope in aggregate, and how can these activities be controlled by land managers to minimize negative impacts?		We need clarification on regional impacts (northern Europe and Asia outside of ecoregion). Outside of our expertise, but would be able to find sources to help address the question.
Fire Regime	Emerging Issues	What is the nature of the link between fire regime and hydrology and will a change in this link have cascading effects on fish, birds, and other species?		This is an advanced modeling exercise that could be outside the scope of an REA. We can model some of these things independently, but this really represents a much larger research agenda.
Saltwater Intrusion	Emerging Issues	How will the use of saltwater for ice roads impact vegetation over time?		As stated now, this isn't a landscape-wide issue, and if included, will likely just be a literature review
Social and Economic Structure	Emerging Issues	We need objective measures for thresholds to identify what constitutes a significant change.	What threshold constitutes significant social or economic change?	Needs clarification. This is very vague and is likely out of scope for an REA
Vegetation	Emerging Issues	Will vegetation change affect active layer depth?		This is likely limited to a literature review at this scale and timeframe.

5. Low Ranked Management Questions

Table K-5. Low ranked MQs provided to AMT 1 Workshop for review. Organized by theme (listed alphabetically), showing source of the question, original question, and rewrite of question (if applicable).

Theme	Source	Original Question	Rewritten Question	UA Feedback
Climate and Weather	Emerging Issues	How will changes in weather pattern/climate affect coastal erosion?		Can be addressed via SNAP models linked to permafrost models from GIPL, but shore-fast ice and storms can only be addressed via the literature.
Climate and Weather	Emerging Issues	What information is needed to understand coupling (or de-coupling) of changes in benthic and water column characteristics with changes in weather?		lit review? No SNAP data available
Climate and Weather	Emerging Issues	What will be potential effects of changing weather conditions on lake depth (re: winter water removal and fish habitat)?	How will lake depth be affected by changing weather conditions, especially with regards to winter water removal and fish habitat?	Needs clarification. This can be addressed via permafrost modeling and perhaps via P-PET models, but results will be regionally generalized rather than site specific.
Climate and Weather	Emerging Issues	There seems to be a similar set of concerns with weather stations as with hydrological gauging stations (cost, maintenance, proper placement, …); can we learn anything from our knowledge of hydrological gauging stations to help deal with these challenges for weather stations?	What is the number, distribution, seasonal use, and short- or long-term placement of hydrological gauging stations on the North Slope and how do these compare with weather stations?	lit review? No SNAP data available
Climate and Weather	NPRA AIM	What is the carbon sequestration potential of BLM-managed lands?		SNAP does not have any data to address this. Lit review might turn up something, but I doubt it. Doing calculations from scratch is probably out of scope.

Theme	Source	Original Question	Rewritten Question	UA Feedback
Climate and Weather	WildREACH	What are the expected changes in snowpack characteristics (depth, density, presence of ice layers), and how might these vary on a regional and local scale?		This is more specific than what our models at SNAP offer. We can offer qualitative discussion, but not spatially explicit analysis.
Climate and Weather	WildREACH	Will increased fogginess/cloudiness exert a negative or positive feedback effect on air temperature in the coastal zone, and what is the expected spatial extent of this effect?		We do not have data at SNAP on fog and clouds
Contaminants	Emerging Issues	Effective regulation of local industry requires a baseline of contaminants present prior to industry in order to best assess what, and how much, contaminants local industry adds to the environments. What is our current knowledge of such a baseline?		Needs clarification. Depends upon the contaminant, but this would largely be left to a literature review.
Erosion	Emerging Issues	What are the erosion risks to communities and to subsistence opportunities and access?	What are the risks of erosion to communities, cultural sites, and subsistence opportunities?	ISER can provide location information on infrastructure and other anthropogenic uses. The UA Team does not currently have anyone that specializes in erosion, or hydrology in general, so some of these may have to be addressed more qualitatively than quantitatively
Erosion	Emerging Issues	What are the links between coastal or riverine erosion and contaminant risk and where is the overlap between erosion and contamination?		ISER can provide location information on infrastructure and other anthropogenic uses. The UA Team does not currently have anyone that specializes in erosion, or hydrology in general, so some of these may have to be addressed more qualitatively than quantitatively
Erosion	Emerging Issues	What are the links between coastal and riverine erosion and changing permafrost conditions?		Good question, but we aren't qualified to weigh in on hydrologic or erosion questions

Theme	Source	Original Question	Rewritten Question	UA Feedback
Erosion	Emerging Issues	What are the impacts to water quality (sediment load, dissolved oxygen, conductivity, etc.) in the fresh water and near shore environments?	What are the impacts of erosion on water quality, including sediment load, dissolved oxygen, and conductivity, in fresh water and near shore environments?	The UA Team does not currently have a hydrologist, so this would be limited to literature review
Erosion	Emerging Issues	How will erosion patterns change with the changing patterns in weather, sea ice, wave climate, and sea level changes and how do we plan for this in the future?	How will erosion patterns change with the changing patterns in weather, sea ice, wave climate, and sea level change?	Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Erosion	WildREACH	Will higher water temperatures, sea level rise, and retreat of summer sea ice cause degradation of the barrier island systems of the Beaufort and Chukchi seas?		Needs clarification, are we including barrier island systems in study area? This could be out of scope.
Erosion	WildREACH	Will alluvial deltas continue to build or will rising sea levels outpace potential increases in sedimentation rates?		Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Erosion	WildREACH	How quickly will shoreline retreat result in newly breached lake basins?		Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Erosion	WildREACH	To what extent will coastal erosion, in combination with sea level rise, cause salinization of low-lying coastal areas?		Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Erosion	WildREACH	Will coastal wet sedge meadows establish at a rate equal to loss of this habitat through erosion and inundation?		Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Fire Regime	Emerging Issues	How will a changing fire regime affect air quality?		This will likely be literature review only.

Theme	Source	Original Question	Rewritten Question	UA Feedback
Fire Regime	Emerging Issues	What is the nature of the link between fire regime and hydrology and will a change in this link have cascading effects on fish, birds, and other species?		This is an advanced modeling exercise that could be outside the scope of an REA. We can model some of these things independently, but this really represents a much larger research agenda.
Fire Regime	Emerging Issues	Will a changing fire regime alter carbon flux and/or CO2 emissions?		We lack expertise in emission modeling
Fish	Emerging Issues	How important are ephemeral streams to fish passage?		This will probably be a difficult question to answer - there is some research on beaded streams, but linking their importance to fish movements would require tagging.
Hydrology	Emerging Issues	Hydrologic data, including storage and transport, are lacking for individually small stream/lake systems, but might these systems be collectively very important?		Needs clarification. Out of expertise.
Hydrology	ArFO MQs	Are permitted water withdrawals from lakes causing temporary or permanent changes in aquatic habitat, and are they consistent with water availability?		Needs clarification. Changes to aquatic habitat can only be determined if data are available. I don't understand the second part - are they asking if withdrawals are greater than inputs?
Hydrology	ArFO MQs	What impacts will oil/gas exploration and development have on water resources and water quality?		ISER can provide location information on infrastructure and other anthropogenic uses. The UA Team does not currently have anyone that specializes in erosion, or hydrology in general, so some of these may have to be addressed more qualitatively than quantitatively
Hydrology	ArFO MQs	Are adequate stream flow and climate data available from areas most likely to be developed for oil and gas exploration and production?	How might oil and gas exploration and production affect stream flow?	ISER can provide location information on infrastructure and other anthropogenic uses. There are many questions about the current level of monitoring that needs to be vetted through the AMT as to whether that is an appropriate use of REA resources.

Theme	Source	Original Question	Rewritten Question	UA Feedback
Hydrology	Emerging Issues	Is the hydrologic cycle undergoing significant and rapid change in response to climate change; is it well understood how this will affect cycle complexity, high/low flows, etc.?	Is the hydrologic cycle undergoing significant and rapid change in response to climate change?	Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Hydrology	Emerging Issues	How can we measure and model duration of outflow of lakes? This is needed to define "full" for lake recharge.		Needs clarification. The UA Team does not currently have a hydrologist
Hydrology	Emerging Issues	How does snow water equivalent vary on a local scale? How do we determine how much water is available? How accurate are current methods of determining basin storage?	How does snow water equivalent vary on a local scale? How do we determine how much water is available?	Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Hydrology	Emerging Issues	How do the coastal plain and foothills differ in water availability?		Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Hydrology	ArFO MQs	Is adequate hydrologic information available to determine whether development is occurring within the 100-year floodplain?	Is there current and potential development within different levels of floodplains?	Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Hydrology	WildREACH	How will changing patterns of seasonal runoff affect stream flow?		Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Hydrology	WildREACH	What is the contribution of groundwater in various systems, and is it sufficient to maintain year-round flow?		Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Hydrology	WildREACH	Will drought conditions and changes in drainage patterns decrease water body connectivity?		Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Hydrology	WildREACH	Which Coastal Plain lakes are susceptible to tapping (rapid drainage) and on what time scale?		Good question, but we aren't qualified to weigh in on hydrologic or erosion questions

Theme	Source	Original Question	Rewritten Question	UA Feedback
Hydrology	Emerging Issues	To what extent and rate is lake drying occurring now and can we predict or model for the future? What is the geographic variation?		Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Hydrology	Emerging Issues	Are there characteristics of lakes (e.g. basin shape, soils/substrate, vegetation, etc.) that are more/less prone to drying?	What are the mechanisms (e.g., changes in active layer, precipitation, evaporation, etc.) that lead to lake drying, and what lake characteristics increase or decrease potential for drying?	Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Hydrology	Emerging Issues	Is there evidence of lake expansion, or formation of new lakes, that would offset lake drying? What are the rates and patterns of this phenomenon?	What are the rates and patterns of lake expansion or formation and will expansion and formation offset drying?	Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Invasive Species	NPRA AIM	What are the known and likely introduction vectors of invasive species and what is the current status of populations?	What are the known and likely vectors for introduction of invasive species?	This question will likely only be addressed through a literature review.
Invertebrates	WildREACH	How does earlier spring thaw affect timing of life cycle events and peak availability to predators?		Phenological question - cannot be answered with spatial data. Literature review only.
Migratory Birds	NPRA AIM	What changes in habitat are driving changes in the distribution and abundance of migratory birds?		Needs clarification. Question at the least needs to be reframed to address what are the potential/expected changes in habitat and how could those influence the distribution of migratory birds. Abundance part of question is out of scope.
Migratory Birds	Emerging Issues	Are there likely to be shifts in species composition and how will this affect subsistence use patterns?		Needs clarification. Question could be reframed to include more specific habitat types that species area associated with.

Theme	Source	Original Question	Rewritten Question	UA Feedback
Migratory Birds	ArFO MQs, NPRA AIM	How has the abundance and distribution of spectacled eiders changed over time in the NPR-A and what is driving this change?	How has the distribution of spectacled eiders changed over time on the north slope? What is driving this change?	Although abundance questions are generally considered out of scope, the USWFS does have has density estimates for Steller's Eider across N. Slope which they have developed into a GIS coverage as birds/km2. However, we are more concerned with current and future distribution than past changes.
Migratory Birds	ArFO MQs	What are current population estimates and productivity of spectacled eiders in the NPRA?	What are current population estimates and productivity of spectacled eiders?	Population estimates, unless the already exist, are outside the scope of an REA.
Migratory Birds	ArFO MQs	What is the current population estimate for yellow-billed loons in the NPR-A?	What is the current population estimate for yellow-billed loons?	Population estimates, unless the already exist, are outside the scope of an REA.
Saltwater Intrusion	Emerging Issues	What species of fish and fish predators are more/less tolerant of salt intrusion?		Duplicate of another question, but could be addressed through a literature review
Saltwater Intrusion	Emerging Issues	To what extent may ice road construction need to rely on the use of saltwater?		ISER can provide location information on infrastructure and other anthropogenic uses, but this is mostly non-spatial.
Saltwater Intrusion	Emerging Issues	How will the use of saltwater for ice roads impact vegetation over time?		As stated now, this isn't a landscape-wide issue, and if included, will likely just be a literature review
Saltwater Intrusion	Emerging Issues	What is currently known about the level of saltwater intrusion on the North Slope; who's measuring it; where; is it being measured adequately?	What is the level of saltwater intrusion?	Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Saltwater Intrusion	Emerging Issues	To what extent is saltwater intrusion occurring now and can we predict or model it for the future? What is the geographic variability?		Good question, but we aren't qualified to weigh in on hydrologic or erosion questions

Theme	Source	Original Question	Rewritten Question	UA Feedback
Sea Ice and Ocean Conditions	Emerging Issues	How will a changing ice edge affect specific species?		Needs clarification. We lack expertise in sea ice modeling
Sea Ice and Ocean Conditions	Emerging Issues	How will sea ice changes affect species' onshore vs. offshore distributions?		Needs clarification. Likely considered out of scope based on time limitations.
Sea Ice and Ocean Conditions	Emerging Issues	What will be the effect on wave regime and how will that relate to erosion patterns?		Good question, but we aren't qualified to weigh in on hydrologic or erosion questions
Sea Ice and Ocean Conditions	Emerging Issues	Will diminished sea ice affect fire regime?		Needs clarification. We lack the capacity to model sea-ice extent
Social and Economic Structure	Emerging Issues	We need objective measures for thresholds to identify what constitutes a significant change.	What threshold constitutes significant social or economic change?	Needs clarification. This is very vague and is likely out of scope for an REA
Social and Economic Structure	Emerging Issues	Many studies are a "snapshot" in time, without follow up to detect change. Need to synthesize existing studies, predictions, recommendations for social and economic impacts of energy development and climate change.		Needs clarification. In part, this is what an REA will do. If there is a more specific question, then we can assess it independently
Social and Economic Structure	Future Needs	What are the effects of weather on infrastructure and communities?		Needs clarification. We cannot model weather, but we do address this partially with climate change impacts. Otherwise, this would be limited to a literature review.
Subsistence	ArFO MQs	Have subsistence cabins and camping areas been impacted by scientific research projects in the NPR-A, and if so, how?	Have subsistence cabins and camping areas been impacted by scientific research projects, and if so, how?	Data is likely to be lacking, but if available we could do this.
Terrestrial Wildlife	Emerging Issues	Need to review the appropriateness of stipulations and their value to caribou		Needs clarification

Theme	Source	Original Question	Rewritten Question	UA Feedback
Terrestrial Wildlife	Emerging Issues	What may be the response of naïve caribou herds to oil and gas exploration?		Needs clarification
Terrestrial Wildlife	WREMSS	What are the condition and trends of wildlife habitat in basins emphasized in the Energy Policy and Conservation Act (EPCA) report?		Needs clarification
Terrestrial Wildlife	WREMSS	What are the stressors or drivers of change that affect wildlife habitat in basins emphasized in the EPCA report?		Needs clarification. Stressors (CA's) and drivers are addressed in each species conceptual model - so to some degree with will be addressed for each CE. However, this assessment is not specific to basins? What role to basins play on the NOS? Requires clarification.
Terrestrial Wildlife	Emerging Issues	What are unique traits, threats, and uses for each caribou herd?		Not appropriate scale for REA
Terrestrial Wildlife	ArFO MQs	What are pre-development numbers of caribou?		We are not certain about the availability of pre-development caribou data.
Terrestrial Wildlife	ArFO MQs	What impacts will oil/gas activity have on populations of ground-nesting birds through effects on predator populations?		Population estimates, unless the already exist, are outside the scope of an REA. The REA timescale is insufficient to link changes in population to oil/gas development.
Vegetation	Emerging Issues	Will we see the loss of unique vegetation types and how will this affect the life histories of other species?	1. Where are habitats for rare species expected to be in the future? 2. Which rare species appear vulnerable to reductions or changes in future habitats	This can be addressed spatially, but question below makes it a little easier to focus on specific species.
Vegetation	NPRA AIM	What is the correlation to predict the types and distribution of vegetative communities and habitats over time?		Needs clarification

Theme	Source	Original Question	Rewritten Question	UA Feedback
Vegetation	NPRA AIM	What are the location and trend of rare species or communities?	What are the population trends of rare species?	We are comfortable with this, but it is a duplicate of another question. Also, there is no known demographic studies of rare plants that we know of.
Vegetation	WildREACH	How will changes in the seasonality of stream discharge and occurrence of flood events influence development of riparian vegetation communities?		This would be limited to a literature review.
Vegetation	Emerging Issues	Will vegetation change affect active layer depth?		This is likely limited to a literature review at this scale and timeframe.
Vegetation	WildREACH	What is the time scale of expected shrub increase, and how will this vary by species/growth form (low vs. tall shrub) and ecoregion?		This is largely out of our expertise and the timescale of an REA.

6. Out of Scope Management Questions

Table K-6. Potential MQs not considered for the North Slope REA.

Theme	Source	Original Question	UA Feedback
Climate and Weather	Emerging Issues	What do we know about, and can we synthesize, information on the number, distribution, seasonal use, and short- or long-term placement of meteorological stations on the North Slope?	out of scope - methods question
Climate and Weather	Emerging Issues	How will changing weather conditions affect ice movement (loss or gathering)?	Out of scope - non-terrestrial
Climate and Weather	Emerging Issues	How does weather condition correlate to oceanographic conditions and how will this affect oil spill modeling?	Out of scope - non-terrestrial
Climate and Weather	Emerging Issues	What parameters are currently being measured at North Slope weather stations and are these correct and sufficient for our analysis and modeling needs?	out of scope - methods question
Climate and Weather	Emerging Issues	Are the data being collected by different types of weather stations, e.g., RAWS and USGS, comparable?	out of scope - methods question
Climate and Weather	Emerging Issues	Is the current location of meteorological stations appropriate and sufficient, for example, for predictive capacity and fire modeling?	out of scope - methods question
Climate and Weather	Emerging Issues	What are the hurdles to facility siting (e.g., wilderness designation, cost, access)?	Out of scope - policy question
Climate and Weather	Emerging Issues	Is the data that is obtained through currently placed meteorological stations linked to any pan-arctic accessible data network; if not, should it be; how; which one?	out of scope - methods question
Climate and Weather	Emerging Issues	What is that state of access to and can we improve access to real time and historic weather data?	out of scope - methods question
Climate and Weather	Emerging Issues	Can access to weather data be facilitated through the NSSI website and can the Projects Database help to identify data gaps, compare data types, share standards, etc.?	out of scope - policy question
Climate and Weather	Emerging Issues	What should various agency roles be in gathering, funding, or accessing real time and historic weather data?	out of scope - policy question

Theme	Source	Original Question	UA Feedback
Contaminants	Emerging Issues	Do we have sufficient information on ice, marine currents, and wind to inform spill models in a changing environment? If not, what are the priority needs and who is doing such modeling?	Out of scope - non-terrestrial
Contaminants	ArFO MQs	What are the effects of coastal and lake-shore erosion on legacy wells and other documented sites containing hazardous materials?	Out of scope - inappropriate scale
Cultural Resources	ArFO MQs, NPRA AIM	How can cultural and paleontological resources give us information on past climate change and the possible effects of climate change on the landscape in the future?	Out of scope - requires new data
Cultural Resources	ArFO MQs	Has the lack of precise measuring and location of cultural and paleontological resources allowed some sites to be compromised?	Out of scope - inappropriate scale
Cultural Resources	ArFO MQs	How can oil and gas activities and BLM activities mesh to minimize or avoid compromise of cultural or paleontological resources and still allow practical means of activity and exploration?	Out of scope - policy question
Erosion	Emerging Issues	How and where is erosion being measured?	Out of scope - methods question
Erosion	Emerging Issues	How have engineering considerations responded to accelerating erosion processes for current and future infrastructure?	Out of scope - inappropriate scale
Erosion	Emerging Issues	Are there mechanisms to consider for adapting to or mitigating for erosion?	Out of scope - methods question
Fire Regime	Emerging Issues	How will estimates of changing fire regime affect development planning? For example, will a changing fire regime alter the suitability of potential facility locations, or impact development activities through air quality (leading to equipment shutdown) and the need to gear up for suppression activities?	Out of scope - policy question
Fire Regime	Emerging Issues	Would comparing burned and unburned locations and their current, historical and potential vegetation on winter range and calving habitat for ungulates help answer these questions?	Out of scope - methods question

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Fire Regime	Emerging Issues	Will current fire behavior models (e.g., FlamMap, FSPro, FARSITE) work under changing climate conditions? Need to be sure to model under differing climate scenarios, not just the most probable scenario. For example, the maps that LandFire produces should be evaluated under different climate scenarios in order to feed appropriate information into the fire behavior models.	Out of scope - methods question
Fire Regime	Emerging Issues	Might the presence of coal deposits affect management strategies for fires?	Out of scope - policy question
Fire Regime	Emerging Issues	May need to update/influence changes in the National Fire Plan re: wildland fire decision support system, village fire protection planning, access to funding for fire response. Can this be done via the State of Alaska's Immediate Action Working Group?	Out of scope - policy question
Fire Regime	Emerging Issues	Will a changing fire regime require the land managers (BLM, DNR, USFWS, NPS) to change their management strategies for fire on the North Slope (full protection status for villages?). Are we set up to do so?	Out of scope - policy question
Hydrology	Emerging Issues	What kind of network of long term gauging stations is needed?	Out of scope - methods question
Hydrology	Emerging Issues	Are there means (experimental or known) that can enhance the ability of energy exploration and development to move forward in water challenged environments?	Out of scope - methods question
Hydrology	ArFO MQs	What differences exist in climate and river flow responses between the coastal plain, foothills, and upland areas in NPR-A, and how might that affect design of oil and gas infrastructure?	Out of scope - policy question
Hydrology	ArFO MQs	Are temporary and permanent stream crossing structures adequately designed and monitored to minimize channel disruption, erosion and sedimentation?	Out of scope - inappropriate scale
Hydrology	Emerging Issues	Do we currently have remote sensing capability for monitoring lakes?	Out of scope - methods question
Hydrology	Emerging Issues	Are current data sets (3-7 years) adequate for estimates of peak, mean and low flows or do we need a minimum of >10 years of data?	Out of scope - methods question

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Hydrology	Emerging Issues	Are alternative technologies being investigated and if so, will they lead to alternative criteria (regulatory requirements) versus science requirements?	Out of scope - methods question
Hydrology	Emerging Issues	Is there a significant data gap in relating annual surface runoff to annual precipitation and what will it take to fill this data gap?	Out of scope - methods question
Invertebrates	WildREACH	What climate-related changes are likely in community composition of macroinvertebrates in stream, lake, and saturated soil environments?	Out of scope - inappropriate scale
Invertebrates	WildREACH	How will changes in the distribution and quality of surface waters and shifts from pelagic to benthic productivity in deep lakes affect availability of macroinvertebrates to fish and wildlife?	Out of scope - inappropriate scale
Marine Activity	Emerging Issues	In what ways will increased access enable increased development?	Out of scope - non-terrestrial
Marine Activity	Emerging Issues	Will increased activity cause more bird strikes?	Out of scope - non-terrestrial
Marine Activity	Emerging Issues	What are the Law of the Sea implications?	Out of scope - non-terrestrial
Marine Activity	Emerging Issues	We will need even greater fed/state/local coordination to avoid regulatory uncertainty for activity management.	Out of scope - non-terrestrial
Marine Activity	Emerging Issues	How will infrastructure expand to serve development and what may be the effect of this expansion?	Out of scope - non-terrestrial
Marine Activity	Emerging Issues	What are, and how will we measure, the cumulative effects of increases in various marine activities?	Out of scope - non-terrestrial
Marine Activity	Emerging Issues	Baseline information is lacking for many categories of information (species, habitats, water quality, …); to the extent it exists, is there adequate access to the data?	Out of scope - non-terrestrial
Marine Activity	Emerging Issues	Will the spread of invasive species increase? If so, which species and which pathways will be important? How can the spread of invasive species be reduced?	Out of scope - non-terrestrial
Marine Activity	Emerging Issues	How will the acoustic ecology change and what is the comparability of prior studies (Gulf of Mexico vs. Arctic)?	Out of scope - non-terrestrial

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Marine Activity	Emerging Issues	How will shipping and other marine operations interfere with species and their pursuit by subsistence hunters (e.g., will whale migrations be deflected and whaling access thus be altered)?	Out of scope - non-terrestrial
Marine Activity	Emerging Issues	To what degree will increased marine discharges of pollutants affect water quality (e.g., for prey species)?	Out of scope - non-terrestrial
Marine Activity	Emerging Issues	What are the risks from the increasing presence of non-ice-hardened cruise ships?	Out of scope - non-terrestrial
Marine Mammals	Emerging Issues	How do we differentiate and assess the separate and combined effects of climate change and development on various species and their interaction?	Out of scope - non-terrestrial
Marine Mammals	Emerging Issues	What will be the metric of successful management in the future (for example, under ESA)?	Out of scope - non-terrestrial
Marine Mammals	Emerging Issues	How might a shift in species distribution from sea to land (e.g., polar bears, walrus) affect land management?	Out of scope - non-terrestrial
Marine Mammals	Emerging Issues	How may this shift affect predator/prey relations on land and/or in marine waters?	Out of scope - non-terrestrial
Marine Mammals	Emerging Issues	Will changes in ocean currents affect species distribution and recruitment (e.g., nearshore currents and larval drift)?	Out of scope - non-terrestrial
Marine Mammals	Emerging Issues	Can prey species shifts in distribution and abundance be better modeled; how and with what precision?	Out of scope - non-terrestrial
Marine Mammals	Emerging Issues	What will be the ecosystem level effects of shifts in the distribution and abundance of fish and other species?	Out of scope - non-terrestrial
Marine Mammals	Emerging Issues	If fish species shift north, will fishing (incl. commercial fishing) patterns change and what will the effect be on management options, on non-target species, ...?	Out of scope - non-terrestrial
Marine Mammals	Emerging Issues	Will shipping affect whale migration and hunter access?	Out of scope - non-terrestrial
Marine Mammals	Emerging Issues	Can we identify species/habitat conservation refugia?	Out of scope - non-terrestrial
Migratory Birds	Emerging Issues	Are current breeding bird surveys sufficient to meet management needs in a changing environment?	Out of scope - methods question

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Migratory Birds	Emerging Issues	How will any changes in migratory waterfowl numbers or distribution alter risks to aircraft from bird strikes?	Out of scope - inappropriate scale
Migratory Birds	ArFO MQs, NPRA AIM	What are pre-development numbers, distribution, and survival rate of molting geese in the Teshekpuk Lake area (TLSA)?	Out of scope - inappropriate scale
Migratory Birds	ArFO MQs, NPRA AIM	How has distribution and abundance of molting geese in the TLSA changed over the last 20 years and what is driving this change?	Out of scope - inappropriate scale
Migratory Birds	ArFO MQs	How has the abundance and distribution of Steller's eider changed over time in the Barrow Triangle and what is driving this change?	Out of scope - inappropriate scale
Migratory Birds	ArFO MQs	What are current population estimates and productivity of Steller's eiders in the Barrow Triangle?	Out of scope - inappropriate scale
Migratory Birds	ArFO MQs	What is the trend in population estimates of nesting snow geese on the Ikpikpuk River delta?	Out of scope - inappropriate scale
Migratory Birds	ArFO MQs	How are the snow geese impacting the nesting and brood-rearing habitat on the Ikpikpuk River delta?	Out of scope - inappropriate scale
Migratory Birds	Emerging Issues	Will the nature of ice edges as locations of food gathering and/or resting places change, and what will be the effect of this change on species' bioenergetics?	Out of scope - non-terrestrial
Migratory Birds	Emerging Issues	What changes may be in store for ice leads as habitat and what may be the effect of any changes in oil spill risks on the likely function/value of ice leads?	Out of scope - non-terrestrial
Permafrost	Emerging Issues	How and where is permafrost being measured; is it adequate; and is the data accessible?	Out of scope - methods question
Permafrost	Emerging Issues	What is the impact of changing permafrost to traditional ice cellars?	Out of scope - inappropriate scale
Permafrost	Emerging Issues	Are current measurement techniques sufficiently precise (e.g., to address subsidence)?	Out of scope - methods question
Permafrost	Emerging Issues	What are the restoration methods for such structures as VSMs in a changing environment?	Out of scope - methods question
Permafrost	Emerging Issues	Is seabed permafrost adequately mapped and what is the interaction between seabed permafrost and permafrost in coastal areas as exploratory drilling and off-shore to on-shore infrastructure is developed?	Out of scope - non-terrestrial

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Permafrost	Emerging Issues	What is the impact on seabed permafrost from noise generated by exploration and production drilling in the marine environment, and how can it be mitigated?	Out of scope - non-terrestrial
Sea Ice and Ocean Conditions	Emerging Issues	How will changing oceanographic conditions alter marine ecosystems (e.g., ability to produce prey)?	Out of scope - non-terrestrial
Sea Ice and Ocean Conditions	Emerging Issues	Will (has) ice melt cause(d) a pulse of contaminants?	Out of scope - non-terrestrial
Sea Ice and Ocean Conditions	Emerging Issues	What will the effects of ocean acidification be, for example on marine food chains, and how does it relate to nearshore discharge?	Out of scope - non-terrestrial
Sea Ice and Ocean Conditions	Emerging Issues	Will ocean current patterns change; how?	Out of scope - non-terrestrial
Sea Ice and Ocean Conditions	Emerging Issues	What is the time span & validity of historic data on temporal and spatial changes in sea ice?	Out of scope - non-terrestrial
Sea Ice and Ocean Conditions	Emerging Issues	How do the timing, duration, and distribution of slush or broken sea ice affect oil spill response?	Out of scope - non-terrestrial
Sea Ice and Ocean Conditions	Emerging Issues	Is the function of sea ice as habitat changing & what do the models project for the long term (50 yrs out)?	Out of scope - non-terrestrial
Sea Ice and Ocean Conditions	Emerging Issues	Is the role of sea ice as a hunting platform for subsistence harvesters changing?	Out of scope - non-terrestrial
Social and Economic Structure	Emerging Issues	What are the institutional arrangements needed to assess the impacts of energy development and climate change on the social and economic structure of the North Slope?	Out of scope - policy question
Social and Economic Structure	Emerging Issues	How do we measure the effects of various management practices on the social structure of villages and people of the North Slope?	Out of scope - methods and policy question
Social and Economic Structure	Emerging Issues	What is the appropriate human health risk assessment data that should be gathered, e.g., to assess the effects of dietary shifts associated with energy development or climate change?	Out of scope - methods question
Social and Economic Structure	Emerging Issues	How do we structure social and economic studies so that they consider both Inupiaq and non-Inupiaq residents of the North Slope?	Out of scope - methods question

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Social and Economic Structure	Emerging Issues	Under NEPA, how do we assess the impacts of oil and gas development on the social and economic structure of North Slope communities, and how does climate change effect that assessment process?	Out of scope - Policy question
Social and Economic Structure	Emerging Issues	How can we achieve a common/standardized set of key social indicators so that socioeconomic data are transferable over time and between studies and locations?	out of scope - methods question
Social and Economic Structure	NPRA AIM	What percentage of IAP decisions is being achieved?	Out of scope - Policy question
Social and Economic Structure	Emerging Issues	Might the North Slope Borough play a role as a "1-stop" (or "first stop") shop for coordination of social and economic studies on the North Slope?	Out of scope - policy question
Social and Economic Structure	Emerging Issues	NSSI coordination across agencies and membership could lead to less duplication of effort (via Projects Database?), better communication, better understanding of information, and facilitate incorporation of traditional and local knowledge.	Out of scope - policy question
Social and Economic Structure	Emerging Issues	How can we best avoid undue burden on North Slope people and communities in the implementation of multiple studies and surveys?	Out of scope - methods question
Social and Economic Structure	Emerging Issues	What might the communities themselves want from surveys and studies?	Out of scope - methods question
Social and Economic Structure	Emerging Issues	How do we involve local people and communities in social and economic studies in a meaningful way?	Out of scope - methods question
Social and Economic Structure	Emerging Issues	If there is to be remuneration, how do we set a fair standard?	Out of scope - methods question
Social and Economic Structure	Emerging Issues	Can NSSI facilitate the development of standards (e.g., minimum data standards) for social and economic studies on the North Slope? If so, how can we best ensure that Principal Investigators will access and follow such standards – for example, and can such standards be posted via the NSSI website and/or linked to the Projects Database?	Out of scope - methods question

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Terrestrial Wildlife	Emerging Issues	Is there a better technology for gathering consistent census data across the Slope?	out of scope - methods question
Terrestrial Wildlife	NPRA AIM	What changes in habitat are driving changes in the distribution and abundance of wildlife – specifically caribou?	Out of scope - time limitation
Terrestrial Wildlife	WREMSS	Are applied mitigation and best management practices for habitat and human disturbance related to energy development effective in the conservation of wildlife habitat?	Out of scope - policy question
Terrestrial Wildlife	WREMSS	Are reclamation activities related to energy development accomplishing wildlife and associated habitat objectives as stated in the activity plans and/or land use plans?	Out of scope - policy question
Terrestrial Wildlife	Emerging Issues	Need to establish a network to share caribou information between and among herd managers and researchers	Out of scope - policy question
Terrestrial Wildlife	Emerging Issues	Better reporting of subsistence and sport harvest data would aid in determining relationship with impacts from exploration and development activities	Out of scope - policy question
Vegetation	Emerging Issues	What other cumulative food web effects may occur with vegetation change?	Out of scope - theoretical
Vegetation	Emerging Issues	Can vegetation change serve as an indicator of cumulative impact?	Out of scope - policy question
Vegetation	Emerging Issues	What form(s) of sampling and protocol will be needed to detect change?	Out of scope - methods question
Vegetation	Emerging Issues	How does/should vegetation change model outputs affect management decisions and timing (e.g., can/should we manage for plant species that favor certain herbivores)?	Out of scope - policy question
Vegetation	NPRA AIM	What are the vegetation impacts from development activities versus background “natural” changes?	Out of scope - methods question
Vegetation	Emerging Issues	Can we differentiate ‘natural’ change from human-induced change?	Out of scope - methods question
Vegetation	WildREACH	How will changes in the length and timing of the growing season influence plant phenology, including seasonal changes in nutritional quality?	Out of scope - this is a research question.

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Vegetation	WildREACH	What is the likelihood of widespread conversion from sedge and sedge-shrub meadow to bog meadow (paludification) and how would this affect herbivore and detritus-based trophic systems?	Out of scope - time limitation
Vegetation	Emerging Issues	Are there good vegetation change models for the North Slope and if not, what can we do to help develop them?	Out of scope - methods question
Vegetation	Emerging Issues	What rate of vegetation change is 'normal' (are there previous change estimates?) and how will its definition affect interpretation of future change rates?	Out of scope - theoretical