BLM

North Slope
Rapid Ecoregional Assessment

MANAGER'S SUMMARY

Alaska

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CONTENTS

Cover photo: *Galbraith Lake and the Brooks Range seen from the North Slope of Alaska. (Justin Fulkerson)*

1 INTRODUCTION

The Bureau of Land Management (BLM) recently developed a landscape approach to enhance management of public lands.[1] As part of this landscape approach, the BLM and collaborators are conducting Rapid Ecoregional Assessments (REAs) in the western United States and Alaska. REAs are designed to transcend management boundaries and synthesize existing data at the ecoregional level, address current problems, and support efforts to project future conditions. BLM, other federal and state agencies, and public stakeholders all benefit from the synthesis and analysis of available data, and in the development and management of shared resources.[2]

GLOSSARY			
ACEC	Area of Critical Environmental Concern	MAGT	Mean Annual Ground Temperature
ADF&G	Alaska Department of Fish and Game	MQ	Management Question
ADNR	Alaska Department of Natural Resources	NHD	National Hydrography Dataset
AKGAP	Alaska Gap Analysis Program	NOS	North Slope
AKNHP	Alaska Natural Heritage Program, University of Alaska Anchorage	NLCD	National Land Cover Database
ALFRESCO	Alaska Frame-based EcoSystem Code	NPR-A	National Petroleum Reserve-Alaska
AMT	Assessment Management Team	NPS	United States National Park Service
AWC	Anadromous Waters Catalog	REA	Rapid Ecoregional Assessment
BLM	Bureau of Land Management	NWAB REA	North West Arctic Borough Rapid Ecoregional Assessment
CA	Change Agent	SNAP	Scenarios Network for Alaska and Arctic Planning, University of Alaska Fairbanks
CE	Conservation Element	Tech Team	Technical Team
DOD	Department of Defense	TEK	Traditional Ecological Knowledge
ESRI	Environmental Services Research Institute	TNC	The Nature Conservancy
GCM	Global Circulation Model	USGS	United States Geological Survey
GIPL	Geophysical Institute Permafrost Lab	UA	University of Alaska
GIS	Geographic Information System	USFS	United States Forest Service
HUC	Hydrologic Unit Code	USFWS	United States Fish and Wildlife Service
ISER	Institute of Social and Economic Research, University of Alaska Anchorage	YKL	Yukon Lowlands – Kuskokwim Mountains – Lime Hills
LCM	Landscape Condition Model		

REAs evaluate questions of regional importance identified by land managers, and assess the status of regionally significant ecological resources, as well as agents of change that are perceived to impact 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 to develop habitat conservation strategies for regionally significant native plants, wildlife, and fish, and other aquatic species; and
- To inform subsequent land use planning, including trade-off evaluation, environmental analysis, and decision-making for other interconnected public land uses and values, such as development, recreation, and conservation.

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

Much of the analysis relies on computer modeling to generate predicted distributions of species and explore future climate and development scenarios that are inherently uncertain. Therefore the primary utility of REAs lies in the generalized patterns observed and predicted. Second, the development of new information by synthesizing existing data offers tangible products to aid in the management of natural resources. Third, REAs are a useful tool for identifying critical yet unavailable information and generating questions for further analysis.

A number of other REAs are underway or have recently been completed in Alaska. These include the Seward Peninsula,[3] Yukon Kuskokwim,[4] and the Central Yukon (in progress). Eleven additional REAs address regions in the lower 48 states.[5]

National and Regional Context

Given that REAs are a national program, there is an opportunity to compare landscape and resource conditions across multiple scales. Each REA assesses how ecosystems are likely to change as climate and land use changes, but recognizes the magnitude and nature of those impacts change across regional and national scales. Alaskan landscapes are largely considered intact and operating under natural conditions. Thus, REAs in Alaska present a unique opportunity to examine the regional effects of climate change, largely without extensive compounding influences of human modification.

At the regional scale, REAs generate a foundation for assessment by compiling disparate datasets into a single resource that can be accessed by managers and GIS professionals for future assessments. Additionally, REAs assess the likely impacts on the landscape and provide a vision for future conditions. This information is already being used to inform regional land use planning efforts for the BLM and has led to multiple projects statewide to better understand the likely impacts of a changing landscape.

Audience

While the BLM has funded this assessment, and has been the primary collaborator in structure and content, the results from the North Slope (NOS) REA are intended to assist a much broader audience. The USFWS, NPS, and DOD are all federal agencies that manage land in the region, or assist with management on state and private lands. The State of Alaska owns approximately 20% of the land in the North Slope study area, and Alaska Native regional and village corporations have significant lands in the region. Substantial effort was invested to engage these and all land managers in the REA throughout the assessment, both formally through the Assessment Management Team (AMT) and Technical Team, and informally through consultation with the North Slope Planning Commission and the use of newsletters, webinars and public presentations. Thus, while BLM has provided the framework and funding for the assessment, the findings belong, and are accessible, to this larger group of land managers.

Report Structure

This executive summary is intended for land managers and the general public to convey the intent, general methodology, primary results, and interpretation of the North Slope REA. Following the introduction we include a description of the baseline conditions, social and economic conditions, impacts of climate warming on the region, perspectives of landscape change, and future opportunities. Inset "case study" boxes are included in this document to highlight notable outcomes from the assessment.

This document is supported by the accompanying Technical Supplement (TS). We encourage readers to refer to the Technical Supplement for detailed introduction, methods, results, and data gaps and limitations. The Technical Supplement also provides additional discussion on resources of conservation concern, climate change, invasive species, and socio-economic conditions. There are also many full page figures included in the Technical Supplement for more detailed viewing of some of the spatial data generated as part of this assessment. Finally, in the coming months all data associated with the REA will be available through the BLM REA data portal:

http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas/dataportal.html

Study Area

The study area encompasses 96,431 square miles of northern Alaska and is composed of three ecoregions: the Beaufort Coastal Plain, Brooks Foothills, and Brooks Range north of the crest of the range,[6] as well as bordering watersheds **(Figure 1)**.

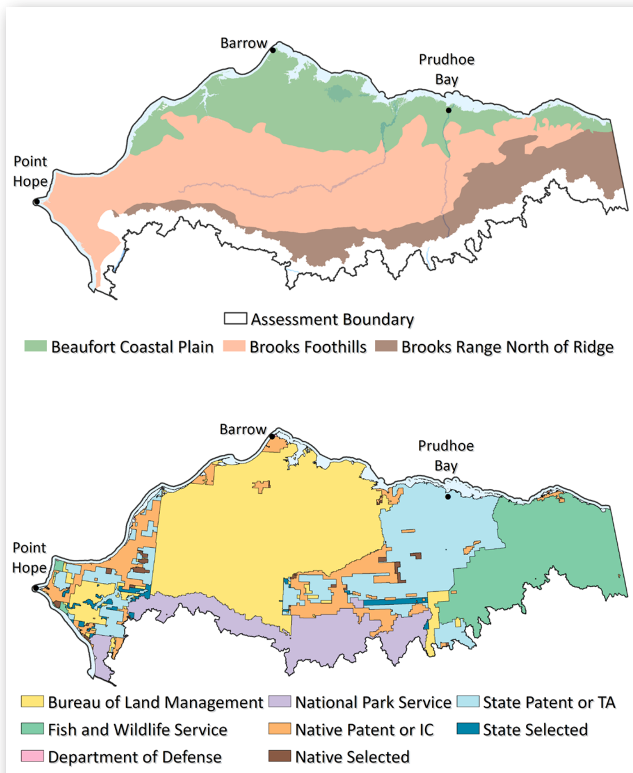

Figure 1. *NOS Ecoregion Study Area: Beaufort Coastal Plain, Brooks Foothills, and Brooks Range north of the crest of the range (top); and land status of major land owners (bottom).*

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 have a major influence on the landscape and resident organisms. Approximately 10,000 people live in ten communities in the study area, with Barrow being the largest community with over 4,000 that serves as the regional hub for goods and services. Approximately 2,000 individuals in the region are transient workers associated with the largest oil field in the United States, Prudhoe Bay, its surrounding oil field industrial complexes, and associated support services. The BLM (39%), the State Department of Natural Resources (20%), the U.S. Fish and Wildlife Service (USFWS) (18%), and the National Park Service (NPS) (12%) manage approximately 89% of the North Slope study area. Please see the Technical Supplement for a more complete description of the physical, ecological, and socio-economic setting.

The Arctic coastal plain of the North Slope (Justin Fulkerson).

REA Elements

To address regionally important questions, significant ecological resources and agents of change, REAs focus on three primary elements:

- Change Agents (CAs) are those features or phenomena that have the potential to affect the size, condition, and landscape context of ecological systems and components **(Table 1)**.
- 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 **(Table 2)**.
- Management questions (MQs) are regionally specific questions developed by land managers that identify important management issues.

Table 1. *Change Agents selected for the North Slope REA.*

Change Agents (CAs)	
Climate: Precipitation; Air Temperature; Thaw date; Freeze date; Climate Biomes	Fire: Return Interval; Vegetation Response
Permafrost: Mean Annual Ground Temp.; Active Layer Thickness	Anthropogenic Uses: Subsistence; Natural Resource Extraction; Transportation and communications; Recreation; Energy Development
Invasive Species	

Table 2. *Terrestrial and Aquatic Coarse- and Fine-Filter Conservation Elements selected for the North Slope REA.*

Terrestrial Fine-Filter CEs	
Nearctic brown lemming	Arctic fox
Caribou	Lapland longspur
Willow ptarmigan	Greater white-fronted goose
Raptor concentration areas	
Aquatic Fine-Filter CEs	
Broad whitefish	Dolly Varden
Arctic grayling	Burbot
Chum salmon	
Terrestrial Coarse-Filter CEs	
Coastal plain moist tundra	Foothills tussock tundra
Coastal plain wetland	Alpine dwarf shrub tundra
Sand sheet wetland	Tidal marsh
Sand sheet moist tundra	Marine beach, barrier islands, spits
Aquatic Coarse-Filter CEs	
Deep connected lakes	Large streams
Shallow connected Lakes	Small streams

One important strength of the REA approach is the integration of current management concerns and current scientific understanding into a comprehensive regional assessment. MQs focus REAs on pertinent management and planning concerns for the region. MQs are also used to create CE and CA lists by identifying critical resources and management concerns for the region. In addition to the MQs, CEs are also identified via an ecoregional conceptual model. A complete list of MQs can be found in the Introduction to the Technical Supplement.

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?

It is the unique combination of scientific and management-driven research questions that make the REAs particularly useful for coordinated regional management of natural resources.

Assessment Approach

The primary REA analysis focuses on exploring the relationships between resources of conservation concern with specific agents of change. The change agents (CAs) are those features or phenomena that have the potential to affect the size, condition, and landscape context of the resources of interest. The change agents include broad factors that have region-wide impacts such as fire, invasive species, and climate change, as well as localized impacts such as development, infrastructure, and extractive energy development **(Table 1)**.

The resources of interest are termed "Conservation Elements" (CEs) and are meant to represent key resources in the ecoregion that can serve as surrogates for the ecological condition across the ecoregion **(Table 2)**. The conservation elements were defined through the "coarse-filter/fine-filter" approach suggested by BLM guidelines; an approach used extensively for regional and local landscape assessments.[7,8] Ecosystem representation are achieved by "coarse-filters" that are dominant habitats, with a limited subset of focal species as "fine-filters" to capture specific resources of interest and those not encompassed by the "coarse-filters."

Ecoregional Conceptual Model

The Ecoregional Conceptual Model portrays an understanding of critical ecosystem components, processes, and interactions necessary for the maintenance of sustainable ecosystems. Specifically these models describe how ecosystem resources interact with one another and describe the relationships between ecosystem resources, agents of change, and ecosystem drivers.

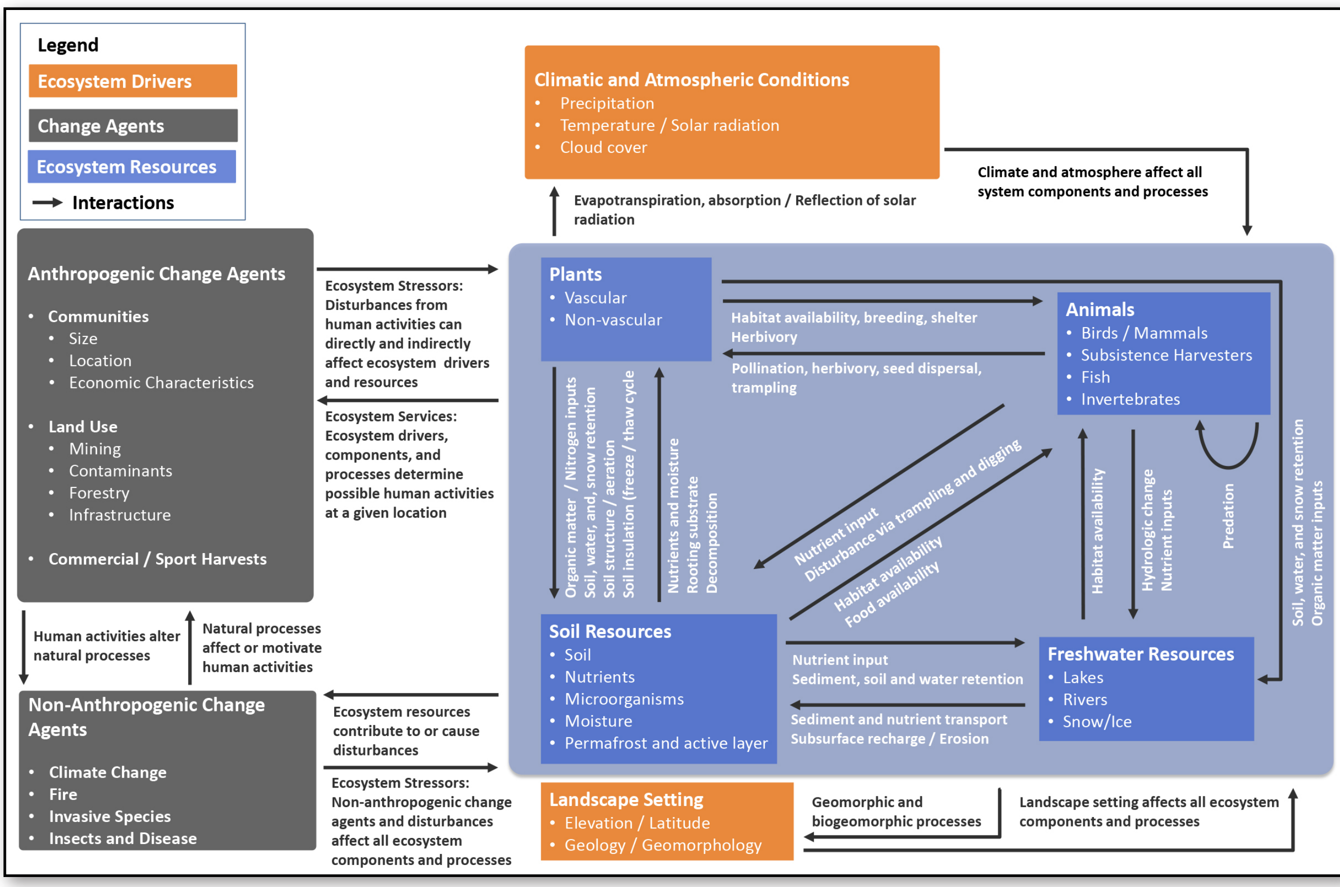

Figure 2. *Conceptual Ecoregional Model for the North Slope REA. The model displays the relationship between principal ecosystem resources, ecosystem drivers, anthropogenic change agents, and non-anthropogenic change agents.*

The Conceptual Ecoregional Model for the North Slope study area provides a coarse-level interpretation of key ecological resources, drivers, and CAs **(Figure 2)**. The model 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 change agents** (land use, development, recreation etc.) and **non-anthropogenic change agents** (climate change, fire, and invasive species).
- **Relationships between ecosystem resources** with interactions between them identifying key ecosystem processes and functions (for example, soil resources provide specific habitat for animals).
- **Relationships of ecosystem drivers and change agents** as external forces for ecosystem resources (for example, climate change alters composition, structure, and productivity of ecosystem resources and climatic conditions provide carbon and nitrogen setting that provides essential components to the ecosystem resources).

Land Owners and Stakeholders

In addition to working with the Assessment Management Team and Technical Team, the University of Alaska (UA) team and BLM State and Field offices also coordinated three community outreach meetings in Barrow, Alaska as part of the North Slope Borough Planning Commission monthly meetings. Representatives from each of the North Slope villages regularly attend these meetings and University of Alaska team members presented at three time steps throughout the assessment (September 2013, October 2014, and September 2015). The purpose of these meetings was to inform the general public and Borough officials about the REA process, its expected outcomes, gather input on conservation elements, change agents, and management questions, and to share final products and assessment outcomes. In addition to these meetings, the UA team also disseminated four printed and electronic newsletters to almost 200 interested land managers and stakeholders in the region.

Native village of Wainwright (Theresa Rzeczycki).

[1] BLM 2014
[2] Bryce et al. 2012
[3] Harkness et al. 2012
[4] Trammell et al. 2014
[5] See http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach/reas.html
[6] Nowaki et al. 2001
[7] Jenkins 1976
[8] Noss 1987

Box 1

Key Results

Landscape Condition

- The NOS study area has higher landscape condition than most national parks in the lower 48.
- Areas with lower landscape condition are localized around existing communities and oil and gas infrastructure.
  - However, if the high development scenario is followed, there is a possibility of a large pipeline being constructed across the NPRA.
- The current landscape is highly intact and only modest reductions in condition are anticipated under medium and high development scenarios.
  - However, the accuracy of existing data, and estimates on the magnitude of future development, are significant data gaps, meaning the current and future landscape condition is likely overestimated.
- Even minor reductions in landscape integrity may have important impacts to resources locally.
  - A shift from highly intact to slightly less intact may result in a shift in species behavior or cause habitat loss in already vulnerable systems.

Climate

- Significant long-term warming is predicted across the study area, particularly in the winter. Inland areas will experience more summer warming than coastal areas, whereas winter warming will be greatest to the east, with an increase of roughly 8 °F by the 2060s.
- Precipitation is also expected to increase, but the high variability between months, years, and models make this trend harder to predict.

Fire

- Fire is likely to remain absent – or almost absent – from some sub-regions. Sporadic tundra fires may occur in all regions of the study area.
- Despite extremely high variability in fire behavior, model outputs do suggest that land managers should expect increased fire risk in coming decades in the Brooks Range and Western Foothills.

Soil Thermal Dynamics

- Model results suggest warming of permafrost and increases in active layer thickness across the North Slope study area, but minimal loss of permafrost at one meter depth.
  - In select 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.
- 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.
  - However, actual thermokarst in these areas is likely to be limited, given limited permafrost thaw.
- Change in active layer is likely to have a greater effect on water availability for ecosystems than changes in precipitation and evapotranspiration.

Invasive Species and Forest Defoliators

- Very few populations of non-native species are currently known from the region.
  - The few infestations of non-native plants are currently restricted to warmer areas in habitats with disturbed substrates.
  - Human population centers in the region are likely receiving non-native plant propagules, but the current climate is believed to curtail establishment.
- Risk of invasion is expected to increase northward as the growing season lengthens in the future.

The Trans-Alaska Pipeline (Jamie Trammell).

Key Results, Cont'd

Anthropogenic

- The population of little over 10,000 people is diffuse throughout the region.
  - Barrow is the largest resident population center, and serves as the services and transportation hub.
  - Resident population increased steadily by 32.6% from 1990 to 2013.
  - Resident population growth seems to have been supported by the taxes on natural resource extraction industries.
- While the actual footprint of the Prudhoe Bay oil and gas industry complex is only 20 sq. miles, it occupies almost 50 times that area, and impacts a much larger area.
- In addition to the oil and gas, gravel, lead and zinc are also extracted at substantial quantities. While other precious minerals and a large deposit of coal can potentially be extracted, market dynamics, access to these locations, and economic feasibility have been significant barriers.
- Economies are a mix of subsistence, cash, and government subsidies. Oil and gas industry and mining have been the primary economic drivers of the local economy. While there is some tourism, its contribution to the local economy is relatively very small. Cost of living is high, primarily driven by energy prices.
  - Caribou is the most hunted terrestrial species for subsistence purposes.
- Other than the industrial development, anthropogenic footprint is primarily restricted to communities.
  - However, trails are extensive throughout the region
  - Location of camps, cabins, and other culturally significant resources signifies the access to, and use of a much larger area by the resident population than is evident from the footprint of resident communities.

Terrestrial Habitats

- Foothills tussock and alpine dwarf shrub tundra are expected to experience significant increase in mean July temperature.
- Almost all CE distributions are associated with a significant increase in growing season in the long term.
  - Barrier islands, beaches and spits growing season may increase 2 weeks by the 2060s.
- Shrubs could increase by as much as 5% in the foothills.
- Nearly all habitats expect to see an increase in the active layer thickness by the 2060s, which is likely to impact water availability across the North Slope.
- About 85% of the coastal plain has a high predisposition for thermokarst.
- Tidal marsh habitats will be most impacted by oil and gas development.

Terrestrial Species

- Species-specific impacts difficult to identify using current literature.
- Over half of current raptor concentration areas, willow ptarmigan, and Lapland longspur habitats are likely to see a significant increase in July temperature by the 2060s.
- Changes in shoulder seasons, especially as it impacts snow versus rain, could negatively impact herbivores through flooding or icing.
- Increased flooding as a result of shoulder season changes in snow versus rain could negatively impact herbivores (caribou, lemmings, etc.).
- Regional warming is likely to affect Arctic foxes by reducing snow cover and prey abundance, as well as increasing competition with red fox.
- Increased shrubs could create more favorable habitat for species like moose and willow ptarmigan.
- Increased water availability and warmth may increase insect abundance.
  - Increased temperatures and water availability could provide more abundant and higher quality forage for species like Lapland longspur and the greater white-fronted goose.
  - Increased temperatures and water availability could increase abundance of biting insects and parasites, having a negative impact on caribou and Arctic fox.
- Willow ptarmigan, Nearctic brown lemming, and caribou could see significant increases in winter precipitation over most of their current distributions.

Aquatic Species and Habitats

- Most aquatic habitats are managed by BLM in the North Slope study area.
- Shallow lake habitats are the most impacted by oil and gas development.
- Spatial data is extremely limited for aquatic resources in the North Slope study area.

2 BASELINE

One of the primary goals of REAs is to develop seamless baseline datasets for the ecoregion of interest. This baseline data for species, habitats, and agents of change provides the foundation of the assessment; it also serves as a critical product for managers to understand the current status of the ecoregion, and provides a benchmark on which change can be measured. Thus, baseline data is an extremely important first step in the REA process.

Data Discovery

From the onset of this REA, the UA team was tasked with identifying, collecting, and synthesizing relevant existing information for the entire study area. Even with the Alaskan arctic being of national and international importance and a focus of much scientific research, acquiring spatial data that comprehensively spans the entire study area was particularly challenging.

Substantial effort was spent identifying datasets relevant for regional analyses. This included extensive online searches, data archive searches, interviews, phone calls, office visits, and primary literature reviews. Data from many state and federal agencies was collected and synthesized. Hundreds of datasets were examined for accuracy and clarity, quality and completeness, and utility for regional management.

Baseline Data Creation

One of the additional benefits provided through this REA is the development of unique baseline datasets for the region. Basic data relating to species distributions was sparse and when available, was typically limited to small areas within the assessment region. We developed, tested, and validated models depicting terrestrial habitats, terrestrial species, and aquatic habitats within the region. The result is a suite of newly developed spatial models depicting distributions for various vegetation assemblages and terrestrial species that did not previously exist for the region.

Due to extremely limited data availability on fish presence in the North Slope, the UA team devoted time to entering fish occurrence data into the BLM-supported RipFish database (see Section J Aquatic Fine-Filter CEs). While this did not generate a spatial product, it ensures that future efforts will have access to 1,800 additional occurrence records to build more robust models of potential fish distribution. For terrestrial habitats, the UA team created the first biophysical setting map for the North Slope by combining an existing vegetation map with physiographic features (see Section G. Terrestrial Coarse-Filter CEs). This represents a key new dataset for understanding current and future potential successional change on the North Slope. For terrestrial species, the UA team identified and validated multiple distribution models for the North Slope, and developed species-specific impact assessments through the attributes and indicators analysis (see Section H. Terrestrial Fine-Filter CEs). These distribution models will be available through an online data portal hosted by the BLM.[9]

Box 2 ***New Baseline Products***

Terrestrial

- Newly released comprehensive vegetation map of the region, mosaicked into nine biophysical settings.
- New caribou forage maps.
- Seasonal caribou distribution maps for the Western Arctic, Teshekpuk, and Central Arctic Herds.
- New synthesized data for passerine species and raptor concentration areas.

Aquatic

- More than 1,800 new fish occurrence points added to the BLM RipFish Database.

Invasive Species

- Current and future invasive plant vulnerability maps.

Climate, Permafrost, Fire

- Estimates of future fire frequency for tundra classes.
- A thermokarst risk map.

Anthropogenic

- Analyzed all Subsistence Advisory Panel (SAP) transcripts.
- Extensive subsistence use species review.
- Identified variables to determine effect of development on harvest of caribou and fish.
- Air quality database of all available models, data, and literature.

[9] See http://www.blm.gov/wo/st/en/prog/more/Landscape_ Approach/reas/dataportal.html

3 SOCIAL & ECONOMIC CONDITION

The North Slope REA study area is vast, with just 12 small population centers, and a total estimated population of almost 11,000 people (2013 census). This includes two non-residential communities, Prudhoe Bay (pop. 2,174) and Red Dog Mine (pop. 309), where no permanent residence is allowed. There has been a notable growth (21.8%, from 6,442 in 1990 to 8,239 in 2013) in the resident population since 1990. If the present trends continue, the region's resident population is expected to steadily increase. Recent growth is largely supported by taxes on natural resource extraction industries that are then used to hire local government and school district personnel. The local health care industry and support services are also funded through substantial federal grants in aid. With the recent decline in world oil prices, tax revenues from oil and gas extraction is expected to be well below the revenues in recent years. The State of Alaska is expecting a deficit of $3 billion, approximately 60% of its annual budget which may similarly impact the North Slope and the North West Arctic Boroughs. Such global and local events have an impact on local population trends, but it is difficult to predict their occurrence or assess their impact.

The North Slope region's oil and gas industry occupies a built area of more than 20 square miles and is spread out over 965 square miles. A new tax structure under the More Alaska Production Act (MAPA) in 2013 has generated new developments in the North Slope oil fields, including new developments by oil giants Conoco Phillips and Exxon Mobil Corporation. While these developments may have significant impact on the land and habitat, local economy is likely to be unaffected in the near future.

Gravel and precious metals mining is also a significant contributor to the local economy and impacts the landscape. Gravel is used primarily for construction of oil and gas industry infrastructure facilities. Most of the gravel industry is limited to the area between Colville and Canning rivers. Precious metal mining is generally restricted to the Red Dog Mine, the world's largest zinc mine, also producing large amounts of lead. Large deposits of high quality coal occur in much of the study area, however are not developed due to access issues. The Ambler mining district has large deposits of several precious metals and will potentially be developed in the near future.

Prudhoe Bay oil and gas facility infrastructure on the North Slope of Alaska (Jamie Trammell)

While the oil and gas industry is the economic engine of the region, a large majority of these jobs are held by non-residents. Local government is the largest employer of the resident population, accounting for approximately 50%-60% of the total jobs. The communities in the North West Arctic Borough (NWAB) benefit significantly due to the presence of the Red Dog Mine as it is well known for its local hire policies. Although, the scale of revenue is much smaller compared to the North Slope Borough revenues from the oil and gas industry.

The cost of living in the region is high, driven primarily by high energy costs. Several proposals for producing energy from the region's abundant alternative sources such as wind and hydro are being funded. The physical impact of these potential new developments will be minimal since most of them are very small installations within the existing footprints of the communities.

The physical remoteness of the communities coupled with high energy prices results in high cost of travel within the region. Barrow is the transportation and services hub in the region. While Kaktovik, Nuiqsut, Atqasuk, Anaktuvik Pass, Wainwright, and Point Lay have scheduled flights from Barrow, the other communities are served through Kotzebue in the NWAB. A land-based transportation network of trails between the population centers connects communities to each other and to areas with abundant subsistence resources. None of the communities other than Prudhoe Bay are connected to the state's road system. Prudhoe Bay is the hub of all oil and gas activities and is connected to the state's highway system through the Dalton Highway.

Tourism in the region is minimal. While the region is home to some of the largest parks and preserves in the nation, the region is remote with many of the region's access points restricted by industrial activities. The future of tourism is limited due to the lack of regional facilities. Despite this, independent companies provide tours in the region to a small clientele.

Despite the region's strong wage employment opportunities and availability of store-bought foods, nearly all residents still practice subsistence harvesting. Subsistence is a major source of diet, and forms an important part of the social and cultural identity of the region. Caribou is the most harvested land mammal in the region, with broad whitefish, Dolly Varden, burbot, grayling, waterfowl, and chum salmon all making up important components of diets in the region.

Communities located along the coast are facing severe challenges due to coastal erosion, receding winter ice, and increasing storm exposure. Kivalina has been the most severely affected coastal community in recent years, with a series of storms and subsequent disaster declarations.

4 CLIMATE WARMING

Air Temperature

There is little question that climate is changing, and will continue to change at a rapid pace, on the North Slope. A vast array of abiotic and biotic processes, from fire frequency to carbon and nutrient cycling to dominant ecosystem type, are driven by air temperature. An assessment of areas most likely to experience the greatest change in average air temperature, and its impact on important resources, is critical to inform proactive regional management.

Air temperature has been steadily rising in the North Slope study area compared to the historical record. Climate warming is projected to continue to increase substantially by the 2060s, particularly in winter months **(Figure 3)**.

Pronounced long term changes in date of freeze and date of thaw are projected to result in an increase in the length of the warm season of between 10 and 16 days (8-15%), with the greatest change in western coastal areas.

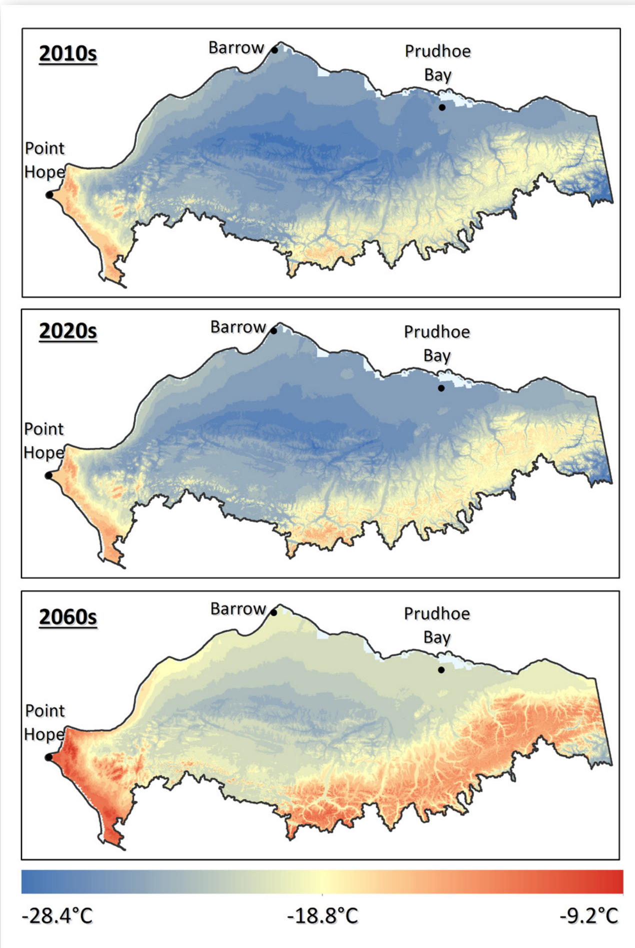

Figure 3. *Mean January temperature for the 2010s, 2020s, and 2060s.*

Precipitation

Warming temperatures are also expected to decrease the snow day fraction, which is defined as the estimated percentage of days on which precipitation would occur as snow as opposed to rain **(Figure 4)**.

Additionally, while the pattern of overall annual precipitation is likely to remain the same, the predicted 5-10% increase in summer precipitation in this relatively dry ecosystem could have important impacts on water availability for vegetation, freshwater and terrestrial species, especially when combined with the anticipated increase in growing season length **(Figure 5)**. However, increases in precipitation may be offset by increases in evapotranspiration.

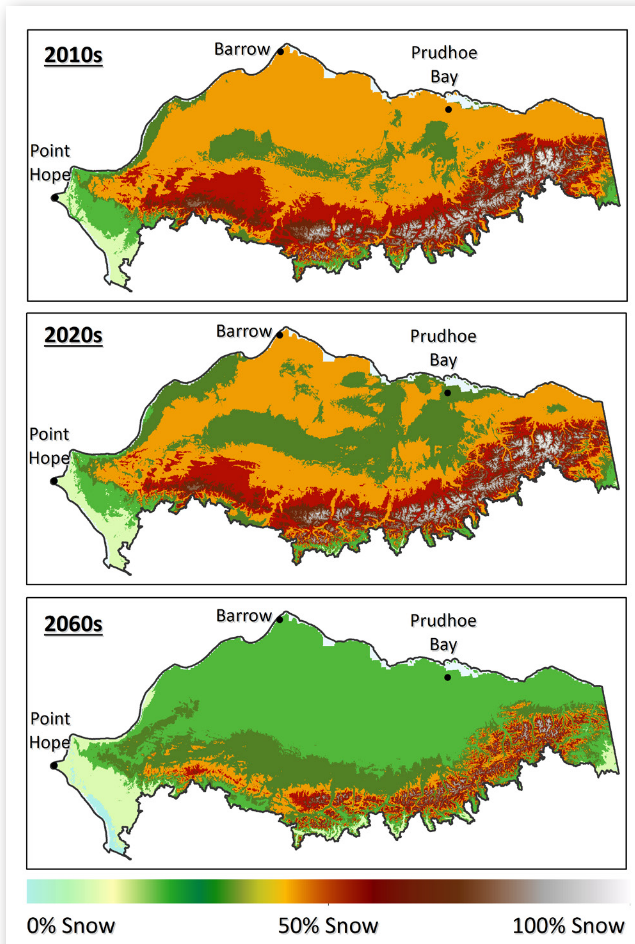

Figure 4*. Estimated percentage of precipitation falling as snow in the month of September for the 2010s, 2020s, and 2060s.*

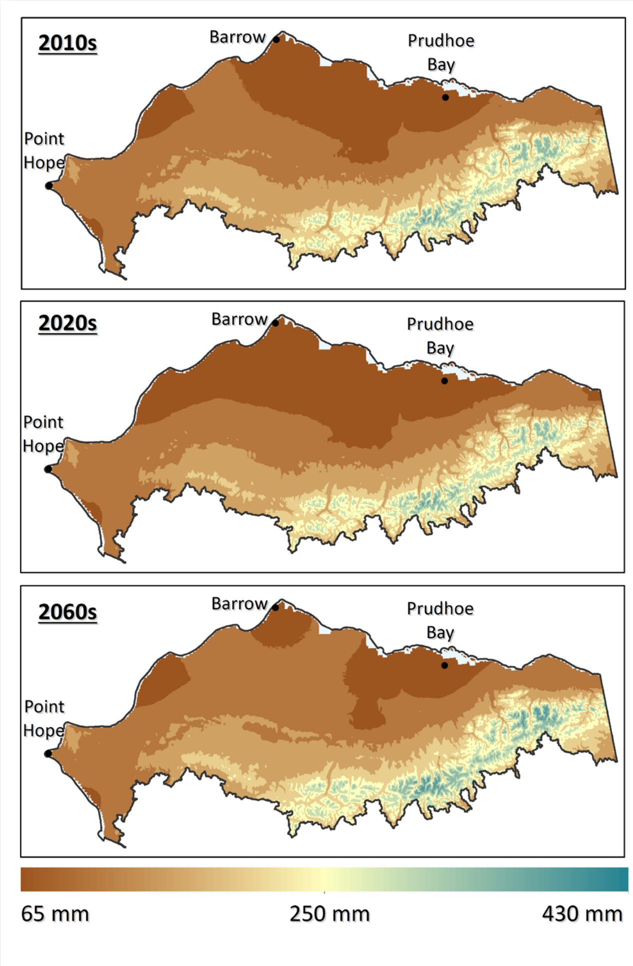

Figure 5. *Summer precipitation projections (mm, rainwater equivalent).*

Vegetation Succession

As air temperature and precipitation increase in the North Slope, we expect continued increases in shrub cover, particularly in the eastern Brooks Range and Foothills **(Figure 6)**. This increase in shrub cover could lead to an increase in food availability for some herbivores like moose, and may also increase the likelihood of fire. The potential increase in shrubs, as well as a continued advancement of treeline, combined with the anticipated warmer summer temperatures could lead to new fire cycles being established in some areas of the North Slope.

Permafrost and the Active Layer

Another impact of a warming climate is the projected increase in mean annual ground temperature, an indicator of permafrost extent, and changes to the active layer thickness. Even minimal permafrost thaw can result in numerous changes on the landscape due to erosion and altered drainage patterns in areas with high thermokarst potential, which encompass most coastal areas and large portions of the coastal plain in the North Slope area. Although widespread permafrost thawing is not forecasted, western areas near Point Hope and Kivalina have the potential to see permafrost loss, and much of the rest of the region is expected to see a 2-4 °C increase in mean annual ground temperature. When combined with local topographic and vegetation characteristics, localized loss of permafrost is certainly possible.

Perhaps the most underestimated impact of these changes to soil thermodynamics are the potential changes to the active layer thickness. Active layer thickness acts as an important control on the ecosystem by determining rooting depth for vegetation, soil-water content, and overall water flow across the landscape. In the near-term we expect to see an average increase in the active layer of approximately 5 cm. By the 2060s, active layer will be, on average, 10 cm deeper, and in some cases, up to 25 cm deeper. These changes in active layer are likely to initiate substantial changes in vegetation and hydrology (see **Box 3** for additional discussion).

Climate-Ecosystem Interactions

Climate data, while modeled at a relatively fine-scale, do not always match the scale of phenomena that affect ecosystem resources, especially the direct and indirect relationships between climate, species, and habitats. Regardless, understanding how major shifts in the physical landscape may alter species and habitat vulnerability offers opportunities to identify areas of greater and lesser concern and helps to direct future study. Impacts of climate change are explored on specific conservation elements in greater depth in the Technical Supplement.

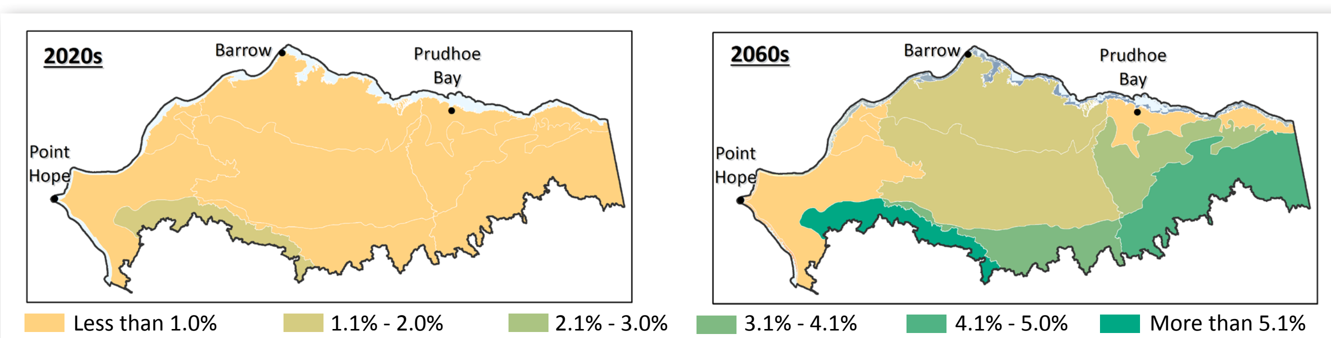

Figure 6. *Percent increase in shrub cover from 2020s, as projected by the Alaska Frame-based EcoSystem Code (ALFRESCO) fire and vegetation model.*

Box 3 Case Study Changes in Active Layer Thickness

Although widespread permafrost thaw is not anticipated for most of the North Slope study area, significant changes in the active layer thickness are anticipated. Active layer thickness plays an important role in determining surface and near-surface groundwater hydrology, vegetation rooting depth, and infrastructure stability.

Figure 7. *Diagram of active layer and permafrost.*

Thus, changes in over 10 cm depth in active layer thickness can have a profound impact on the physical landscape. In most areas, active layer thickness is only expected to increase by 4-6 cm in the near term (by the 2020s), but by the 2060s (long term) we expect to see a significantly deeper active layer in over 60% of the North Slope study area **(Figure 8)**.

A longer growing season combined with an increased active layer 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*) have the ability to grow over 1 m tall when favorable site conditions exist. Subtle increases in canopy height in tundra vegetation can lead to widespread shifts in life form dominance from graminoid to shrub tundra, and even shrubland to forest. The Alaska Frame-based EcoSystem Code (ALFRESCO) model suggests an increase in shrub tundra and a decrease in graminoids, even without considering the increase in the active layer, further suggesting that a more favorable climate for vegetation and a deeper active layer will likely combine to dramatically change the vegetation composition across the North Slope study area.

Additionally, if the active layer becomes deeper than the protective layer, rapid thawing of ice wedges can occur[1]. This can increase the thermokarst potential, and lead to a substantial increase in surface water. This change could trigger a shift from moist tundra to open water and herbaceous wetlands in areas with low drainage capacity. Regions that are able to shed excess water may develop more robust drainage networks that could lead to drier polygon centers[2]. This conversion could then have profound ecological implications on nutrient availability and productivity[3,4].

Impacts to hydrology are critically important in a region that averages only 14 inches of precipitation annually. Changes in overall water availability could change instream habitats, affecting important subsistence resources like broad whitefish *(Coregonus nasus)* and Arctic grayling *(Thymallus arcticus)*.

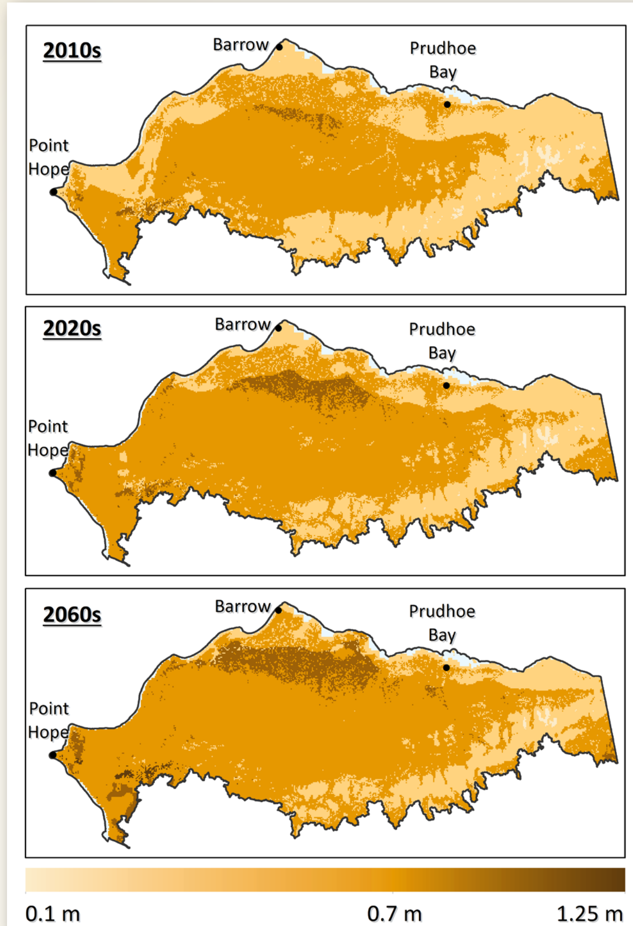

Figure 8. *Current (2010s), near-term future (2020s), and long-term future (2060s) active layer thickness.*

Changes in the active layer are especially important to consider in conjunction with the other agents of change. As the region continues to develop oil and gas infrastructure, it is important to consider the interactive effects of the different agents. For example, the impact of ice roads on tussock vegetation is important to consider as it too can influence the active layer and can lead to a shift from moist tundra to wet sedge vegetation. Additionally, road berms and dust accumulation can also lead to a deeper active layer. Conversely, a deeper active layer will likely have impacts on where suitable infrastructure can be located on the North Slope, resulting in suboptimal placement.

Polygonal ground (Keith Boggs).

[1] Bolton et al. 2014

[2] McGuire 2013

[3] Szumigalski and Bayley 1997

[4] Thormann and Bayley 1997

Box 4 *Case Study* Invasive Species Vulnerability Changing with Climate Warming and Development

Invasive species are organisms not native to the ecoregion whose introduction does or is likely to cause economic or environmental harm. Invasive species are recognized as one of the major challenges to resource management globally.[1,2] In Alaska and the circumpolar North, invasive species are not known to have caused the degree of damage observed at lower latitudes.[3,4,5] However, an increasing number of examples of ecological and economic harm are recognized in the state,[6,7,8,9,10] and invasive species are expected to become more problematic with future changes in land-use, coupled with increases in temperature and growing season lengths.[3]

As non-native plant seed movements closely follow patterns of human movements and their goods, non-native species are undoubtedly being imported into the region. Established populations are very uncommon, however, and are restricted to the southern margin of the study area. Despite surveys in Dead Horse, Barrow, and other high-use areas mature non-native plants have not been recorded **(Figure 9)**. This pattern is strongly suggestive of climatic factors limiting non-native plant establishment.

Nine non-native species have been documented from 39 infestation records, encompassing just 24.3 total acres. Surveys of an additional 195 sites, covering 2,080 acres, did not detect non-native plant species. Thus, the current impact of non-native species on the regional ecology is considered minimal.

Common dandelion (Taraxacum officinale) in recently disturbed ground at Pump Station 3 along the Alyeska Pipeline.

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. By the 2060s however, the area expected to resist non-native plant invasion becomes dramatically reduced. The region is expected to become vulnerable to invasions of cold-tolerant non-native species such as dandelion, foxtail barley, and narrow-leaved hawksbeard. 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.

The fine-scale invasion vulnerability model, combining higher probability sites for non-native plant importation and establishment, suggests that the region currently and into the near term is likely to have a non-native plant species restricted to a very small area **(Figure 9)**. By 2060 however, all villages and the human footprint associated with the oil fields is expected to increase in probability of non-native plant invasion.

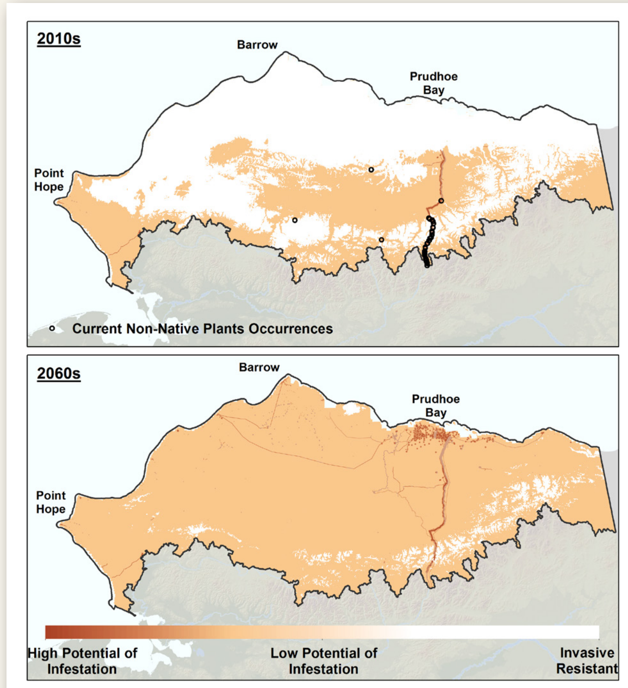

Figure 9. *Modeled infestation vulnerability in the North Slope study area.*

Additionally, numerous floodplain shrubland habitats that intersect current or proposed future right-of-ways or infrastructure is expected to warm to the degree that is likely to make them vulnerable to invasion by cold-tolerant species.

Overall, we anticipate that invasive plant establishment will be geographically restricted under near- and long-term scenarios and that most resources will not be strongly impacted by this change agent. 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. 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.

[1] Pimentel et al. 2005
[2] USDA 2013
[3] Carlson and Shephard 2007
[4] Sanderson et al. 2012
[5] Lassuy and Lewis 2013
[6] Croll et al. 2005
[7] Carlson et al. 2008
[8] Spellman & Wurtz 2011
[9] Nawrocki et al. 2011
[10] Schwörer et al. 2012

Box 5 *Case Study* Climate Warming and Caribou

Caribou are circumpolar in their distribution, occurring in arctic tundra and boreal forest regions in North America and Eurasia.[1] 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 cycle: 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 the Yukon and Northwest Territories of Canada. These herds support a wealth of predator biodiversity and are an important source of food sustaining the health and culture of northern communities.[2]

Caribou (Rangifer tarandus) (Diwakar Vadapalli).

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 also 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 also modify the effects of climate change, creating variety in local impacts.[3]

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.[4,5] For the four North Slope herds combined, mean July temperatures are expected to increase by more than 1.3 °C over 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.

Climate models indicate that warm season length (number of days between date of thaw and date of freeze) 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 habitats. 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 would likely increase.[6] Increases in growing season length are projected to 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 10)**.

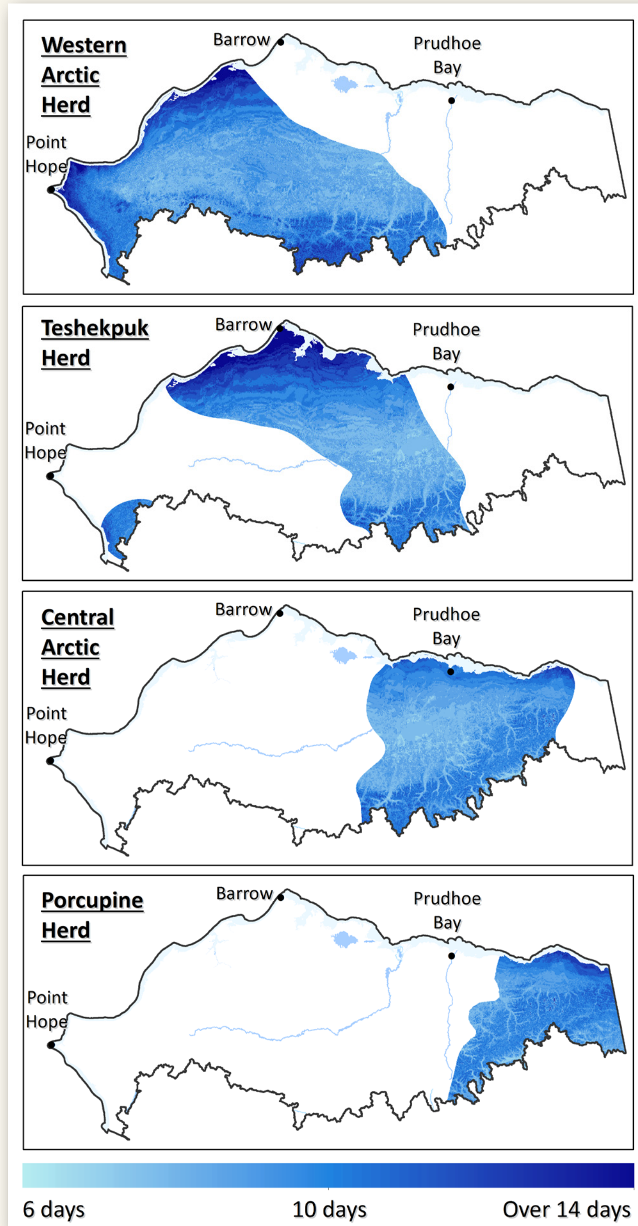

Figure 10. *Change in length of growing season from 2010s to 2060s for Western Arctic, Teshekpuk, Central Arctic, and Porcupine herds.*

[1] MacDonald and Cook 2009
[2] McLennan et al. 2012
[3] Joly 2011
[4] Sparks and Menzel 2002
[5] Stone et al. 2002
[6] Griffith et al. 2002

5 LANDSCAPE CHANGE

An overall goal of the REA is to provide land managers with a vision of the direction and magnitude of change they can expect on their land and neighboring lands. By assessing the potential for overlapping agents of change (CAs) with critical ecosystem resources (CEs), land managers can better understand the location and nature of impacts on resources (for example, fire impacts on a specific species), as well as the cumulative impacts of fire, climate change, invasive species, and development on the resources of interest.

To document the potential changes to the ecoregion, we first developed a comprehensive understanding of all the driving factors and the context of the landscape. This was done at both the ecoregional scale **(Figure 2)** as well as the individual CE scale **(Figure 11)**, using conceptual models.

The relationships identified in the conceptual models were then used to evaluate the various ways in which change agents might impact ecosystem resources. The simplest and most straightforward approach was to assess the overlap between ecosystem resources and specific agents of change.

We also assessed the status of each ecosystem resource by summarizing the landscape condition for each resource. A landscape condition model, which is described below, was used to represent the relative degree of human modification, where some anthropogenic features, such as the Dalton Highway, were assigned a greater impact that then diffuses more slowly relative to other features, such as ice roads. A more complete description is in the Landscape Condition section below.

To better understand overall landscape status, landscape fragmentation was also evaluated, utilizing the landscape condition to determine intact landscapes. Additionally, we examined the potential cumulative impact of all the agents of change by identifying the areas that are likely to experience the most change in the near and long term. A more complete description and examples of these various metrics of landscape change are listed below, as well as their potential importance for regional resource management.

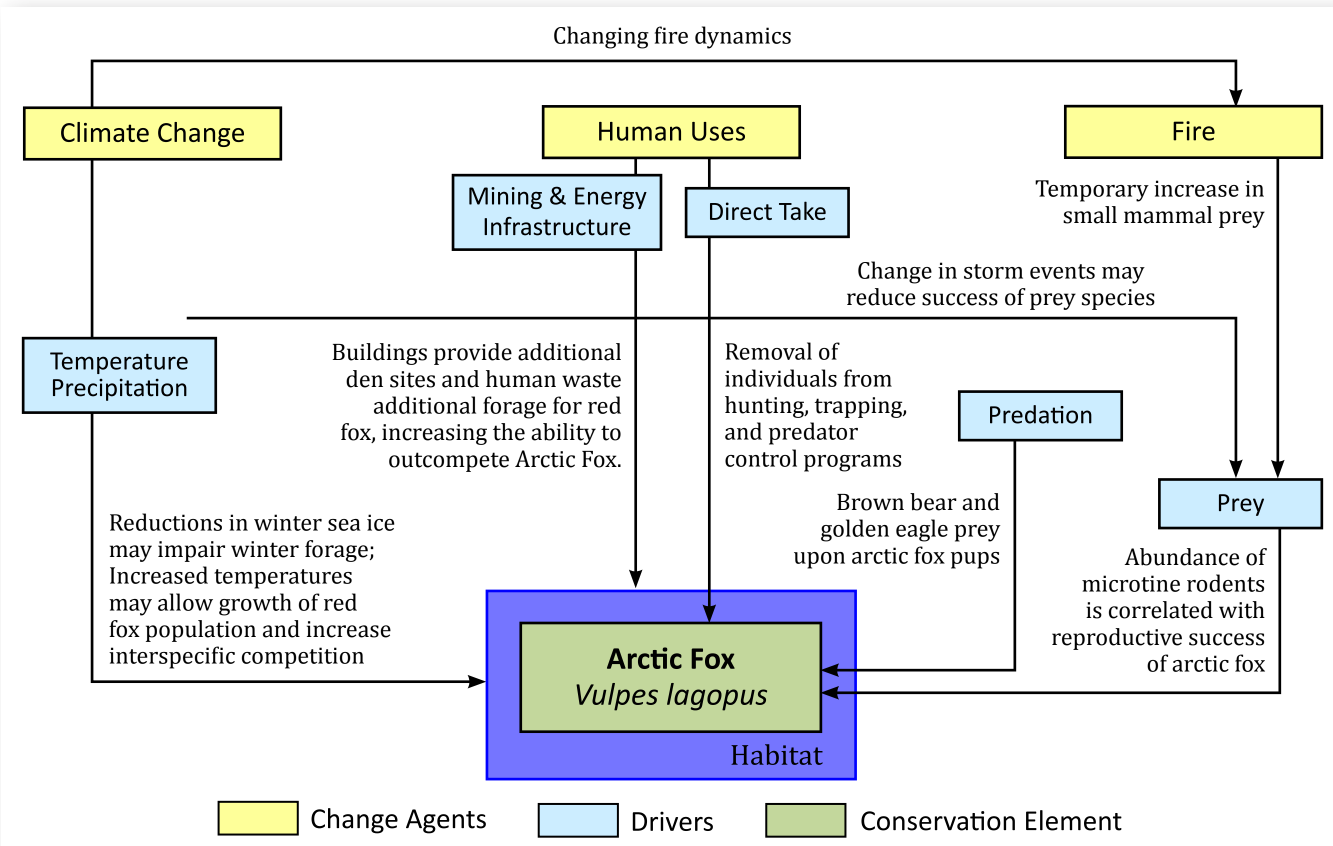

Figure 11. *Conceptual model for Arctic fox.*

Toolik Field Station in the foothills of the Brooks Range, administered by the Institute of Arctic Biology at the University of Alaska Fairbanks (Diwakar Vadapalli)

Conceptual Models

Conceptual models were built for each individual ecosystem resource, as well as for the broader ecoregion. From the broader ecoregional conceptual model **(Figure 2)**, we identified the key ecosystem resources that needed to be examined more closely (i.e. the Conservation Elements). By selecting CEs that represent key ecological resources, we provide a framework in which overall ecological integrity can be assessed. Meaning, if all CEs in the ecoregion are considered to have good status and habitat quality, then we would assume the broader ecosystem has high integrity.

The individual CE conceptual models provided specific linkages between CAs and the CE. 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. Every conceptual model was supported and referenced by scientific literature. These conceptual models represent the current state-of-the-knowledge for these species and systems and can be useful in future studies.

Quantifying Change

Overlap of Conservation Elements & Change Agents

For some species and habitats, overlays of simple climate variables (i.e. average summer temperature) with the distribution of CEs were used to assess potential change (see **Box 6** for an example). For other species, interpolated climate variables were developed that more directly link potential changes to CE life history. An example of this is in **Box 5**, where we discuss the implications of length of growing season on the distribution of the four major caribou herds. Many similar CE × CA overlaps were performed and can be found in Sections G, H, and I of our Technical Supplement.

Landscape Condition

We understand from the literature that different land uses have different impacts on the ecosystem.[10,11,12,13] Using thousands of studies documenting these impacts, NatureServe developed a model called the Landscape Condition Model (LCM) that weights the different land uses according to their overall impact on the landscape, and assigns a distance at which the impact is no longer felt on the landscape. This produces a continuous dataset of landscape condition for the entire assessment area **(Figure 12)**. This then in turn was used to inform landscape integrity and conservation element status (below). Additional details about the inputs and specific methods used in the LCM can be found in Section F of the Technical Supplement.

Landscape condition is a simple way of understanding the relative integrity of a given area. If human modification is minimal, we expect areas to be functioning well. Furthermore, landscape condition is something that can be assessed under future time steps and scenarios, making it a useful decision-support tool. For example, the LCM is providing information to the Western Governors Association on overall landscape integrity through their Crucial Habitat Assessment Tool (CHAT) for all western states (including Alaska).

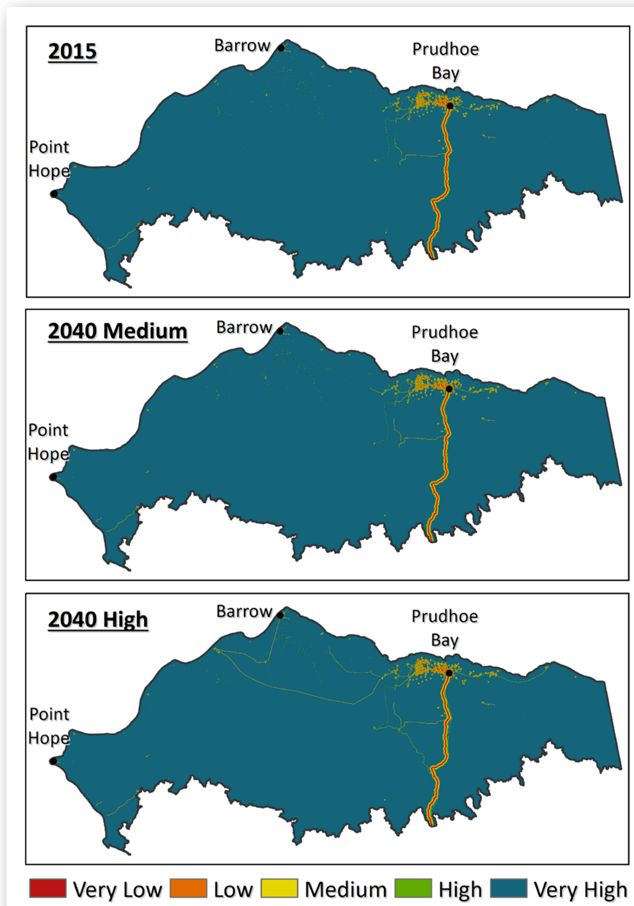

Figure 12. *Current (2015), Medium (2040), and High Scenario (2040) landscape condition.*

Working with the North Slope Science Initiative's (NSSI) scenarios project we incorporated future human footprint estimates from their scenario exercises (see Technical Supplement Section E). We did this by creating a Landscape Condition Model for current conditions, and for both medium and high development scenarios, as projected into the year 2040 **(Figure 12)**. The NSSI scenarios project is currently ongoing and the development scenarios used for the REA should be considered interim products subject to change. However, given the regional focus of the REA, the overall pattern and summarized changes in landscape condition are likely representative of future development.

The Dalton Highway (Diwakar Vadapalli).

At the ecoregional level, it is no surprise that the landscape condition for the region is very high. Even under the high development scenario, the landscape is expected to remain in good condition. This is because human modification is highly localized in the oil and gas development area of the North Slope, and although the activity is sometimes intense, the overall landscape condition is, and is expected to remain, very high **(Figure 12)**. For context, the majority of the North Slope has landscape condition scores that are well above even the most protected areas of the contiguous United States. Estimates on the magnitude and spatial distribution of future oil and gas development were unavailable for this assessment; therefore, estimates of landscape integrity in the medium and high development scenarios underestimate the actual impact of future oil and gas development. This highlights a key information gap that has the potential to limit managers' abilities to appropriately anticipate future conditions in this rapidly changing environment.

Given the overall intactness of the North Slope study area, land managers and scientists alike have an important question to ask about ecosystem thresholds. The degradation from "very high" to "high" may seem numerically small, but could have larger ecological effects not captured by this analysis. It is very likely that degradation from "very high" to "high" has a different ecological meaning than degradation from "moderate" to "low". Sensitive species that inhabit the high condition regions of the landscape could be lost with that small degradation. Thus, the very high condition could be an important target to monitor and manage for in the future.

Additionally, some of the landscape impacts are disproportionally concentrated on specific ecosystem resources. A key example of this is on the coastal plain where landscape condition is much lower than the rest of the ecoregion (left image). While this is largely driven by oil and gas infrastructure in and around Prudhoe Bay, it is an important consideration when assessing future climate stressors to that system as well.

Landscape Integrity

Considering landscape condition without considering the context can be misleading, so we also calculated the level of fragmentation in the North Slope study area. By lumping high condition landscapes together, we were able to set some context for the landscape condition and highlight ways in which the connectivity of landscapes may change over time.

First we assessed those patches of landscape with the highest landscape condition that were over 50,000 acres to represent the "highest" integrity landscapes. We then assessed the high condition landscapes that were between 10,000 and 50,000 acres to represent "high" landscape integrity areas. Finally, we identified those high condition landscapes below 10,000 acres as being vulnerable to change. **Figure 13** shows how landscape integrity is likely to change in the near and long term.

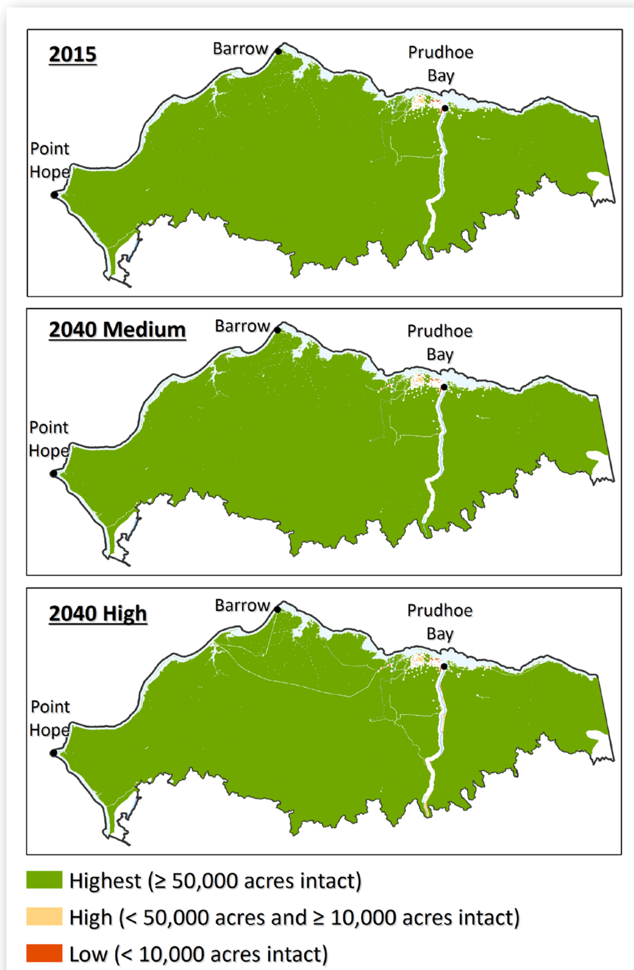

Figure 13. *Current (2015), Medium (2040), and High Scenario (2040) landscape condition.*

Similar to overall landscape condition, we anticipate landscape integrity will remain very high for the North Slope study area. Although most of the region is highly intact, there are some key areas around Prudhoe Bay where landscape condition is high but fragmentation has rendered them vulnerable to change. Additionally, under the high development scenario, increased fragmentation of high condition landscapes could be anticipated near Wainwright and areas surrounding Nuiqsut.

One of the key outcomes from this and the other landscape change metrics is the ability to use the information provided here to focus monitoring efforts. Knowing where changes are most likely to occur (CE × CA overlap, cumulative impacts), managers can more intently focus monitoring efforts in those areas. Likewise, if certain areas are considered vulnerable to change, monitoring and possible protection of those places becomes an option before the resources are compromised.

It is apparent that managers in the North Slope have a unique opportunity to work within an intact system. Novel opportunities exist for monitoring the effects of specific land uses given the reference condition that exists across most of the study area, which is increasingly important given climate-accelerated changes anticipated for the region. Most importantly, managers have the opportunity to develop land use plans in ways that sustain the intact landscapes, which is not the case for many landscapes in the contiguous United States.

Conservation Element Status

The UA team also assessed the status of each ecosystem resource by overlaying the distribution with a landscape condition **(Figure 16)**. This analysis provides an idea of the quality of habitat for each conservation element, both currently and into the future.

Our analysis showed that all CEs have access to high condition habitats throughout the North Slope study area. Some species and habitats do appear to occupy lower condition landscapes (Central Arctic Caribou herd, marine beach/barrier islands, floodplain shrublands, and tidal marsh) than others, suggesting that some ecosystem resources may be more stressed than others. However, in all cases over 90% of the CE distribution fell on high condition landscapes, indicating that at the ecoregional-scale, ecosystem resources are likely not being significantly impacted by human modification.

Caribou on the North Slope (Diwakar Vadapalli).

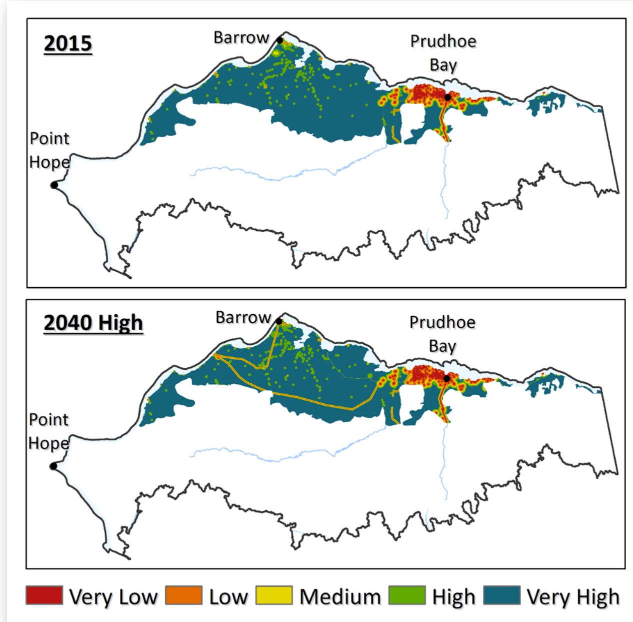

Figure 16. *Current (2015) and 2040 high-development scenario landscape condition within the greater white-fronted goose current distribution.*

By understanding the status of habitats, managers can better anticipate how vulnerable different species and habitats might be to future changes. If a species' habitat is already degraded due to human modification (for example, near a road and existing mining activities), the species may be more vulnerable to other changes (for example, increased summer temperature or introduction of an invasive species). Given that each CE represents a key ecosystem function, when all CEs have good status (meaning high landscape condition) then we expect overall ecosystem function, and ecological integrity, to be high.

Cumulative Impacts

As a final approach to quantifying the likely changes to the landscape, the UA team performed a cumulative impact analysis. The cumulative impact analysis represents 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.

The cumulative impacts analysis identifies important thresholds at which a particular agent of change would likely elicit a management response. All CAs were included (January temperature, July temperature, annual precipitation, mean ground temperature (permafrost), active layer thickness, relative flammability, landscape condition (representing the human footprint), and invasive species vulnerability). Details on the nature and value of these thresholds can be found in Section F of the Technical

Supplement. The model results were combined to determine how many CAs are likely to change in any given watershed **(Figure 17)**, allowing us to identify those areas that are likely to experience the most landscape stressors in the future.

The results from this part of the analysis tells a more comprehensive story about landscape change that differs from the individual CAs and landscape condition/integrity analyses. It is clear from the cumulative impact analysis that, while changes are relatively minimal in the near term, most of the region is likely to change in significant ways in the long term. Areas along the Dalton Highway and Prudhoe Bay are likely to experience two to three of the CAs acting on the landscape in the near-term, while most of the region is likely to see significant changes in six to seven CAs in the long-term, potentially leading to novel climates and ecosystems. Potential change appears particularly high along the foothills to coastal plain transition **(Figure 17)**. Segmenting these results into jurisdictional boundaries **(Table 3)** highlights the collaborative opportunity land managers have in the region to monitor and manage for these simultaneous changes that are not unique to any agency or stakeholder.

Landscape Change Summary

While the region maintains high ecological integrity, it is apparent that the North Slope will change in the future. This assessment has highlighted some of the ways in which we expect ecosystem resources to respond, but substantial work is still required before we can fully understand the nature and impact of these changes. This is especially important given that most of the change will likely come from the combined change in climate and climate-driven processes.

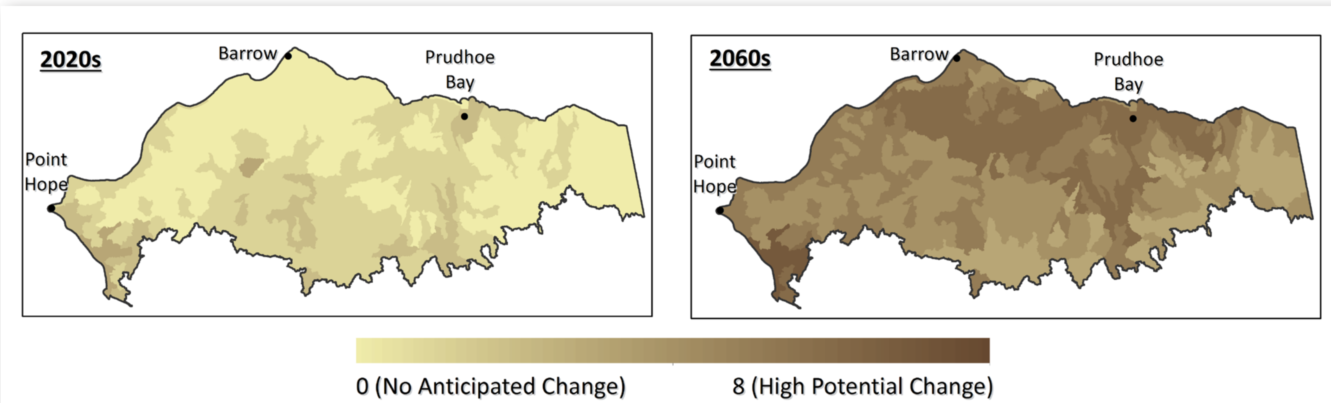

Figure 17. *Near-term future (2020s) and long-term future (2060s) cumulative impact score.*

Table 3. *Areas in km2 per cumulative impact score (CI) and land management agency.*

Land Management Status	CI = 3	CI = 4	CI = 5	CI = 6	CI = 7	CI = 8
Bureau of Land Management	1,102	43,678	21,515	30,196	874	-
Fish and Wildlife Service	18,635	19,120	3,446	4,633	< 1	-
Military	-	-	60	18	3	-
National Park Service	13,729	9,788	3,330	1,432	886	< 1
Native Patent or IC	1,984	10,226	6,676	3,441	805	< 1
Native Selected	11	681	688	213	81	-
Private	-	-	< 1	-	-	-
State Patent or TA	3,954	13,410	17,204	13,866	1,060	< 1
State Selected	334	1,564	801	137	173	-

[10] Leinwand 2010
[11] Theobald et al. 2012
[12] Theobald 2010
[13] Reed et al. 2012

Box 6 *Case Study* Vulnerability of Aquatic Habitats

There are thousands of lakes within the North Slope study area that range from small and shallow (generally <1.6 m deep) to large deep lakes such as Teshekpuk Lake. 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 uses for local residents (e.g., subsistence harvest of fish and wildlife).

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 **(Figure 14)**.[1] Increased snow cover will insulate lakes and result in thinner ice. Reduced ice cover will create new habitat, especially in lakes that are currently 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.

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.

Loss of permafrost, particularly when coupled with thermokarst-prone conditions, increases the potential for lakes (especially shallow lakes) to shrink or dry out in the study area.[2] Thawing of permafrost has also been linked to increases in substrate permeability and increased drainage for all lakes.[2] Lakes may drain entirely with permafrost melting, or lake levels may rise with increased inflow. Thawing permafrost could temporarily increase nutrient loading to lakes and increase primary productivity.[3] Nutrient loading would likely 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.[4]

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 15)**. 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 the thickness of the active layer.

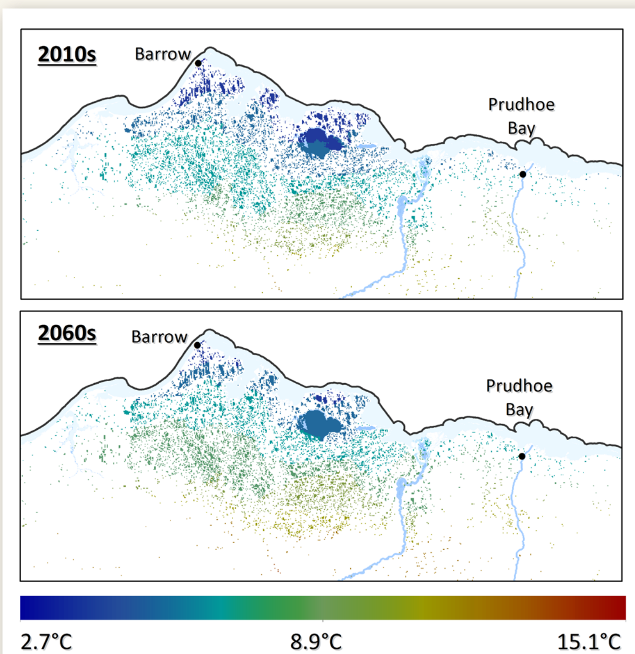

Figure 14. Current (2010s) and long-term future (2060s) mean summer (June, July, August) air temperatures within the lake distribution from Barrow to Prudhoe Bay.

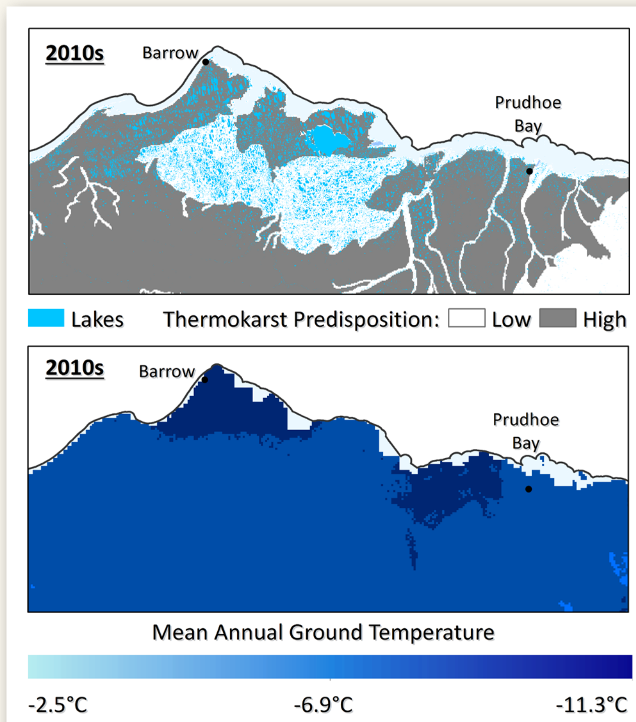

Figure 15. Thermokarst predisposition for lakes and mean average ground temperature from Barrow to Prudhoe Bay.

[1] Schindler and Smol 2006

[2] Roach et al. 2013

[3] Hobbie et al. 1995

[4] Walter et al. 2007

Box 7 *Case Study* Regional Warming Impact on Arctic Foxes

Regional warming has the potential to affect Arctic foxes *(Vulpes lagopus)* negatively by impacting habitat condition and availability. Further, changes in prey availability, primarily through increased competition with red fox *(Vulpes vulpes)* and changes in lemming *(Lemmus sp.)* abundance could also have a negative impact on Arctic fox.

The Arctic fox's greatest predator and competitor is the red fox. Red fox are superior hunters to Arctic fox and are known to even 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.[1] 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 when this occurs.[2] This would likely cause increased competition for den sites and the potential for reduction in the Arctic fox population.[3,4]

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.[5,6] 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[5]. Warmer temperatures could also result in changes in snow dynamics, a shorter snow season, reduced snow extent in late winter, and changes in snow depth, compaction, and icing. The UA team used projected monthly snowfall (precipitation × snow day fraction) and projected non-summer rainfall for estimating potential changes in snow depth. 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 18). These results are described in detail in the technical supplement.

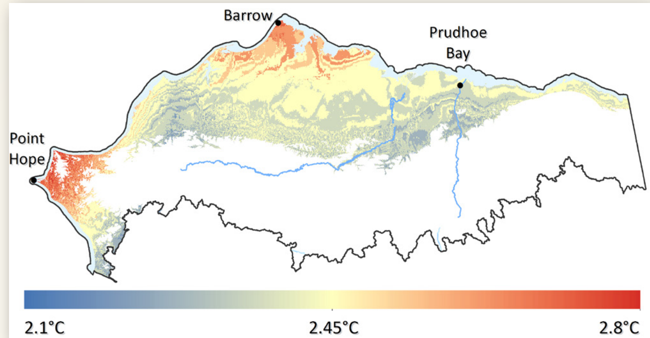

Figure 18. *Change in mean annual temperature from 2010s to 2060s within the modeled distribution of the Arctic fox.*

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. Declines in Arctic fox numbers have already been attributed to loss of lemming cycling in certain Scandinavian populations[6].

Arctic fox (Vulpes lagopus). Photograph by Rama, Wikimedia Commons, Cc-by-sa-2.0-fr

[1] Hersteinsson and Macdonald 1992
[2] Pamperin et al. 2006
[3] Burgess 2000
[4] Szor et al. 2008
[5] Stickney 2014
[6] IUCN

Box 8 *Case Study* Geomorphology, Coastal Erosion, and Salinization

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[1,2].

Patterns of coastal erosion relate to coastline elevation, orientation, geomorphology, sediment size, and permafrost nature[3]. The average rate of erosion along Alaska's Arctic Coast is -1.4 m/y with a maximum of -18.6 m/y occurring in some areas[4]. The rate of erosion is in fact accelerating; along the Beaufort Sea Coast the rate has doubled over the last 50 years[2]. 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[5].

Significant sediment aggradation, however, has been occurring in the prograding deltas of larger rivers[6], as well as the forelands at Point Hope. The persistence of these prograding features is largely dependent on the degree to which sedimentation keeps pace with sea level rise.[7] Barrier islands, spits, bluffs, beaches, tidal marshes, coastal wetlands and moist tundra and coastal lakes are the most highly-affected environments.

Erosion along arctic coastlines is exacerbated by thermal degradation of interstitial and massive ice. Thawing of ice-rich polygon centers and melting of massive ice wedges causes subsidence of the tundra surface along low-relief, protected coastlines. The subsequent ingress of seawater creates a drowned landscape, and 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[8,9]. Here, lake margins may be compromised by tapping from adjacent streams, lakes or ocean, breaching from high lake levels, headward gully erosion, or thaw slump formation[8]. In some cases lake drainage may occur catastrophically; for example, an 80 ha lake was drained in 72 hours by the formation of a thermos-erosional gully[8]. 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[10]. It is likely that Prudhoe and Pogik Bays were formed in this manner[5,6] and that Teshekpuk Lake awaits a similar fate[10].

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[11,12]. 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 km2)

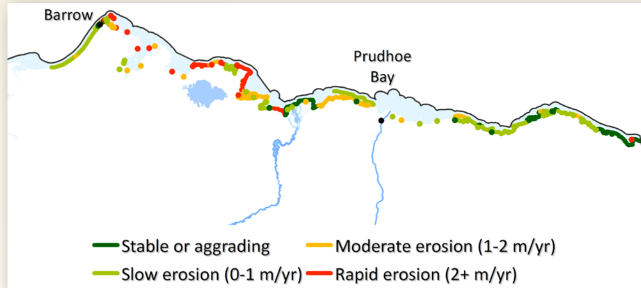

Figure 19. *A compilation of coastal erosion rates documented for the Chukchi and Beaufort Sea coastlines.*

of the landscape, while 41% (477 km2) is susceptible to salinization from storm surge flooding[5,13].

The introduction of sediment and salts to coastal habitats may weaken or kill resident species. Salt-killed tundra is typically colonized by ruderal salt-tolerant plant species[14,15].

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[16]. While not documented, the conversion of freshwater lakes to saline waterbodies in the Arctic is likely to alter benthic food webs and energy resources[5].

The scale of habitat conversion to saline types is indicated by the notable shift of molting Black Brant from inland freshwater lakes to coastal marshes over the last 30 years. This change in distribution is correlated to expansion of preferred forage plants on saltwater-deposited sediment[12,17]. In tidal flats and marshes in Canadian Arctic, grubbing by dense populations of snow geese resulted in conversion of these habitats to hypersaline barrens[12,18,19,20].

The Chukchi and Beaufort coasts represent dynamic landscapes that are undergoing significant changes in habitat conditions. These changes are expected to continue to have repercussions on numerous wildlife species. 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[16].

[1] Jones et al. 2009
[2] Ping et al. 2011
[3] Aguire et al. 2008
[4] Gibbs and Richmond, unpublished data
[5] Arp et al. 2010
[6] Hopkins and Hartz 1978
[7] Martin et al. 2009
[8] Jones and Arp 2015
[9] Hinkel et al. 2005
[10] Mars and Houseknecht 2007
[11] Jorgenson et al. 2006
[12] Tape et al. 2013
[13] Jones et al. 2008
[14] Jorgenson et al. 1997
[15] Flint et al. 2008
[16] NSSI 2014
[17] Jorgenson and Heiner 2003
[18] Gauthier et al. 2006
[19] Jefferies 1977
[20] Jefferies and Rockwell 2002

6 FUTURE OPPORTUNITIES

The North Slope study area is one of the most extensively studied regions in Alaska and while spatial data is available for much of the region, comprehensive regional-scale spatial datasets in many cases either do not exist, are considered highly inaccurate, or the relationship between a specific change agent and conservation element is unclear or unknown. These data gaps were highlighted throughout the assessment (in each section) to provide managers and researchers a tool to determine what data are lacking for the region and hopefully leverage new projects for these efforts (see list of critical data needs below). The UA Team made every attempt in this REA to represent spatially complex interactions between ecosystem processes and their drivers to understand regional trends and to help address management concerns. While we were successful at modeling and mapping many of these interactions in the REA, developing ecologically meaningful criteria to examine these relationships is still needed. Once these relationships are further defined, developing integrative models that link ecosystem response to the multitude of landscape drivers at multiple scales will help managers gain a better understanding of the interactive impacts of landscape change in the North Slope. The UA team is confident that the models and data used represent the best available knowledge about the system and the potential impacts of the known agents likely to change the North Slope. This REA is an important first step for multiagency land-use planning efforts, developing regional monitoring strategies, and to subsequent scenario planning projects that examine multiple ranges of possible futures. We highly recommend scenario planning as it is a dynamic tool that enables land managers to identify potential decisions that achieve desired conservation and development outcomes for their organizations and missions, and would aid BLM in developing collaborative landscape approaches to enhancing management of public lands.

Chukchi Sea coastline near Point Hope, Alaska (Scott Guyer).

Box 9

Crucial Data Gaps

Aquatics

- No existing aquatic habitat classification exists.
- Outdated National Hydrography Dataset (NHD) and Digital Elevation Model (DEM).
- No information on stream order or stream gradient .
- Lack of fish occurrence data.
- Lack of data on long-term trends and temporal change for fish.
- Lack of data on fish populations and movements.
- Lack of understanding of hydrologic conditions and no hydrologic models.
- Limited gauging stations.
- Limited water temperature data and no water temperature models.

Terrestrial

- No standard vegetation map and classification available for all modeling efforts.
- No accuracy assessment available for the vegetation maps used in the assessment.
- No comprehensive soil survey for the ecoregion.
- Minimal understanding of vegetation succession.
- Caribou collar data for delineating migration corridors unavailable.
- No comprehensive current or historic shoreline maps.
- No spatial data for land birds and their habitat over time.
- Lake margins, riparian corridors, and tidal marshes data of low resolution (> 30 m).
- Kernel density for the Porcupine caribou herd unvailable.
- Raw telemetry data for the Western Arctic, Teshekpuk, and Central Arctic caribou herds unavailable.
- The Nearctic brown lemming and raptor distribution models are known to be inaccurate.
- No specific information regarding threshold values linking species to specific CA responses.

Climate, Permafrost, Fire

- Climate data unavailable at a finer scale than monthly mean data.
- No daily climate data to account for extreme events.
- No precipitation differentiation between rain and snow, or any direct measure of snow pack.
- Lack of long-term climate stations and permafrost bore holes to validate models.
- Climate data and permafrost data only available at a coarse resolution.
- No climate monitoring stations above 500m.
- Limited data on fire severity and fire history.
- Lack of clear linkages between climate variables that can be modeled and factors important to species survival.

Invasive Species

- Invasive species survey data lacking for most of the study area.

Anthropogenic

- Much social and economic data is not amenable to aggregate to a regional scale.
- Data available for the North Slope Borough not always available for the North West Arctic Borough.
- Road and other land use data not consistently created or validated across jurisdictional boundaries.
- Local road and trail data are incomplete.
- Limited subsistence resource surveys and none systemically sampled annually; thus only existing and available datasets used. No air quality models are available for the entire region.
- No air quality models are available for the entire region.
- No water withdrawal maps.
- No comprehensive infrastructure dataset is available publically, and the magnitude of future oil and gas development is unknown for the region.
- No method for tracking food sharing across the ecoregion, limiting the ability to understand region-wide impacts of changes in subsistence species accessibility.
- No systematic sampling of contaminants exists for the region.
- Snow and ice road data limited to NPR-A.
- No spatial data on gravel pits and mines.

Literature Cited

Aguire, A., C. E. Tweedie, J. Brown, and A. Gaylord. 2008. Erosion of the Barrow Environmental Observatory coastline 2003-2007, northern Alaska. Pages 7-12 in D. L. Kane and K.M. Hinkel, eds. Proceedings of the Ninth International Conference on Permafrost. Held at: The University of Alaska, Fairbanks. June 29 - July 3, 2008. Published by: Institute of Northern Engineering, University of Alaska Fairbanks.

Arp, C. D., B. M. Jones, J. A. Schmutz, F. E. Urban, and M. T. Jorgenson. 2010. Two mechanisms of aquatic and terrestrial habitat change along an Alaskan Arctic coastline. Polar Biology 33:1629-1640.

BLM. 2014. The BLM's Landscape Approach for Managing Public Lands. http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach.html.

Bolton, W. R., V. E. Romanovsky, A. D. McGuire, G. Grosse, and M. J. Lara. 2014. Initial conceptualization and simulation of arctic tundra landscape evolution using the Alaska Thermokarst Model. AGU 2014 abstract.

Bryce, S., J. Strittholt, B. Ward, and D. Bachelet. 2012. Colorado Plateau Rapid Ecoregional Assessment Final Report. Prepared for: National Operations Center, Bureau of Land Management, U.S. Department of the Interior. Dynamac Corporation and Conservation Biology Institute, Denver, Colorado. 183 pp.

Burgess, R. 2000. Arctic fox. Pages 159-173 in J. Truett, and S. Johnson, eds. The natural history of an arctic oil field: Development and the biota. Academic Press. San Diego, California.

Carlson, M. L., I. Lapina, M. Shephard, J. Conn, R. Densmore, P. Spencer, J. Heys, J. Riley, and J. Nielsen. 2008. Invasiveness ranking system for non-native plants of Alaska. USDA Forest Service, R10-TP-143. 218 pp.

Carlson, M. L., and M. Shephard. 2007. Is the spread of non-native plants in Alaska accelerating? Pages 111-127 in Meeting the challenge: invasive plants in Pacific Northwest ecosystems, Portland, OR. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, En. Tech. Rep. PNW-GTR-694.

Croll, D. A., J. L. Maron, J. A. Estes, E. M. Danner, and G. V. Byrd. 2005. Introduced predators transform subarctic islands from grassland to tundra. Science 307:1959-1961.

Flint, P., E. Mallek, R. King, J. Schmutz, K. Bollinger, and D. Derksen. 2008. Changes in abundance and spatial distribution of geese molting near Teshekpuk Lake, Alaska: interspecific competition or ecological change? Polar Biol. 31:549–556.

Gauthier, G., J. F. Giroux, and L. Rochefort. 2006. The impact of goose grazing on arctic and temperate wetlands. Acta Zoologica Sinica 52:108-111.

Geck, J. 2007. A GIS-Based Method to Evaluate Undeveloped BLM Lands in Alaska. Science and stewardship to protect and sustain wilderness values. Eighth World Wilderness Congress Symposium, Anchorage, AK, USDA Forest Service.

Gibbs, A. E., B. M. Richmond, and L. Erikson. 2008. Regional shoreline change along the North Slope of Alaska. Eos Trans. AGU, 89. Held at: American Geophysical Union Fall Meeting, December 15-19.

Griffith, B., D. Douglas, N. Walsh, D. Young, T. McCabe, D. Russell, R. White, R. Cameron, and K. Whitten. 2002. Section 3: The Porcupine Caribou Herd. In: Douglas, D., P. Reynolds, and E. Rhode (eds.). 2002. Arctic Refuge Coastal Plain Terrestrial Wildlife Research Summaries. Biological Science Report USGS/BRD 2002-0001. U.S. Geological Survey, U.S. Department of the Interior. Reston, Virginia.

Harkness, M., M. Reid, N. Fresco, S. Martin, H. Hamilton, S. Auer, S. Marchenko, J. Bow, I. Varley, P. Comer, P. Crist, and, L. Kutner. 2012. Seward Peninsula – Nulato Hills – Kotzebue Lowlands Rapid Ecoregional Assessment Report. Prepared for: U.S. Department of the Interior, Bureau of Land Management.

Hinkel, K. M., R. C. Frohn, F. E. Nelson, W. R. Eisner, and R. A. Beck. 2005. Morphometric and spatial analysis of thaw lakes and drained thaw lake basins in the western Arctic Coastal Plain, Alaska. Permafrost and Periglacial Processes 16:327–341.

Hobbie, J., L. Deegan, B. Peterson, E. Rastetter, G. Shaver, G. Kling, J. O'Brien, F. Chapin, M. Miller, G. Kipphut, W. Bowden, A. Hershey, and M. McDonald. 1995. Long-term measurements at the arctic LTER site. Pages 391-409 in T. M. Powell and J. H. Steele, eds. Ecological Time Series, Chapman Hall Publ., New York.

Hopkins, D. M., and R. W. Hartz. 1978. Coastal morphology, coastal erosion, and barrier islands of the Beaufort Sea, Alaska. Open File Rep. 78-1063. United States Department of the Interior, Geological Survey.

Hersteinsson, P., and D. Macdonald. 1992. Interspecific competition and the geographical distribution of red and Arctic foxes (Vulpes vulpes and Alopex lagopus). Oikos 64:505-515.

IUCN. 2014. Arctic foxes and climate change: out-foxed by arctic warming. Available online at http://cmsdata.iucn.org/downloads/fact_sheet_red_list_arctic_foxes.pdf. Accessed 3Oct 2014.

Jefferies, R. L. 1977. The vegetation of salt marshes at some coastal sites in arctic North America. Journal of Ecology 65:661-672.

Jefferies, R. L., and R. F. Rockwell. 2002. Foraging geese, vegetation loss and soil degradation in an arctic salt marsh. Applied Vegetation Science 5:7-16.

Jenkins, R. E. 1976. Maintenance of natural diversity: approach and recommendations. In: K. Sabol (ed.) Transactions–Forty-First North American Wildlife and Natural Resources Conference; 1976 March; Washington, D.C. Pp. 441-451.

Joly, K. 2011. Linkages between large-scale climate patterns and the dynamics of Arctic caribou populations. Ecography. 34(2). 345-352.

Jones, B. M., and C. D. Arp. 2015. Observing a catastrophic thermokarst lake drainage in northern Alaska. Permafrost and Periglacial Processes, DOI 10.1002/ppp.1842.

Jones, B. M., C. D. Arp, M. T. Jorgenson, K. M. Hinkel, J. A. Schmutz, and P. L. Flint. 2009. Increase in the rate and uniformity of coastline erosion in Arctic Alaska. Geophysical Research Letters 36: L03503, doi:10.1029/2008GL036205.

Jones, B. M., K. M. Hinkel, C. D. Arp, and W. R. Eisner. 2008. Modern erosion rates and loss of coastal features and sites, Beaufort Sea coastline, Alaska. Arctic 61:361-372.

Jorgenson, M. T., J. E. Roth, E. R. Pullman, R. M. Burgess, M. K. Raynolds, A. A. Stickney, M. D. Smith, and T. M. Zimmer. 1997. An ecological land survey for the Colville River Delta, Alaska, 1996. Prepared for: ARCO Alaska, Inc., Anchorage, Alaska, ABR, Inc. 180 pp.

Jorgenson, M. T., and M. Heiner. 2003. Ecosystems of northern Alaska. Unpublished 1:2.5 million-scale map produced by ABR, Inc., Fairbanks, AK and The Nature Conservancy, Anchorage, AK.

Jorgenson, M. T, Y. L. Shur, and E. R. Pullman. 2006. Abrupt increase in permafrost degradation in Arctic Alaska. Geophys. Res. Lett. 33:L02503, doi:10.1029/2005GL024960.

Lassuy, D. R., and P. N. Lewis. 2013. Invasive species: human-induced. Pages 450-457 in H. Meltofte, ed. Arctic Biodiversity Assessment: Status and Trends in Arctic Biodiversity. Conservation of Arctic Flora and Fauna (CAFF), Arctic Council.

Leinwand, I. I. F., D. M. Theobald, J. Mitchell, and R. L. Knight. 2010. Landscape dynamics at the public-private interface: A case study in Colorado. Landscape and Urban Planning 97: 182-193.

MacDonald, S., and J. Cook. 2009. Recent mammals of Alaska. University of Alaska Press. Fairbanks, Alaska. 399 pp.

Mars, J. C., and D. W. Houseknecht. 2007. Quantitative remote sensing study indicates doubling of coastal erosion rate in past 50 yr along a segment of the Arctic coast of Alaska. Geology 35:583-586.

McGuire, A. D. Modeling Thermokarst Dynamics in Boreal and Arctic regions of Alaska and Northwest Canada: A White Paper, unpublished white paper, 28 Feb 2013.

McLennan, D. , T. Bell, D. Berteaux, W. Chen, L. Copland, R. Fraser, D. Gallant, G. Gauthier, D. Hik, C. Krebs, I. Myers-Smith, I. Olthof, D. Reid, W. Sladen, C. Tarnocai, W. Vincent, and Y. Zhang. 2012. Recent climate-related terrestrial biodiversity research in Canada's Arctic national parks: review, summary, and management implications. Biodiversity. 13(3). 157–173.

Nawrocki, T., H. Klein, M. Carlson, L. Flagstad, J. Conn, R. DeVelice, A. Grant, G. Graziano, B. Million, and W. Rapp. 2011. Invasiveness ranking of 50 non-native plant species for Alaska. Report prepared for the Alaska Association of Conservation Districts. Alaska Natural Heritage Program, University of Alaska Anchorage, Anchorage, AK. 253 pp.

Noss, R. F. 1987. From plant communities to landscapes in conservation inventories: A look at The Nature Conservancy (USA). Biological Conservation 41: 11-37.

North Slope Science Initiative (NSSI). (2014). Emerging issue summary coastal salinization. Retrieved January 6, 2015, from http://www.northslope.org/issues/.

Nowacki, G., P. Spencer, M. Fleming, T. Brock, and T. Jorgenson. 2001. Ecoregions of Alaska: 2001. U.S. Geological Survey Open-File Report 02-297 (map).

Pamperin, N. J., E. H. Follmann, and B. Petersen. 2006. Interspecific killing of an Arctic fox by a red fox at Prudhoe Bay, Alaska. Arctic 59:361–4.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecological Economics 52:273-288.

Ping, C. L., G. J. Michaelson, L. Guo, M. T. Jorgenson, M. Kanevskiy, Y. Shur, F. Duo, and J. Liang. 2011. Soil carbon and material fluxes across the eroding Alaska Beaufort Sea coastline. J. Geophys. Res. 116, G02004.

Post, E., and M. Forchhammer. 2008. Climate change reduces reproductive success of an Arctic herbivore through trophic mismatch. Philosophical Transactions of the Royal Society B. 363. 2369-2375.

Reed, S. E., J. L. Boggs, and J.P. Mann. 2012. A GIS tool for modeling anthropogenic noise propagation in natural ecosystems. Environmental Modelling & Software 37: 1-5.

Reid, D., D. Berteaux, and K. Laidre. 2013. Chapter 3: Mammals. In: Arctic Biodiversity Assessment: Status and Trends in Arctic Biodiversity. Conservation of Arctic Flora and Fauna (CAFF), Arctic Council. 64 pp.

Roach J., B. Griffith, D. Verbyla. 2013. Landscape influences on climate-related lake shrinkage at high latitudes. Global Change Biology 19: 2276-2284.

Sanderson, L. A., J. A. McLaughlin, and P. M. Antunes. 2012. The last great forest: a review of the status of invasive species in the North American boreal forest. Forestry 85:329-339.

Schwörer, T., R. Federer, and H. Ferren. 2012. Investments in statewide invasive species management programs in Alaska: 2007-2011. CNIPM presentation.

Sparks, T., and A. Menzel. 2002. Observed changes in seasons: an overview. International Journal of Climatology. 22(14). 1715-1725.

Spellman, B. T., and T. L. Wurtz. 2011. Invasive sweetclover (Melilotus alba) impacts native seedling recruitment along floodplains of interior Alaska. Biological Invasions 13:1779-1790.

Stickney, A. A., T. Obritschkewitsch, and R.M. Burgess. 2014. Shifts in Fox Den Occupancy in the Greater Prudhoe Bay Area, Alaska. Arctic, 67: 196-202.

Stone, R., E. Dutton, J. Harris, and D. Longenecker. 2002. Earlier spring snowmelt in northern Alaska as an indicator of climate change. Journal of Geophysical Research. 104(10). ACL10-1 – ACL 10-13.

Strittholt, J. R., R. Nogueron, J. Bergquist, and M. Alvarez. 2006. Mapping Undisturbed Landscapes in Alaska: An Overview Report. Washington, D.C., World Resources Institute.

Szor, G., D. Berteaux, and G. Gauthier. 2008. Finding the right home: distribution of food resources and terrain characteristics influence selection of denning sites and reproductive dens in Arctic fox. Polar Biology 31:351-362.

Szumigalski, A. R., and S. E. Bayley. 1997. Net aboveground primary production along a peatland gradient in central Alberta in relation to environmental factors. Ecoscience 4:385-393.

Theobald, D. M. 2010. Estimating natural landscape changes from 1992 to 2030 in the conterminous US. Landscape Ecology 25: 999–1011.

Theobald, D. M., S. E. Reed, K. Fields, and M. Soule. 2012. Connecting natural landscapes using a landscape permeability model to prioritize conservation activities in the United States. Conservation Letters 5: 123-133.

Thormann, M. N., and S. E. Bayley. 1997. Aboveground net primary production along a bog-fen-marsh gradient in southern boreal Alberta, Canada. Ecoscience 4:374-384.

Schindler, D., and J. Smol. 2006. Cumulative effects of climate warming and other human activities on freshwaters of arctic and subarctic North America. Ambio 35:160-168.

Tape, K. D., P. L. Flint, B. W. Meixell, and B. V. Gaglioti. 2013. Inundation, sedimentation, and subsidence creates goose habitat along the Arctic coast of Alaska. Environ. Res. Lett. 8:1-9.

Trammell, E. J., M.L. McTeague, K.W. Boggs, M.L. Carlson, N. Fresco, T. Gotthardt, L. Kenney, and D. Vadapalli. 2014. Yukon River Lowlands – Kuskokwim Mountains – Lime Hills Rapid Ecoregional Assessment Technical Supplement. Prepared for the U.S. Department of the Interior, Bureau of Land Management, Denver, Colorado.

United States Department of Agriculture (USDA). 2013. The PLANTS Database. Retrieved from http://plants.usda.gov/java/

Walter, K., L. Smith, and F. Chapin. 2007. Methane bubbling from northern lakes: present and future contributions to the global methane budget. Phil. Trans. R. Soc. 365:1657-1676.

Brooks Range from the North Slope of Alaska (Justin Fulkerson).

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