

Terrestrial Coarse-Filter Conservation Elements

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Summary

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

Contents

1. Summary of Terrestrial Coarse-Filter Conservation Elements	1
1.1. Methods	2
1.2. Results	8
1.3. Applications	34
1.4. Limitations	35
1.5. Literature Cited	36
2. Coastal Plain Moist Tundra	39
2.1. Introduction	39
2.2. Conceptual Model	40
2.3. Abiotic Change Agents Analysis	41
2.4. Current Status and Future Landscape Condition	43
2.5. Literature Cited	45
3. Coastal Plain Wetland	46
3.1. Introduction	46
3.2. Conceptual Model	47
3.3. Abiotic Change Agents Analysis	48
3.4. Current Status and Future Landscape Condition	49
3.5. Literature Cited	51
4. Sand Sheet Moist Tundra	52
4.1. Introduction	52
4.2. Abiotic Change Agents Analysis	54
4.3. Current Status and Future Landscape Condition	56
4.4. Literature Cited	58
5. Sand Sheet Wetland	59
5.1. Introduction	59
5.2. Conceptual Model	60
5.3. Abiotic Change Agents Analysis	61
5.4. Current Status and Future Landscape Condition	62
5.5. Literature Cited	64
6. Foothills Tussock Tundra	65

6.1.	Introduction	65
6.2.	Conceptual Model.....	66
6.3.	Abiotic Change Agents Analysis	66
6.4.	Current Status and Future Landscape Condition	72
6.5.	Literature Cited	74
7.	Alpine Dwarf Shrub Tundra	77
7.1.	Introduction	77
7.2.	Conceptual Model.....	78
7.3.	Abiotic Change Agents Analysis	79
7.4.	Current Status and Future Landscape Condition	81
7.5.	Literature Cited	83
8.	Floodplain Shrubland.....	84
8.1.	Introduction	84
8.2.	Conceptual Model.....	86
8.3.	Abiotic Change Agents Analysis	87
8.4.	Invasive Species.....	90
8.5.	Current Status and Future Landscape Condition	90
8.6.	Literature Cited	92
9.	Marine Beach, Barrier Islands, and Spits.....	94
9.1.	Introduction	94
9.2.	Conceptual Model.....	97
9.3.	Abiotic Change Agents Analysis	97
9.4.	Current Status and Future Landscape Condition	98
9.5.	Literature Cited	100
10.	Tidal Marshes	101
10.1.	Introduction	101
10.2.	Conceptual Model.....	103
10.3.	Abiotic Change Agents Analysis	104
10.4.	Current Status and Future Landscape Condition	104
10.5.	Literature Cited	106
11.	Coastal Erosion and Coastal Salinization	107
11.1.	Introduction	107

11.2.	Methods	108
11.3.	Trajectories of Change	109
11.4.	Limitations.....	115
11.5.	Literature Cited	116
12.	Impacts of Oil and Gas Development on Vegetation	119
12.1.	Introduction	119
12.2.	Methods	119
12.3.	Results.....	120
12.4.	Literature Cited	136

Management Questions

MQ TC 2 (Permafrost Conditions and Vegetation).....	24
MQ TC 4 (Coastal Erosion and Coastal Salinization).....	107
MQ TC 1 (Impacts of Oil and Gas Development on Vegetation).....	119

Tables

Table G-1. Terrestrial Coarse-Filter CEs, area, and percent of study area occupied.....	2
Table G-2. Datasets used in the analysis of Terrestrial Coarse-Filter CEs.	3
Table G-3. Physiographic divisions and landcover classes used in developing the Terrestrial Coarse-Filter CE distribution maps. Vegetation classes are from the combined NSSI Landcover and Vegetation Map of Northern, Western, and Interior Alaska unless otherwise noted. NWI = National Wetlands Inventory.	5
Table G-4. Percent area of each CE that will increase 0 - 1.3 °C and > 1.3 °C in temperature in the near term (2020s) and long term (2060s).	13
Table G-5. Mean temperature values by CE for current (2010s), near term (2020s), and long term (2060s). Change in annual temperature between current and long-term future.....	14
Table G-6. Current, near-term future, and long-term future mean length of growing season in days (LOGS).	18
Table G-7. Mean summer (June, July, August) and winter (December, January, February) precipitation in mm for current (2010s), near (2020s), and long term (2060s). Change by sub-region is the difference between long term and current.....	19
Table G-8. Mean annual precipitation by CE for current (2010s), near term (2020s), and long term (2060s). Change in annual precipitation is the difference between current and long term.	19

Table G-13. ALFRESCO projections by sub-region for percent canopy cover of forest for decades representing current, near-term future, and long-term future conditions. Change is represented by the difference between 2060s and 2010s..... 70

Figures

Figure G-1. Complete existing vegetation coverage of North Slope study area provided by combination of NSSI Landcover Map and Vegetation Map of Northern, Western, and Interior Alaska.....	4
Figure G-2. Terrestrial sub-regions provide potential for both North to South and East to West comparison of spatial patterns within the North Slope study area.....	7
Figure G-3. Map of Terrestrial Coarse-Filter CE distributions within the North Slope study area.	9
Figure G-4. Current, near-term and long-term temperature projections for July.	11
Figure G-5. Current, near-term and long-term projected mean January temperatures.....	12
Figure G-6. Current, near-term future, and long-term future length of growing season in the North Slope study area.	16
Figure G-7. Current, near-term future, and long-term future length of growing season by Terrestrial Coarse-Filter CE. Error bars represent one standard deviation in length of growing season.	17
Figure G-8. Schematic of the ALFRESCO model showing potential vegetation transitions.	21
Figure G-9. Current, near-term future, and long-term future ALFRESCO projections for vegetation canopy cover summarized by ecoregion.	22
Figure G-10. ALFRESCO projections for change in vegetation canopy cover by sub-region between current and long-term conditions.....	23
Figure G-11. Projected long-term changes in shrub tundra modeled in ALFRESCO summarized by ecological sub-region.	24
Figure G-12. Active layer thickness for current, near term, and long term.	26
Figure G-13. Current, near-term future, and long-term future active layer thickness by CE. Error bars show standard deviation across entire CE distribution.	28
Figure G-14. Thermokarst predisposition in the North Slope study area.	29
Figure G-15. Percent area of each CE with a high thermokarst predisposition.	30
Figure G-16. Current distribution of the coastal plain moist tundra CE in the North Slope study area (A) and coastal plain moist tundra with high-centered polygons (B).....	39
Figure G-17. Conceptual model for coastal plain moist tundra.	40
Figure G-18. Length of growing season (LOGS) for current and long-term future and change in LOGS clipped to the coastal plain moist tundra and wetlands CE distributions in the North Slope study area..	42

Figure G-19. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of coastal plain moist tundra in the North Slope study area.	44
Figure G-20. Current distribution of the coastal plain wetland CE in the North Slope study area (A) and coastal plain wetlands and low-centered polygonal tundra along the margin of an oriented thermokarst lake (B).	46
Figure G-21. Conceptual model for coastal plain wetland.	48
Figure G-22. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of coastal plain wetlands in the North Slope study area...	50
Figure G-23. Current distribution of the sand sheet moist tundra CE in the North Slope study area (A) and sand sheet moist tundra (B).....	52
Figure G-24. Conceptual model for sand sheet moist tundra.	54
Figure G-25. Length of growing season for current and long term future and change in LOGS clipped to the sand sheet moist tundra and wetlands CE distributions in the North Slope study area.....	55
Figure G-26. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of sand sheet moist tundra in the North Slope study area.	57
Figure G-27. Current distribution of the sand sheet wetland CE in the North Slope study area (A) and sand sheet basin wetlands separated by an ancient dune ridge (B).	59
Figure G-28. Conceptual model for sand sheet wetland.	61
Figure G-29. Figure Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of sand sheet wetland in the North Slope study area.....	63
Figure G-30. Current distribution of the foothills tussock tundra CE in the North Slope study area (A) and a vegetation transect in foothills tussock tundra in NPR-A (B).....	65
Figure G-31. Conceptual model for foothills tussock tundra.	66
Figure G-32. Length of growing season for current and long term future and change in LOGS clipped to the foothills tussock tundra distribution in the North Slope study area.	68
Figure G-33. Projected relative flammability across the North Slope study area.	71
Figure G-34. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of foothills tussock tundra in the North Slope study area.	73
Figure G-35. Current distribution of the alpine dwarf shrub tundra CE in the North Slope study area. ...	77
Figure G-36. Conceptual model for alpine dwarf shrub tundra.	78
Figure G-37. Length of growing season for current and long term future and change in LOGS clipped to the alpine dwarf shrub tundra distribution in the North Slope study area.....	80

Figure G-38. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of alpine dwarf shrub tundra in the North Slope study area.	82
Figure G-39. Distribution model for floodplain shrublands within the North Slope study area.	84
Figure G-40. Conceptual model for the floodplain shrubland CE.	87
Figure G-41. Known poplar stand locations and Summer Warmth Index for the current and long term future in the North Slope study area.	89
Figure G-42. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the floodplain shrubland distribution in the North Slope study area.	91
Figure G-43. Current distribution of marine beach, barrier islands, and spits in the North Slope study area.	94
Figure G-44. Barrier island and attendant spit, Chukchi Sea (Shorezone).	95
Figure G-45. A well-developed beach along the Chukchi Sea coast, southwest of Barrow (Shorezone)... ..	96
Figure G-46. Conceptual model for marine beach, barrier island, and spit.	97
Figure G-47. Landscape condition within the beach, barrier island, and spit CE for the current status and two future development scenarios.	99
Figure G-48. Current distribution of the tidal marsh CE in the North Slope study area.	101
Figure G-49. Tidal marsh fringing a protected drainage, Chukchi Sea coast (Shorezone).	102
Figure G-50. Conceptual model for tidal marsh.	103
Figure G-51. Landscape condition within the Tidal Marsh CE for the current status and two future development scenarios.	105
Figure G-52. Longshore transport of sediment at Point Hope, Chukchi Sea (Shorezone).	109
Figure G-53. A compilation of coastal erosion rates documented for the Chukchi and Beaufort Sea coastlines.	111
Figure G-54. Subsiding tundra showing inland flooding of low-center polygons and block failure of polygonal tundra along the Beaufort Sea coastline (Shorezone)	113
Figure G-55. Drained lake, salt-killed tundra and block failure along the Teshekpuk Lake Special Area, Beaufort Sea coastline (Shorezone).	114
Figure G-56. Process model for MQ TC 1.	120
Figure G-57. Landscape condition for the current oil and gas footprint.	122
Figure G-58. Landscape condition for the current oil and gas footprint within the distribution of coastal plain wetlands and moist tundra CEs.	123
Figure G-59. Landscape condition for the current oil and gas footprint within the distribution of sand sheet wetlands and moist tundra CEs.	124

Figure G-60. Landscape condition for the current oil and gas footprint within the distribution of floodplain shrublands.	125
Figure G-61. Landscape condition for the current oil and gas footprint within the distribution of barrier islands, beaches, and spits.	126
Figure G-62. Landscape condition for the current oil and gas footprint within the distribution of tidal marshes.	127
Figure G-63. Landscape condition for the current oil and gas footprint within the distribution of foothills tussock tundra.	128
Figure G-64. Landscape condition for the current oil and gas footprint within the distribution of alpine dwarf shrub.	128

1. Summary of Terrestrial Coarse-Filter Conservation Elements

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

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

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

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

Conservation Element	Area (km²)	% of Study Area
Tidal Marsh	350	0.1
Marine Beach, Barrier Island, and Spit	141	0.1
Coastal Plain Wetland	17,216	6.9
Coastal Plain Moist Tundra	18,834	7.5
Sand Sheet Wetland	3,829	1.5
Sand Sheet Moist Tundra	6,670	2.7
Foothills Tussock Tundra	83,114	33.3
Alpine Dwarf Shrub	35,967	14.4
Floodplain Shrubland	4,878	2.0

1.1. Methods

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

For each Terrestrial Coarse-Filter CE we:

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

Distribution Modeling

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

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

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

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

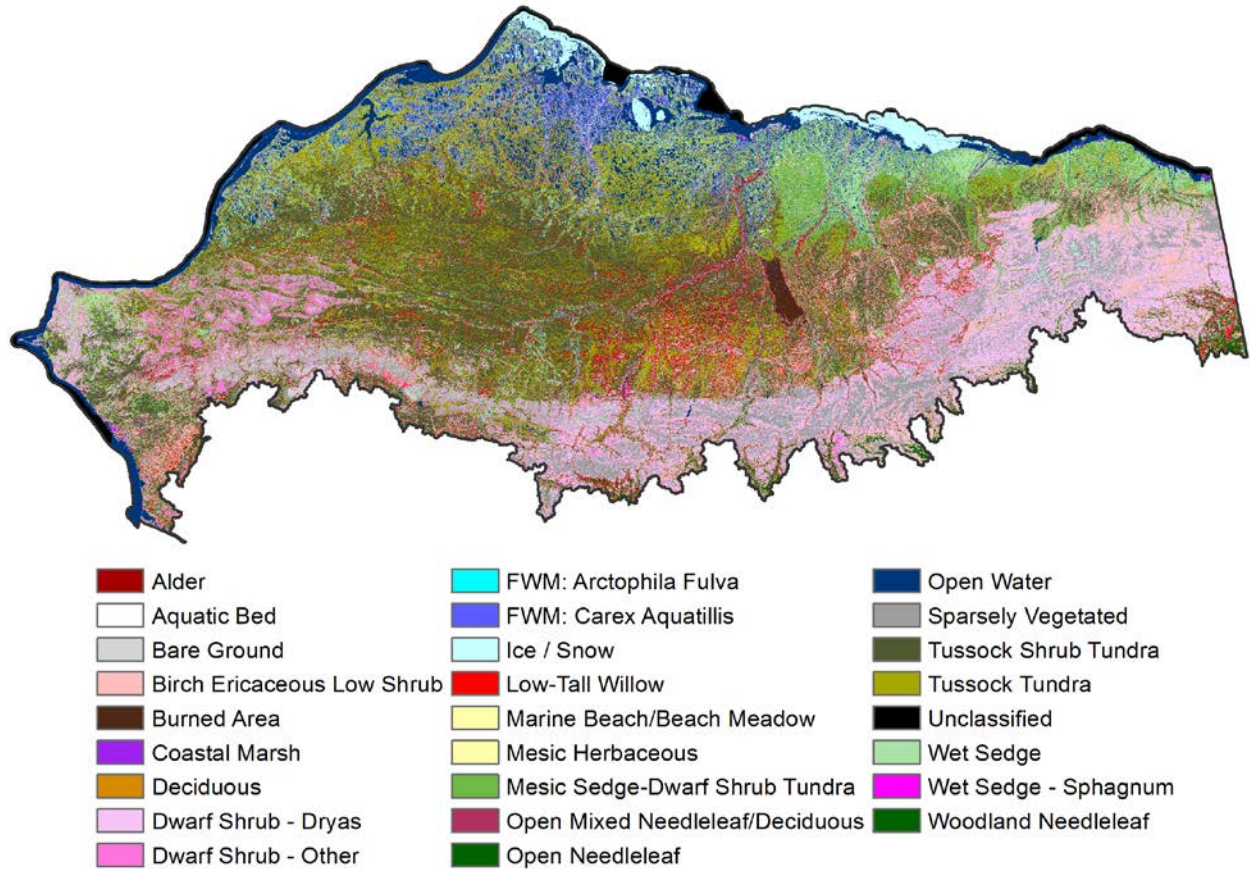


Figure G-1. Complete existing vegetation coverage of North Slope study area provided by combination of NSSI Landcover Map and Vegetation Map of Northern, Western, and Interior Alaska.

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

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

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

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

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

Conceptual Models

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

CE x CA Intersections

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

The key CA variables evaluated in this analysis include: **temperature**, **precipitation**, **change in length of growing season**, **permafrost** (active layer thickness and thermokarst potential), **fire** (ALFRESCO and

vegetation change), and **invasive plants**. Modeled climate, permafrost, and fire data were developed by the Scenarios Network for Alaska and Arctic Planning (SNAP) at the International Arctic Research Center at the University of Alaska Fairbanks. Detailed information about these models can be found in Section C. Abiotic Change Agents.

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

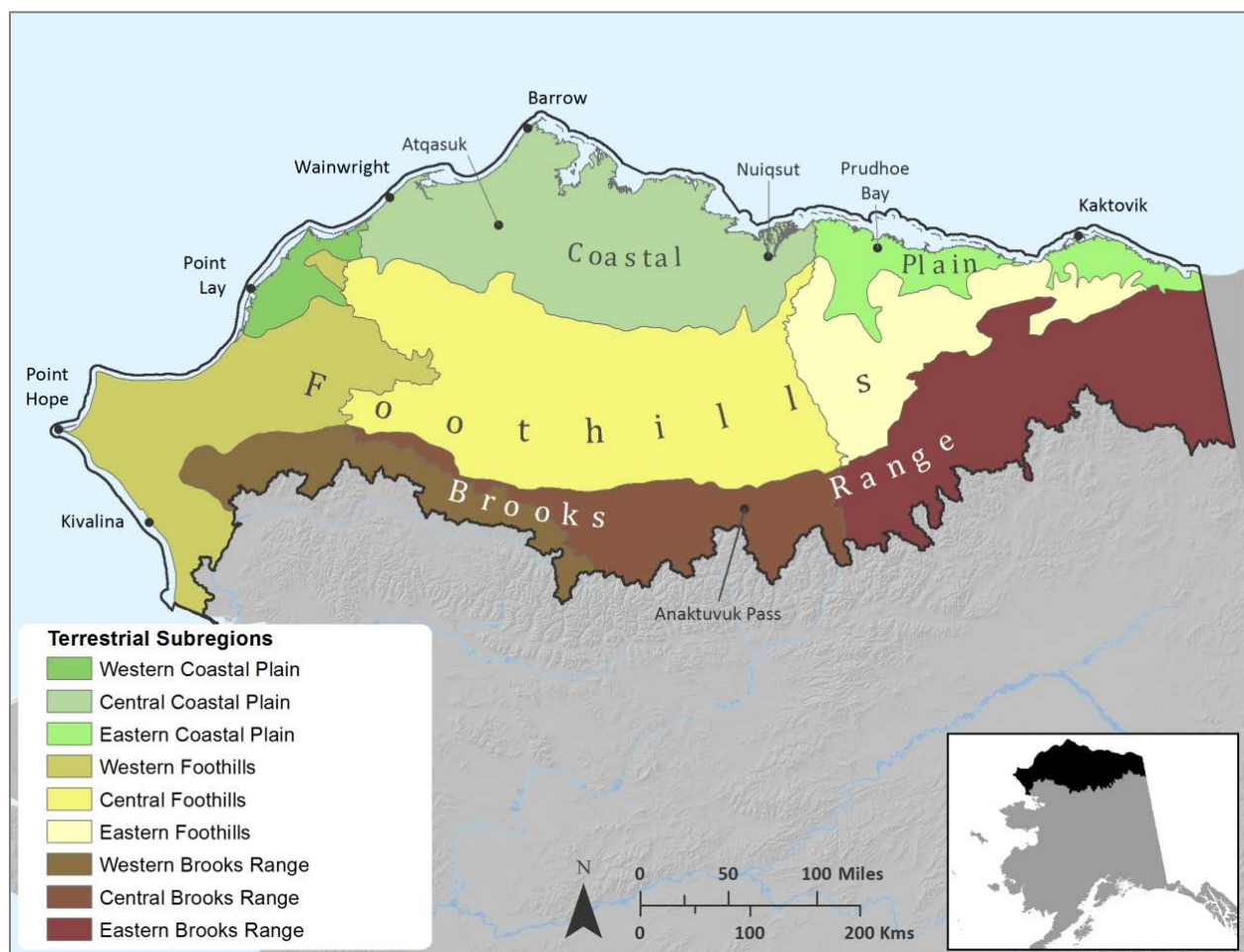


Figure G-2. Terrestrial sub-regions provide potential for both North to South and East to West comparison of spatial patterns within the North Slope study area.

Status Assessment

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

Relative Management Responsibility

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

1.2. Results

Distribution Models

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

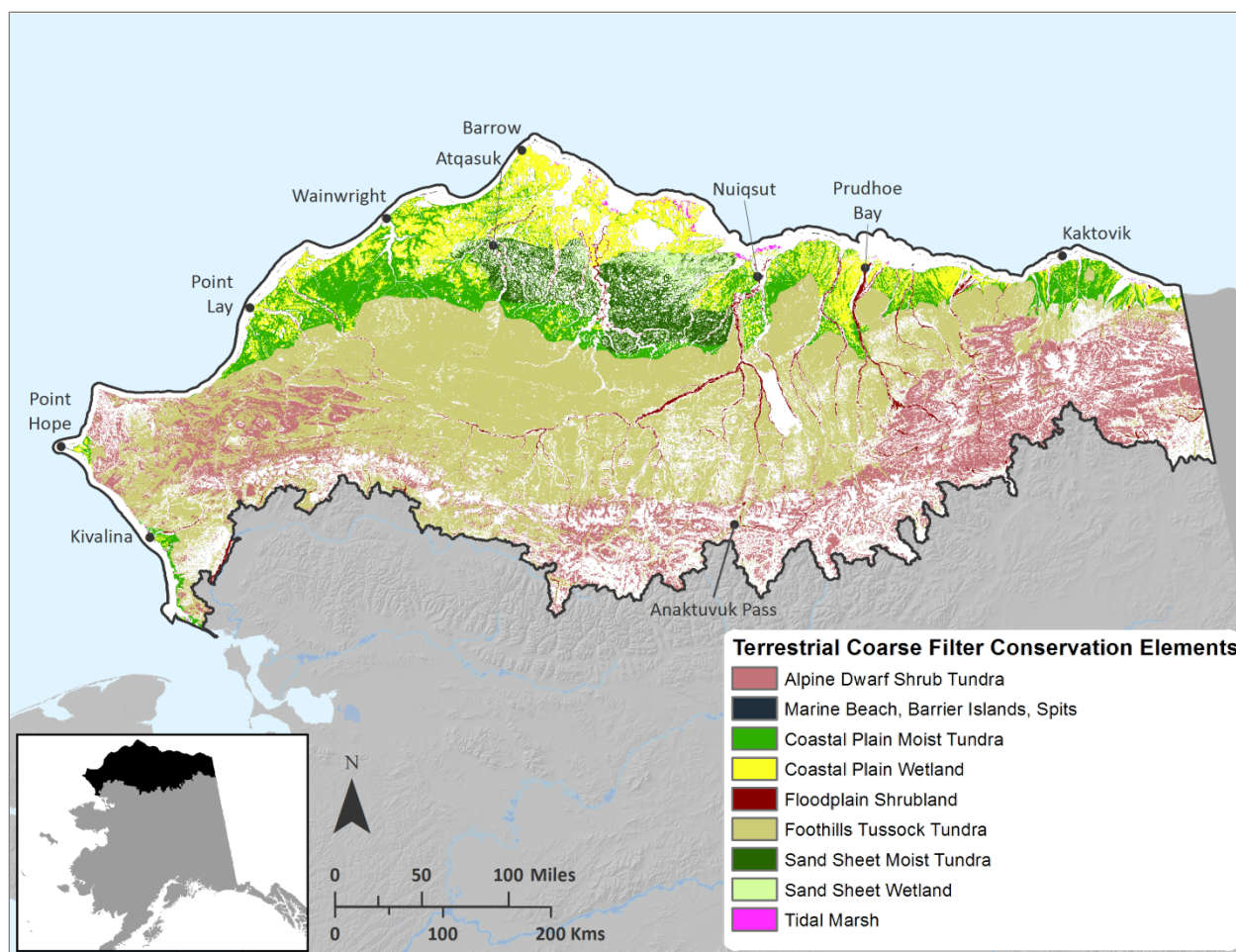


Figure G-3. Map of Terrestrial Coarse-Filter CE distributions within the North Slope study area.

Climate Variables

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

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

than those associated with increased precipitation. Results for changes in temperature, length of growing season, and precipitation across all CEs are presented in the following sections.

Temperature

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

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

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

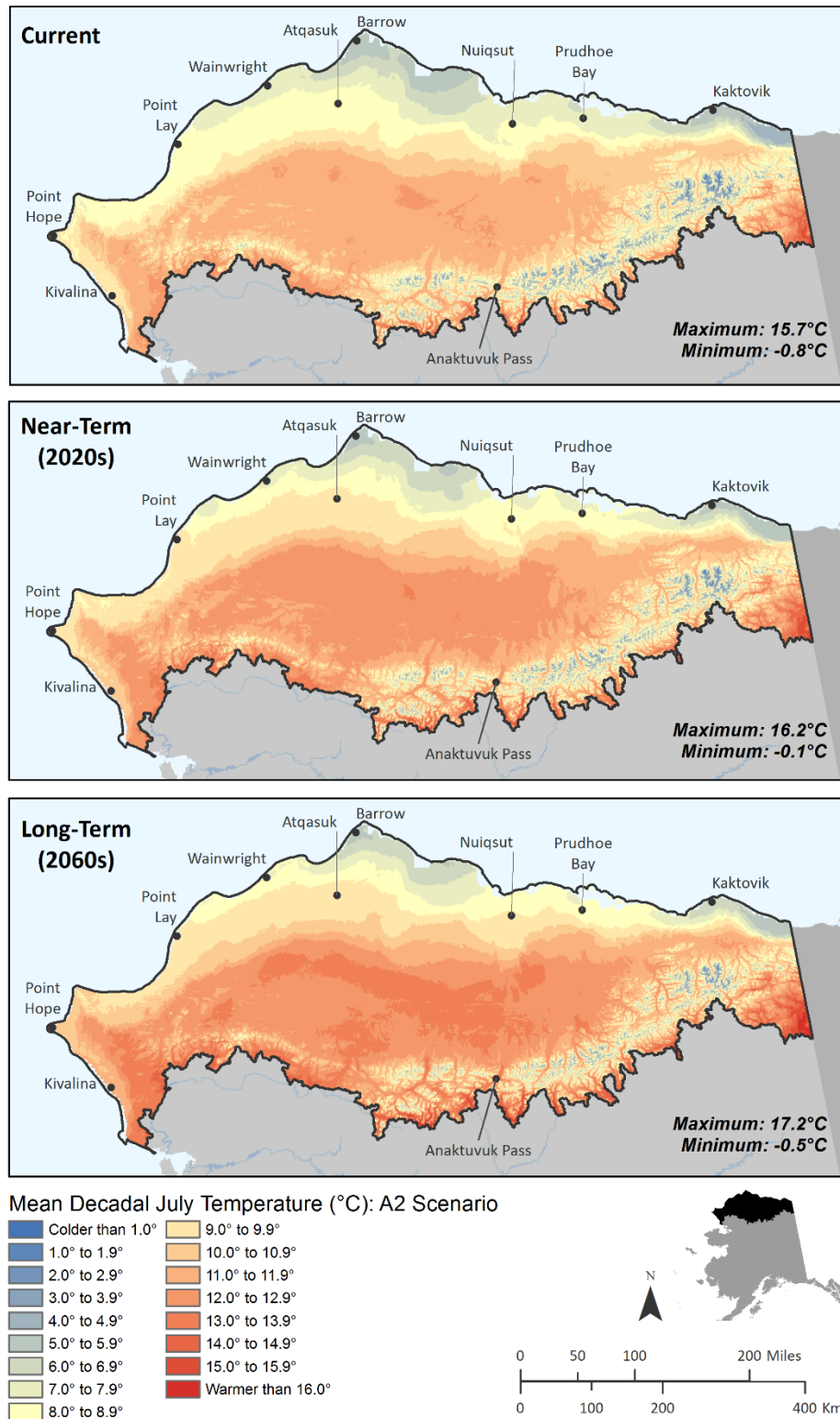


Figure G-4. Current, near-term and long-term temperature projections for July.

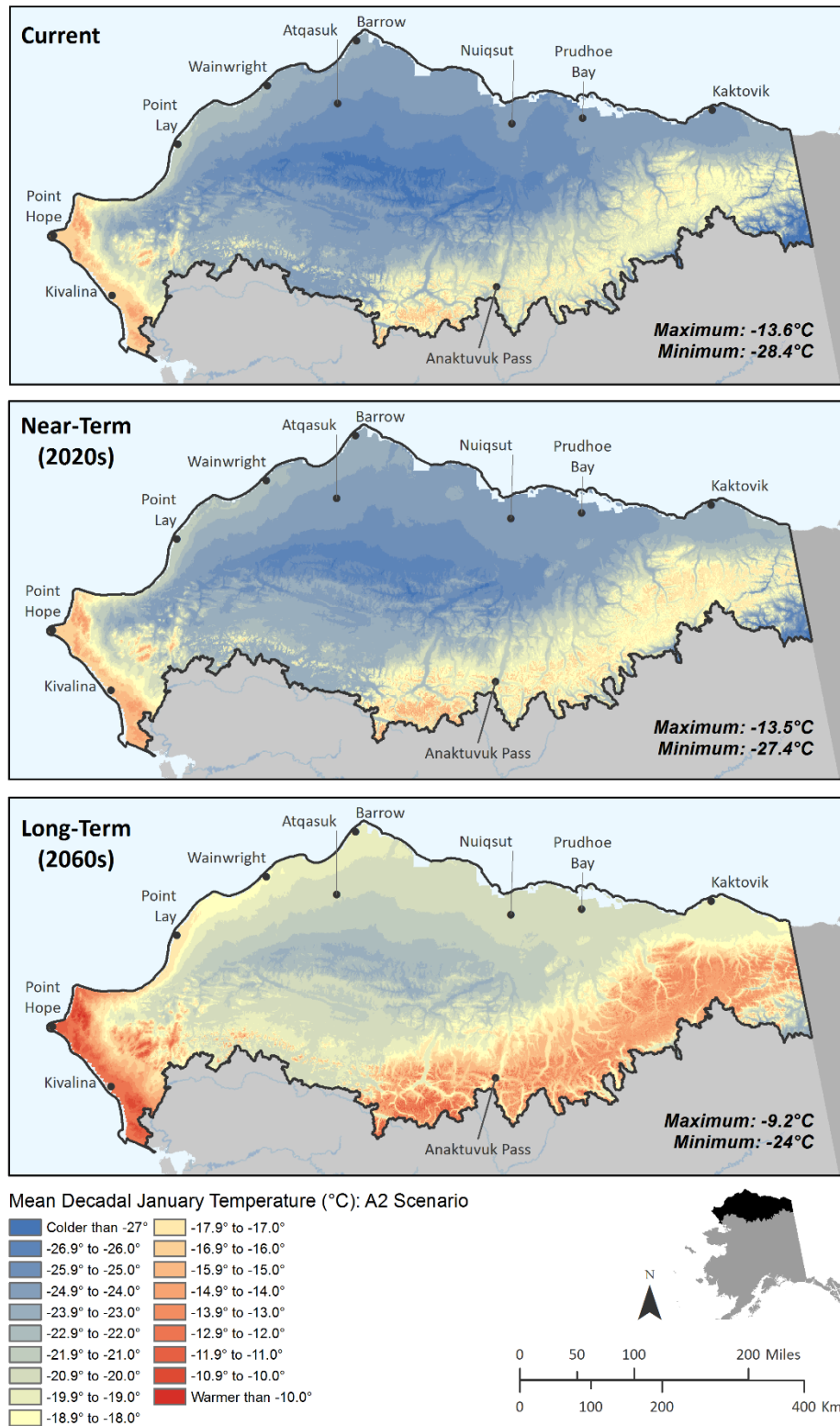


Figure G-5. Current, near-term and long-term projected mean January temperatures.

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

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

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

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

Growing Season Length

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

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

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

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

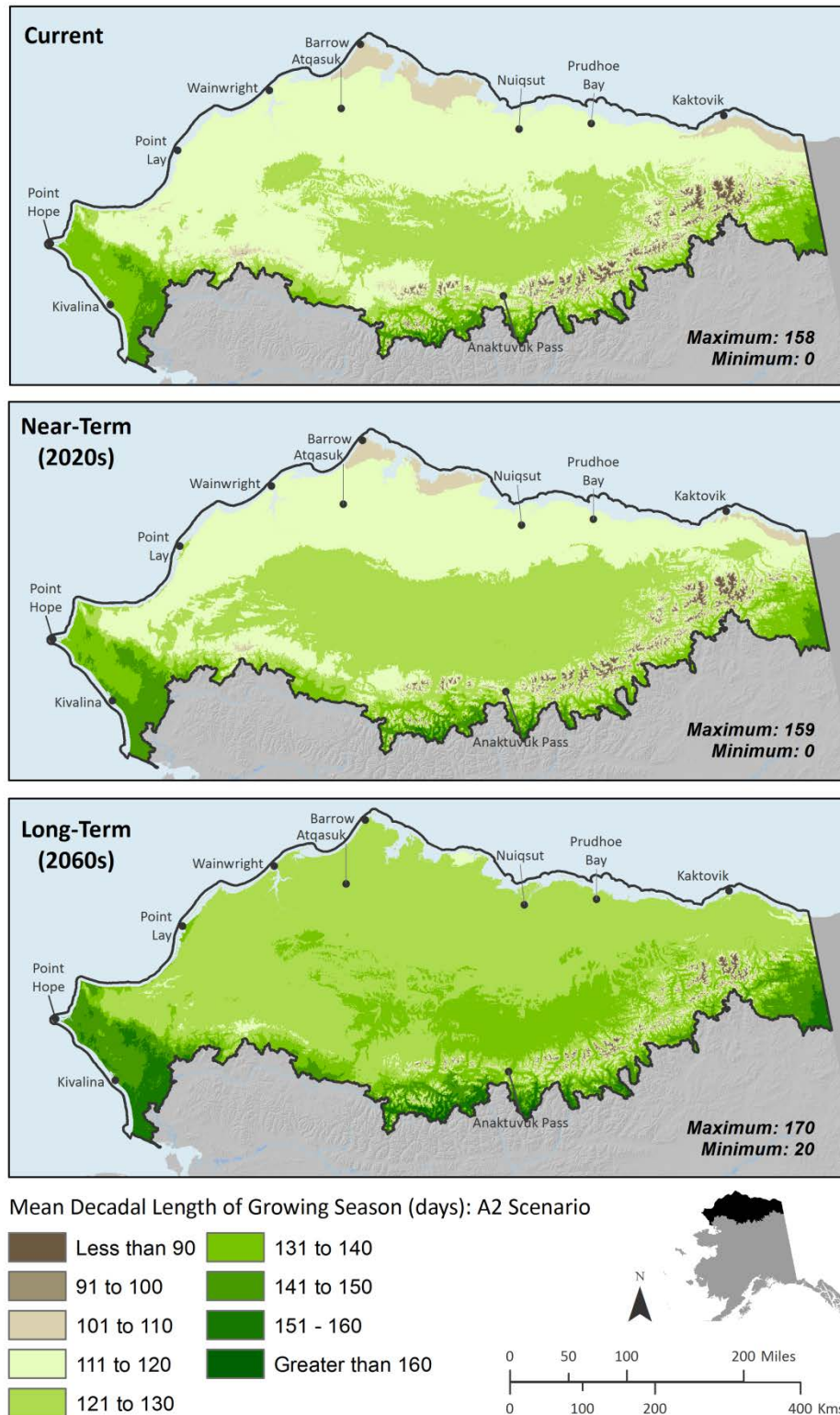


Figure G-6. Current, near-term future, and long-term future length of growing season in the North Slope study area.

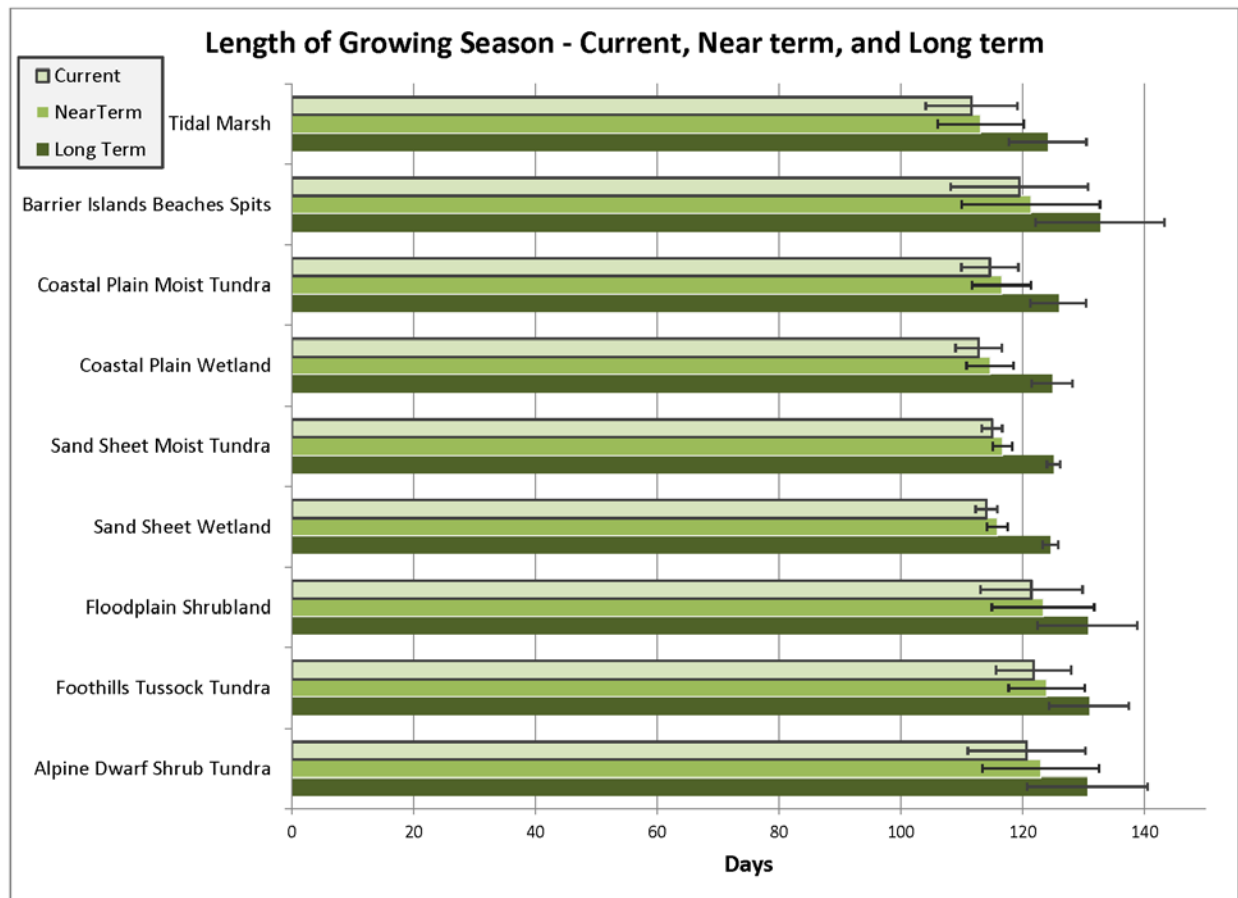


Figure G-7. Current, near-term future, and long-term future length of growing season by Terrestrial Coarse-Filter CE. Error bars represent one standard deviation in length of growing season.

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

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

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

Precipitation

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

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

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

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

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

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

Unlike summer precipitation, winter precipitation (December, January, and February) is projected to increase across all sub-regions. The greatest amount of change is projected in the Brooks Range. The changes in precipitation across both the near term and long term are only of moderate significance. The inter-model mean standard deviation across the study area is 4.6 mm, therefore, variation in monthly, seasonal, or annual precipitation of less than 4.6 mm is considered not statistically distinguishable from baseline values. Projected shifts of 4.6 - 9.2 mm can be considered possibly significant, and a shift of

more than 9.2 mm can be considered significantly different from baseline values (See C-1.3 for more information).

It is difficult to predict the impact that these projected increases in precipitation will have on vegetation. While summer precipitation is predicted to increase, evapotranspiration and evaporation associated with increased temperatures will also increase, tempering the overall impact. Analysis of snow day fraction (see Section C-1.3) suggests changes to the timing of the formation of the snow pack and potentially a deeper snowpack in the Brooks Range, which could result in a shift in the timing of water availability from runoff. A deeper snowpack could also provide thermal insulation to vegetation and protect shrubs from desiccating winter winds and blowing ice-abrasion. Precipitation and snowpack projections should be interpreted cautiously because modeled variability from year to year is of greater magnitude than the projected trend associated with climate change. Moreover, the slight increases in winter precipitation predicted by these models may not result in increased snowfall across the North Slope study area, because associated warming may mean that a greater percentage of this precipitation falls as rain. The ability of the landscape to store or shed water will likely have more impact on moisture status than changes to precipitation. If greater winter precipitation occurs as snow, we might anticipate increases in shrub growth in Tussock Tundra, Floodplain Shrublands, and Alpine Dwarf Shrub CEs in particular.

Fire and Vegetation Change

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

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

ALFRESCO also simulates the responses of vegetation to transient climatic changes. The model assumptions reflect the hypothesis that fire regime and climate are the primary drivers of landscape-level changes in the distribution of vegetation in the circumpolar arctic/boreal zone. Transitions from one vegetation class to another within ALFRESCO can occur post-fire, but can also be driven by climate variables in the absence of fire (see Section C-2 for more detail about ALFRESCO). Potential transitions, and the climate factors or other events that drive these transitions are illustrated in the ALFRESCO transition model (Figure G-8).

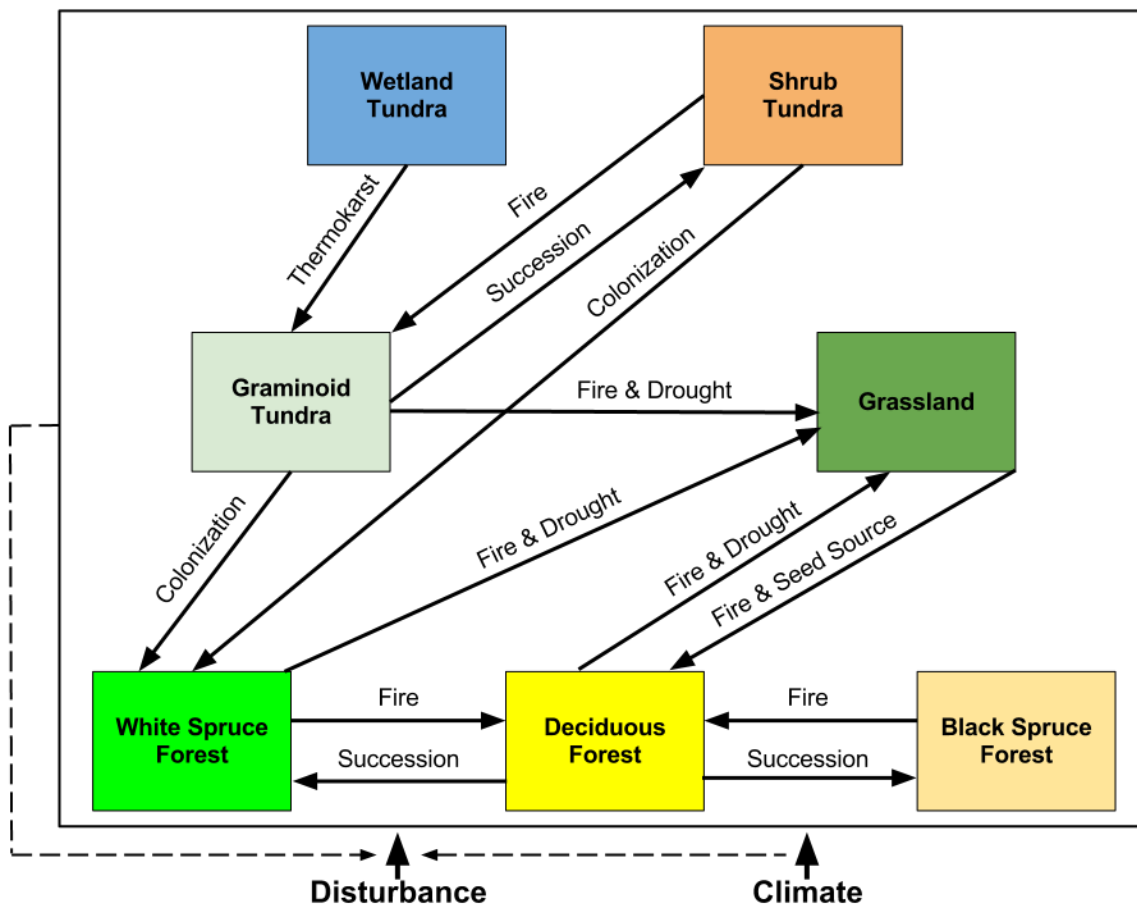


Figure G-8. Schematic of the ALFRESCO model showing potential vegetation transitions.

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

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

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

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

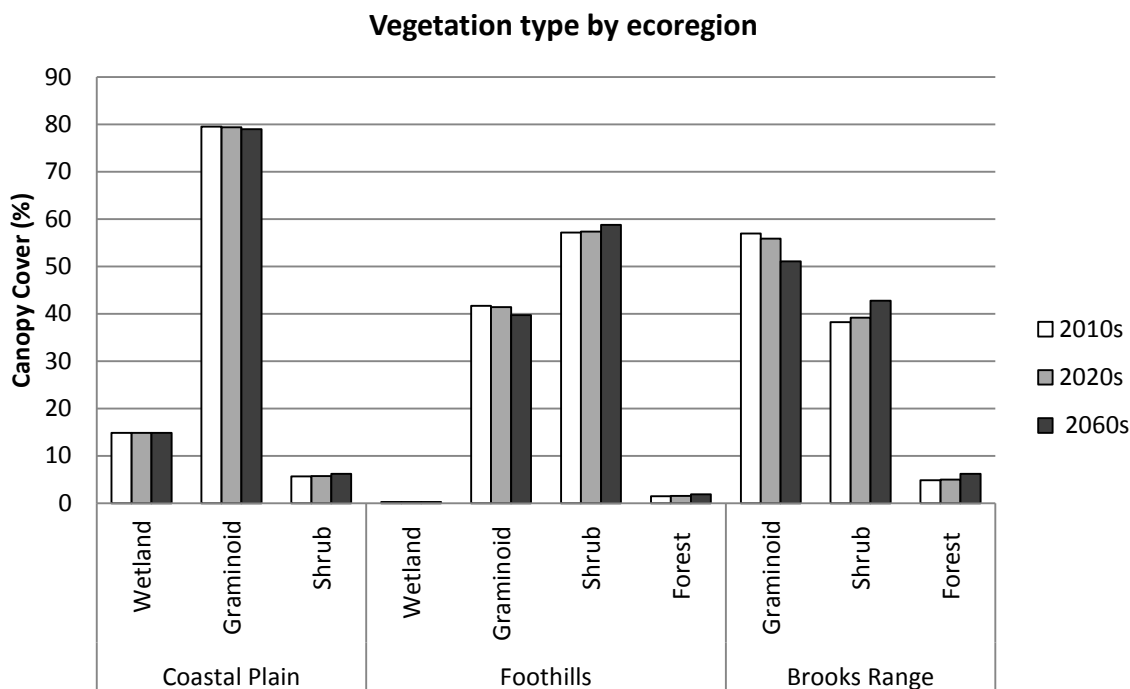


Figure G-9. Current, near-term future, and long-term future ALFRESCO projections for vegetation canopy cover summarized by ecoregion.

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

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

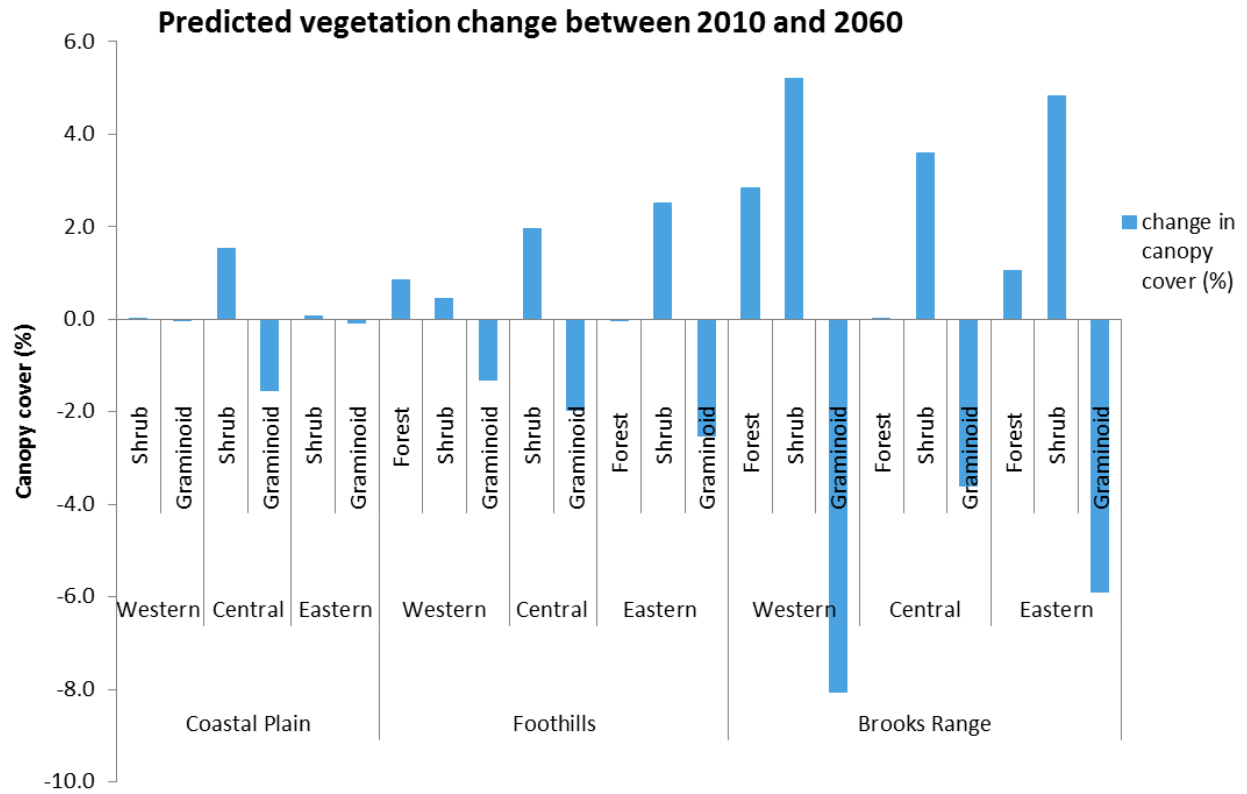


Figure G-10. ALFRESCO projections for change in vegetation canopy cover by sub-region between current and long-term conditions.

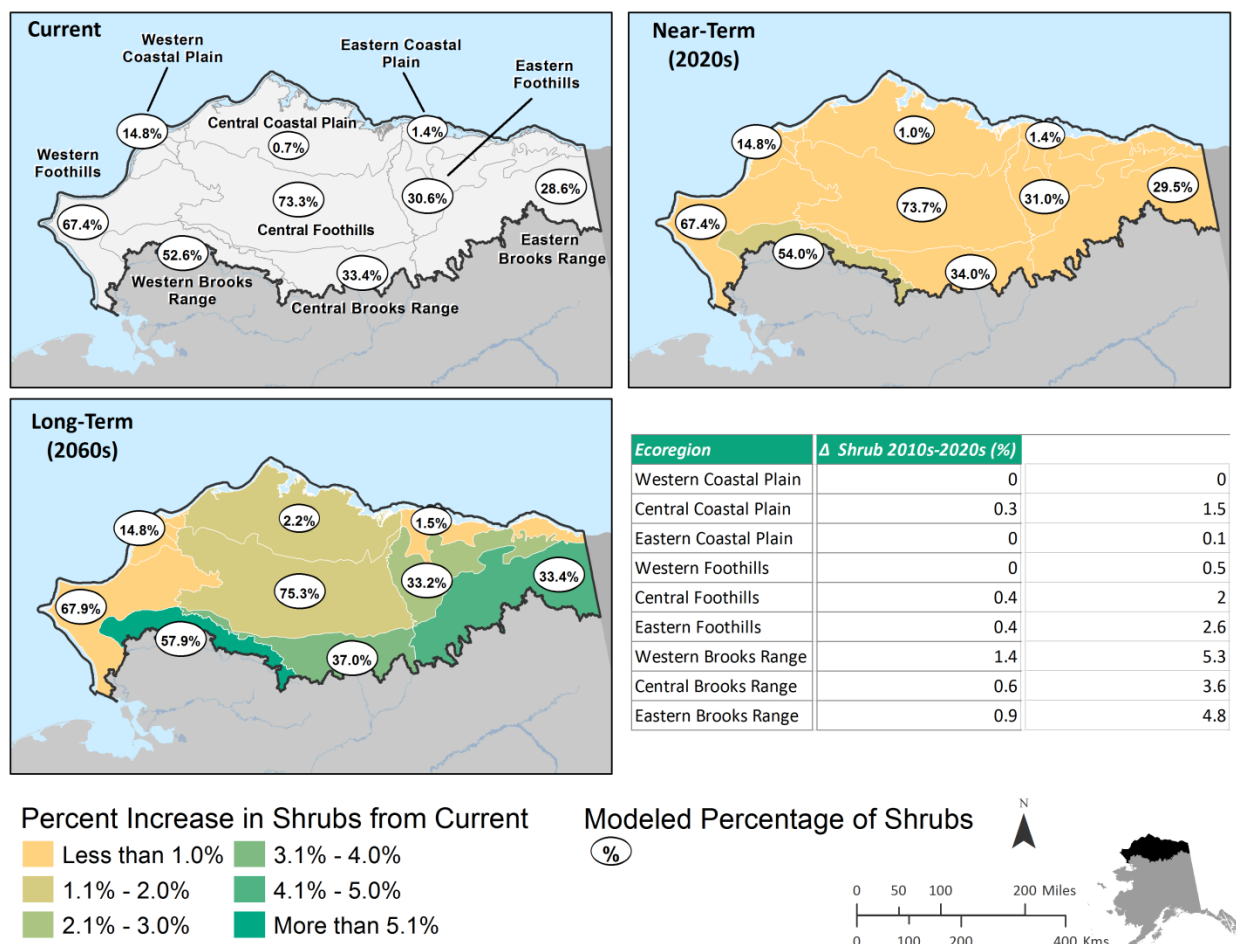


Figure G-11. Projected long-term changes in shrub tundra modeled in ALFRESCO summarized by ecological sub-region.

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

Permafrost Conditions and Vegetation

MQ TC 2	What are the changes in habitat and vegetation related to changing permafrost conditions, and what will these changes mean to wildlife and habitats?
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The North Slope study area is largely underlain by continuous permafrost. Discontinuous permafrost occurs in limited areas around water bodies and coastal zones. Permafrost on the North Slope of Alaska has warmed 2.2 – 3.9 °C (4 – 7 °F) over the last century (Mars and Houseknecht 2007, NASA 2015).

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

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

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

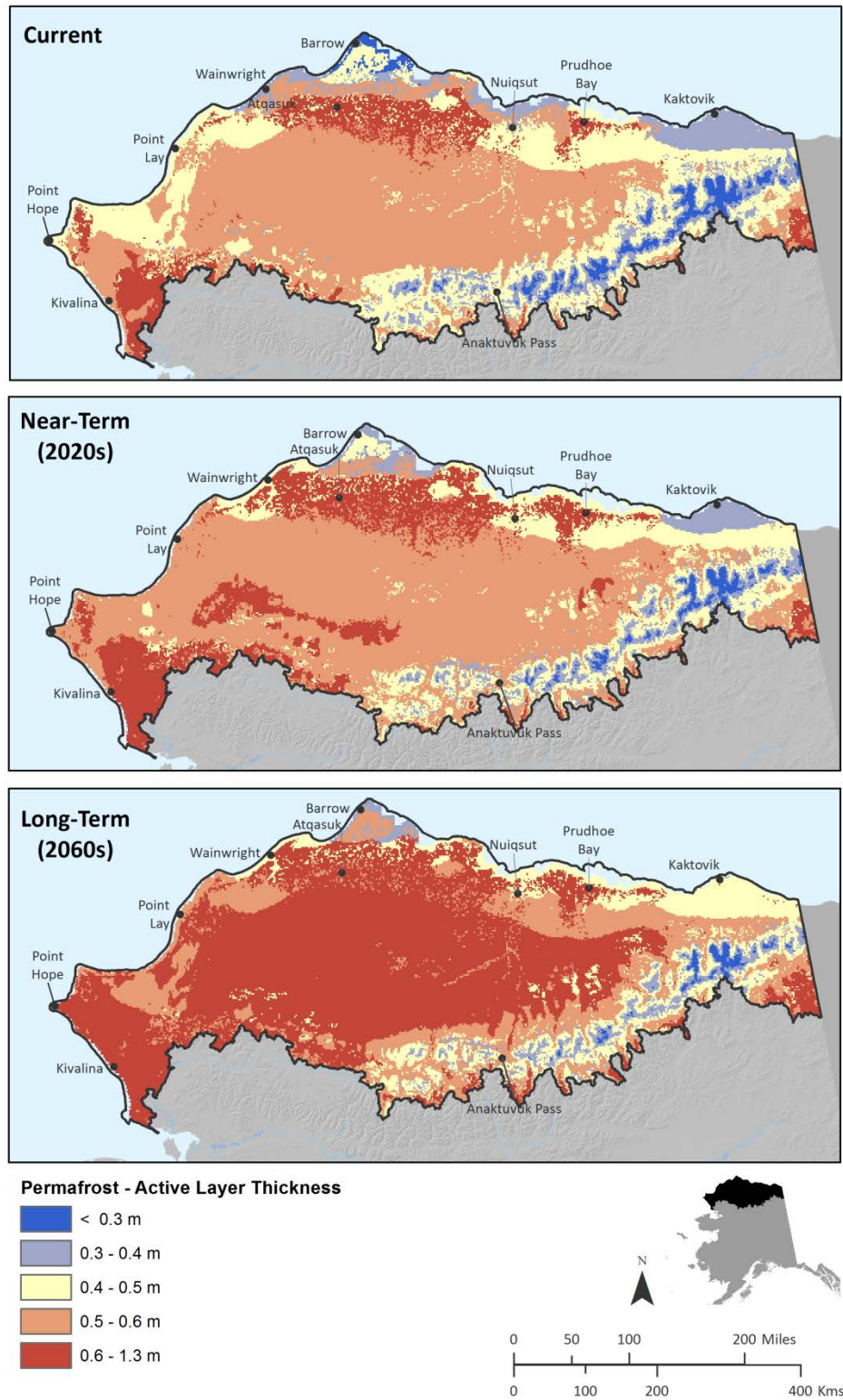


Figure G-12. Active layer thickness for current, near term, and long term.

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

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

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

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

Active Layer Thickness

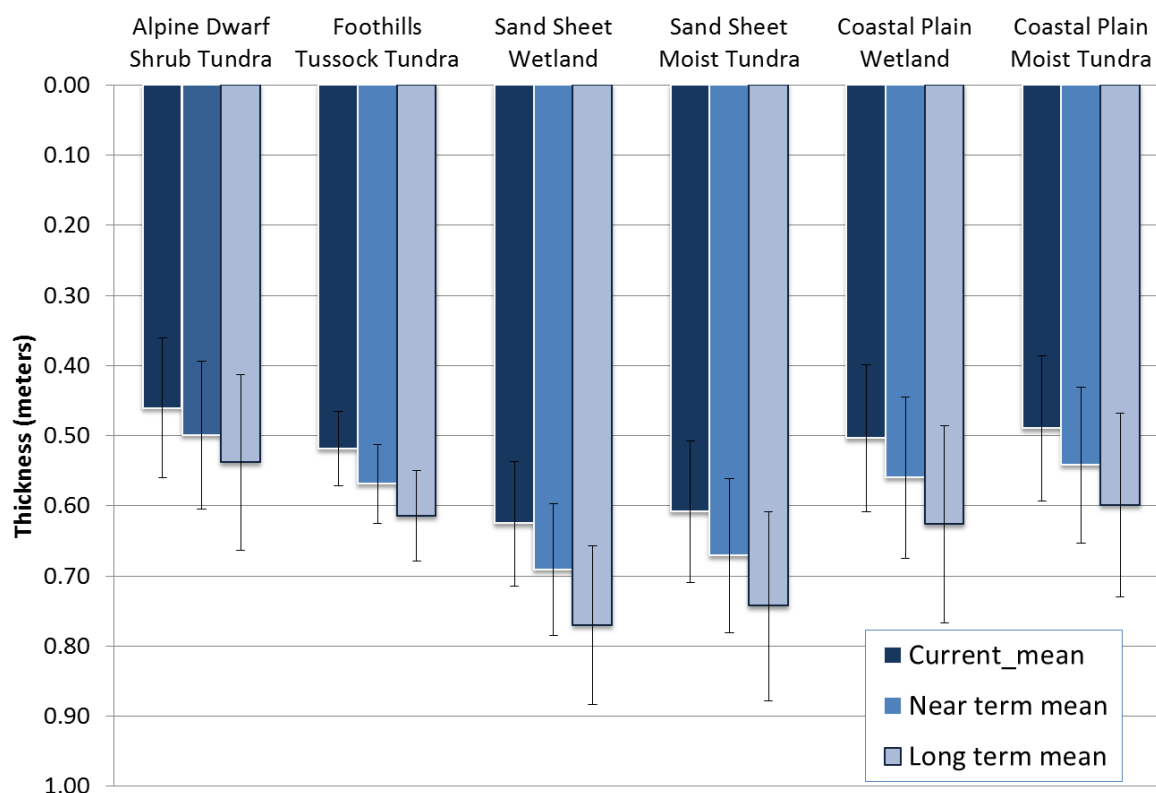


Figure G-13. Current, near-term future, and long-term future active layer thickness by CE. Error bars show standard deviation across entire CE distribution.

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

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

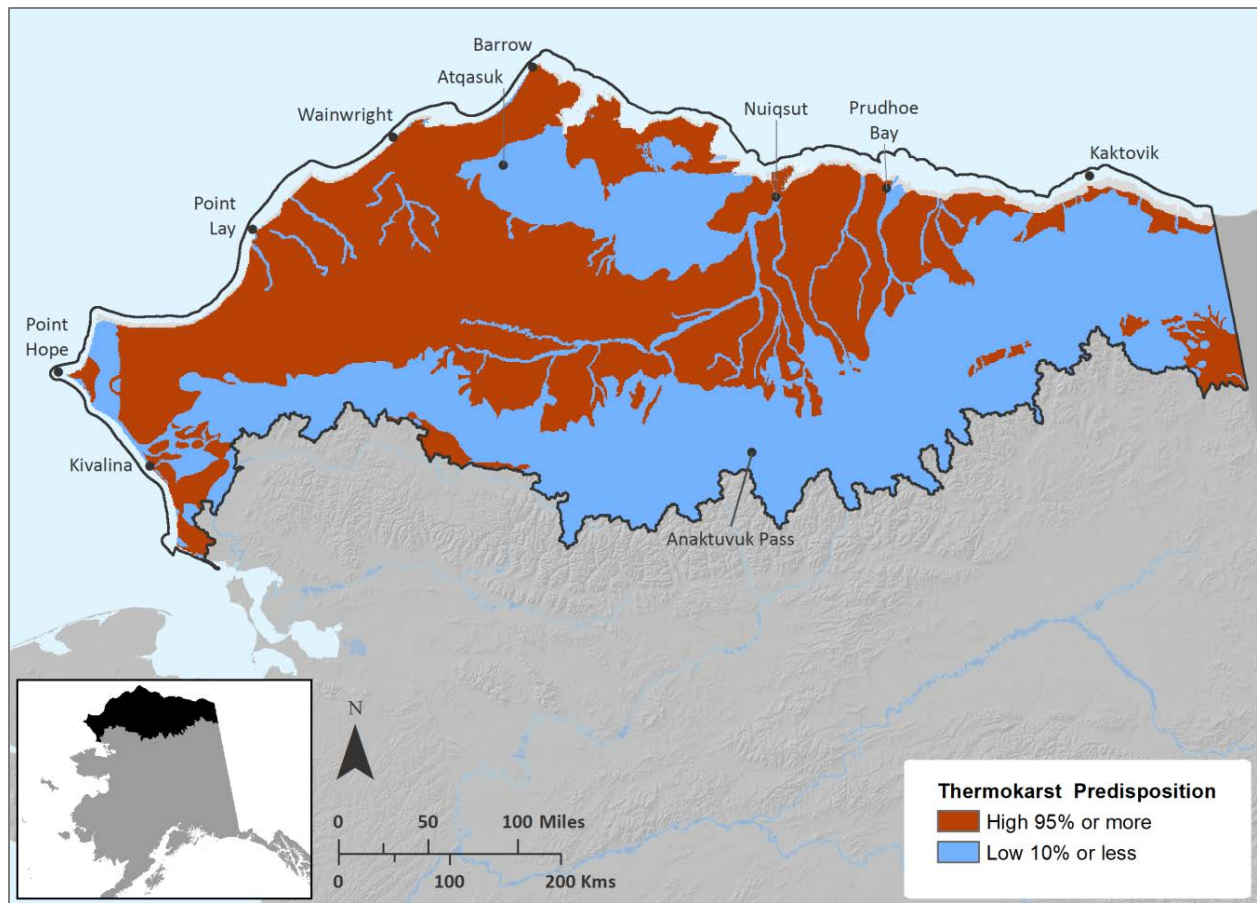


Figure G-14. Thermokarst predisposition in the North Slope study area.

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

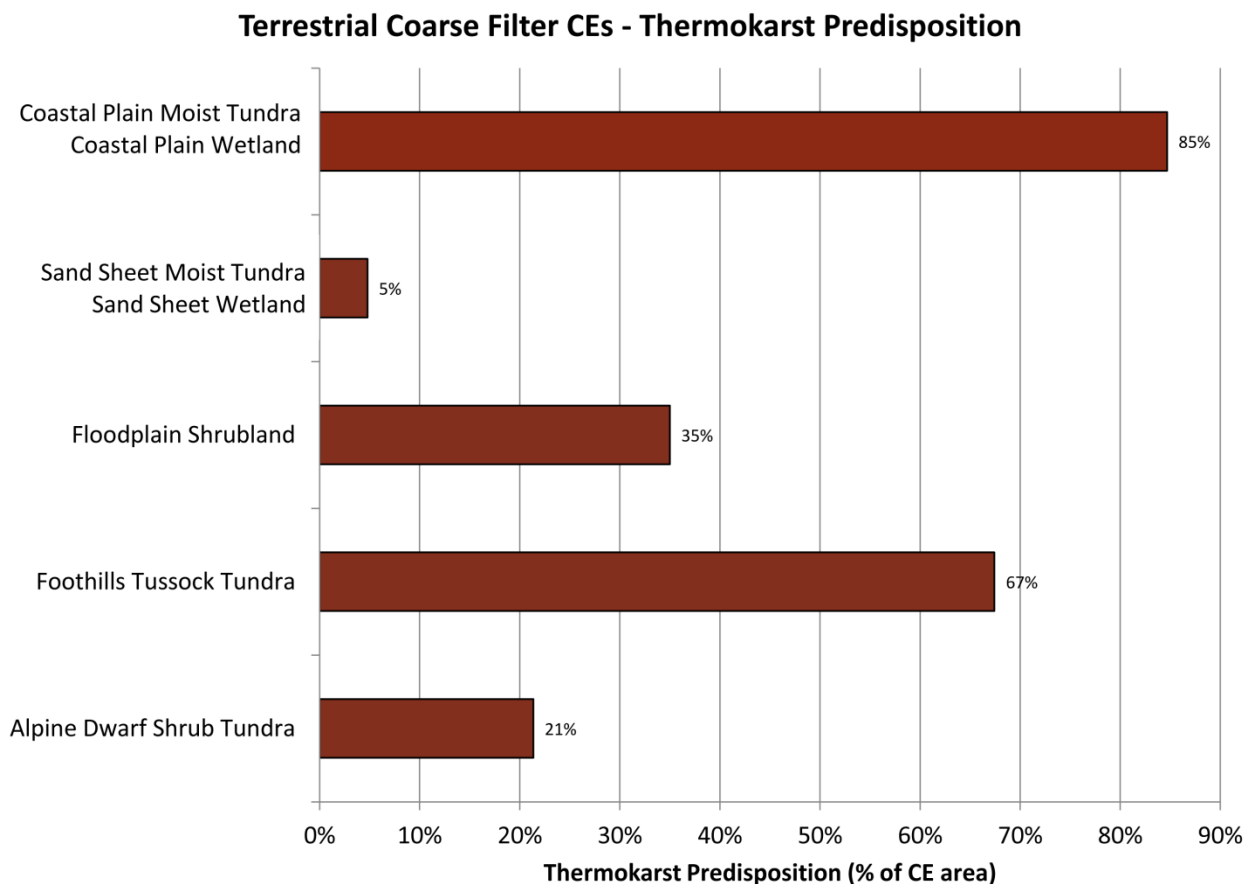


Figure G-15. Percent area of each CE with a high thermokarst predisposition.

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

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

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

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

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

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

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

Invasive Species

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

Landscape Condition

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

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

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

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

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

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

Relative Management Responsibility

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

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

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

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

1.3. Applications

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

1.4. Limitations

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

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

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2. Coastal Plain Moist Tundra

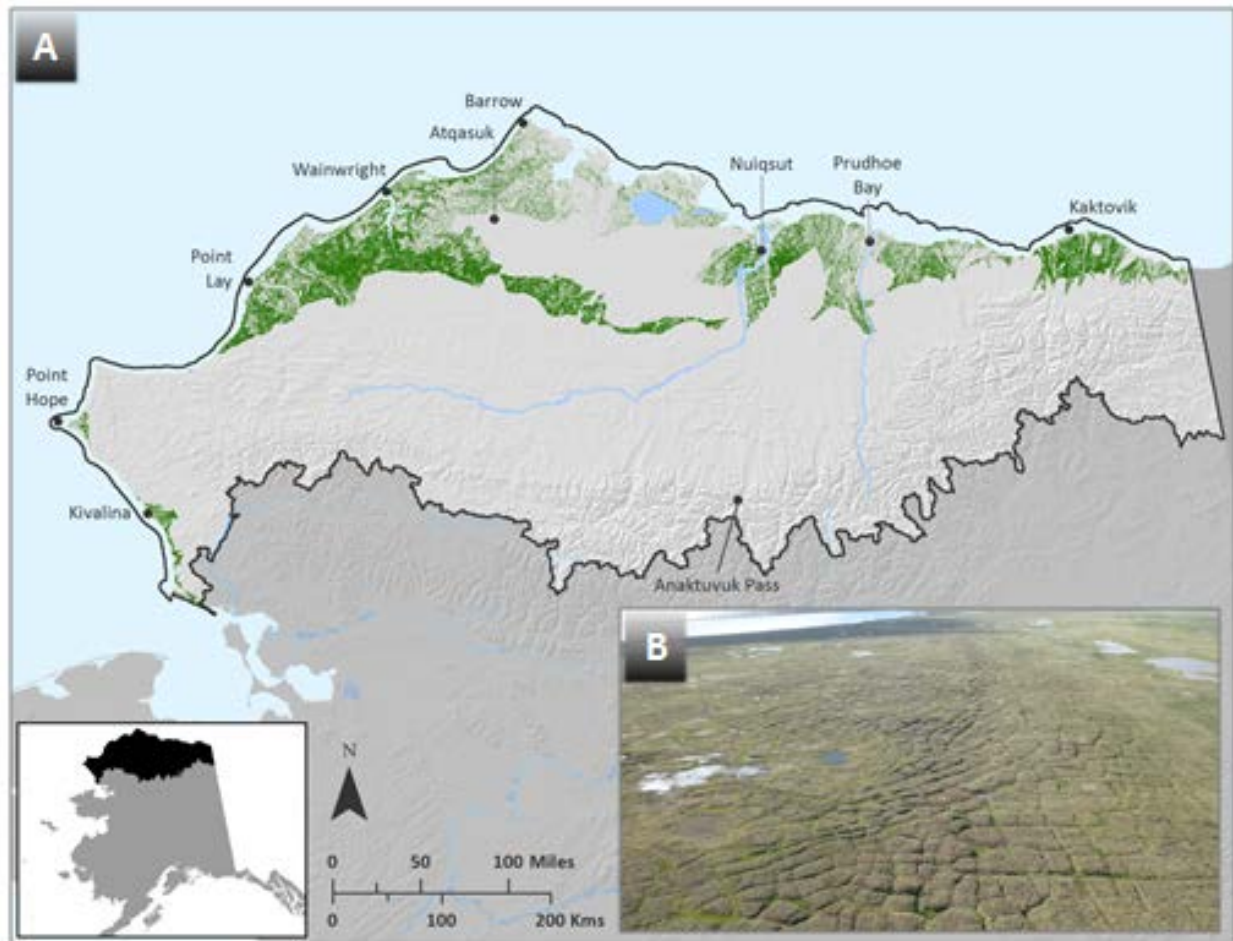


Figure G-16. Current distribution of the coastal plain moist tundra CE in the North Slope study area (A) and coastal plain moist tundra with high-centered polygons (B).

2.1. Introduction

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

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

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

2.2. Conceptual Model

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

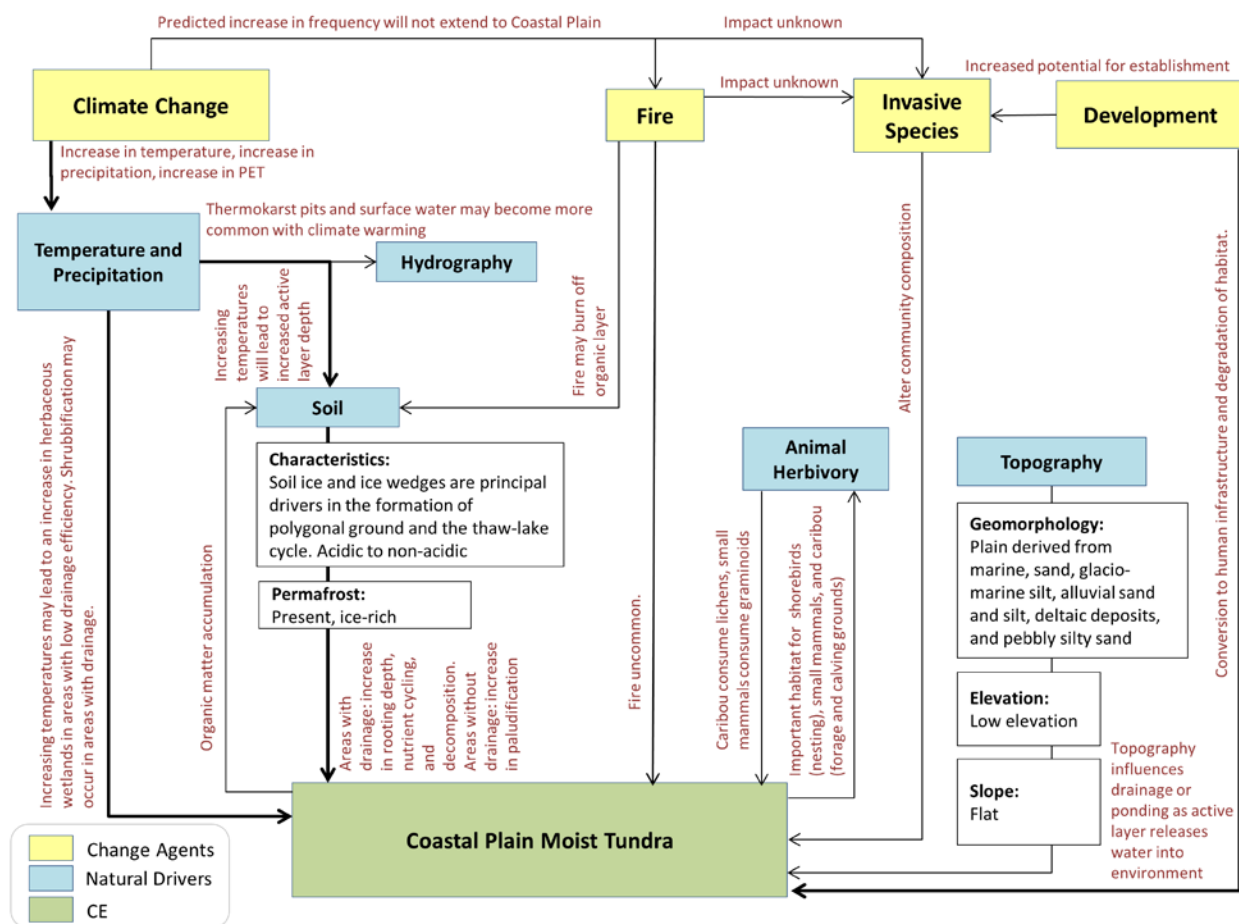


Figure G-17. Conceptual model for coastal plain moist tundra.

2.3. Abiotic Change Agents Analysis

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

Temperature

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

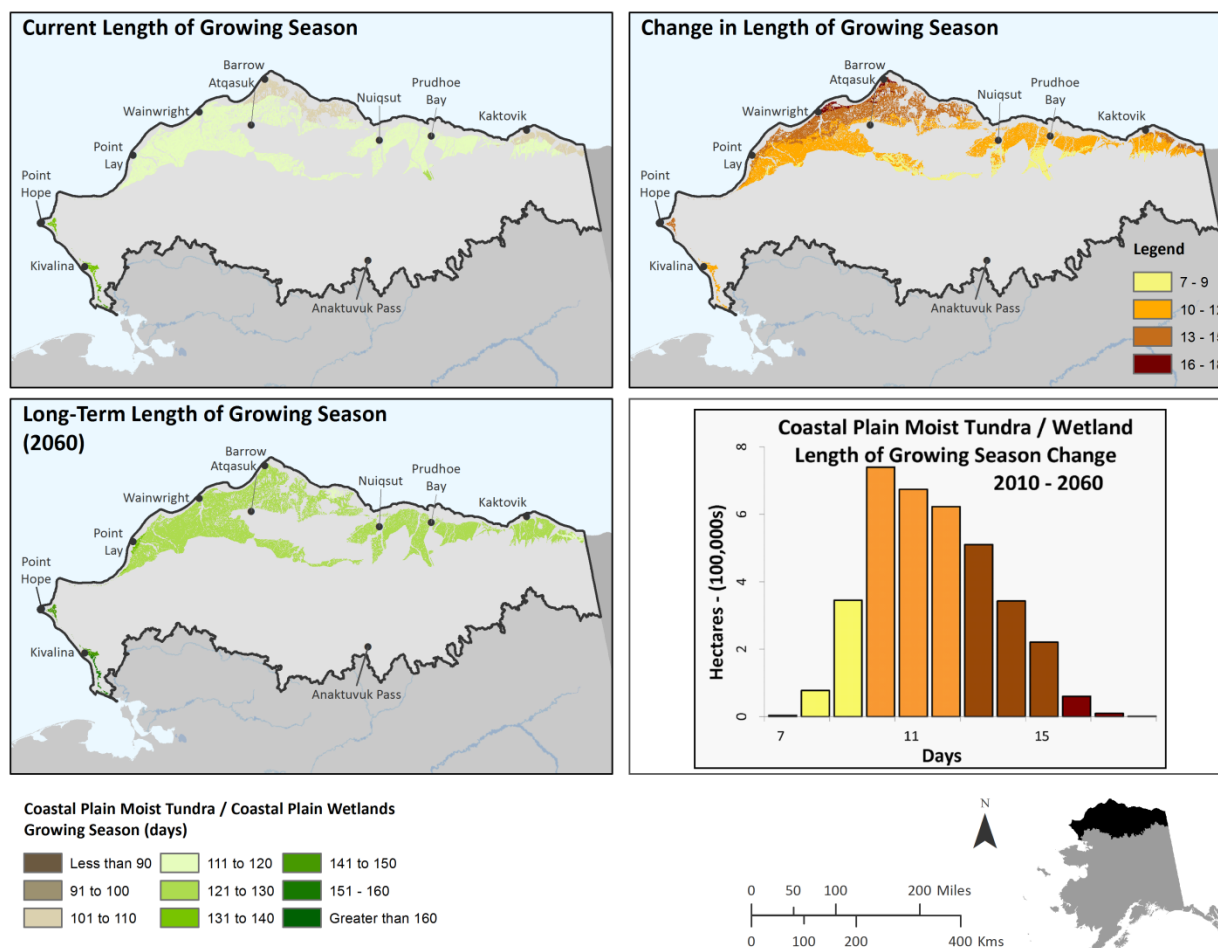


Figure G-18. Length of growing season (LOGS) for current and long-term future and change in LOGS clipped to the coastal plain moist tundra and wetlands CE distributions in the North Slope study area.

Permafrost

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

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

drainage networks and deepening polygon troughs with drier polygon centers (McGuire 2013). Tundra in better drained regions may exhibit an increase in shrub height and cover facilitated by increased active layer and longer growing season (Sturm et al. 2001, Wahren et al 2005, Tape et al. 2006).

2.4. Current Status and Future Landscape Condition

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

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

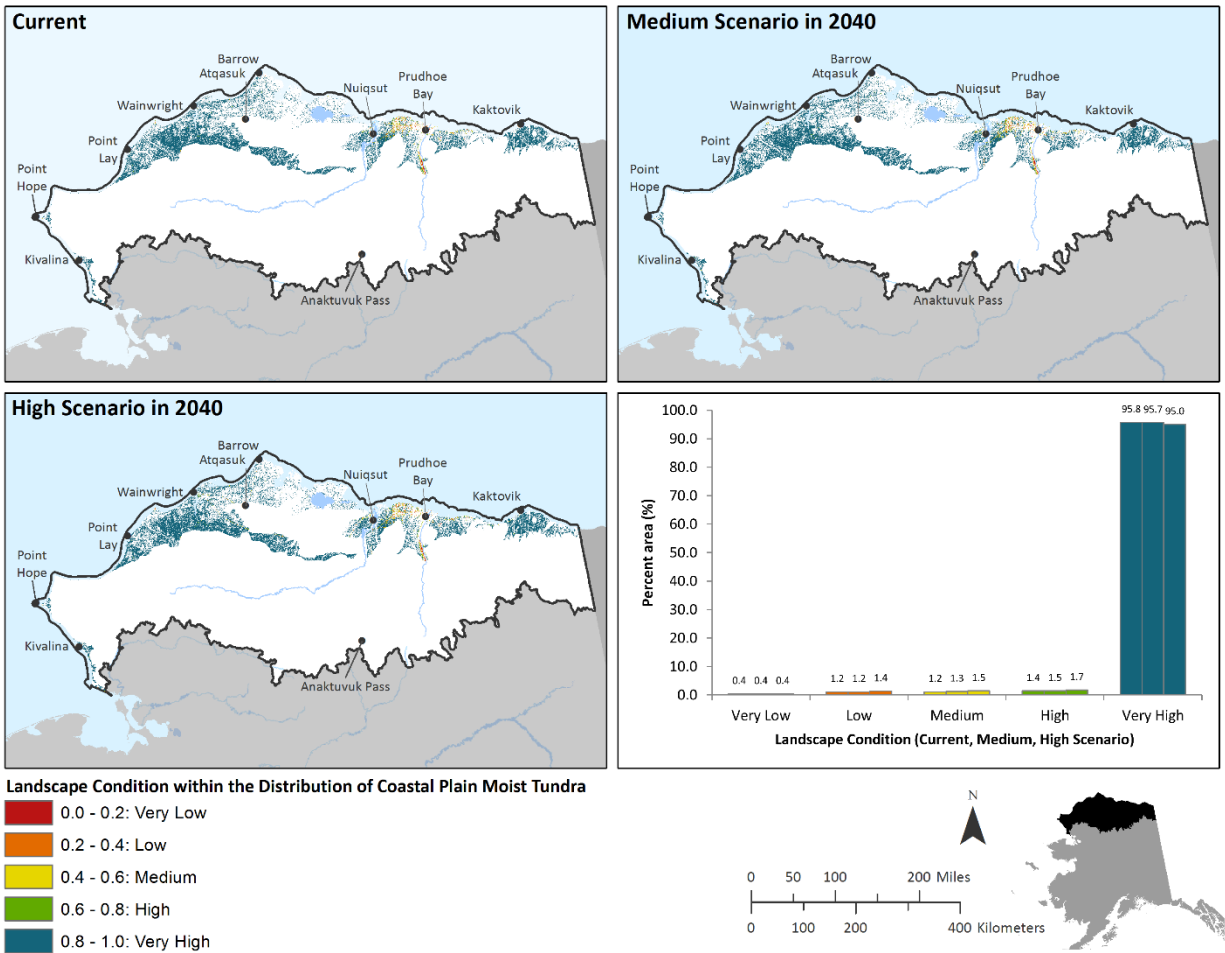


Figure G-19. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of coastal plain moist tundra in the North Slope study area.

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3. Coastal Plain Wetland

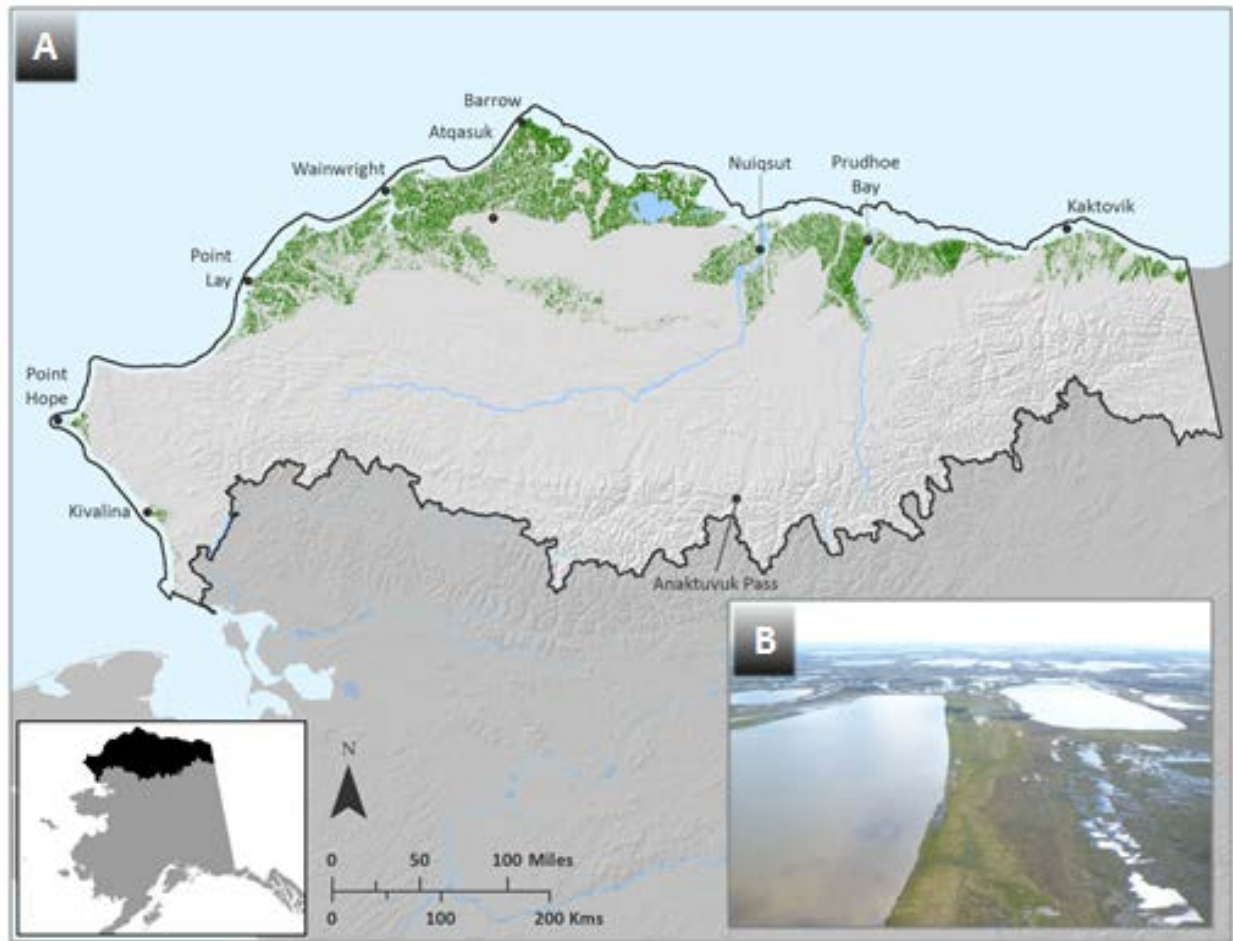


Figure G-20. Current distribution of the coastal plain wetland CE in the North Slope study area (A) and coastal plain wetlands and low-centered polygonal tundra along the margin of an oriented thermokarst lake (B).

3.1. Introduction

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

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

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

Thermokarst Lake Cycle

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

3.2. Conceptual Model

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

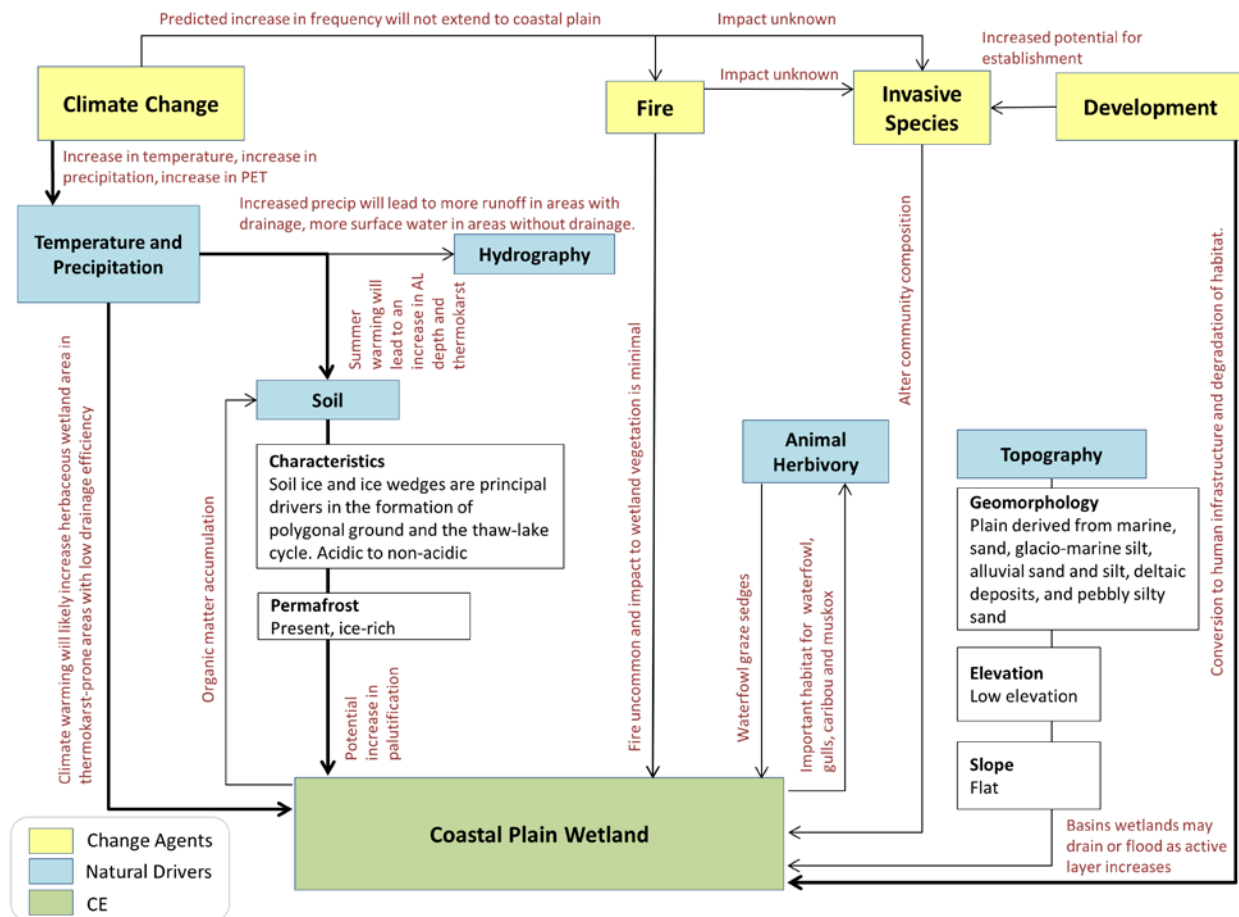


Figure G-21. Conceptual model for coastal plain wetland.

3.3. Abiotic Change Agents Analysis

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

Temperature

Increases in July temperature both in the near and long term are not expected to be significant across most of the coastal plain ecoregion. By the 2060s significant increases ($> 1.3^{\circ}\text{C}$) are projected for only 2% of the of coastal plain wetland distribution (Table G-4). In the long term (2060s) the average projected increase in July temperature across the CE distribution is 1.0°C , and mean annual increase is predicted to be 2.5°C (Table G-5). Although the change in temperature appears to be slight, the increase is projected to lead to a lengthening of the growing season by 12.1 days (Table G-6), driven more by the warming shoulder seasons (Section C-1). While temperature models show that warmest

summer temperatures occur in the in the southern portion of the CE (Figure G-4), the greatest amount of change in the length of growing season is projected to occur in northern portion of the CE, with projected increases of 16 to 18 days in the long term around the communities of Wainwright and Barrow (Figure G-18).

Permafrost

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

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

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

3.4. Current Status and Future Landscape Condition

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

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

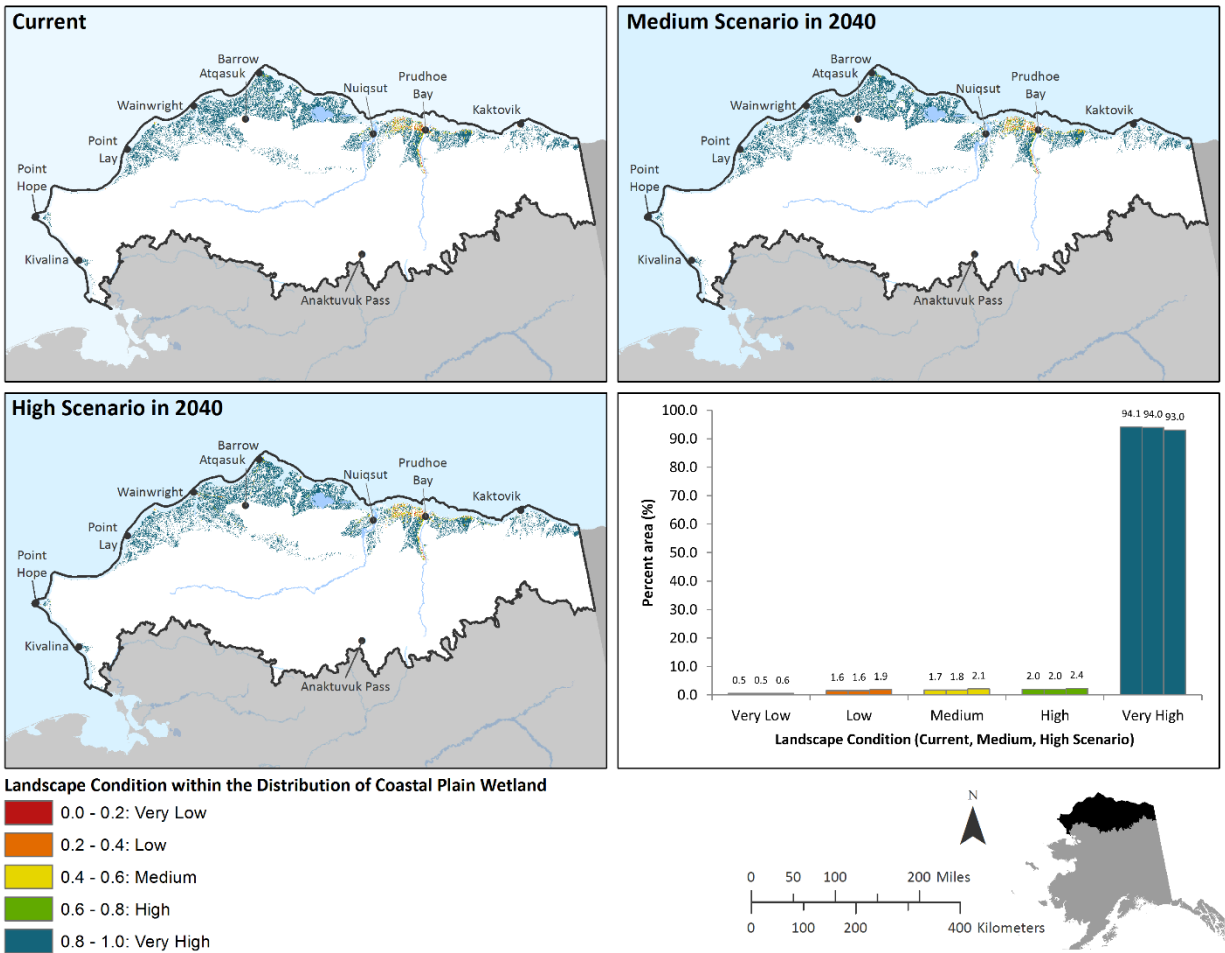


Figure G-22. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of coastal plain wetlands in the North Slope study area.

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4. Sand Sheet Moist Tundra

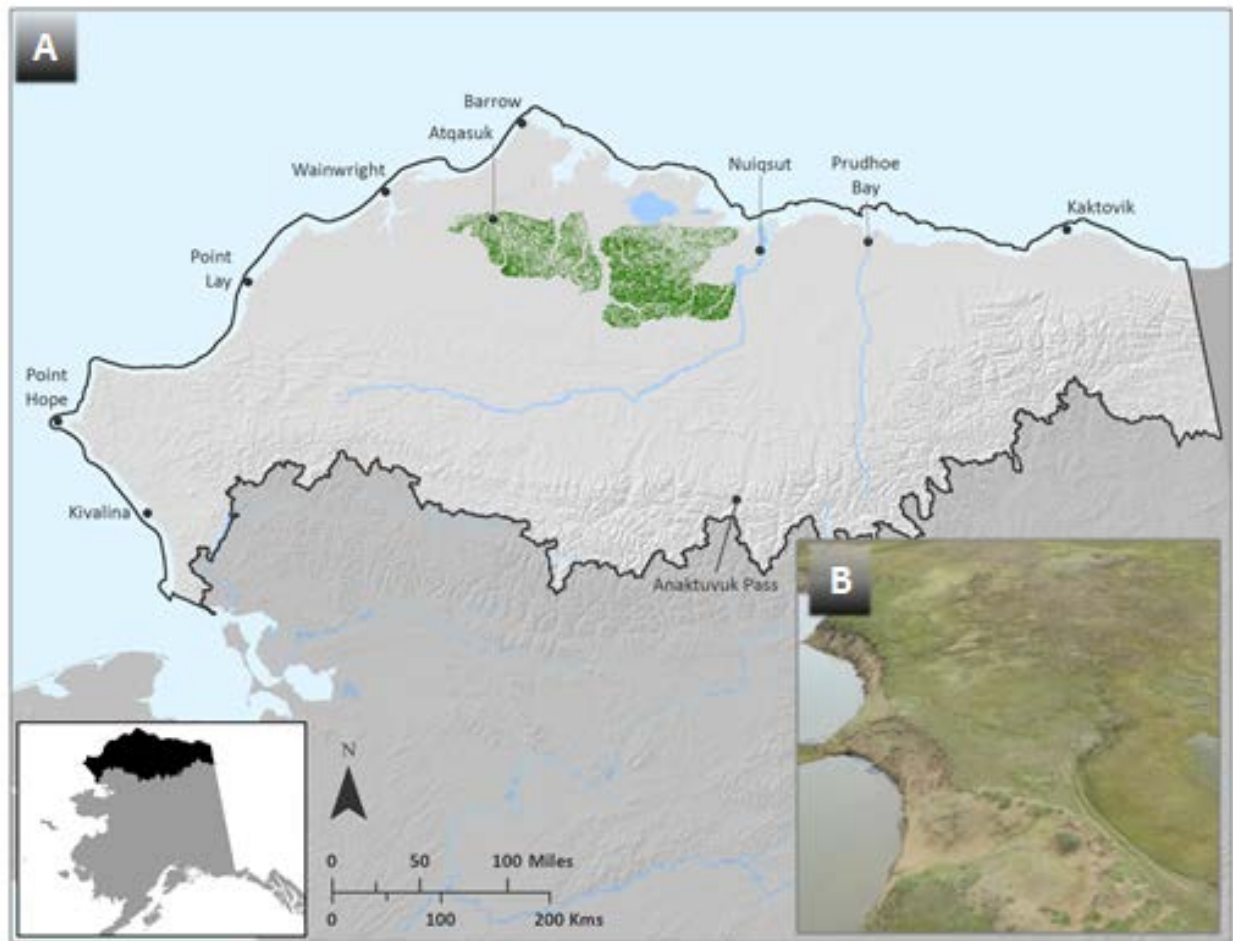


Figure G-23. Current distribution of the sand sheet moist tundra CE in the North Slope study area (A) and sand sheet moist tundra (B).

4.1. Introduction

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

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

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

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

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

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

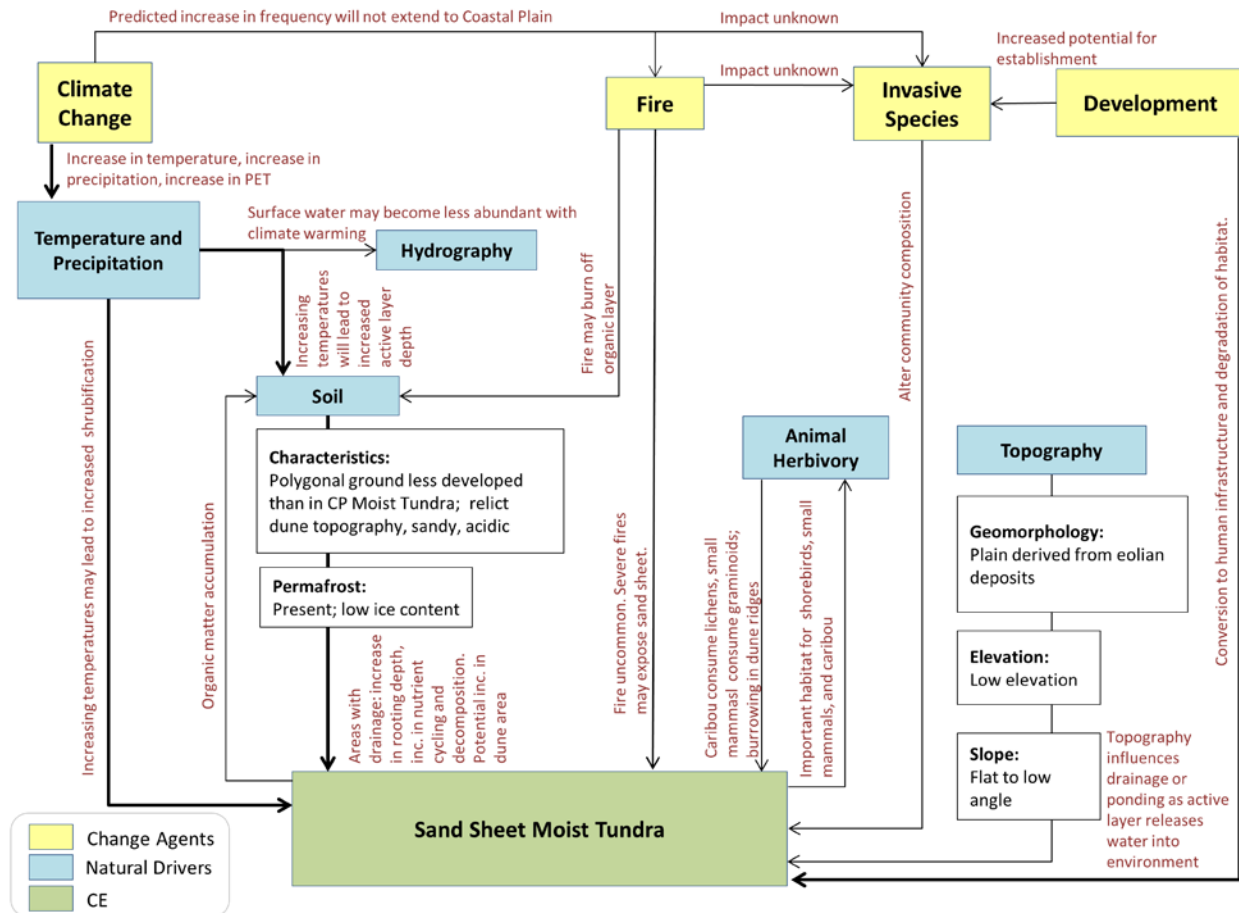


Figure G-24. Conceptual model for sand sheet moist tundra.

4.2. Abiotic Change Agents Analysis

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

Temperature

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

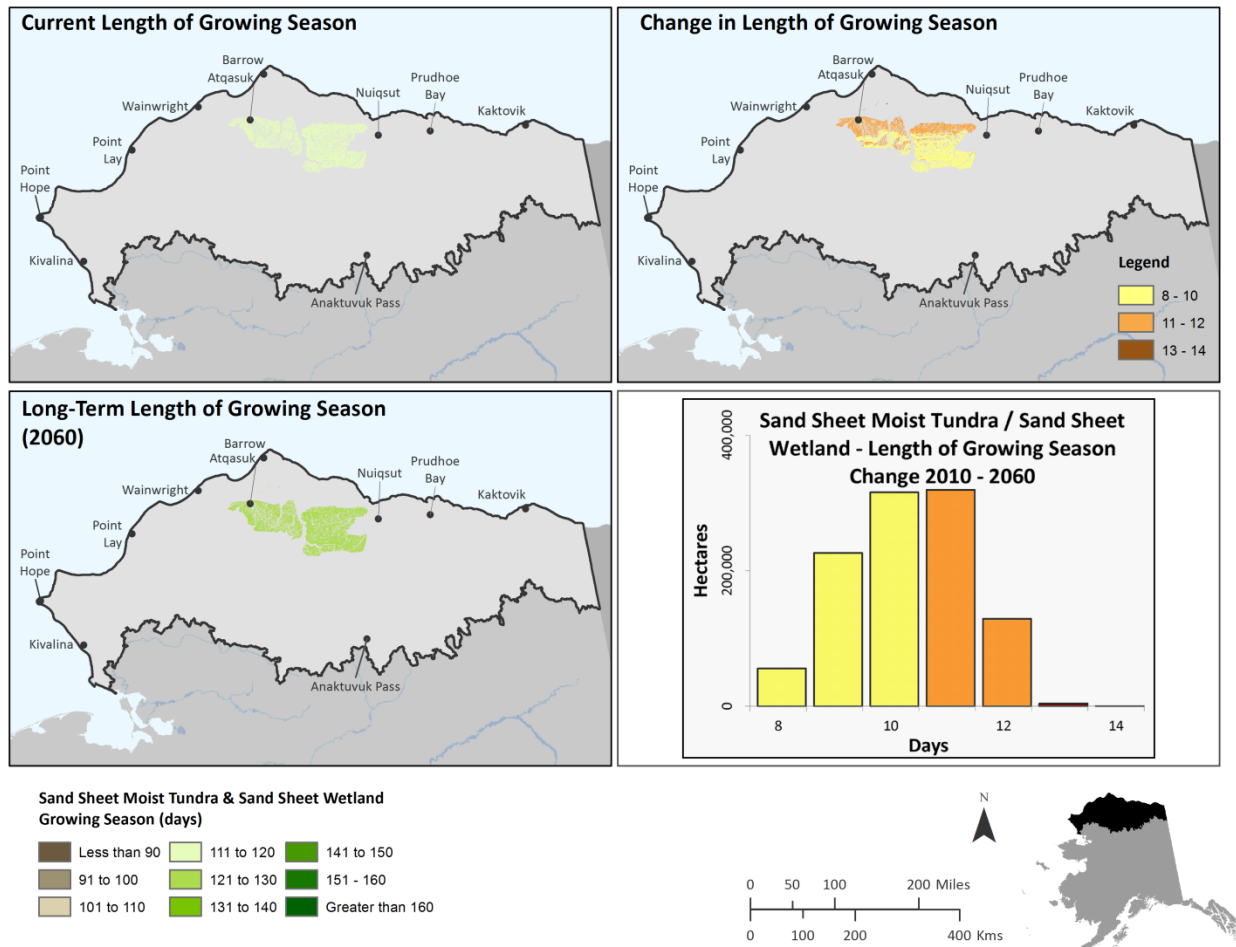


Figure G-25. Length of growing season for current and long term future and change in LOGS clipped to the sand sheet moist tundra and wetlands CE distributions in the North Slope study area.

Fire

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

Permafrost

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

4.3. Current Status and Future Landscape Condition

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

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

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

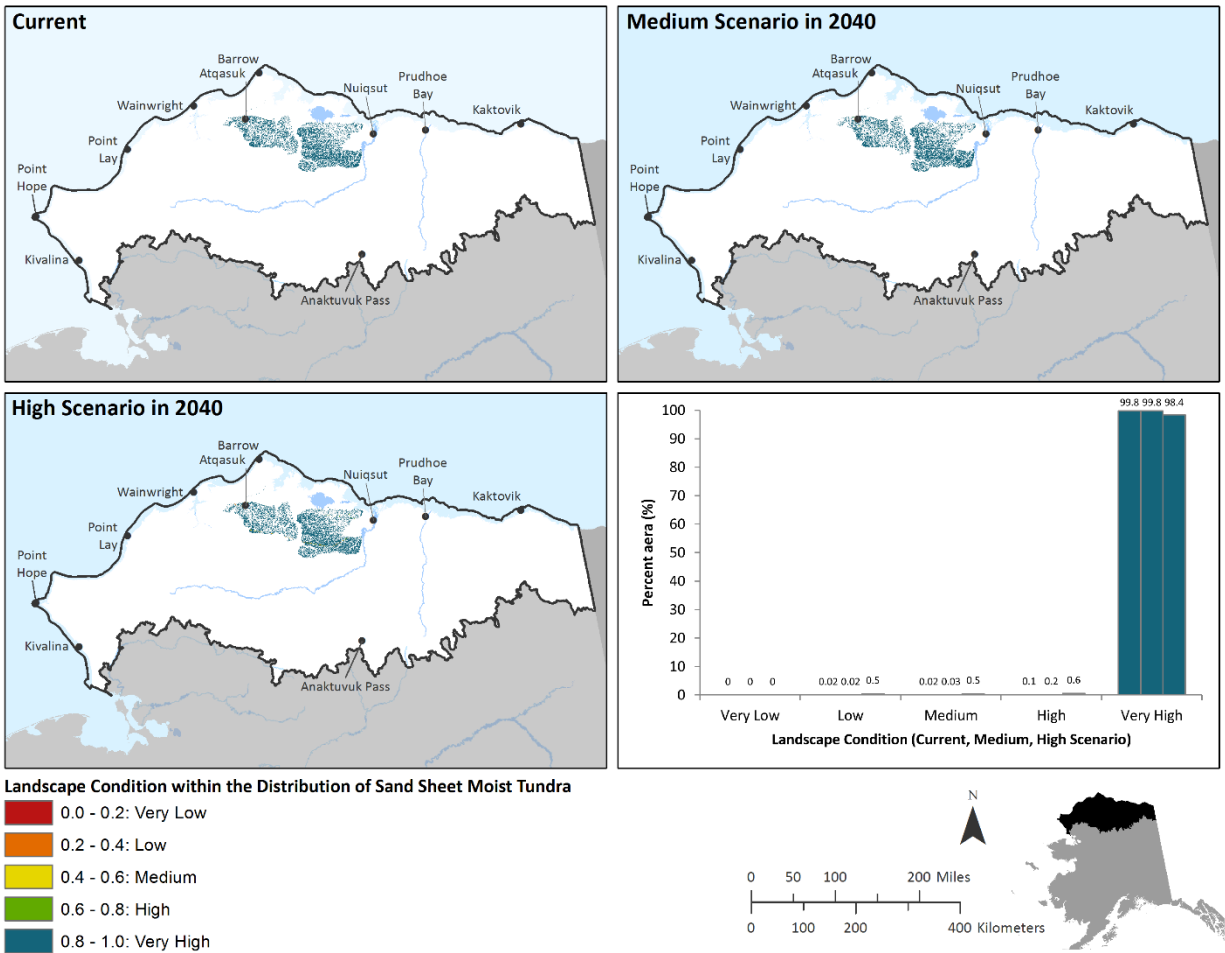


Figure G-26. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of sand sheet moist tundra in the North Slope study area.

4.4. Literature Cited

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5. Sand Sheet Wetland

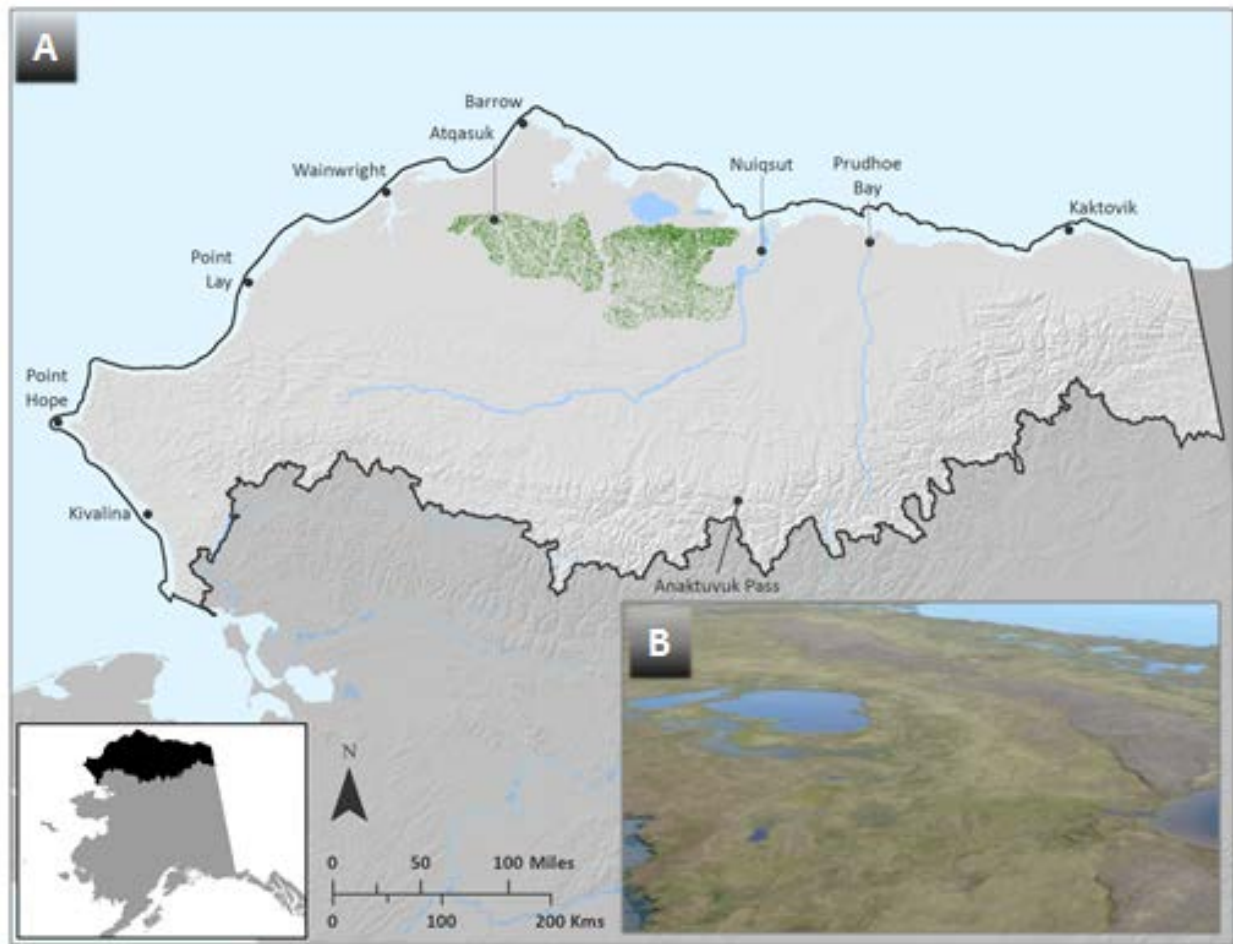


Figure G-27. Current distribution of the sand sheet wetland CE in the North Slope study area (A) and sand sheet basin wetlands separated by an ancient dune ridge (B).

5.1. Introduction

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

Vegetation composition of the sand sheet wetland CE is very similar to that of the coastal plain wetland CE. Marshes and wet sedge meadows occur in basins and along lake margins. The most common species

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

5.2. Conceptual Model

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

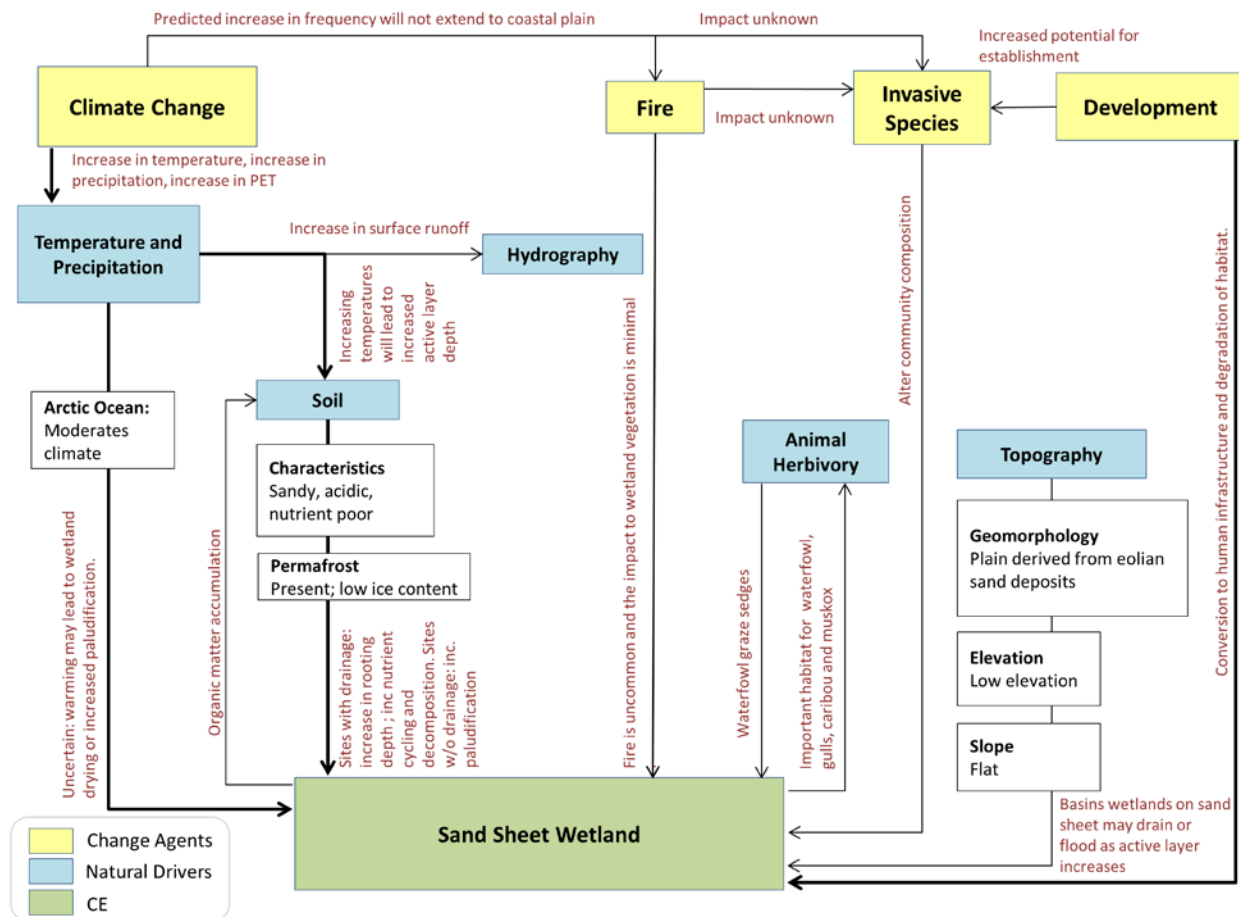


Figure G-28. Conceptual model for sand sheet wetland.

5.3. Abiotic Change Agents Analysis

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

Temperature

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

Fire

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

Permafrost

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

5.4. Current Status and Future Landscape Condition

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

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

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

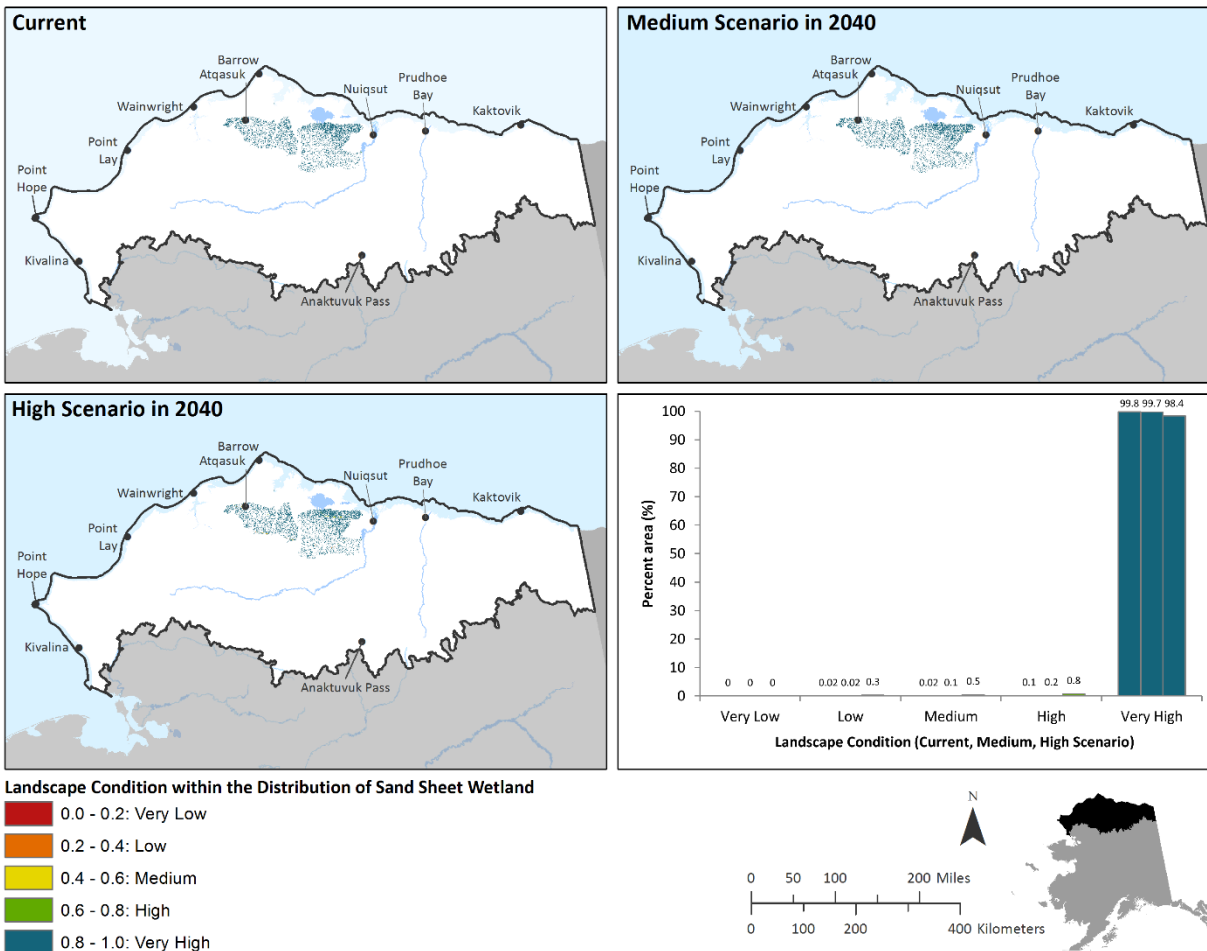


Figure G-29. Figure Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of sand sheet wetland in the North Slope study area.

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6. Foothills Tussock Tundra

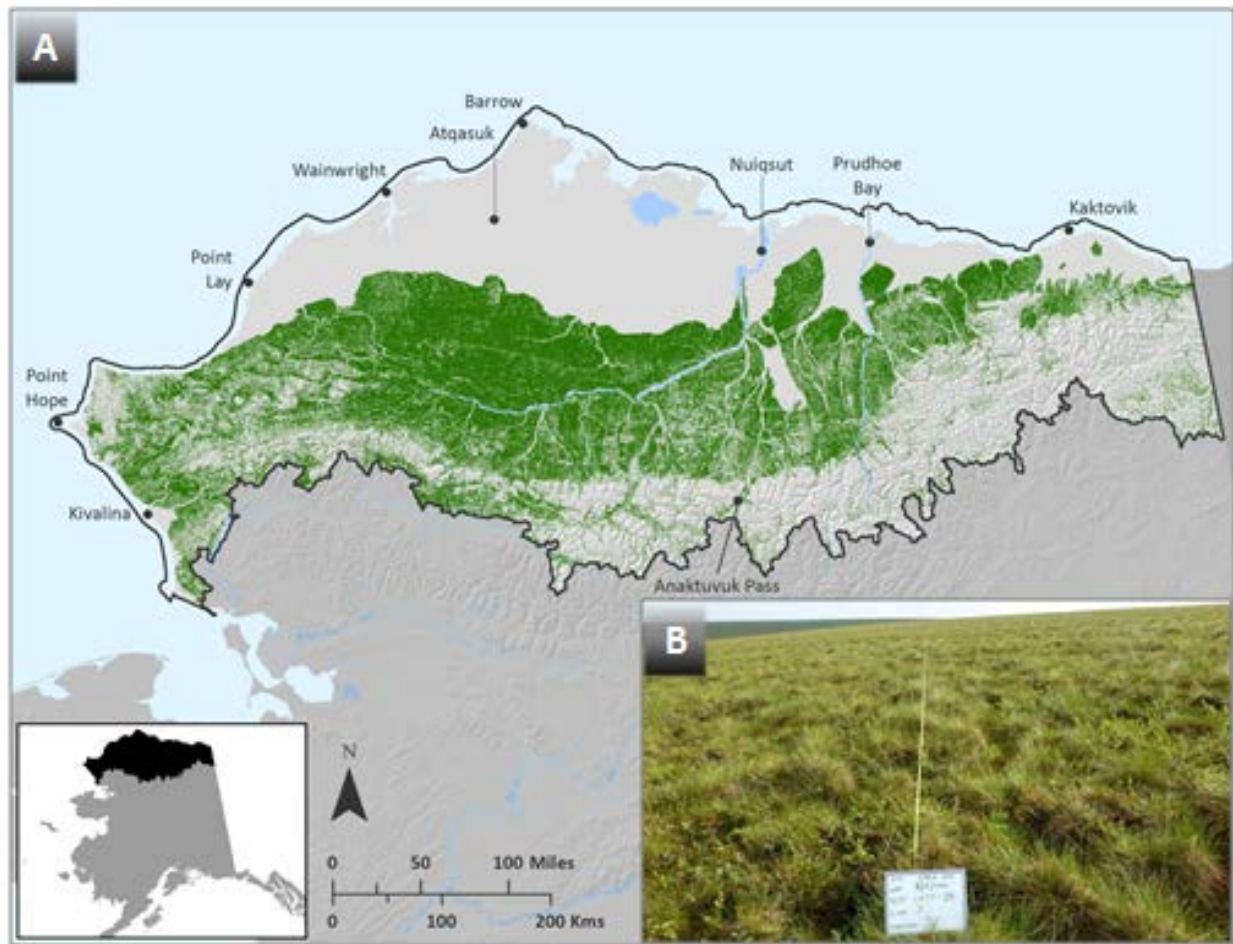


Figure G-30. Current distribution of the foothills tussock tundra CE in the North Slope study area (A) and a vegetation transect in foothills tussock tundra in NPR-A (B).

6.1. Introduction

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

The sedge *Eriophorum vaginatum* is typically the dominant tussock-former, but dominance may transition to *Carex lugens* on somewhat unstable slopes, often in conjunction with solifluction features (Walker et al. 1994). Shrub cover is variable, but generally exceeds 25% and is comprised of *Betula nana*, *Rhododendron tomentosum*, *Salix pulchra*, and/or *Vaccinium vitis-idaea*. Forb cover and richness are low

with *Rubus chamaemorus*, *Petasites frigidus*, and *Polygonum bistorta* commonly represented. The non-vascular community is well-developed and consistent in mature tussock tundra. Common bryophytes include *Hylocomium splendens* and species of the *Sphagnum*, *Aulacomnium* and *Polytrichum* genera; lichens are commonly represented by *Cladina*, *Flavocetraria* and *Peltigera* species.

6.2. Conceptual Model

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

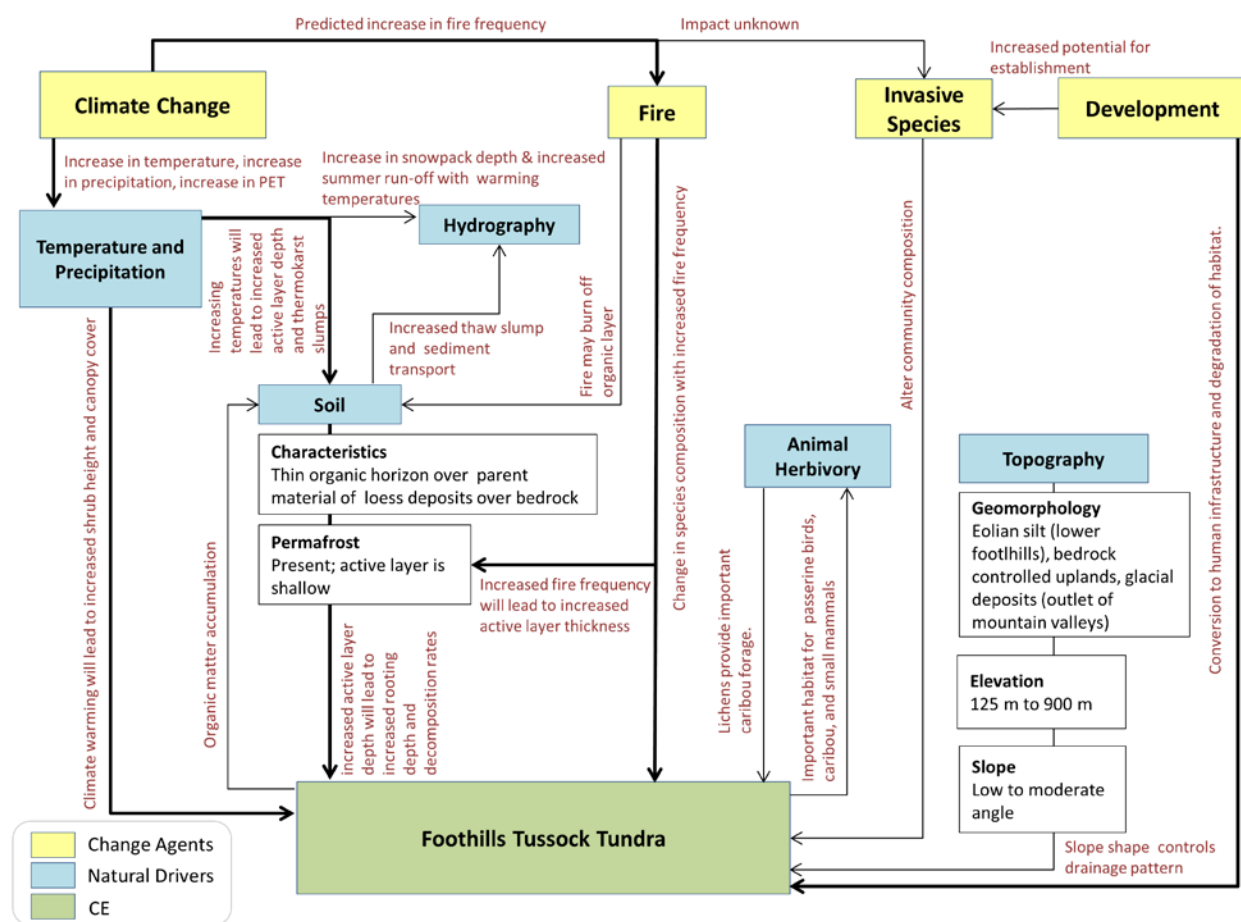


Figure G-31. Conceptual model for foothills tussock tundra.

6.3. Abiotic Change Agents Analysis

We explored the impact of four climatic change agents on foothills tussock tundra: temperature (July temperature and length of growing season), total annual precipitation, permafrost (active layer

thickness and thermokarst predisposition), and fire. Warming is expected to affect vegetation communities directly through temperature effects on plant growth and indirectly primarily through changes to the underlying permafrost and soil properties. Precipitation changes linked to snowpack depth will affect the winter thermal regime, and climate-induced changes to fire frequency, successional trajectories, and plant range expansion are also expected to impact CE habitat.

Temperature

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

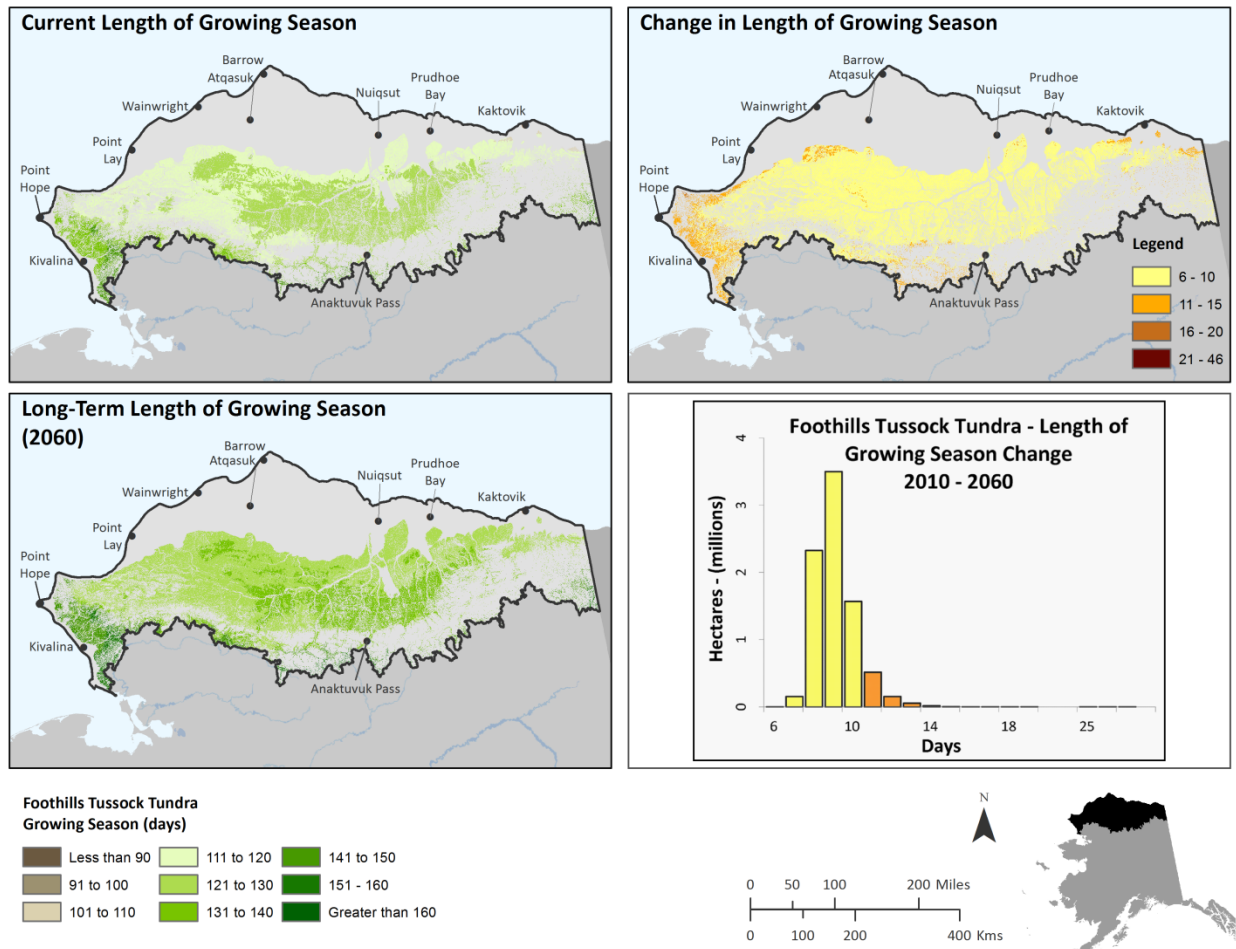


Figure G-32. Length of growing season for current and long term future and change in LOGS clipped to the foothills tussock tundra distribution in the North Slope study area.

Precipitation

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

Fire and Vegetation Succession:

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

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

Graminoids, primarily *Eriophorum vaginatum*, dominate the upper canopy layer within the foothills tussock tundra CE. Average graminoid height is 31.4 cm (SD 5.5) and average shrub height is 27.0 cm (SD 7.8) (NPRA Assessment Inventory and Monitoring Program, unpublished data on file with BLM). Given

the narrow margin between canopy heights of the two life forms, a relatively small increase in shrub height could shift canopy dominance from graminoid to shrub resulting in cascading effects on composition and habitat within the CE.

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

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

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

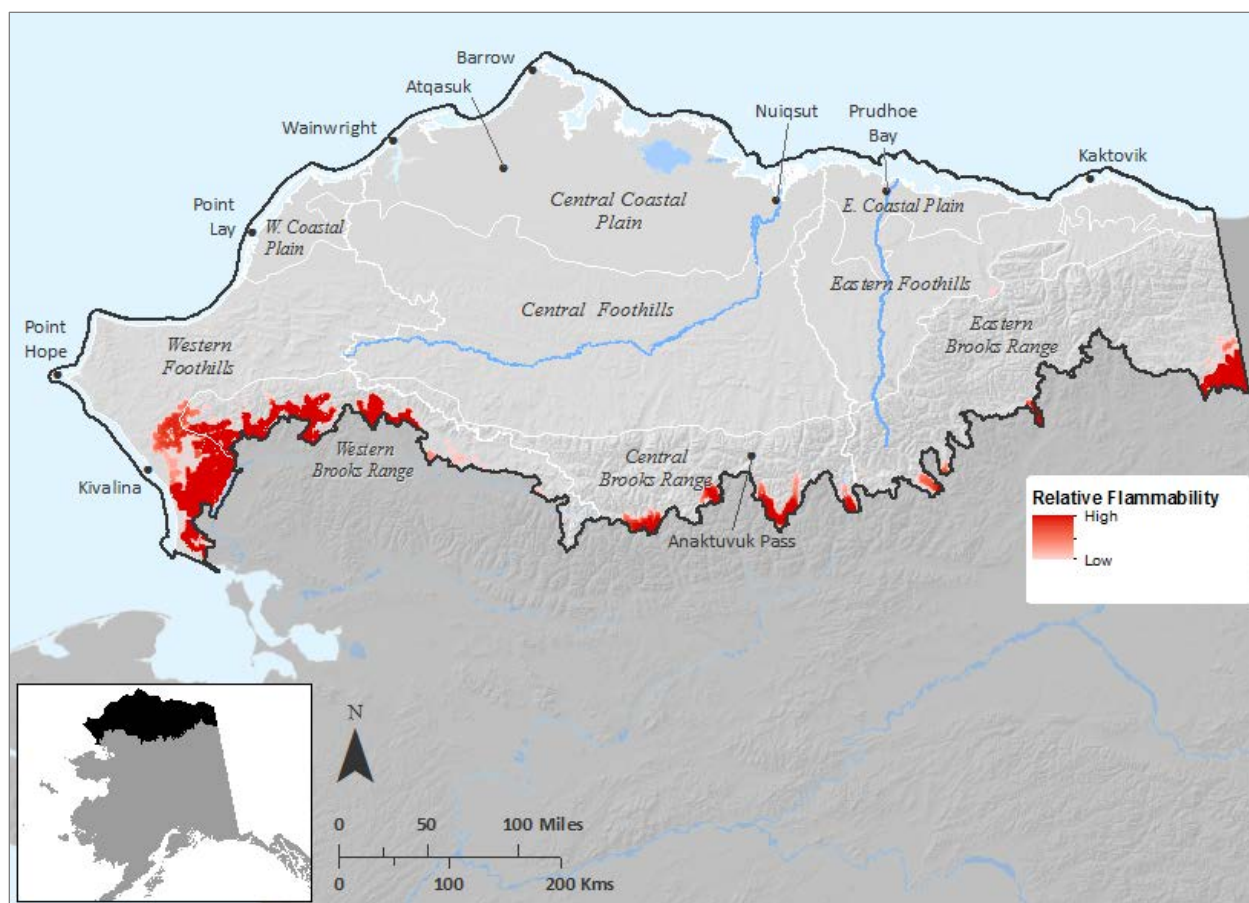


Figure G-33. Projected relative flammability across the North Slope study area.

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

Permafrost

Increased temperatures will lead to an increase in active layer thickness (ALT) which will allow vascular plants to root at greater depth. Current ALT for the foothills tussock tundra CE is modeled at 0.52 m and is projected to increase to 0.61 m in the long term (Table G-9). Active layer thickness is strongly correlated to species composition, with slight increases in seasonal thaw depth potentially facilitating shifts from tundra to shrubland or from shrubland to forest, depending on the minimum rooting depths of the species in question. Thus, the projected increase of 9 cm in ALT in foothills tussock tundra may

transition tussock shrub tundra to a vegetation type dominated by low shrubs. However, these changes are complex in nature; and are linked not only change in the permafrost condition, but also to associated changes in temperature, snow cover, and tundra fire (Myers-Smith et al. 2011; see Section C. Abiotic Change Agents).

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

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

6.4. Current Status and Future Landscape Condition

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

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

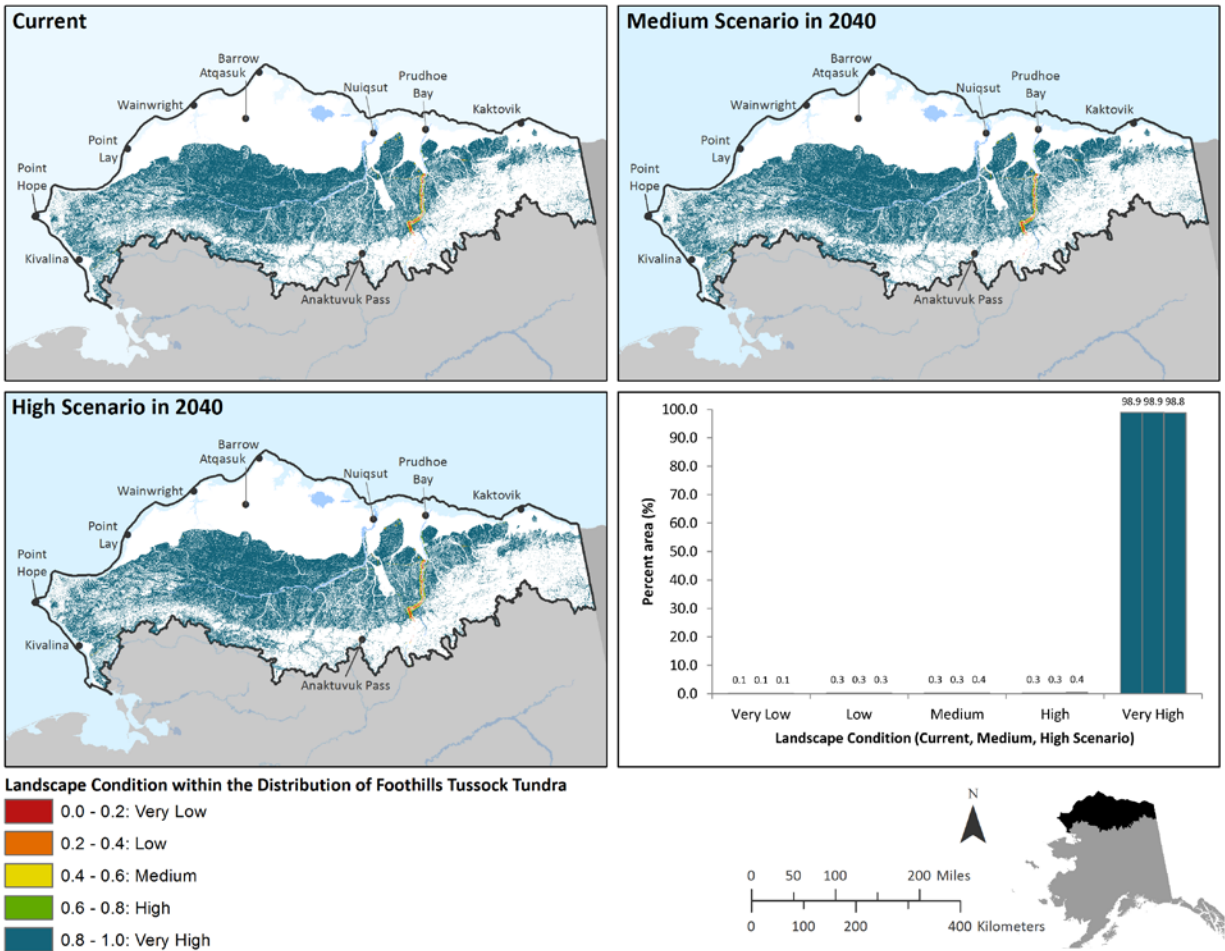


Figure G-34. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of foothills tussock tundra in the North Slope study area.

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7. Alpine Dwarf Shrub Tundra

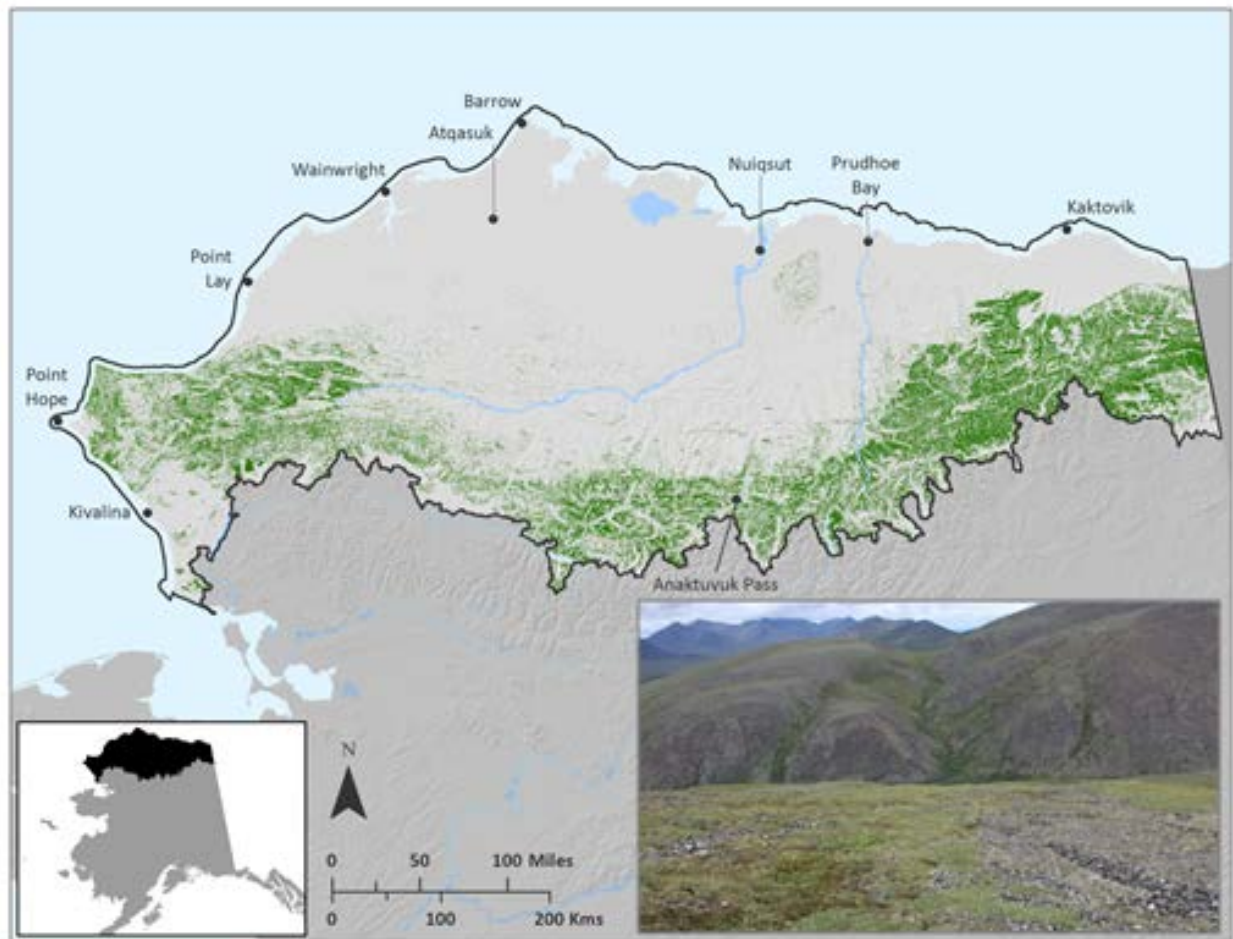


Figure G-35. Current distribution of the alpine dwarf shrub tundra CE in the North Slope study area.

7.1. Introduction

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

The dominant shrubs are *Dryas octopetala*, *Cassiope tetragona*, and *Salix* spp. (including *Salix reticulata*, *S. arctica*, *S. phlebophylla*, and *S. pulchra*). *Cassiope tetragona* tends to be more abundant on north-facing slopes and late-lying snowbeds (Bliss 1988), while *Dryas octopetala* is more abundant on south-facing slopes and rounded, wind-swept summits. *Dryas octopetala* typically grows on sites with low

snow cover on circum-neutral or basic soils (Komárková 1979). Other common shrubs include *Arctostaphylos alpina*, *Vaccinium uliginosum*, *V. vitis-idaea*, *Diapensia lapponica*, and *Loiseleuria procumbens*. *Carex lugens* can be common on low angle sites with adequate soil moisture. A wide variety of alpine forbs are present with low cover. Common non-vascular species include *Hylocomium splendens*, *Racomitrium lanuginosum*, *Dicranum* spp., *Polytrichum* spp., *Umbilicaria* spp., *Cladina* spp., *Peltigera* spp., and *Cetraria* spp.

7.2. Conceptual Model

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

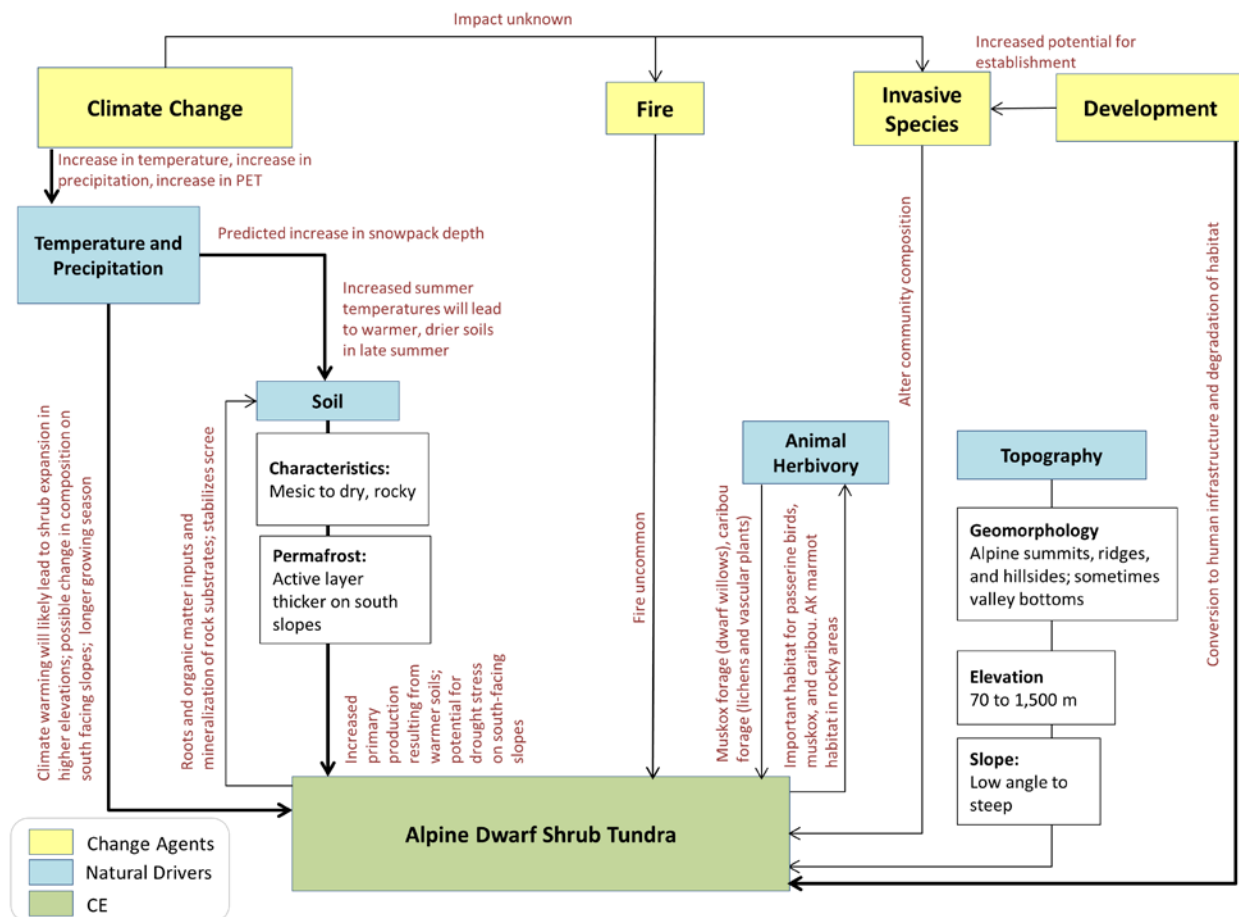


Figure G-36. Conceptual model for alpine dwarf shrub tundra.

7.3. Abiotic Change Agents Analysis

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

Temperature

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

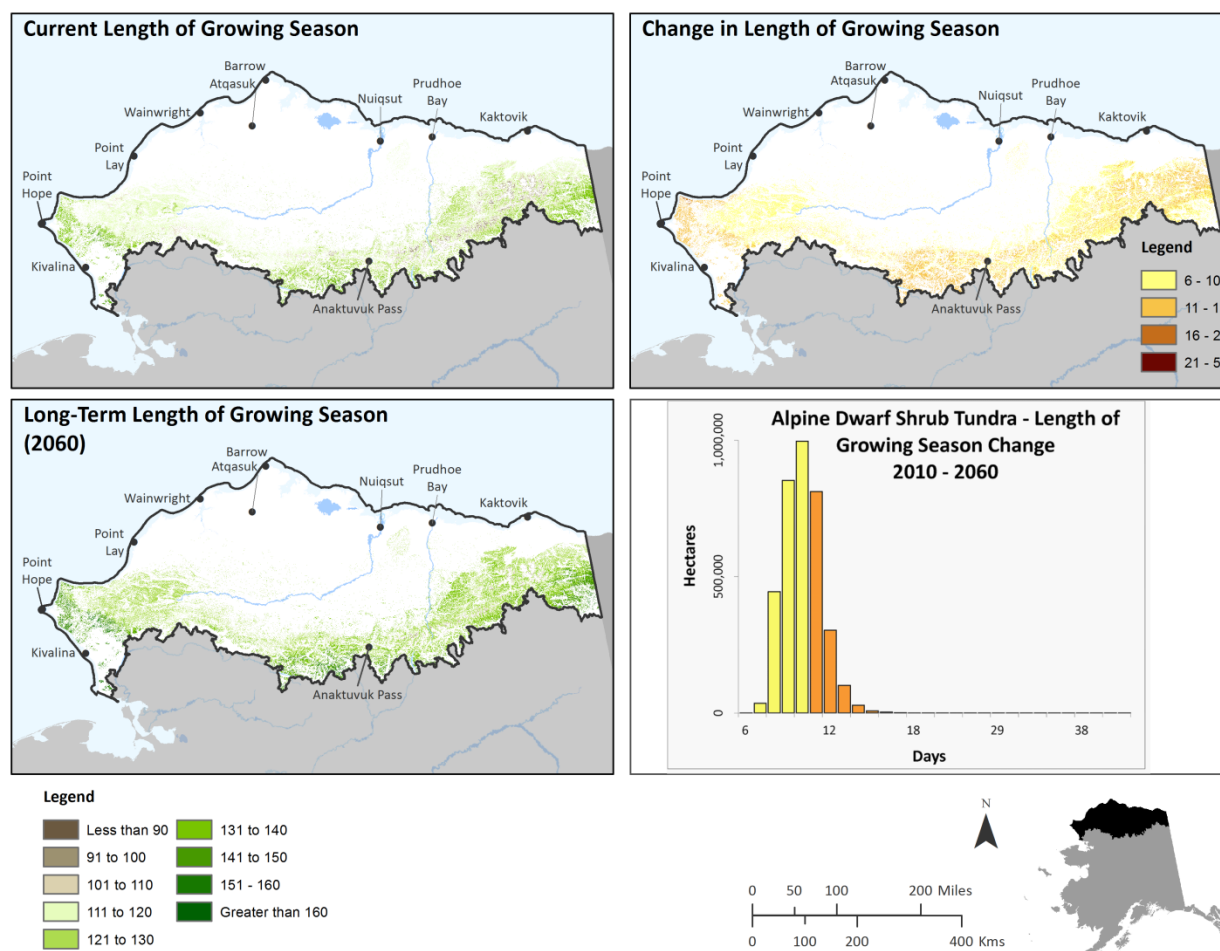


Figure G-37. Length of growing season for current and long-term future and change in LOGS clipped to the alpine dwarf shrub tundra distribution in the North Slope study area.

Precipitation

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

Fire and Vegetation Change

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

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

Permafrost

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

7.4. Current Status and Future Landscape Condition

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

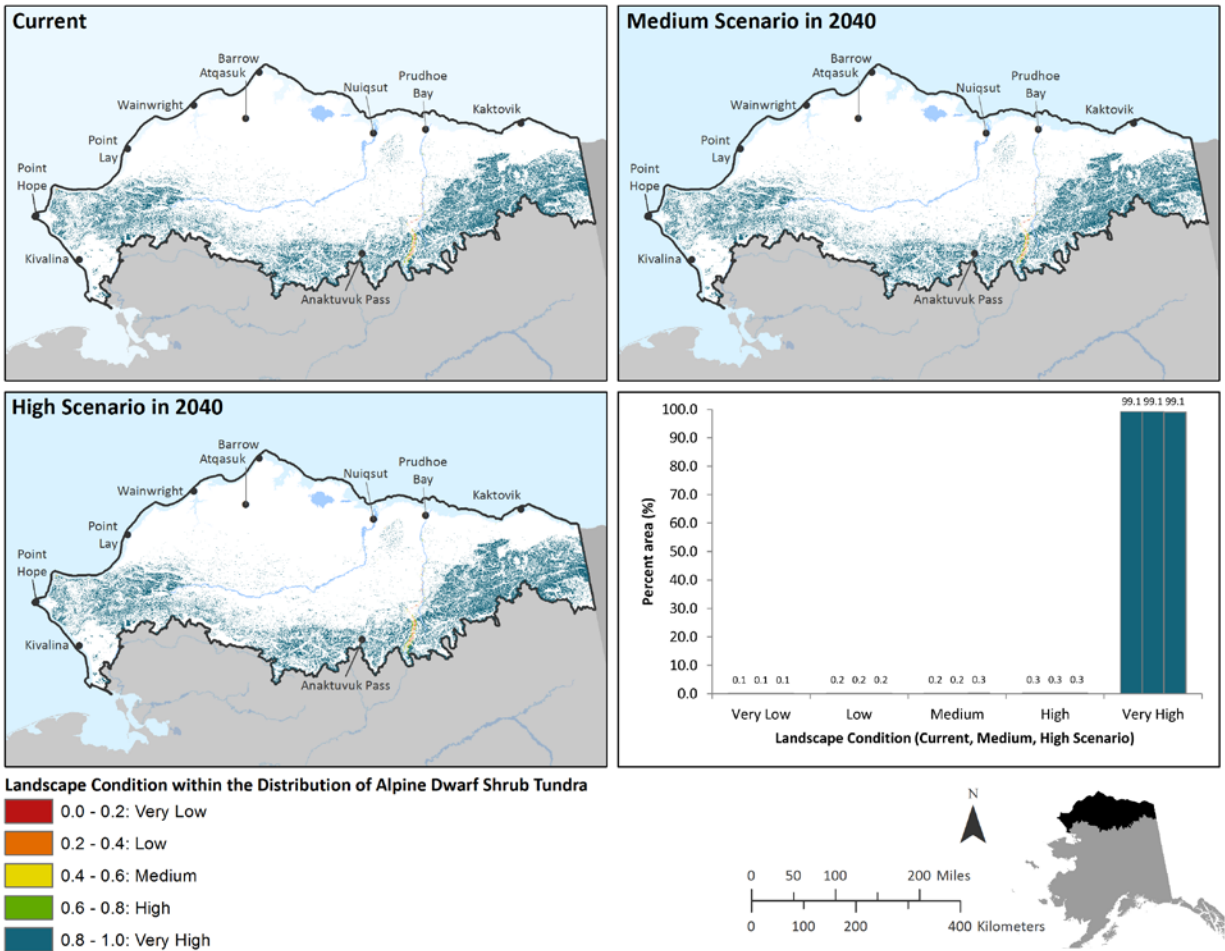


Figure G-38. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the distribution of alpine dwarf shrub tundra in the North Slope study area.

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8. Floodplain Shrubland

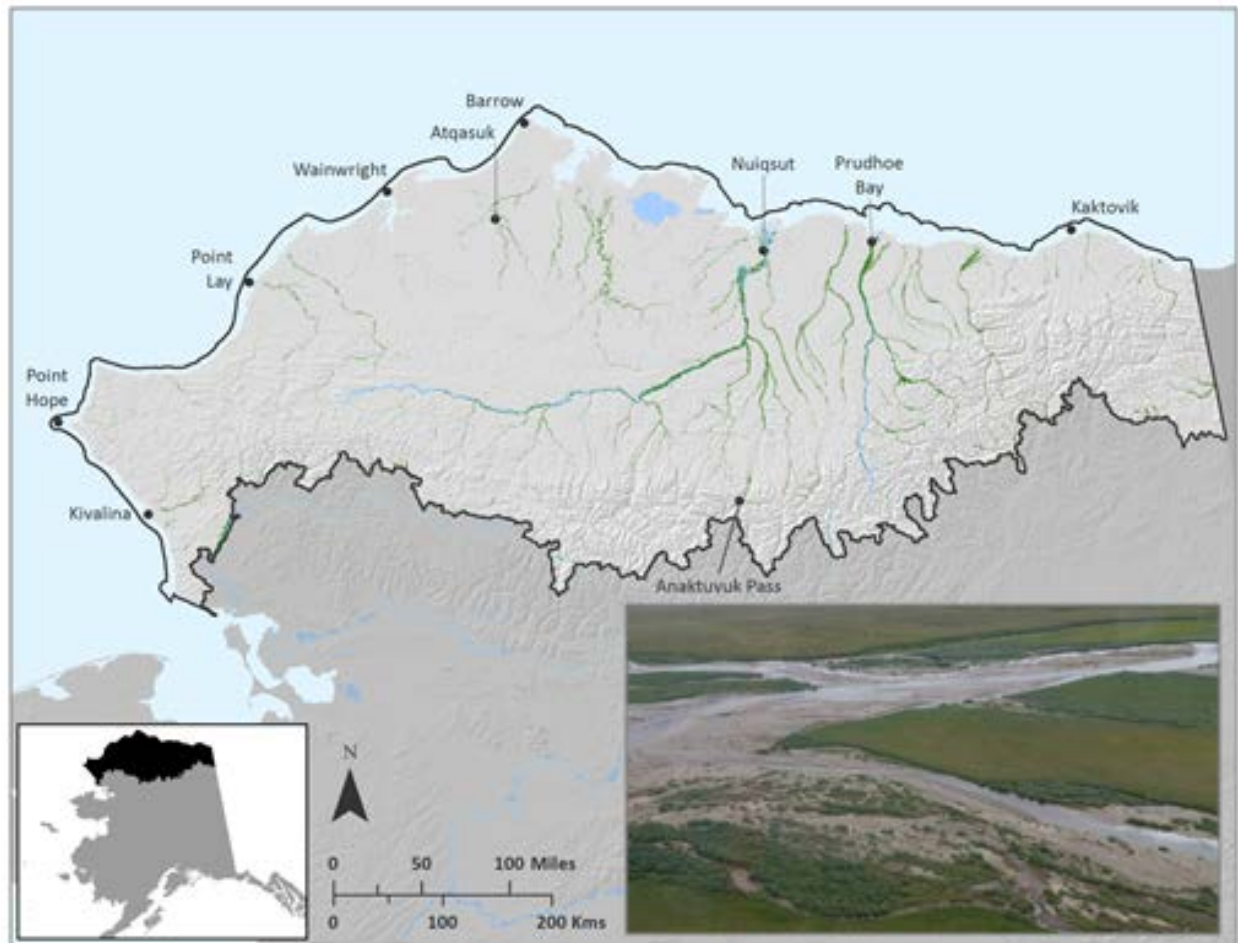


Figure G-39. Distribution model for floodplain shrublands within the North Slope study area.

8.1. Introduction

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

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

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

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

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

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

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

Early Seral Vegetation Communities

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

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

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

Mid Seral Vegetation Communities

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

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

Late Seral Vegetation Communities

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

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

8.2. Conceptual Model

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

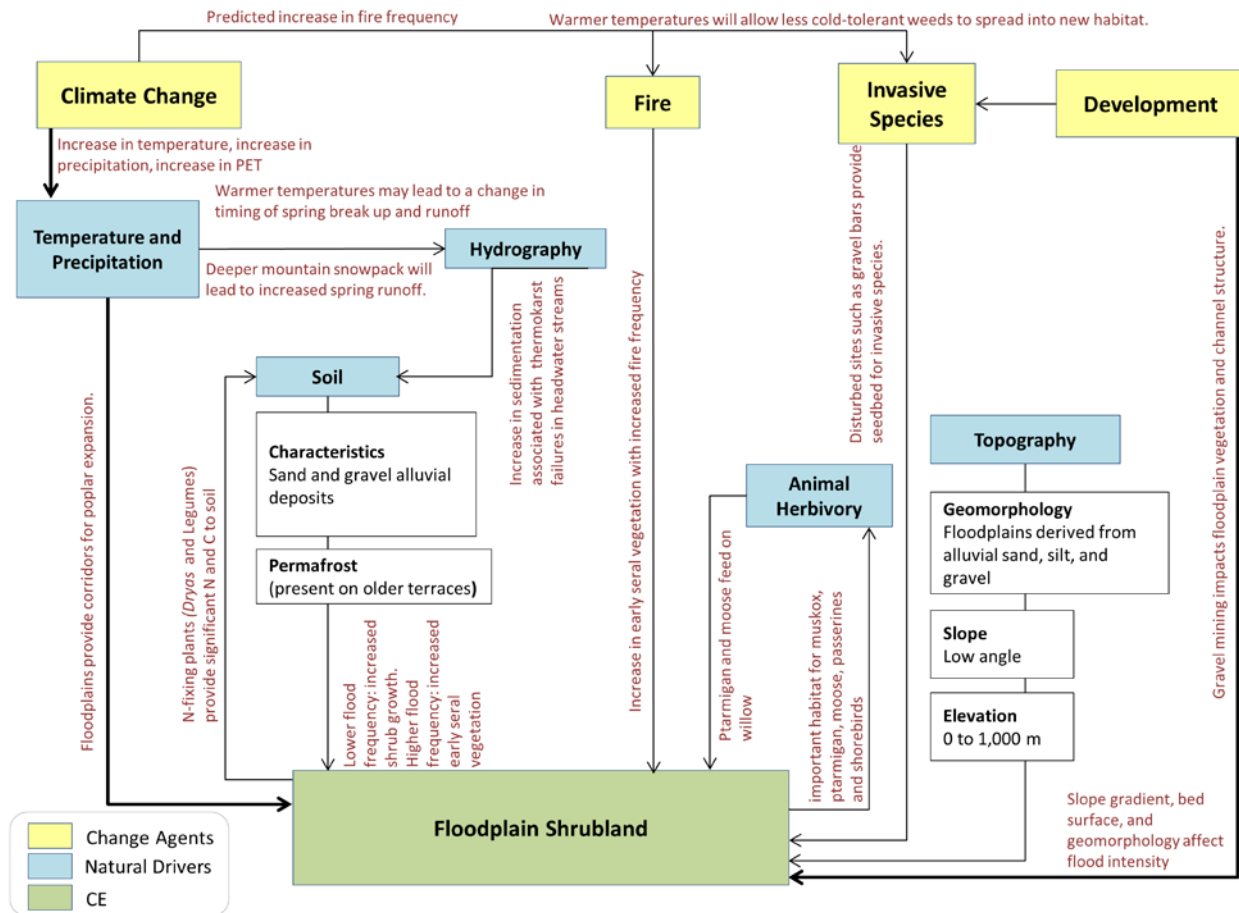


Figure G-40. Conceptual model for the floodplain shrubland CE.

8.3. Abiotic Change Agents Analysis

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

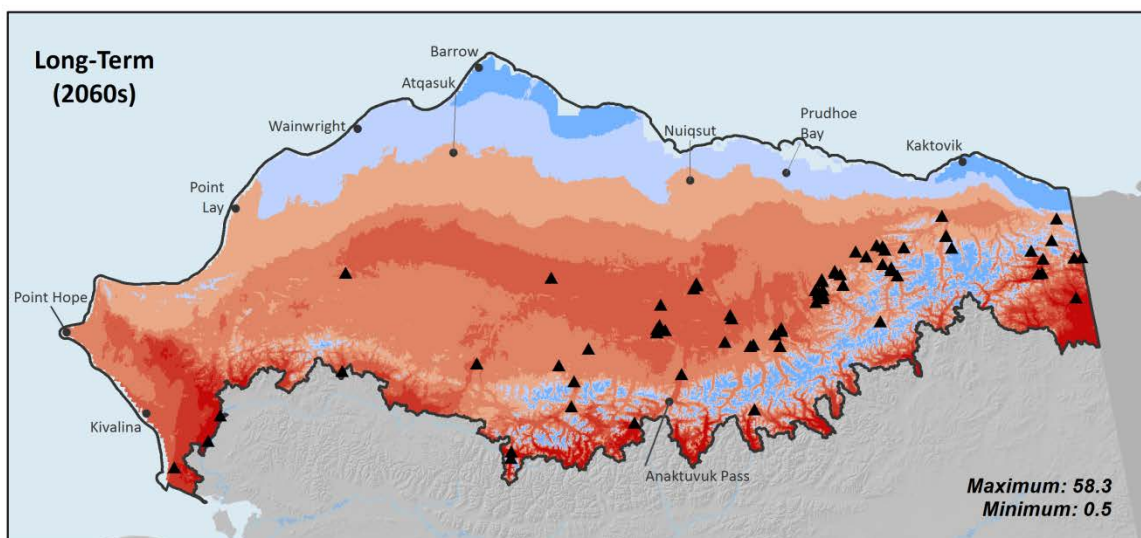
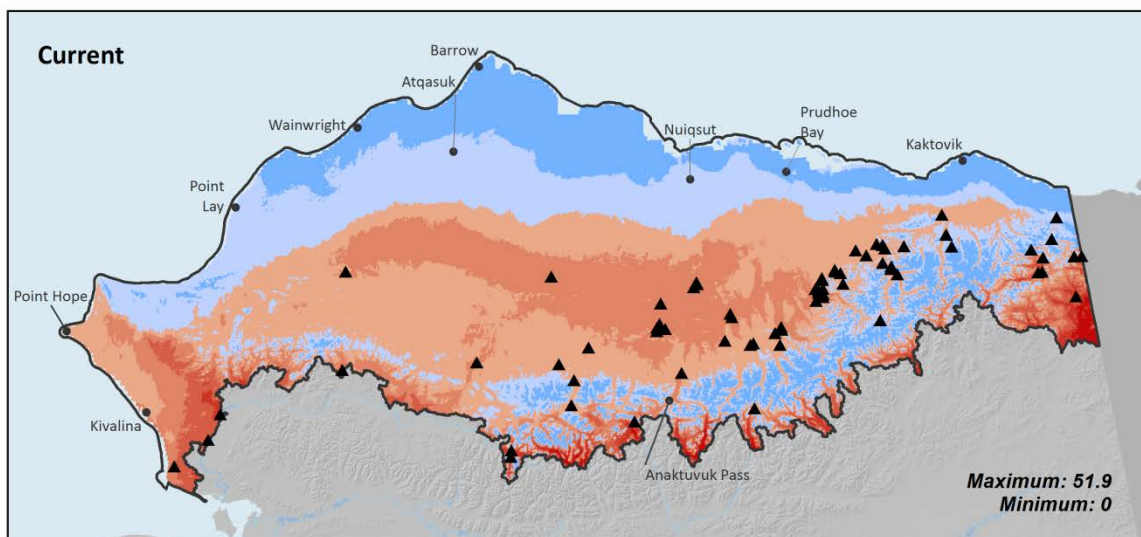
Temperature

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

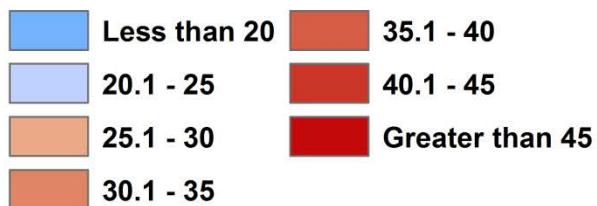
Fire and Vegetation Change

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

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



Summer Warmth Index (°C): A2 Scenario



▲ Known poplar locations

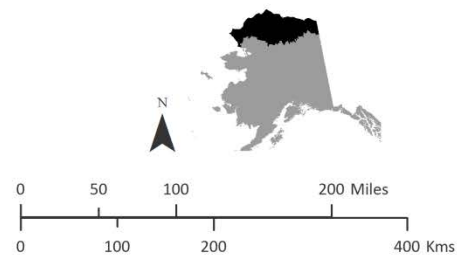


Figure G-41. Known poplar stand locations and Summer Warmth Index for the current and long term future in the North Slope study area.

8.4. Invasive Species

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

8.5. Current Status and Future Landscape Condition

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

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

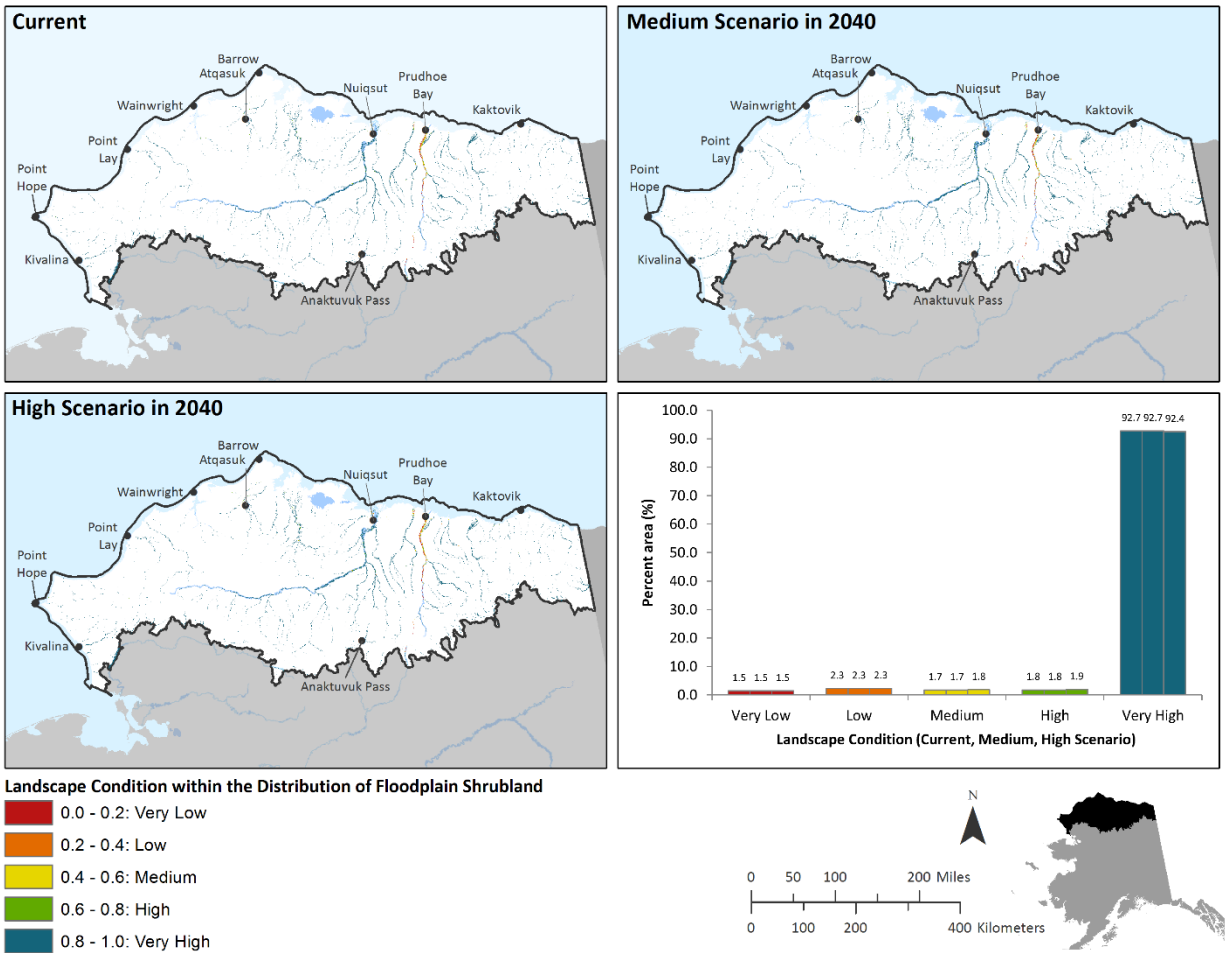


Figure G-42. Landscape condition modeled for current condition and two development scenarios, medium and high, clipped to the floodplain shrubland distribution in the North Slope study area.

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9. Marine Beach, Barrier Islands, and Spits

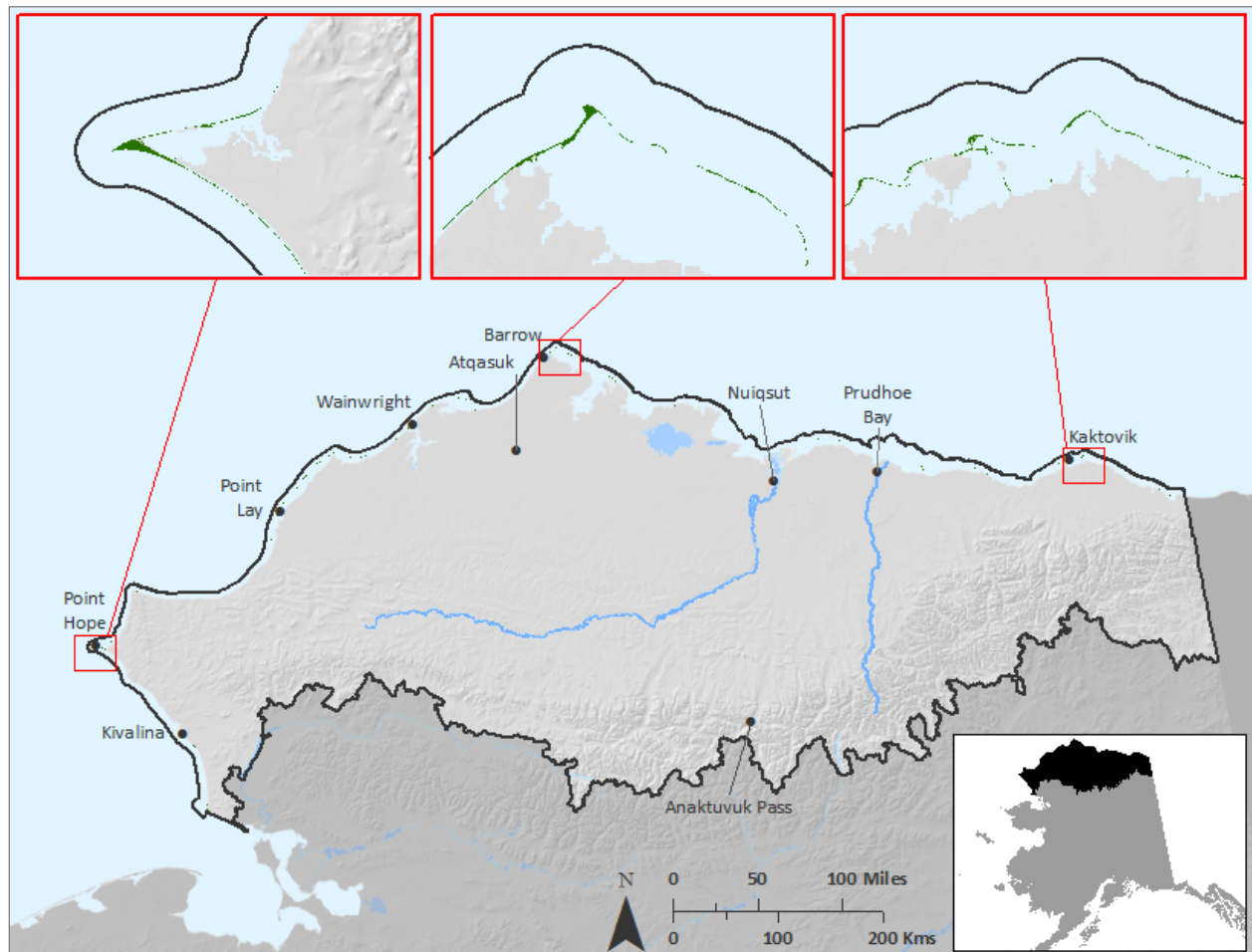


Figure G-43. Current distribution of marine beach, barrier islands, and spits in the North Slope study area.

9.1. Introduction

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

on the constructed barrier island. Of particular note are the barrier islands enclosing the Chukchi Sea's Kasegaluk Lagoon, which at 185 km, represents one of the longest systems in North America.



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

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

While barrier islands and spits are largely devoid of vegetation, sparse vegetation may develop in protected dune areas that are older than 30-40 years (Hopkins and Hartz 1978, Short 1979). Pioneer species tolerant of salt and sand accumulation are the first to establish. The beachgrass, *Leymus mollis* is

most common on topographic highs, with the succulent, halophytic forb, *Honckenya peploides* occurring on lower, often tidal substrates. Due to the challenges of germination posed by wind and desiccation in a dune environment, most species reproduce vegetatively and quickly develop to clonal stands (Carter 1988, Howard et al. 1977).

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

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



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

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

9.2. Conceptual Model

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

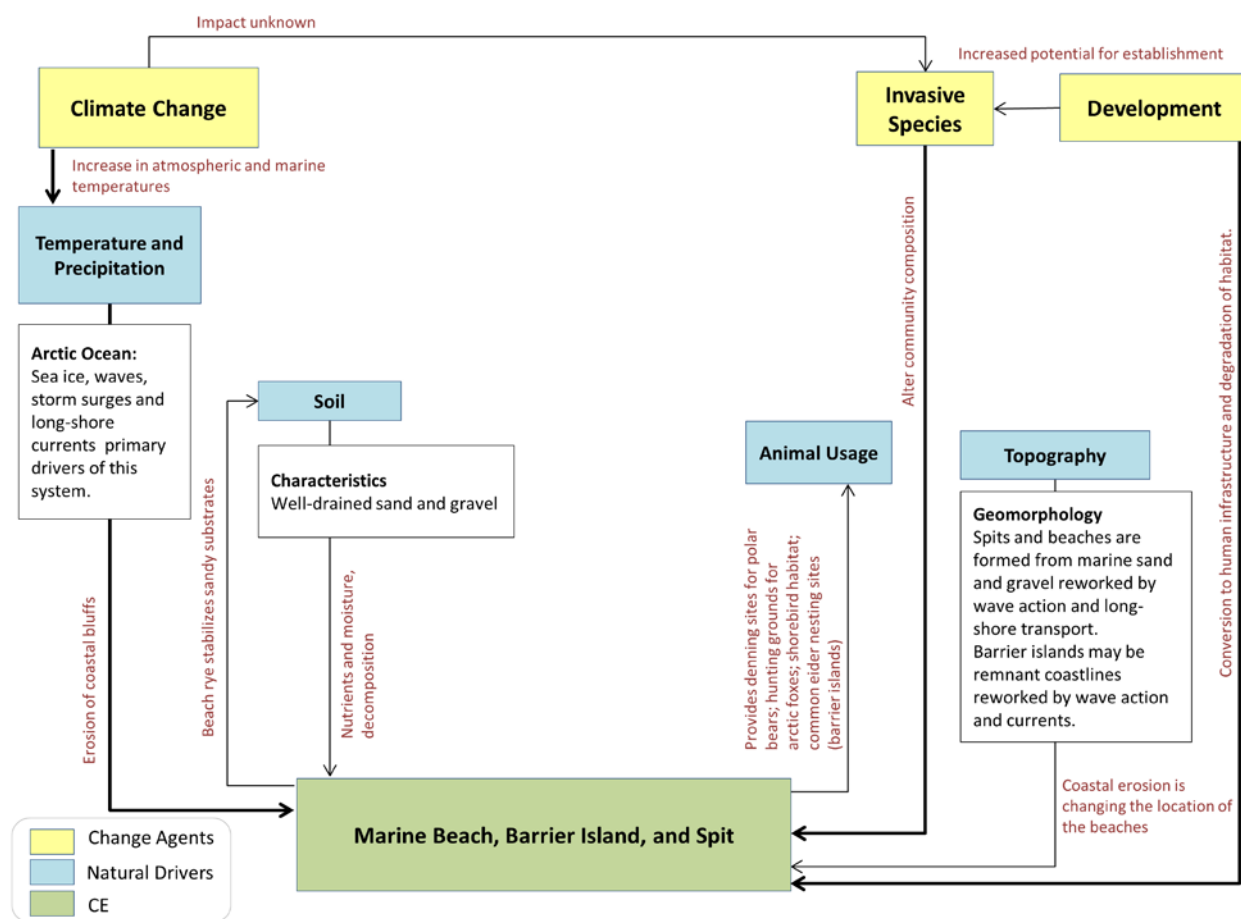


Figure G-46. Conceptual model for marine beach, barrier island, and spit.

9.3. Abiotic Change Agents Analysis

Only 27% of the Marine Beach, Barrier Island and Spit CE is projected to experience significant (with significance indicated by change greater than 1.3 °C, Table G-4) increases in July temperature in the

long-term, while the entire CE is projected to experience significant long-term increase in January (long-term increase of 4.3 °C, Table G-5) and annual (long-term increase of 2.5 °C increase, Table G-5) temperatures. These long-term increases in temperature may degrade permafrost in remnant barrier islands and increase the effects of thermal erosion.

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

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

9.4. Current Status and Future Landscape Condition

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

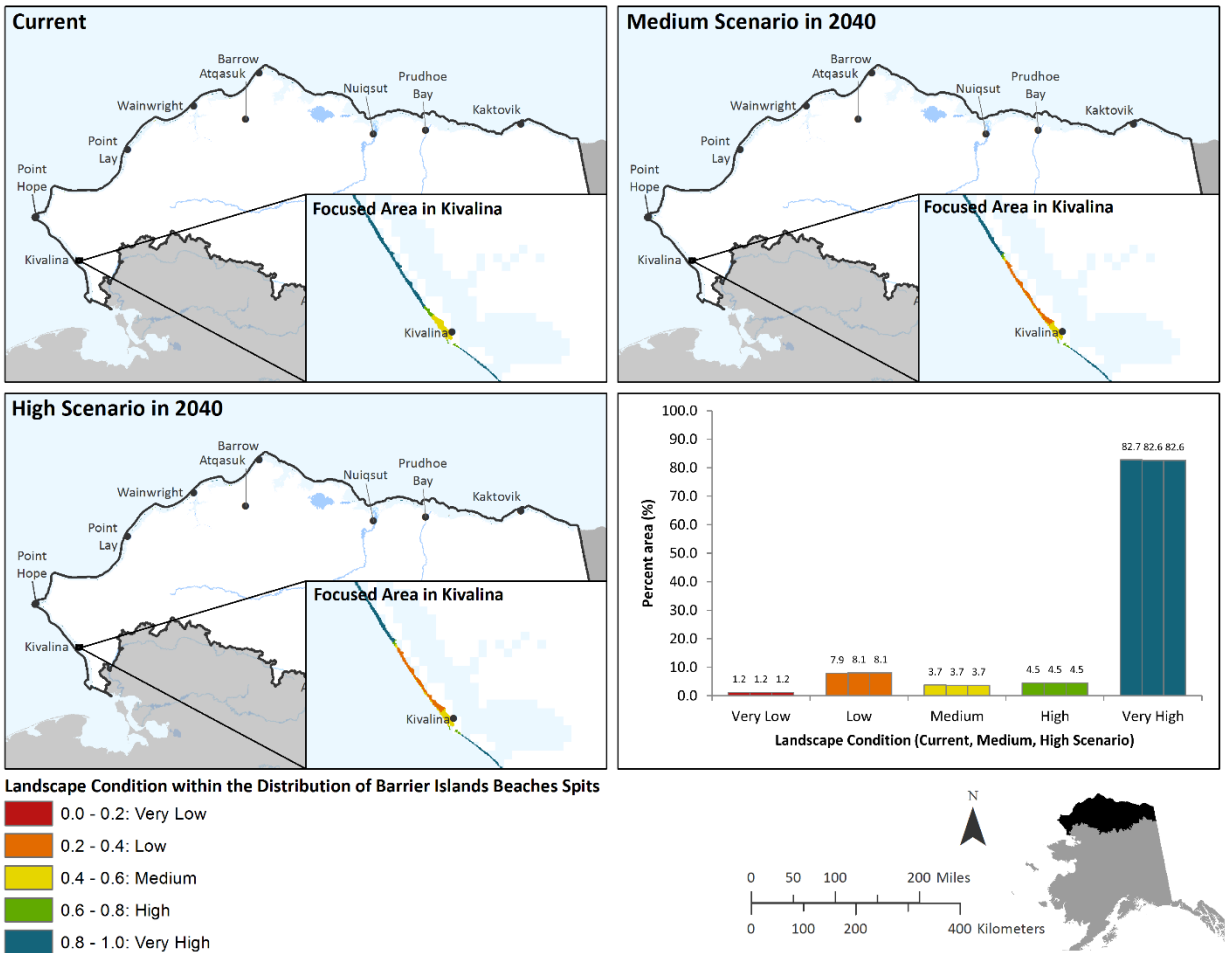


Figure G-47. Landscape condition within the beach, barrier island, and spit CE for the current status and two future development scenarios.

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10. Tidal Marshes

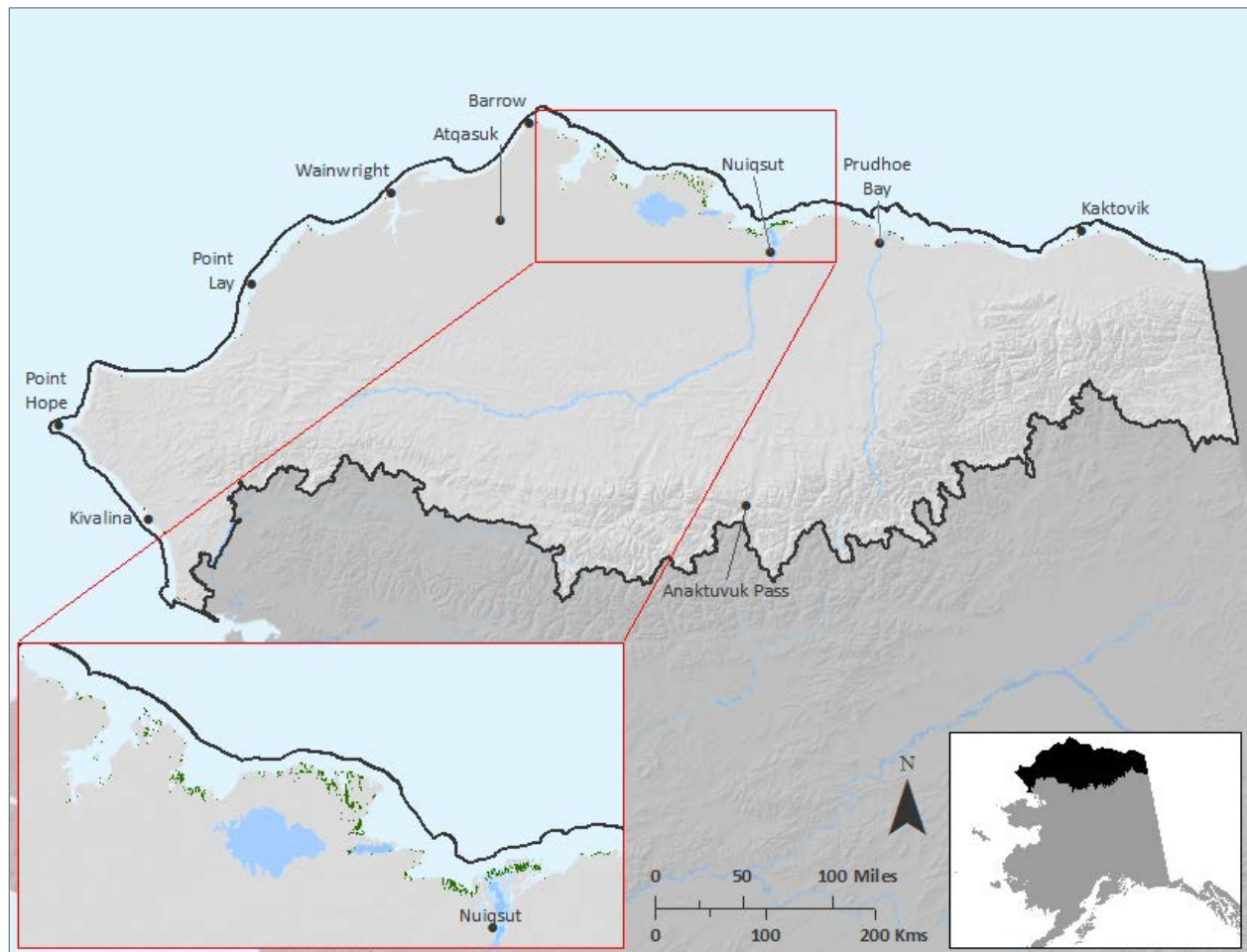


Figure G-48. Current distribution of the tidal marsh CE in the North Slope study area.

10.1. Introduction

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



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

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

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

Due to the periodic reworking of shoreline sediments by storm events, tide marshes along exposed coastlines develop as small (less than 20 m²) mosaics of vegetation with up to 80% cover of bare mud and sand. Unvegetated tidal flats are pioneered by the clonal, halophytic grass *Puccinellia phryganodes* with the halophytic, succulent forbs, *Stellaria humifusa* and *Cochlearia officinalis* colonizing the seaward edge (Jefferies 1977). In contrast, extensive marshes with continuous cover of emergent vegetation may develop in sheltered lagoons and estuaries. Here, the salt-tolerant grasses, *Arctophila fulva* and *Dupontia fisheri*, the forb *Hippuris tetraphylla* and the sedge *Carex ramenskii* are frequent; *C. subspathacea* also occurs but is restricted to areas of secondary erosion (Jefferies 1977).

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

10.2. Conceptual Model

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

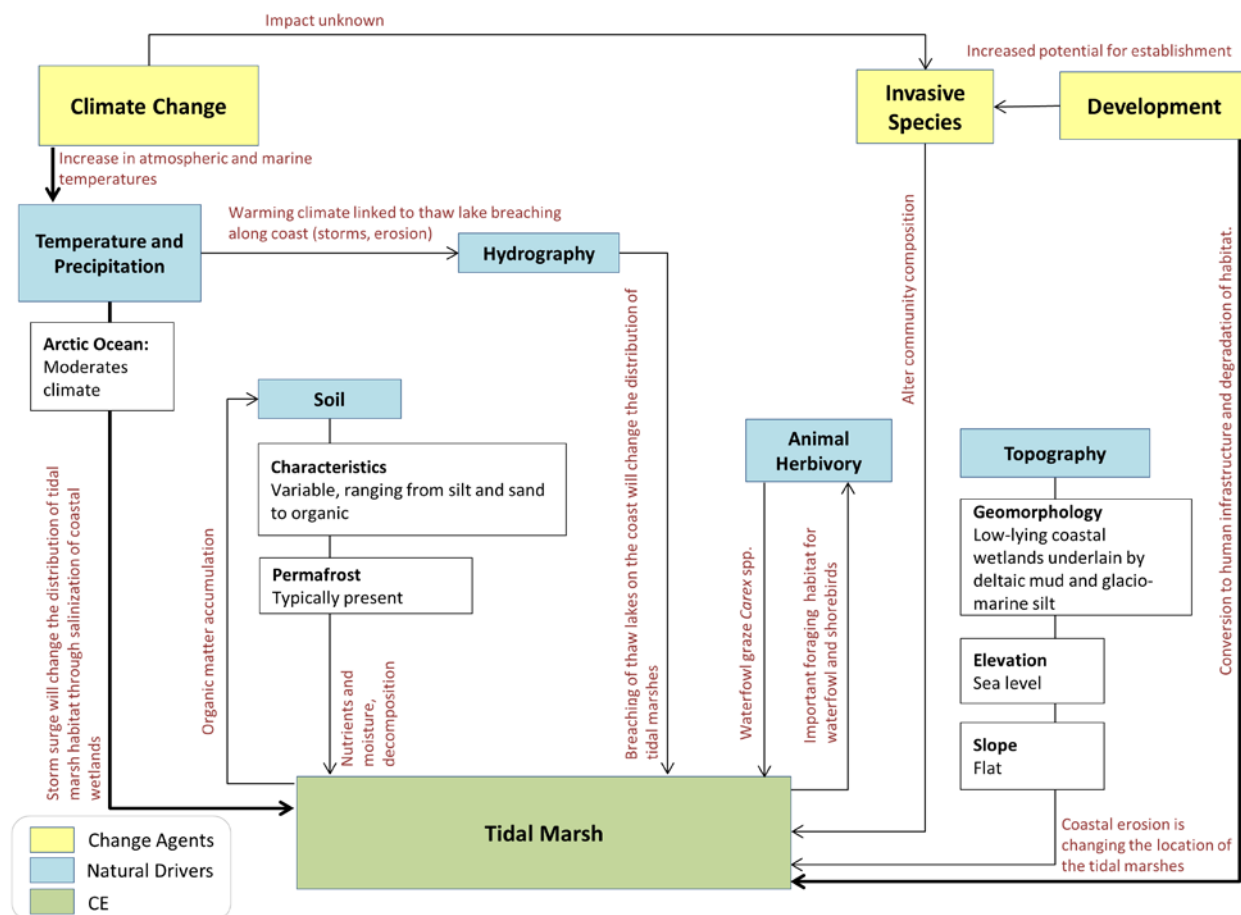


Figure G-50. Conceptual model for tidal marsh.

10.3. Abiotic Change Agents Analysis

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

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

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

10.4. Current Status and Future Landscape Condition

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

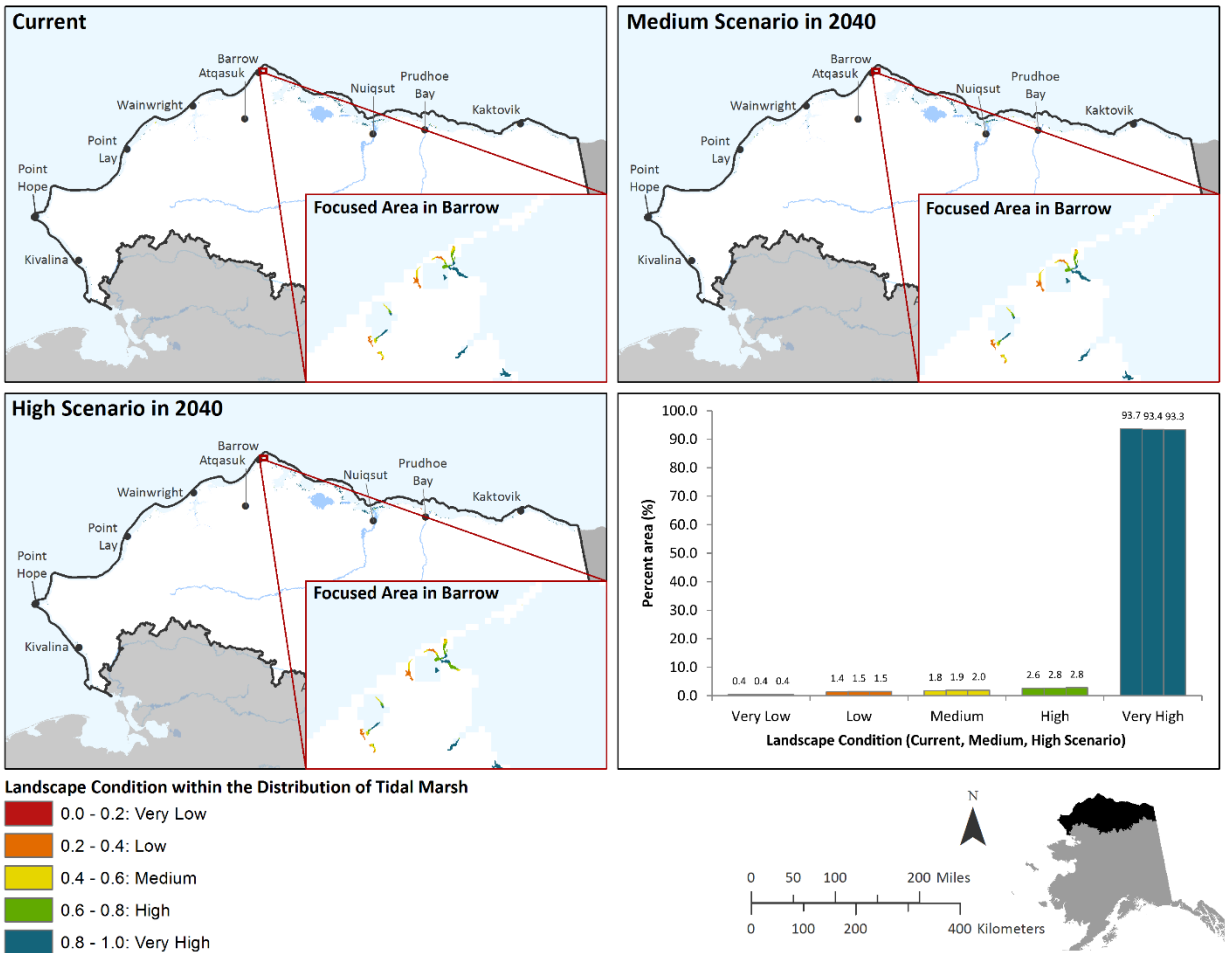


Figure G-51. Landscape condition within the Tidal Marsh CE for the current status and two future development scenarios.

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11. Coastal Erosion and Coastal Salinization

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

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

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

Erosion

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

inlets in barrier island complexes. Coastal erosion, caused by permafrost thaw and subsidence of polygonal tundra, coupled with new sedimentation, and colonization by halophytic vegetation has occurred along some North Slope estuaries, and is believed to be at least partially responsible for redistribution of molting Black Brant from inland lakes to coastal marshes (Tape et al. 2013).

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

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

Salinization

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

11.2. Methods

To answer this question we reviewed current studies and compiled available information documenting coastal erosion and inundation. For study sites at which specific rates of erosion have been defined, we classified erosion rates into four categories: stable or aggrading, slow (0 - 1 m/year), moderate (1 - 2 m/year), and rapid (2+ m/year) in order to present a spatial depiction of erosion rates. Projecting future

rates of salinization of low-lying habitats is more difficult because inundation is a result of several interacting factors including storm surge and timing, presence of sea ice, and permafrost subsidence. We compiled information on the impact to coastal habitats from inundation and salinization, but conducting a spatial analysis of the expected changes is beyond the scope of this assessment.

11.3. Trajectories of Change

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



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

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

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

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

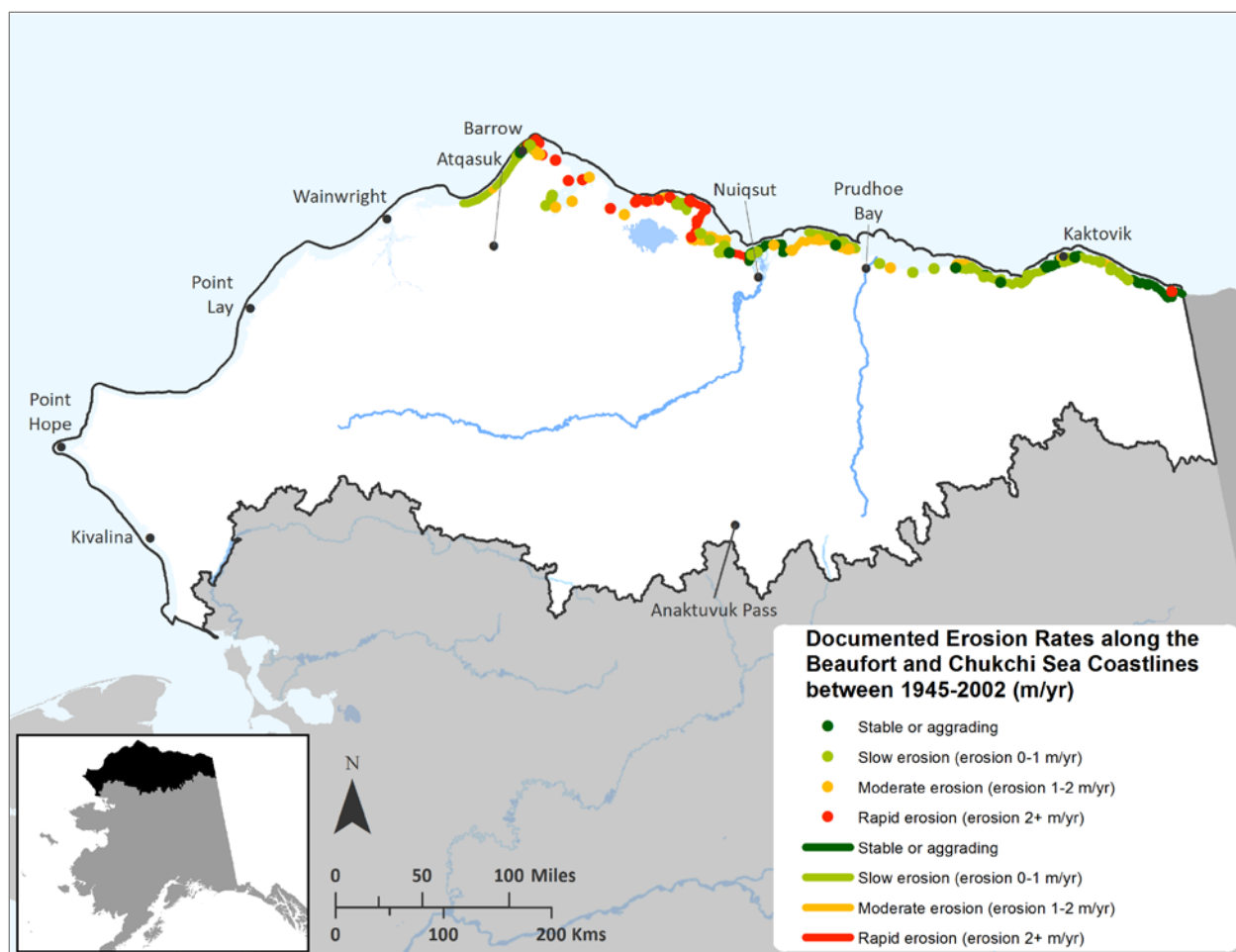


Figure G-53. A compilation of coastal erosion rates documented for the Chukchi and Beaufort Sea coastlines.

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

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

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

Thermokarst and Thermal Erosion

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



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

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

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

Succession Following Salinization

The intact, ice-rich permafrost that underlies the thermokarst lakes and polygonal tundra of the Arctic Coastal Plain becomes a liability to the landforms it supports in a warming climate. Because much of the nearshore environment is less than one meter above sea level, higher storm surges across an already subsiding terrain are expected to extend the reach of saltwater flooding and through increased thermal conductivity of saturated soils, further promote thaw subsidence (Jorgenson et al. 2006, Tape et al. 2013). It is estimated that along coastlines experiencing extreme thaw subsidence and erosion, such as that fronting the Teshekpuk Lake Special Area, salt-killed tundra occupies 6% (71 km²) of the landscape, while 41% (477 km²) is susceptible to salinization from storm surge flooding (Arp et al. 2010, Jones et al. 2008).



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

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

The conversion of freshwater aquatic habitat to brackish lakes and estuaries has not been the subject of extensive study. Salinity has been shown to be elevated in many nearshore lakes, likely due to the

introduction of salts during storm surges. The evaporation of freshwater during the open water season increases salt concentrations in lake systems that are not flushed by freshwater inflow (NSSI 2014). While not documented, the conversion of freshwater lakes to saline waterbodies in the Arctic is likely to alter benthic food webs and energy resources (Arp et al. 2010).

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

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

11.4. Limitations

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

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12. Impacts of Oil and Gas Development on Vegetation

MQ TC 1	What are the impacts of oil/gas development (i.e. gravel pad and road construction; pipeline construction) on vegetation and hydrology? (Known impacts include burial, dust, saline runoff, and altered soil moisture.)
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12.1. Introduction

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

12.2. Methods

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

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

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

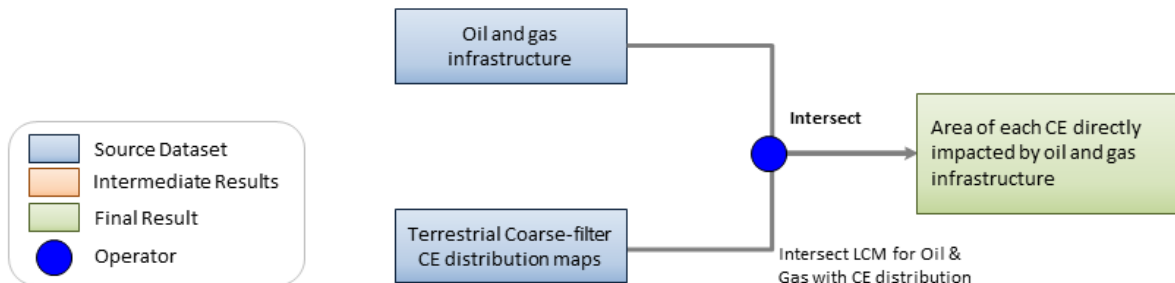


Figure G-56. Process model for MQ TC 1.

12.3. Results

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

Current infrastructure and exploration is largely concentrated in the coastal plain, and this is reflected in the area impacted within the coastal plain wetland and moist tundra CEs. In coastal plain wetlands, 343 km² were scored as *low* or *very low* condition, and in coastal plain moist tundra, 280 km² were similarly classified as impacted (Figure G-58). In contrast, the sand sheet portion of the coastal plain was relatively unimpacted by oil and gas activities with most of the disturbance originating from winter travel corridors. The entire distributions of the sand sheet wetland and moist tundra CEs were scored as *high* or *very high* condition (Figure G-59).

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

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

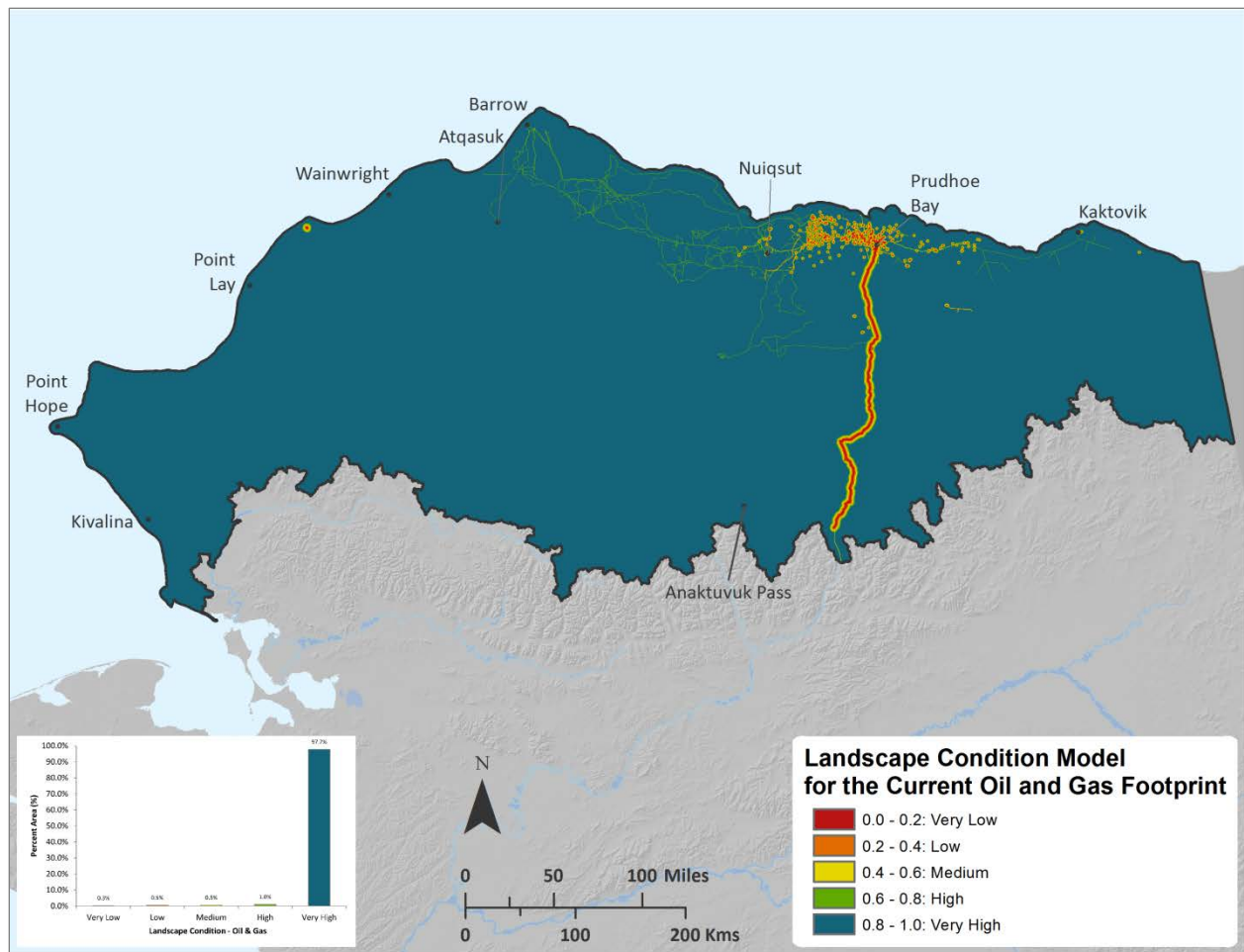


Figure G-57. Landscape condition for the current oil and gas footprint.

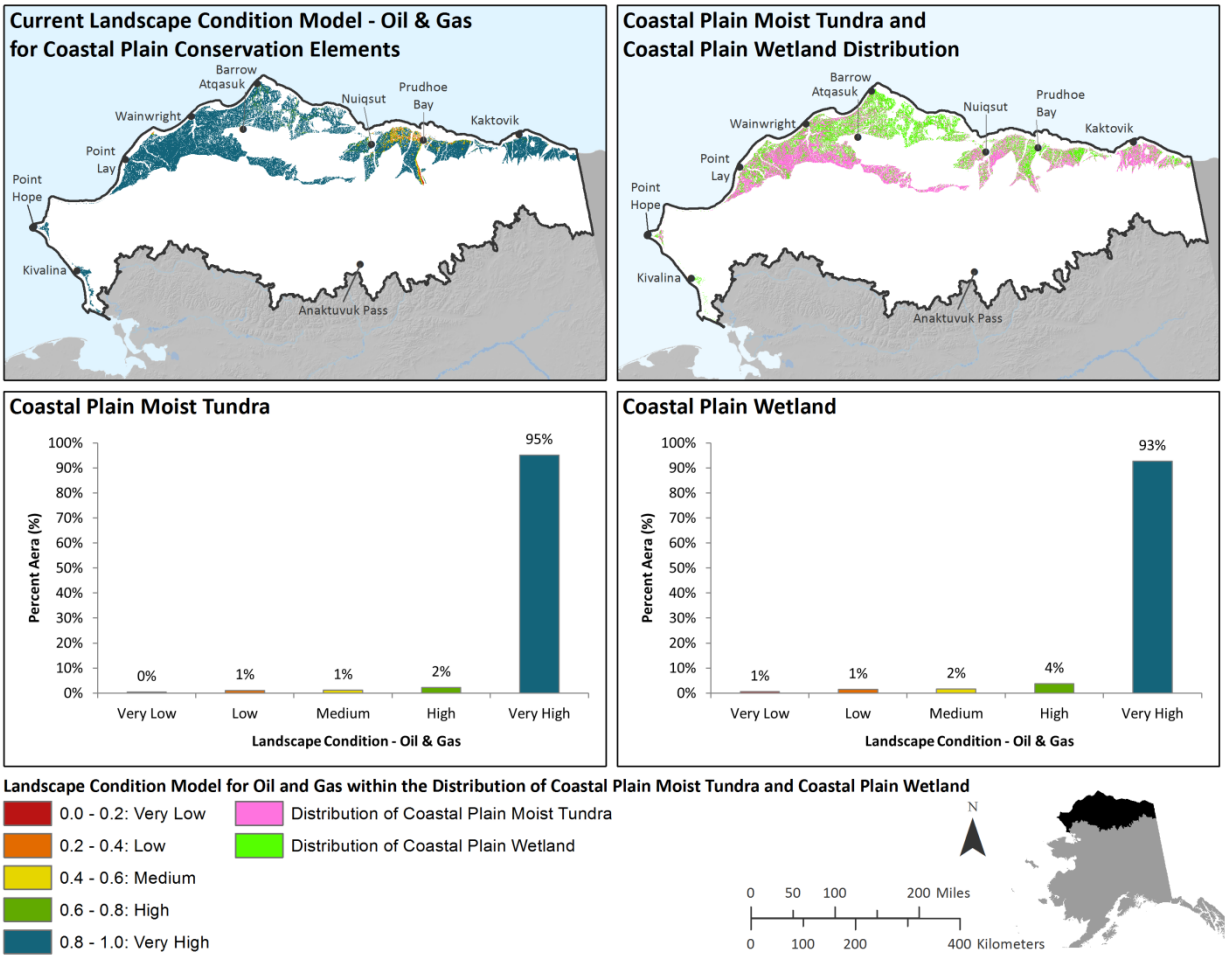


Figure G-58. Landscape condition for the current oil and gas footprint within the distribution of coastal plain wetlands and moist tundra CEs.

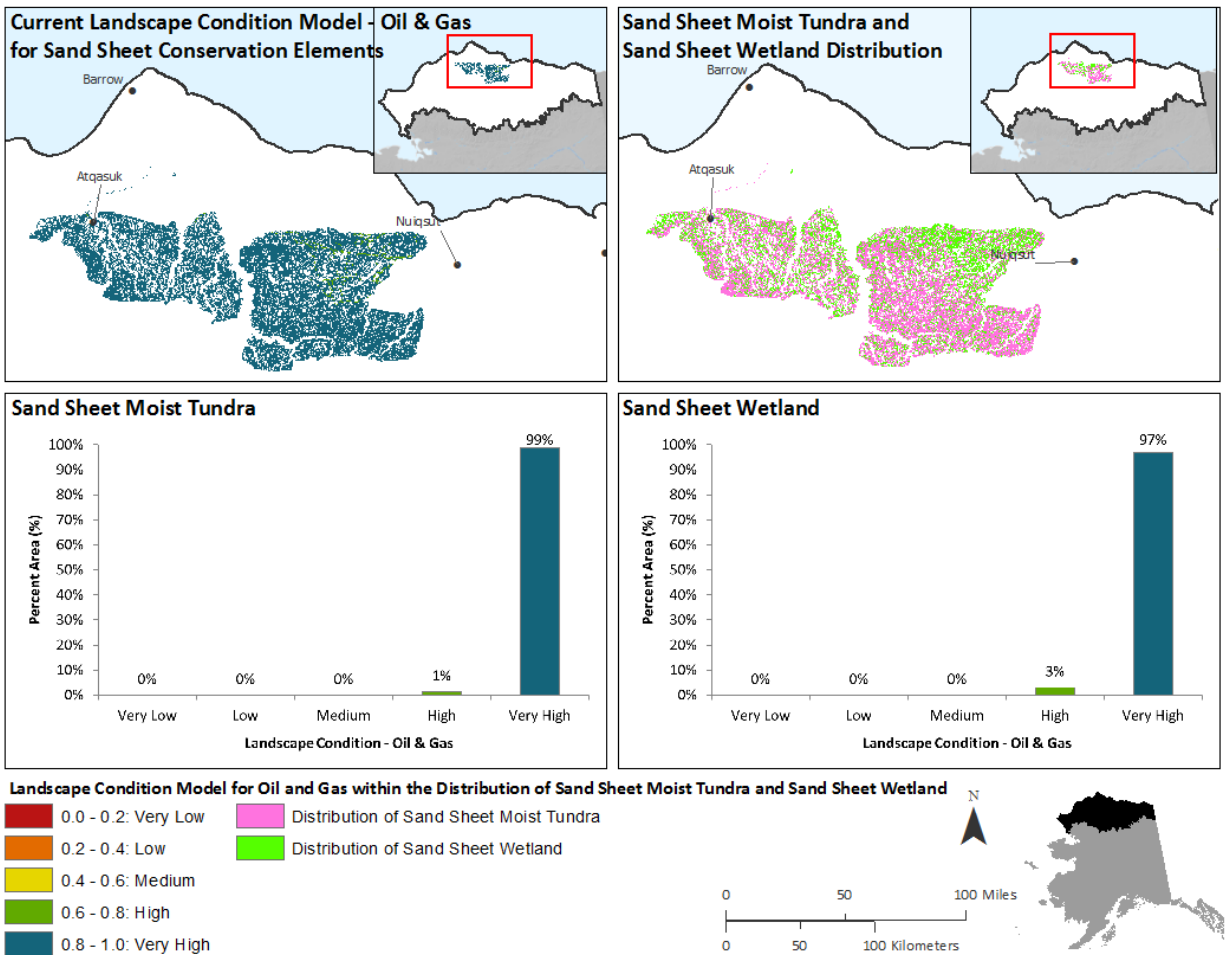


Figure G-59. Landscape condition for the current oil and gas footprint within the distribution of sand sheet wetlands and moist tundra CEs.

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

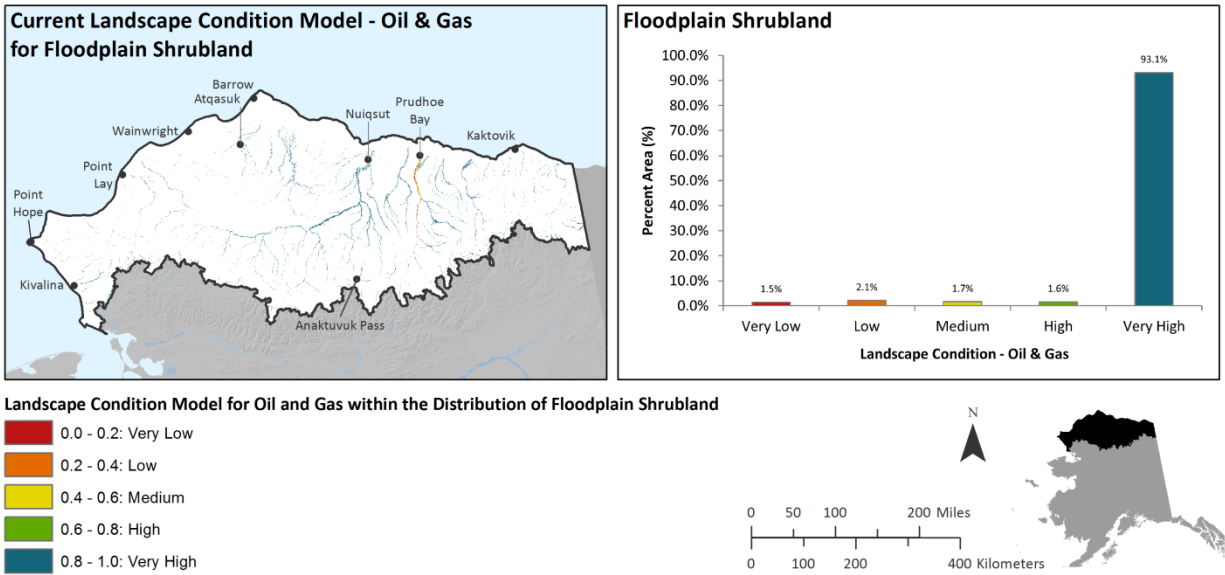


Figure G-60. Landscape condition for the current oil and gas footprint within the distribution of floodplain shrublands.

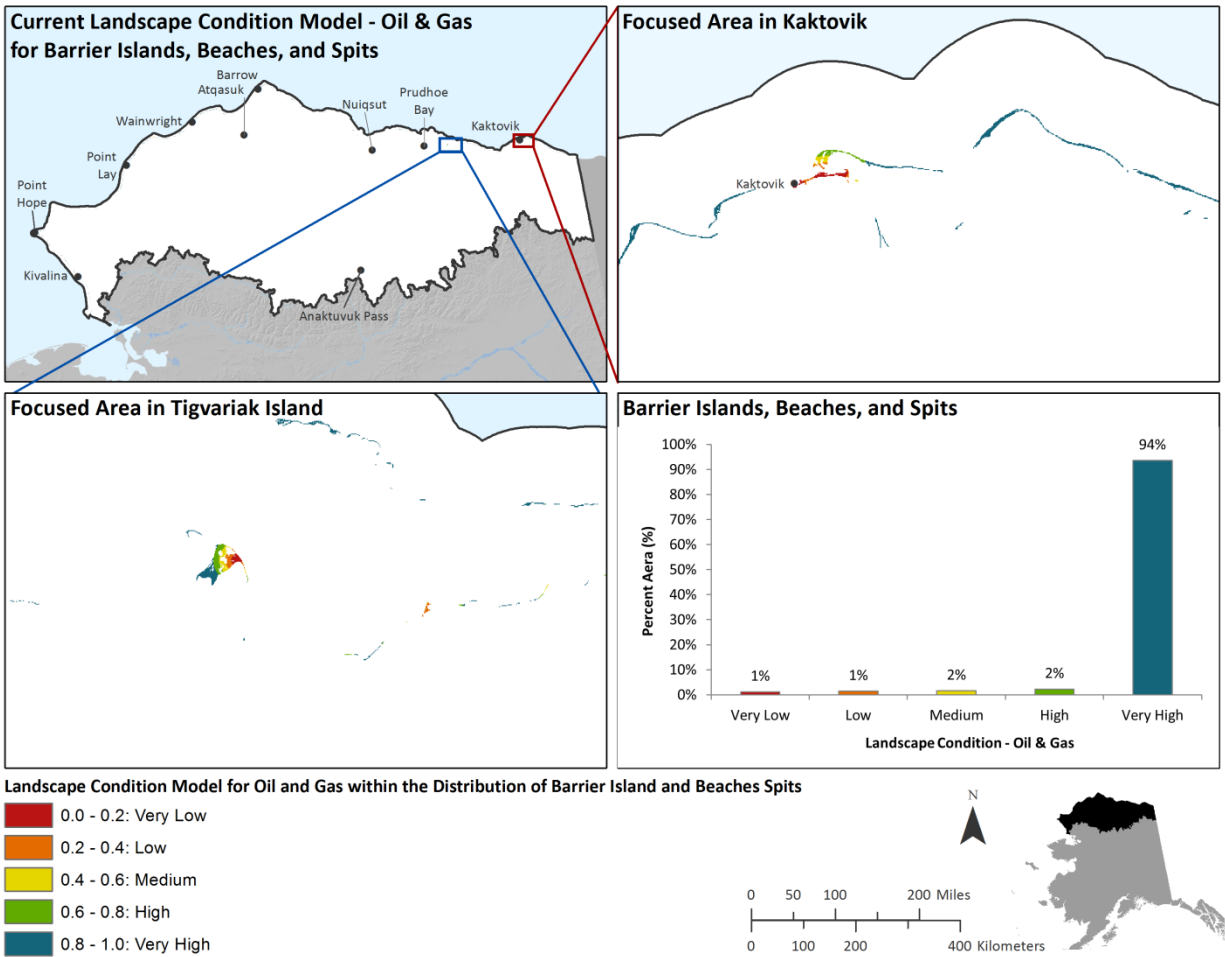


Figure G-61. Landscape condition for the current oil and gas footprint within the distribution of barrier islands, beaches, and spits.

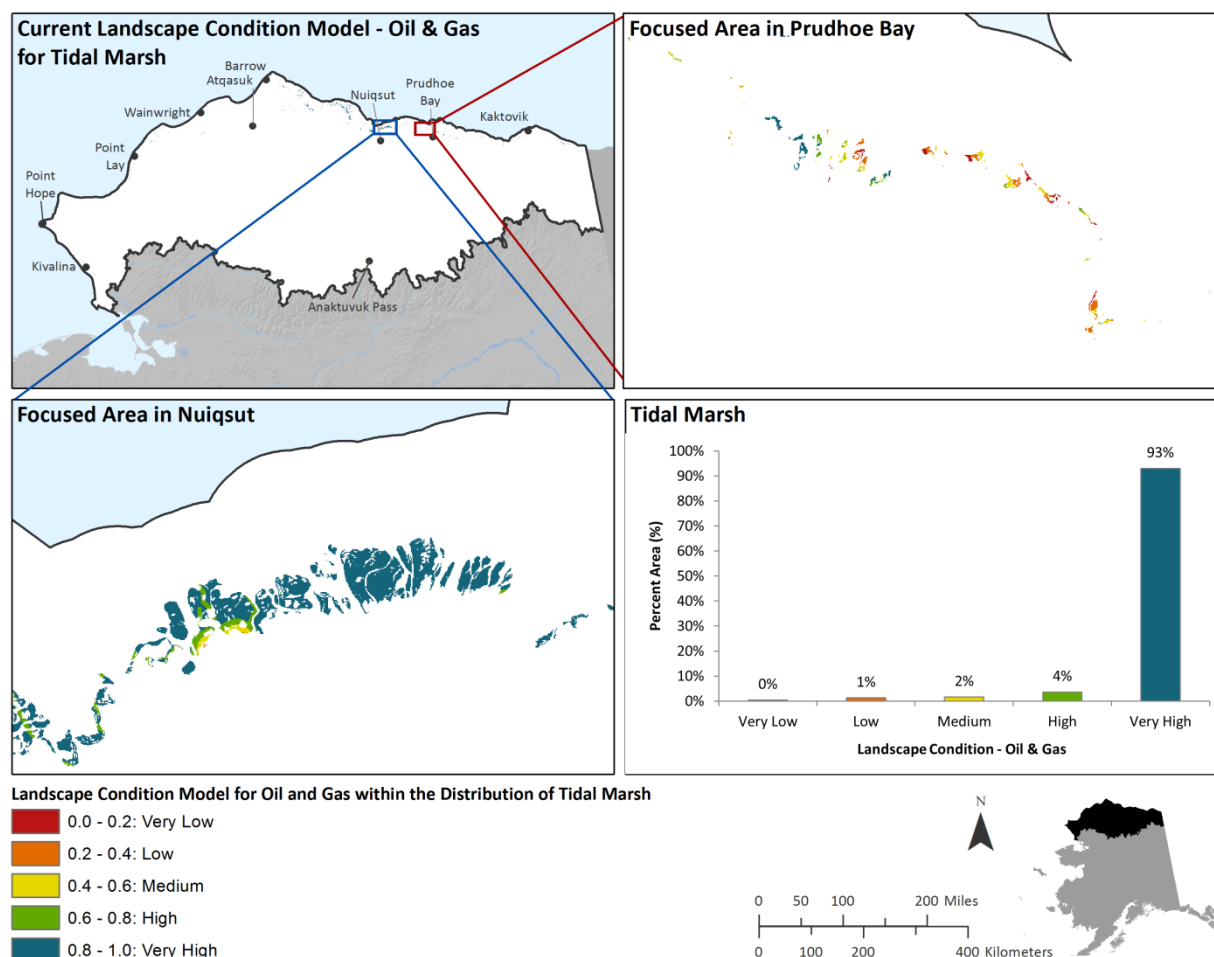


Figure G-62. Landscape condition for the current oil and gas footprint within the distribution of tidal marshes.

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

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

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

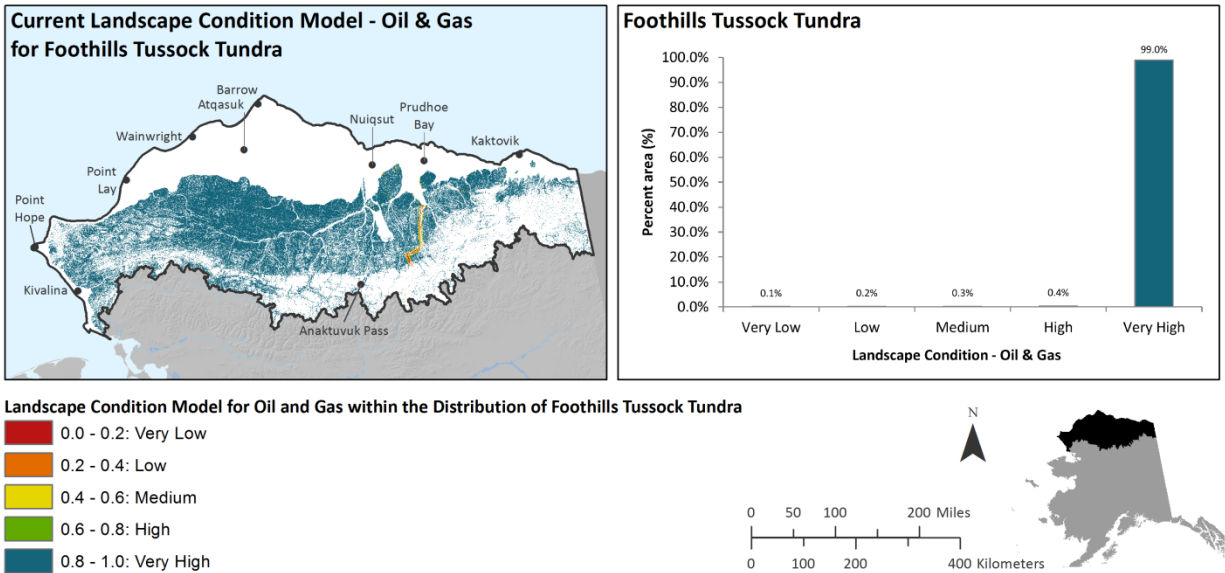


Figure G-63. Landscape condition for the current oil and gas footprint within the distribution of foothills tussock tundra.

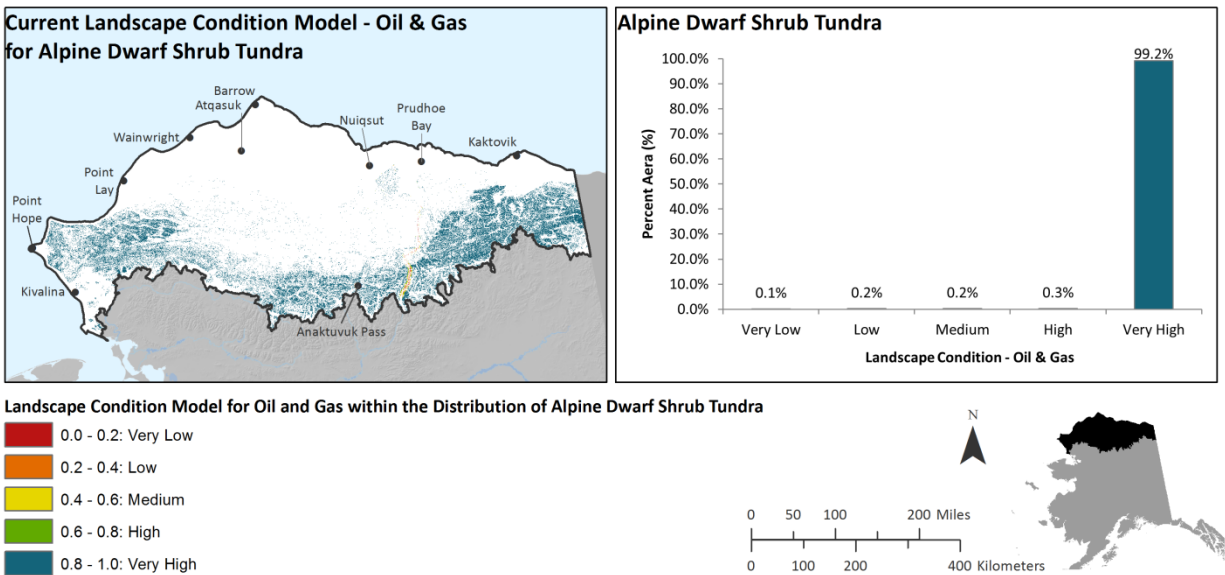


Figure G-64. Landscape condition for the current oil and gas footprint within the distribution of alpine dwarf shrub.

Exploration and Winter Tundra Travel

Oil and gas production industries require off road travel across the tundra in winter for: (1) seismic exploration activity; (2) ice road construction for exploratory drilling; and (3) routine maintenance of infrastructure such as pipelines. Modern exploration techniques and equipment coupled with limitations on the timing of tundra travel have mitigated the most severe impacts on vegetation, active layer, and permafrost characteristics; however, evidence of past practices, such as travel on unfrozen ground or

removal of vegetation during seismic testing, remains visible on the landscape today. Current practices specify minimum snow depths and ground hardness before tundra travel is allowed, but impacts to the vegetation and underlying permafrost can still occur. The footprint created by seismic exploration over the past decades covers a larger geographic area than all other direct human impacts combined (NRC 2003). We did not include the historic seismic exploration lines in the current oil and gas footprint, instead we presented a literature review with reference to impacts to the Terrestrial Coarse-Filter CEs.

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

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

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

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

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

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

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

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

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

Permafrost Subsidence and Thermokarst

Changes to the active layer and permafrost subsidence can have significant and lasting impacts on vegetation and surface water. Ice-rich permafrost has an ice volume that exceeds the total pore space of

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

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

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

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

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

Source: Alaska Permafrost Map (Jorgenson 2008)

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

Long-Term Infrastructure Development

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

Heavy vehicular travel on gravel roads can lead to dust accumulation on the adjacent tundra. Everett (1980) measured dust fall during the summer at several locations along the Dalton Highway and recorded dust loads of over 5 kg/m² at 8 m from the road bed on the downwind side of the highway. Dust loads were higher in the high density road area around Deadhorse. The alkalinity of the road dust was sufficient to neutralize acidic tundra in some areas and the upper few centimeters of soil had shifted from acidic to alkaline (Everett 1980).

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

Spills

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

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

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

Invasive Plant Species Introduction

Disturbance associated with oil and gas exploration and development creates potential pathways for the introduction of non-native plants. Exposed surfaces provide an easily colonized habitat and the movement of people and equipment provides vectors for seed importation. Currently, occurrences of

non-native plants within the REA study area are primarily restricted to the Dalton Highway, however, warming temperatures and new development will increase the chance of invasion in the future (see Section D. Biotic Change Agents).

Impacts on Hydrology

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

Drainage Patterns

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

Gravel Mining

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

Groundwater Contamination

As part of the oil extraction process, fluids (or natural gas) are often injected into existing wells to enhance oil recovery. In enhanced recovery operations, pressure does not fracture surrounding permafrost or rock formations. There has not been any documented damage to the subsurface reservoirs as a result of enhanced recovery; however, there have been several instances of drilling fluid leaking to the surface, either through over-pressurization and escape, or a cracked well casing releasing

fluids near the surface (NRC 2003). Waste fluids are also injected into the ground for permanent disposal. In the case of waste injections, the method involves fracturing the surrounding subsurface features to accommodate the input of liquid waste, which is injected below the impermeable permafrost layer. This method removes the waste fluids from problematic surface pits, which were used in the early years of development, but the contamination of ground water sources is still a potential risk because the method involves fracturing subsurface rock and ice, and the hydrology below the permafrost is poorly understood (NRC 2003). High-volume hydraulic fracturing has not been widely used on the North Slope, but it is considered an option in the Great Bear oil field south of Prudhoe Bay. Small-scale fracturing has long been used in the conventional fields of Prudhoe to release oil from porous sedimentary rocks.

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

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

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Terrestrial Fine-Filter Conservation Elements

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Summary

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

Contents

1. Introduction to Terrestrial Fine-Filter Conservation Elements	1
2. Methods	3
2.1. Distribution Modeling	3
2.2. Conceptual Models	6
2.3. Attributes and Indicators	6
2.4. CE × CA Intersections	7
2.5. Status Assessments	7
2.6. Relative Management Responsibility	9
3. Core Analysis Results	10
3.1. Annual Temperature	10
3.2. Growing Season Length	11
3.3. Precipitation	12
3.4. Fire	14
3.5. Landscape Condition	15
3.6. Distribution on Public and Private Lands	17
3.7. Literature Cited	19
4. Nearctic brown lemming (<i>Lemmus trimucronatus</i>)	20
4.1. Introduction	20
4.2. Conceptual Model	21
4.3. Attributes and Indicators	22
4.4. Distribution Model	24
4.5. Abiotic Change Agents Analysis	24
4.6. Current Status and Future Landscape Condition	31
4.7. Limitations and Data Gaps	32
4.8. Literature Cited	33
5. Arctic fox (<i>Vulpes lagopus</i>)	35
5.1. Introduction	35
5.2. Conceptual Model	36
5.3. Attributes and Indicators	37
5.4. Distribution Model	39

5.5.	Abiotic Change Agents Analysis	39
5.6.	Current Status and Future Landscape Condition	45
5.7.	Limitations and Data Gaps	47
5.8.	Literature Cited	48
6.	Barren Ground Caribou (<i>Rangifer tarandus granti</i>)	50
6.1.	Introduction	50
6.2.	Methods	51
6.3.	Conceptual Model	52
6.4.	Attributes and Indicators	53
6.5.	Seasonal Distribution and Movement Patterns	56
6.6.	Abiotic Change Agents Analysis	65
6.7.	Current Status and Future Landscape Condition	66
6.8.	Harvest and Predation	69
6.9.	Limitations	69
6.10.	Literature Cited	71
7.	Caribou Seasonal Forage	74
7.1.	Introduction	74
7.2.	Methods	78
7.3.	Distribution	79
7.4.	Abiotic Change Agent Analysis	90
7.5.	Limitations	94
7.6.	Literature Cited	96
8.	Lapland longspur (<i>Calcarius lapponicus</i>)	99
8.1.	Introduction	99
8.2.	Conceptual Model	100
8.3.	Attributes and Indicators	101
8.4.	Distribution Model	103
8.5.	Abiotic Change Agents Analysis	103
8.6.	Current Status and Future Landscape Condition	109
8.7.	Limitations and Data Gaps	110
8.8.	Literature Cited	111
9.	Baseline Data for Landbirds	113

9.1.	Introduction	113
9.2.	Methods	113
9.3.	Results	116
9.4.	Limitations	121
9.5.	Literature Cited	122
10.	Willow Ptarmigan (<i>Lagopus lagopus</i>)	123
10.1.	Introduction	123
10.2.	Conceptual Model	124
10.3.	Attributes and Indicators	125
10.4.	Distribution Model	128
10.5.	Abiotic Change Agents Analysis	129
10.6.	Current Status and Future Landscape Condition	134
10.7.	Limitations and Data Gaps	135
10.8.	Literature Cited	136
11.	Greater White-fronted Goose (<i>Anser albifrons</i>)	138
11.1.	Introduction	138
11.2.	Conceptual Model	139
11.3.	Attributes and Indicators	140
11.4.	Distribution Model	143
11.5.	Abiotic Change Agents Analysis	143
11.6.	Current Status and Future Landscape Condition	148
11.7.	Limitations and Data Gaps	150
11.8.	Literature Cited	151
12.	Raptor Concentration Areas	153
12.1.	Introduction	153
12.2.	Conceptual Model	155
12.3.	Attributes and Indicators	156
12.4.	Distribution Model	158
12.5.	Abiotic Change Agents Analysis	159
12.6.	Current Status and Future Landscape Condition	165
12.7.	Limitations and Data Gaps	167
12.8.	Literature Cited	168

Management Questions

MQ TF 4 (Seasonal Distribution and Movement Patterns).....	56
MQ TF 2 (Caribou Seasonal Forage).....	74
MQ TF 1 (Baseline Data for Landbirds).....	113

Tables

Table H-1. Terrestrial Fine-Filter Conservation Elements (CEs), including trophic functional group, and reason for inclusion in the North Slope REA.....	2
Table H-2. Assessment of model accuracy for all Terrestrial Fine-Filter CEs including the total number of occurrence points obtained for the CE, the total number of points used in the accuracy assessment, classification success (CS) values, and model quality summary.	5
Table H-3. List of human modification variables used in the Landscape Condition Model (LCM) for the current scenario (C) and the future (2040) medium (M) and high (H) development scenarios.	8
Table H-4. Predicted change from current (2010s) to the near-term future (2020s) and long-term future (2060s) in mean July temperature, mean January temperature, and mean annual temperature within the distribution of individual Terrestrial Fine-Filter CEs in the North Slope study area.....	11
Table H-5. Predicted change from current (2010s) to the near-term future (2020s) and long-term future (2060s) in length of growing season within the distribution of individual Terrestrial Fine-Filter CEs in the North Slope study area.	12
Table H-6. Predicted change from current (2010s) to the near-term future (2020s) and long-term future (2060s) in annual precipitation, winter precipitation, and spring precipitation in rainwater equivalents within the modeled distribution of individual Terrestrial Fine-Filter CEs.....	14
Table H-7. Percent of Terrestrial Fine-Filter CE modeled distribution area associated with relative landscape condition (very low to very high) for current, future medium scenario (2040) and future high scenario (2040) in the North Slope study area.	16
Table H-8. Percentage of total CE area by land manager in the North Slope study area.	17
Table H-9. Attributes and indicators for the Nearctic brown lemming.....	23
Table H-10. Datasets used for Nearctic brown lemming.....	24
Table H-11. Predicted change over the near-term (2020) and long-term (2060) in abiotic change agent, length of growing season, within the distribution of the Nearctic brown lemming in the North Slope study area.	30
Table H-12. Summary of abiotic change agents used in the assessment for Nearctic brown lemming and projected effects.	31
Table H-13. Attributes and indicators for the Arctic fox.	38

Table H-14. Datasets used for Arctic fox.	39
Table H-15. Predicted change over the near-term (2020) and long-term (2060) in abiotic change agents, mean annual temperature, mean July temperature, and mean January temperature, within the distribution of the Arctic fox in the North Slope study area.....	40
Table H-16. Predicted change over the near-term (2020) and long-term (2060) in abiotic change agents, mean July temperature and length of growing season, within the distribution of the individual Terrestrial Fine-Filter CEs in the North Slope study area.	43
Table H-17. Summary of abiotic change agents used in the assessment for Arctic fox and projected effects.	45
Table H-18. Summary of caribou population size and trend by herd in 2013.....	51
Table H-19. Pre-existing datasets selected for analysis of caribou herd distribution (other datasets were digitized from Griffith et al. 2002 or hand-delineated based on a variety of sources).	52
Table H-20. Attributes and indicators for caribou.....	54
Table H-21. Change in summer, winter, and annual temperature from 2010s to 2060s for caribou calving and summer ranges.	66
Table H-22. Forage quality attributes by season appended to the landcover classes in the North Slope landcover map.	79
Table H-23. Percent of study area occupied by good, moderate, or low quality caribou forage per season.	80
Table H-24. Attributes and indicators for the Lapland longspur.	102
Table H-25. Datasets used for the Lapland longspur.....	103
Table H-26. Predicted change over the near-term (2020) and long-term (2060) in abiotic change agents, mean July temperature and length of growing season, within the distribution of the Lapland longspur in the North Slope study area.	105
Table H-27. Summary of abiotic change agents used in the assessment for Lapland longspur and projected effects.	109
Table H-28. Data sources included in the development of the baseline landbird database for the North Slope REA.	114
Table H-29. Passerine species composition by family (in bold) for all survey data combined for the time period 1948 – 2009. An asterisk* denotes species with fewer than 20 detections.	118
Table H-30. Attributes and indicators for the willow ptarmigan.	126
Table H-31. Datasets used for willow ptarmigan.	129
Table H-32. Predicted change over the near-term (2020) and long-term (2060) in abiotic change agents, mean July temperature and length of growing season, within the distribution of the Lapland longspur within the North Slope study area.....	132

Table H-33. Summary of abiotic CAs used in the core analysis assessment for willow ptarmigan and projected effects.	134
Table H-34. Attributes and indicators for the greater white-fronted goose.....	141
Table H-35. Datasets used for greater white-fronted goose.....	143
Table H-36. Summary of abiotic change agents used in the assessment greater white-fronted goose and projected effects.	148
Table H-37. Attributes and indicators for raptor concentration areas.	157
Table H-38. Datasets used for raptor concentration areas.	158
Table H-39. Summary of abiotic change agents used in the assessment of raptor concentration areas and projected effects.	165

Figures

Figure H-1. Example and explanation of attributes and indicators for willow ptarmigan (<i>Lagopus lagopus</i>).....	7
Figure H-2. Current modeled distribution of Nearctic brown lemming (<i>Lemmus trimucronatus</i>) in the North Slope study area (A) and a Nearctic brown lemming in snow (B).	20
Figure H-3. Conceptual model for the Nearctic brown lemming.	22
Figure H-4. Modeled change in date of freeze (DOF) at current, near-term future (2020s), and long-term future (2060s) time intervals within the current distribution of Nearctic brown lemming.	26
Figure H-5. Seasonal changes in cumulative snowfall (mm rainwater equivalent) for the North Slope study area, summarized by terrestrial sub-region. Note that these data do not account for loss due to thaw or sublimation, and do not predict the depth, compaction, or icing of snow.....	27
Figure H-6. Modeled change in snow day fraction for October and November between current and long-term (2060) time steps within the current distribution of the Nearctic brown lemming.	28
Figure H-7. Estimated current (2010s) and long-term (2060s) shoulder season and winter rainfall by sub-region.	29
Figure H-8. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current distribution of Nearctic brown lemming.....	32
Figure H-9. Current modeled distribution of Arctic fox (<i>Vulpes lagopus</i>) in the North Slope study area (A) and juvenile Arctic fox, photo from Animal Diversity Web (B).....	35
Figure H-10. Conceptual model for Arctic fox (<i>Vulpes lagopus</i>) in the North Slope study area.	37
Figure H-11. Changes in mean annual temperature within the distribution of the Arctic fox.....	40
Figure H-12. Number of neonatal dens of Arctic and red foxes in the Prudhoe Bay area, 2005 – 2013 (adapted from Stickney 2014).	41

Figure H-13. Projected snowfall (mm rainwater equivalent) summarized by three-month period (SON, DJF, MAM) and ecological sub-region.	42
Figure H-14. Projected changes in active layer thickness within the modeled distribution of the Arctic fox (A), and distribution of fox den sites and known occurrences (B).....	44
Figure H-15. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current distribution of Arctic fox in the North Slope study area.	46
Figure H-16. Generalized range maps for the four barren ground caribou herds present in the North Slope study area: Western Arctic Herd, Teshekpuk Herd, Central Arctic Herd, and Porcupine Herd.....	50
Figure H-17. Conceptual model for caribou in the North Slope study area.	53
Figure H-18. Annual distribution of Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds.	56
Figure H-19. Generalized movement patterns of North Slope caribou herds by approximate date range.	57
Figure H-20. Generalized calving distribution of parturient females and calves of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds.....	59
Figure H-21. Generalized summer (post-calving to late summer) distribution of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds.....	61
Figure H-22. Generalized winter distribution of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds.....	63
Figure H-23. Current landscape condition within the current total annual range of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds in the North Slope study area.	68
Figure H-24. 2040 high-development scenario landscape condition within the current total annual range of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds in the North Slope study area.	69
Figure H-25. Conceptual diagram of general caribou foraging preferences by season.	76
Figure H-26. Good and moderate quality caribou forage during calving season within the North Slope study area.	80
Figure H-27. Distribution of wet sedge and wet sedge – <i>Sphagnum</i> on the North Slope.....	81
Figure H-28. Distribution of tussock tundra on the North Slope.....	82
Figure H-29. Distribution of tussock shrub tundra on the North Slope.	83
Figure H-30. Distribution of low – tall willow on the North Slope.	84
Figure H-31. Good and moderate quality caribou forage during summer (late June through early August) within the North Slope study area.....	85
Figure H-32. Distribution of Mesic Sedge-Dwarf Shrub Tundra and the Mesic Herbaceous landcover class on the North Slope.....	86

Figure H-33. Good and moderate quality caribou forage during winter within the North Slope study area.	87
Figure H-34. Distribution of birch ericaceous low shrub on the North Slope.	88
Figure H-35. Distribution of dwarf shrub – <i>Dryas</i> and dwarf shrub – other on the North Slope.	89
Figure H-36. Distribution of the sparsely vegetated landcover class on the North Slope.	90
Figure H-37. Change in date of thaw from 2010s to 2060s within caribou calving habitat for the Western Arctic, Teshekpuk, Central Arctic, and Porcupine herds.	91
Figure H-38. Change in length of growing season from 2010s to 2060s for Western Arctic, Teshekpuk, Central Arctic, and Porcupine herds.	92
Figure H-39. Current modeled distribution of Lapland longspur (<i>Calcarius lapponicus</i>) in the North Slope study area (A) and Lapland longspur male and female at nest (B).	99
Figure H-40. Conceptual model for the Lapland longspur.	101
Figure H-41. Modeled decrease in date of thaw (DOT) between 2010s and 2060s within the current distribution of the Lapland longspur.	105
Figure H-42. Predicted change in length of growing season from 2010s to 2060s within the modeled distribution of the Lapland longspur.	106
Figure H-43. Projected vegetation change (based on ALFRESCO modelling) by ecological sub-region in the North Slope study area.	108
Figure H-44. Current, medium-development scenario, and high-development scenario landscape condition within the current distribution of Lapland longspur in the North Slope study area.	110
Figure H-45. Process model for MQ TF 1.	114
Figure H-46. Location of baseline passerine survey data for the time period 1948-2009. This dataset includes 14,508 occurrence records for 59 passerine species from 40 unique data sources.	117
Figure H-47. Species composition and number of detections by species for all survey locations combined, 1948 – 2009.	119
Figure H-48. NSSI landcover class summary at avian occurrence locations.	120
Figure H-49. Current modeled distribution of willow ptarmigan (<i>Lagopus lagopus</i>) in the North Slope study area (A) and willow ptarmigan (B).	123
Figure H-50. Conceptual model for the willow ptarmigan.	125
Figure H-51. Distribution of occurrence records for the willow ptarmigan in the North Slope study area.	128
Figure H-52. Modeled change in May temperature (A) and date of thaw (B) from the 2010s to the 2060s within the current distribution of the willow ptarmigan.	130
Figure H-53. Modeled change in June precipitation from the 2010s to the 2060s within the current distribution of the willow ptarmigan.	131

Figure H-54. Projected long-term (2060) change in shrub tundra by ecological sub-region (adapted from Fresco et al. 2014, this study).	133
Figure H-55. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current distribution of Willow Ptarmigan in the North Slope study area.	135
Figure H-56. Current modeled distribution of greater white-fronted goose (<i>Anser albifrons</i>) in the North Slope study area from density estimates provided by Platte, unpubl. data (A) and greater white-fronted goose (B).	138
Figure H-57. Conceptual model for greater white-fronted goose.....	140
Figure H-58. Current, near-term future, and long-term future (left to right bars within clusters, respectively) date of thaw within the current modeled distribution of the greater white-fronted goose.	144
Figure H-59. Change in summer temperature (JJA) within the current modeled distribution of the greater white-fronted goose.	145
Figure H-60. Change in precipitation (mm) within the current modeled distribution of the greater white-fronted goose at current (left bars), near-term (2020; center bars), and long-term (2060; right bars) time steps.....	146
Figure H-61. Distribution of greater white-fronted goose intersected with modeled distribution of thermokarst predisposition in the North Slope study area.	147
Figure H-62. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current distribution of greater white-fronted goose in the North Slope study area.	149
Figure H-63. Documented occurrences for peregrine falcon, gyrfalcon, and rough-legged hawk in the North Slope study area.	153
Figure H-64. Conceptual model for raptor concentration areas.	155
Figure H-65. Current distribution of raptor concentration areas in the North Slope study area.	159
Figure H-66. Changes in mean summer (June, July, and August) temperature (2010s to 2060s) within the modeled raptor concentration area in the North Slope study area.	161
Figure H-67. Length of growing season at current, near-term future (2020s), and long-term future (2060s) time intervals within the modeled raptor concentration area in the North Slope study area. ..	162
Figure H-68. Spring precipitation (March, April, and May) in mm within the modeled distribution of raptor concentration areas.	163
Figure H-69. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current raptor concentration areas in the North Slope study area.	166

1. Introduction to Terrestrial Fine-Filter Conservation Elements

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

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

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

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

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

2. Methods

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

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

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

For each Terrestrial Fine-Filter CE we:

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

2.1. Distribution Modeling

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

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

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

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

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

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

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

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

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

2.2. Conceptual Models

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

2.3. Attributes and Indicators

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

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

The CA driving the associated key attribute		A measurable aspect of the key attribute that can be used in analysis		Thresholds associated with the indicator that allow us to quantify the level of impact on a CE using 4 distinct categories			
A factor that affects the survival and long-term viability of a CE		A brief description of interaction between key attribute and CE					
CA or Driver	Ecological Attribute	Indicator (unit of measure)	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Anthropogenic	Habitat quality / reproductive success ²⁶	Landscape condition model	Risk of predation by raven and red fox increases within 5 km of infrastructure.	< 5km	5 - 7 km	> 7 km from	> 10 km

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

2.4. CE × CA Intersections

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

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

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

2.5. Status Assessments

The overall “status” of each CE was assessed by intersecting the CE-specific distribution model with the Landscape Condition Model (LCM) at current (2010) and future (2040) time steps. The LCM is a measurement of the impact of the human footprint on a landscape. The LCM categorizes human

modifications into different levels of impact (site impact score), based on the current state of knowledge about the impacts of specific human land uses (see Section F. Landscape and Ecological Integrity).

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

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

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

2.6. Relative Management Responsibility

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

3. Core Analysis Results

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

3.1. Annual Temperature

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

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

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

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

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

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

3.2. Growing Season Length

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

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

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

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

3.3. Precipitation

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

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

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

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

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

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

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

3.4. Fire

Due to lack of adequate fire frequency and fire return interval data layers at the appropriate spatial scale, we did not intersect the distribution of the Terrestrial Fine-Filter CEs with any fire-related datasets. Instead, we relied heavily on descriptions from the results of the CA Fire Section of this report and quantitative accounts from the literature to describe the expected effects of changes in wildfire on wildlife habitats. We also made correlative inferences about vegetation change affects and their impacts on wildlife based on results of the ALRESCO model. Because ALFRESCO models vegetation succession

both with and without fire events, it offers a perspective on climate-driven landscape-level change. Overall, wildfire is expected to become a more frequent driver of change in wildlife habitats in the North Slope study area, although it will remain rare except south of the crest of the Brooks Range. ALFRESCO predicts increased fire frequency in the foothills and Brooks Range sub-regions. Fire is likely to remain absent – or almost absent – from the coastal plain sub-regions. Even with increased fire frequency, the area burned is expected to remain relatively low. Implications for wildlife are varied, and include increased productivity of early successional vegetation, and changes in forage quantity and quality (e.g., reduced lichen abundance in caribou winter range south of the North Slope study area). When applicable, the ramifications of fire are discussed within the individual Terrestrial Fine-Filter CE sections that follow.

3.5. Landscape Condition

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

Most of the North Slope study area is considered relatively pristine (very high condition), with intense impacts being more localized (see Section F. Landscape and Ecological Integrity). When the current distribution of the Terrestrial Fine-Filter CEs was compared to the LCM at current, medium development, and high development, over 96% of predicted habitat for all CEs, except greater white-fronted goose, was considered in very high condition (Table H-7). During the nesting period, greater

white-fronted geese have a foraging range of 3-10km and contaminant leaks within the nest vicinity could have a negative effect on individual health and reproductive success (Schoen and Senner 2002). Therefore, distance decay values for greater white-fronted goose in relation to oil and gas activities were higher (10,000 m) than any other CE. Even with this large buffer for oil- and gas-related disturbance, over 81% of predicted habitat for this species was considered in very high condition for all scenarios (Table H-7).

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

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

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

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

3.6. Distribution on Public and Private Lands

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

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

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

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

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

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

3.7. Literature Cited

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4. Nearctic brown lemming (*Lemmus trimucronatus*)

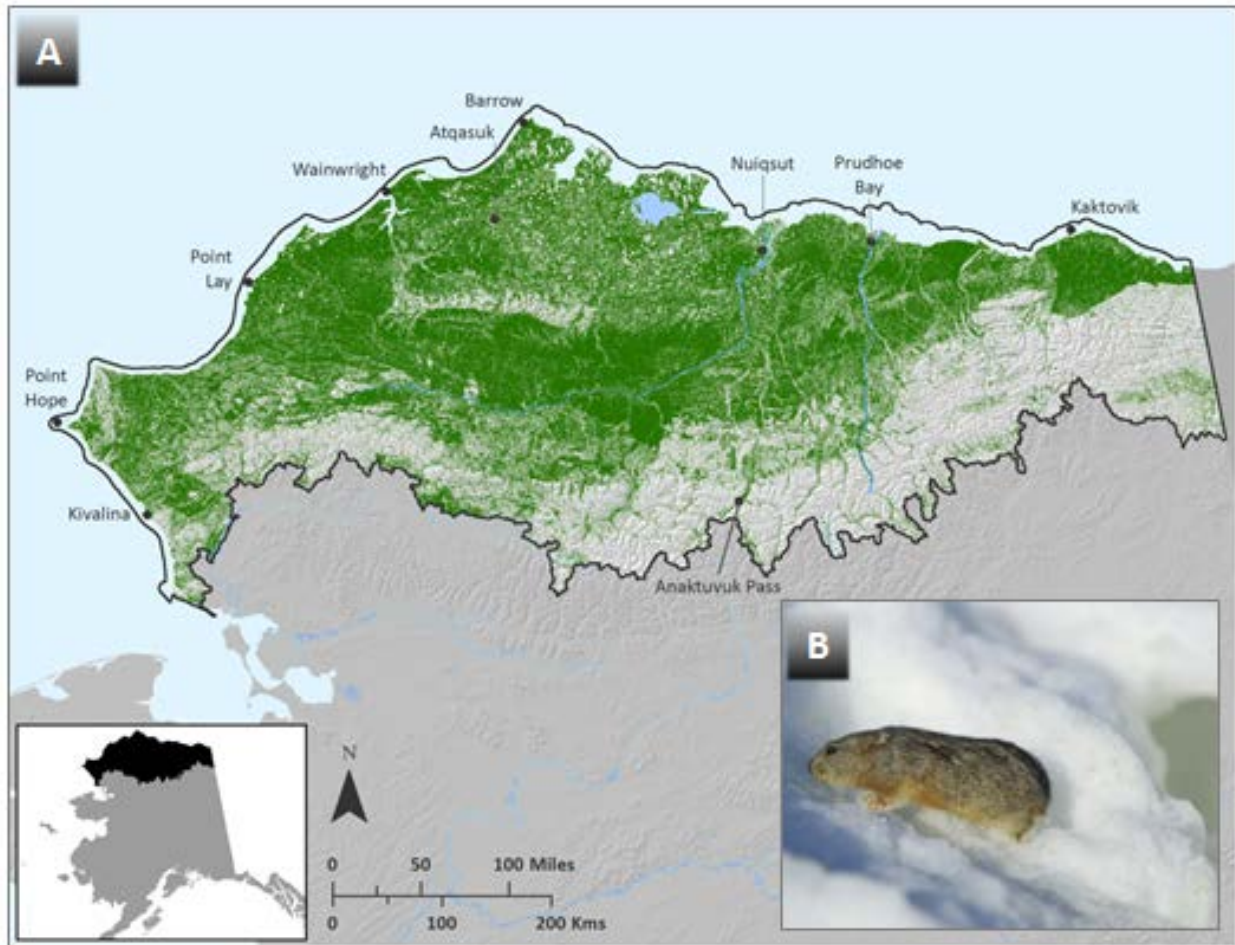


Figure H-2. Current modeled distribution of Nearctic brown lemming (*Lemmus trimucronatus*) in the North Slope study area (A) and a Nearctic brown lemming in snow (B).

4.1. Introduction

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

from satellite images (Olofsson et al. 2012). Changes in lemming abundance may dramatically alter the composition of tundra food webs, and the productivity of numerous other birds and mammals, from year to year (e.g., Angerbjörn et al. 1999, Gilg et al. 2009, Robinson et al. 2014).

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

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

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

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

4.2. Conceptual Model

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

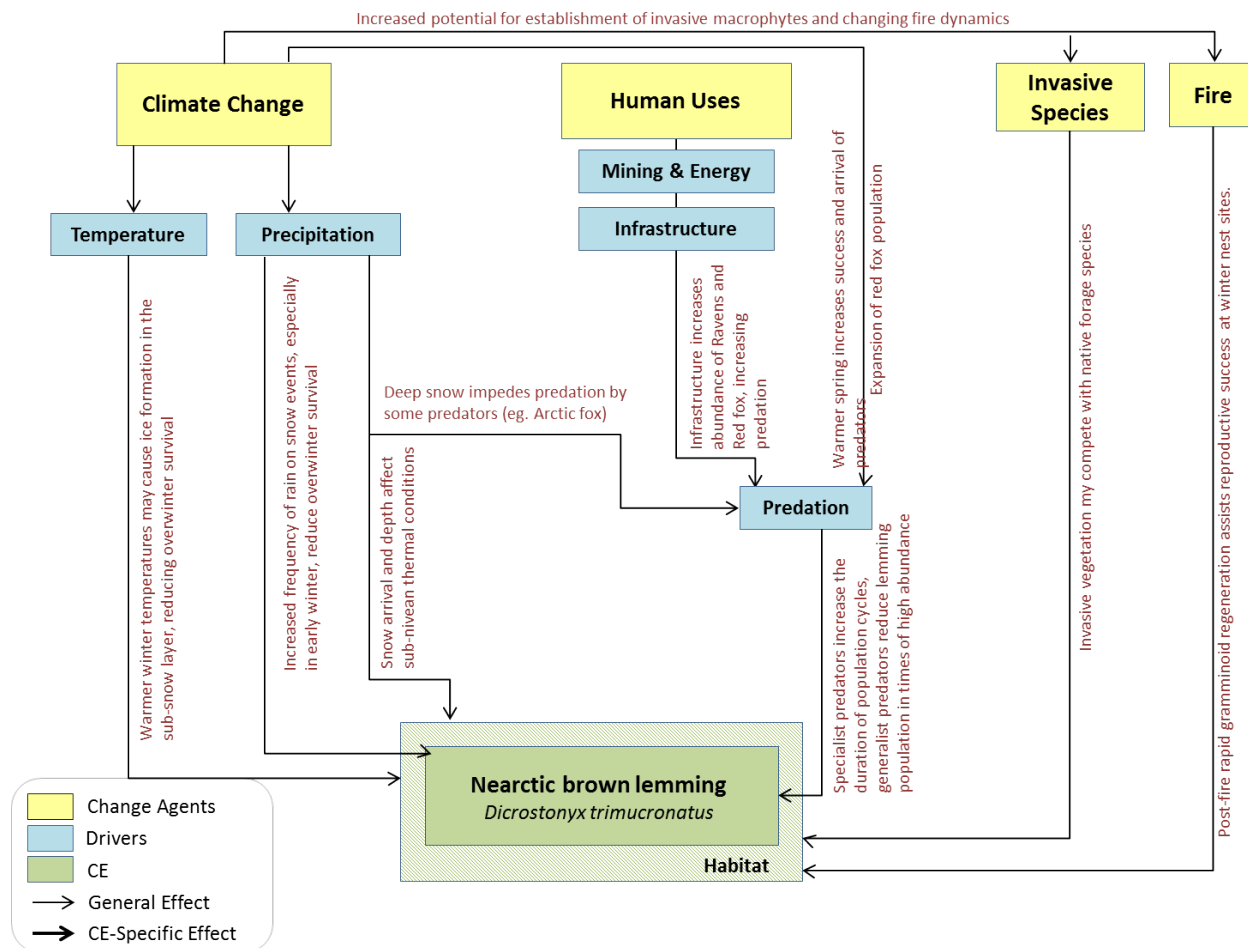


Figure H-3. Conceptual model for the Nearctic brown lemming.

4.3. Attributes and Indicators

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

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

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

¹ Based on Duchesne et al. 2011, Reid et al. 2011, and McLennan et al. 2012.

² Based on McLennan et al. 2012.

³ Based on Duchesne et al. 2011, Hansen et al. 2011, Reid et al. 2011, and McLennan et al. 2012.

⁴ Based on Martin 2012.

⁵ Based on Pitelka et al. 1955, Cannings and Hammerson 2004, and Liebezeit et al. 2009.

4.4. Distribution Model

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

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

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

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

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

4.5. Abiotic Change Agents Analysis

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

Snow Volume, Date of Freeze, and Snow Day Fraction

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

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

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

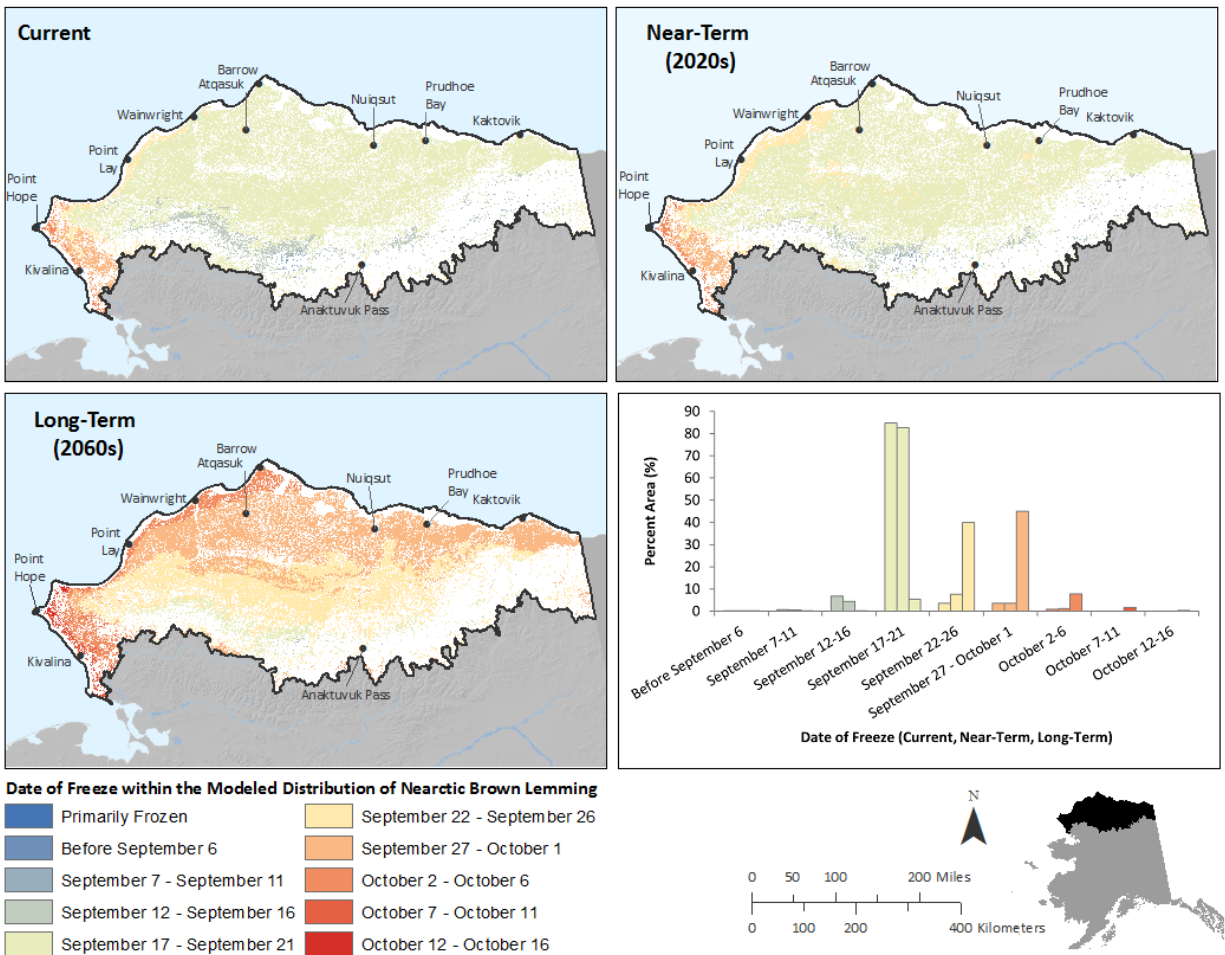


Figure H-4. Modeled change in date of freeze (DOF) at current, near-term future (2020s), and long-term future (2060s) time intervals within the current distribution of Nearctic brown lemming.

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

Modeling snow depth and condition is extremely complicated because it requires estimating not only cumulative snowfall, but also effects such as drifting, compaction, thaw, sublimation, and icing. Thus, we lacked a comprehensive spatial layer representing total snow depth to allow a direct comparison between snow depth and lemming distribution. However, we were able to examine estimated snowfall (precipitation x snow day fraction) both on a monthly basis and cumulatively, across the winter season (Figure H-5). Results suggest that while total snow volume is expected to increase by 2060 during the

autumn and winter months across the North Slope study area, there will likely be net losses to snow volume in late winter and spring in some sub-regions, particularly on the Arctic coast.

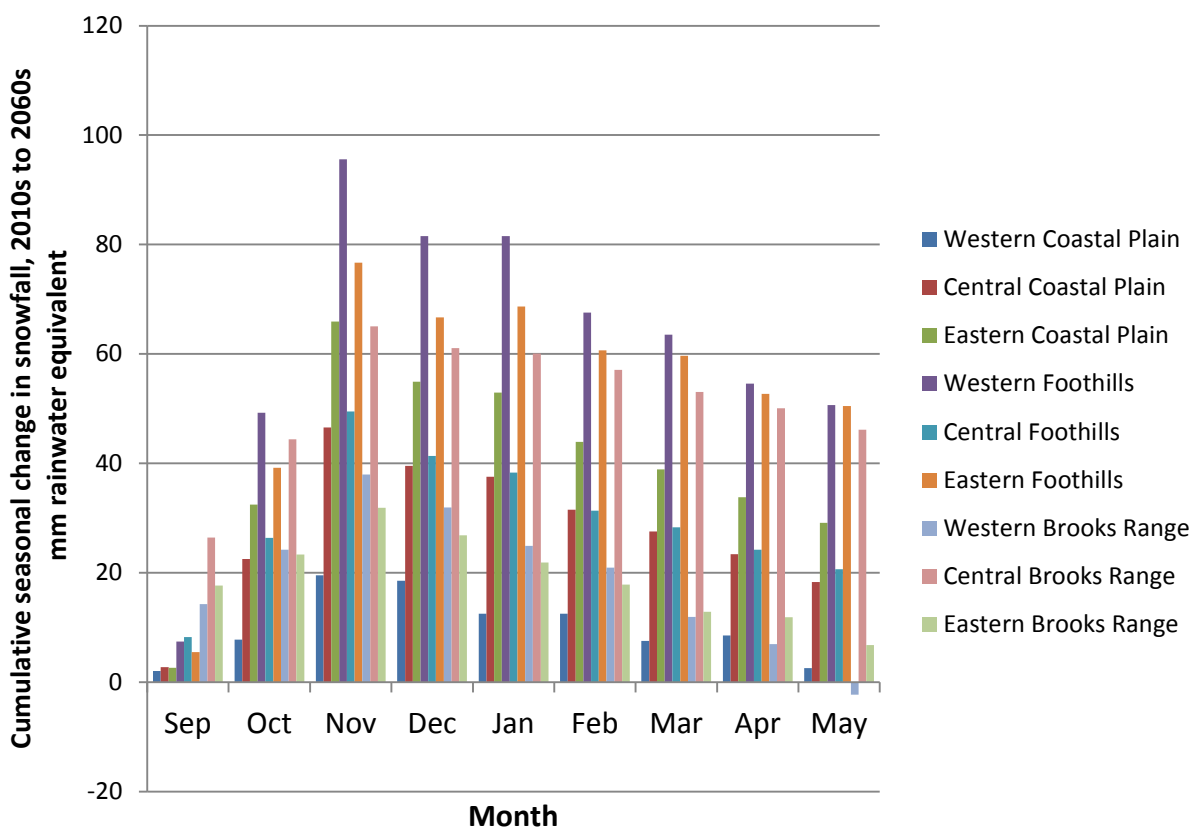


Figure H-5. Seasonal changes in cumulative snowfall (mm rainwater equivalent) for the North Slope study area, summarized by terrestrial sub-region. Note that these data do not account for loss due to thaw or sublimation, and do not predict the depth, compaction, or icing of snow.

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

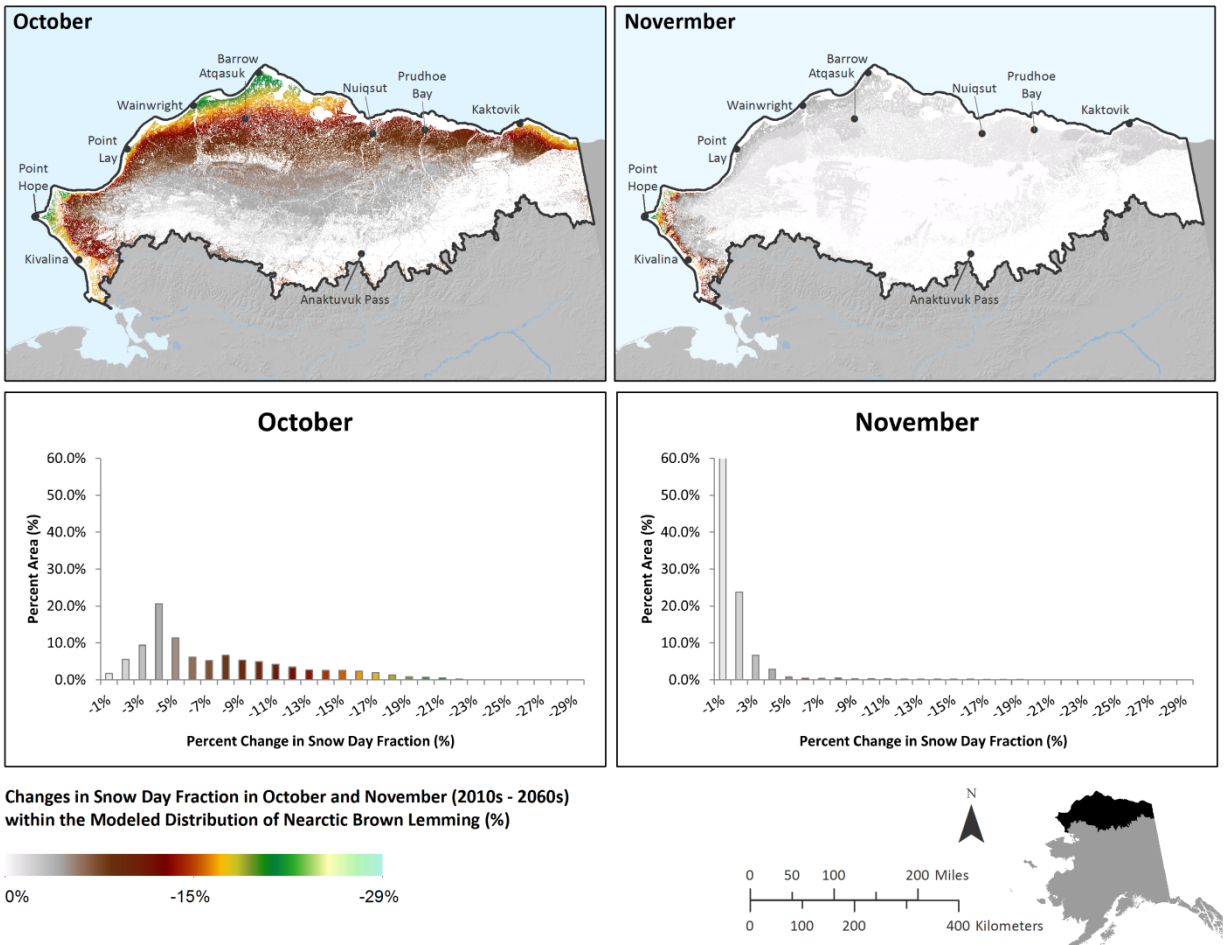


Figure H-6. Modeled change in snow day fraction for October and November between current and long-term (2060) time steps within the current distribution of the Nearctic brown lemming.

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

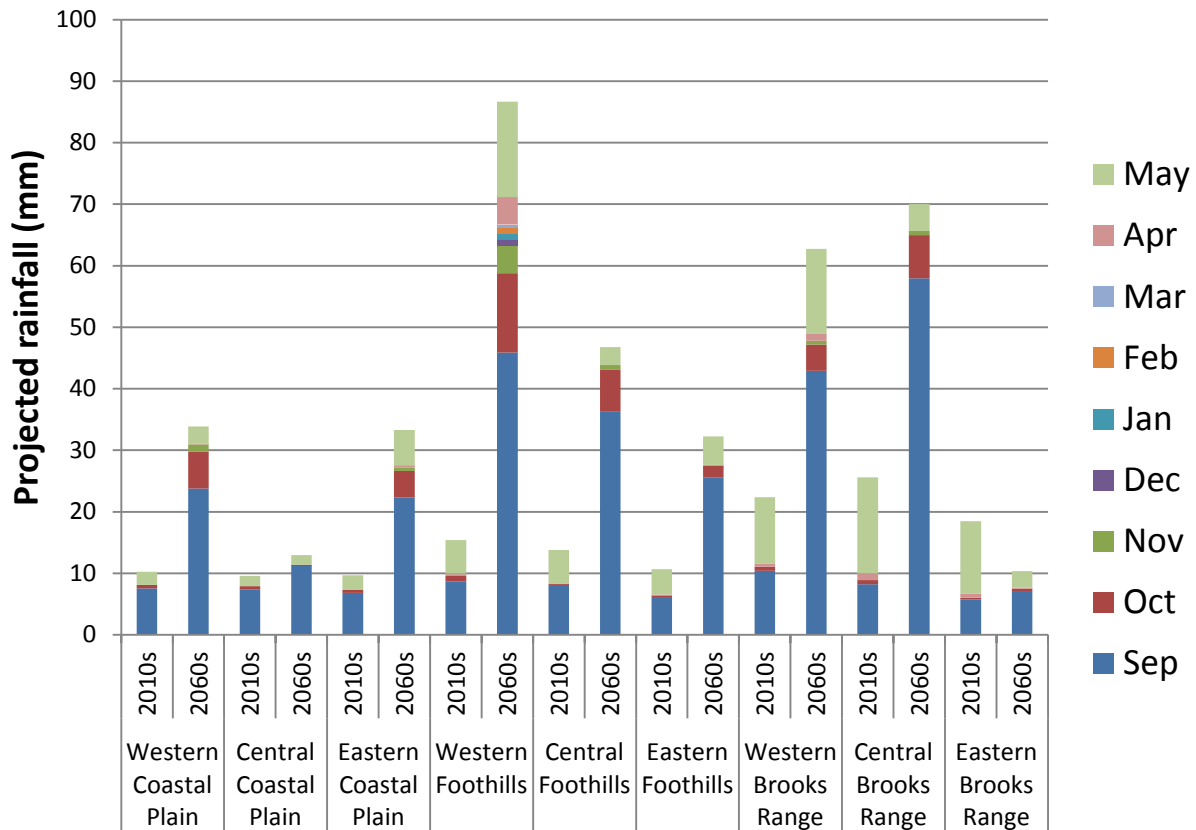


Figure H-7. Estimated current (2010s) and long-term (2060s) shoulder season and winter rainfall by sub-region.

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

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

particularly detrimental to predators (e.g. arctic fox, gyrfalcon) that are adapted to make use of the years of greatest prey abundance (Gilg et al. 2009).

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

Growing Season Length

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

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

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

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

Climate Summary

Overall, our assessment of abiotic climate variables suggest the Nearctic brown lemmings will be moderately to highly vulnerable to climate change, due to its close association with the snow pack and associated snow dynamics. These changes will be most pronounced in the long-term future (Table H-12). This species relies heavily on snow cover for winter insulation and predator avoidance. Snow volume is predicted to increase during the autumn months across the North Slope study area, yet there will likely

be net losses during winter and spring, which can affect overwinter survival. By 2060, DOF is expected to be delayed by 2 weeks, which could be both harmful (less time under snow, increased exposure to predation) or beneficial (greater winter food storage) to brown lemmings. Projected increases in early winter icing events can restrict access to lemming forage and reduce overwinter survival. Projected increases in growing season length and associated warmer temperatures in the near-term will likely be beneficial to lemmings directly through increased vegetation biomass (summer forage) and allow for greater winter food storage, while long-term changes may result in losses of preferred graminoid habitats as they are replaced with shrubbier habitats.

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

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

4.6. Current Status and Future Landscape Condition

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

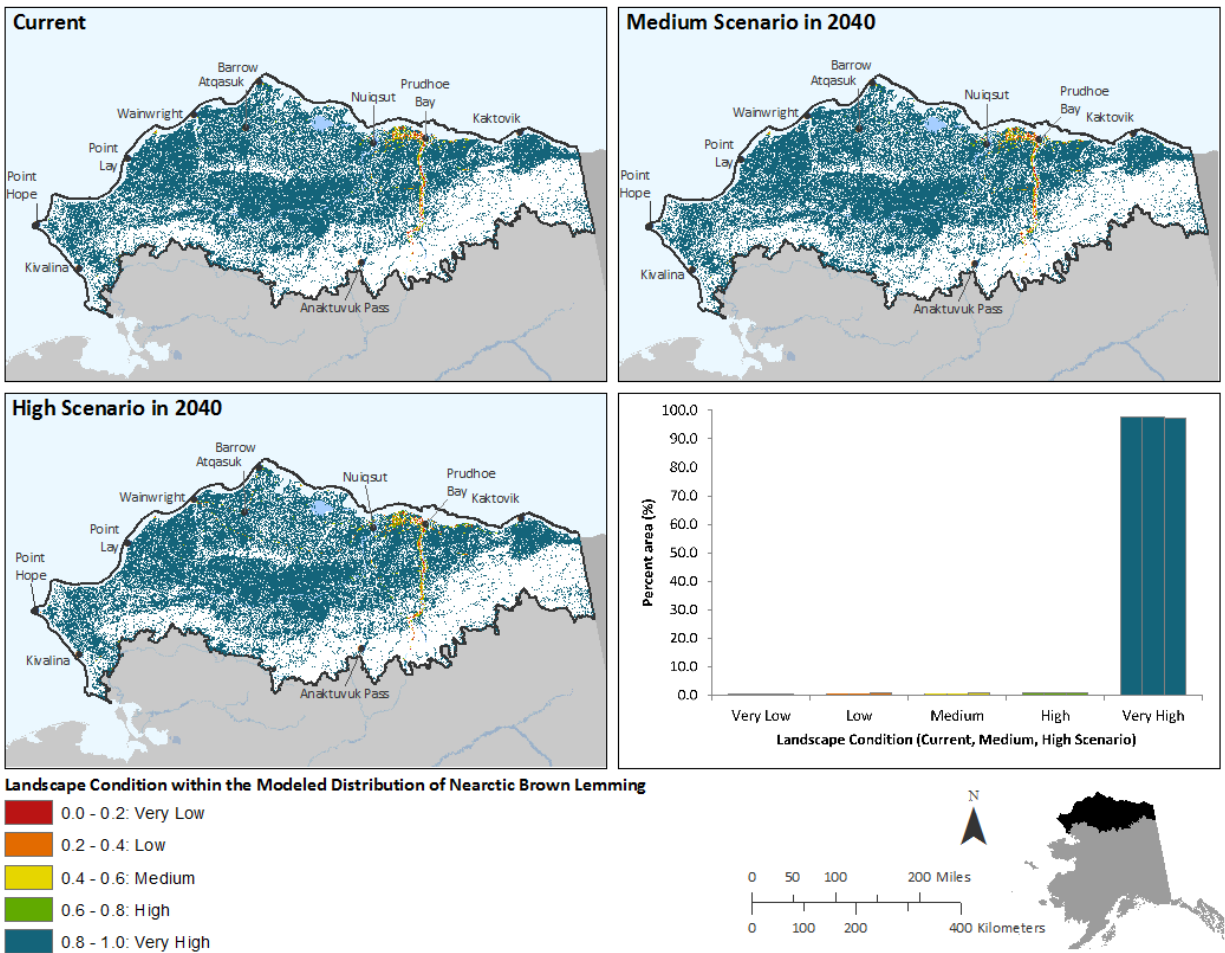


Figure H-8. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current distribution of Nearctic brown lemming in the North Slope study area.

4.7. Limitations and Data Gaps

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

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5. Arctic fox (*Vulpes lagopus*)

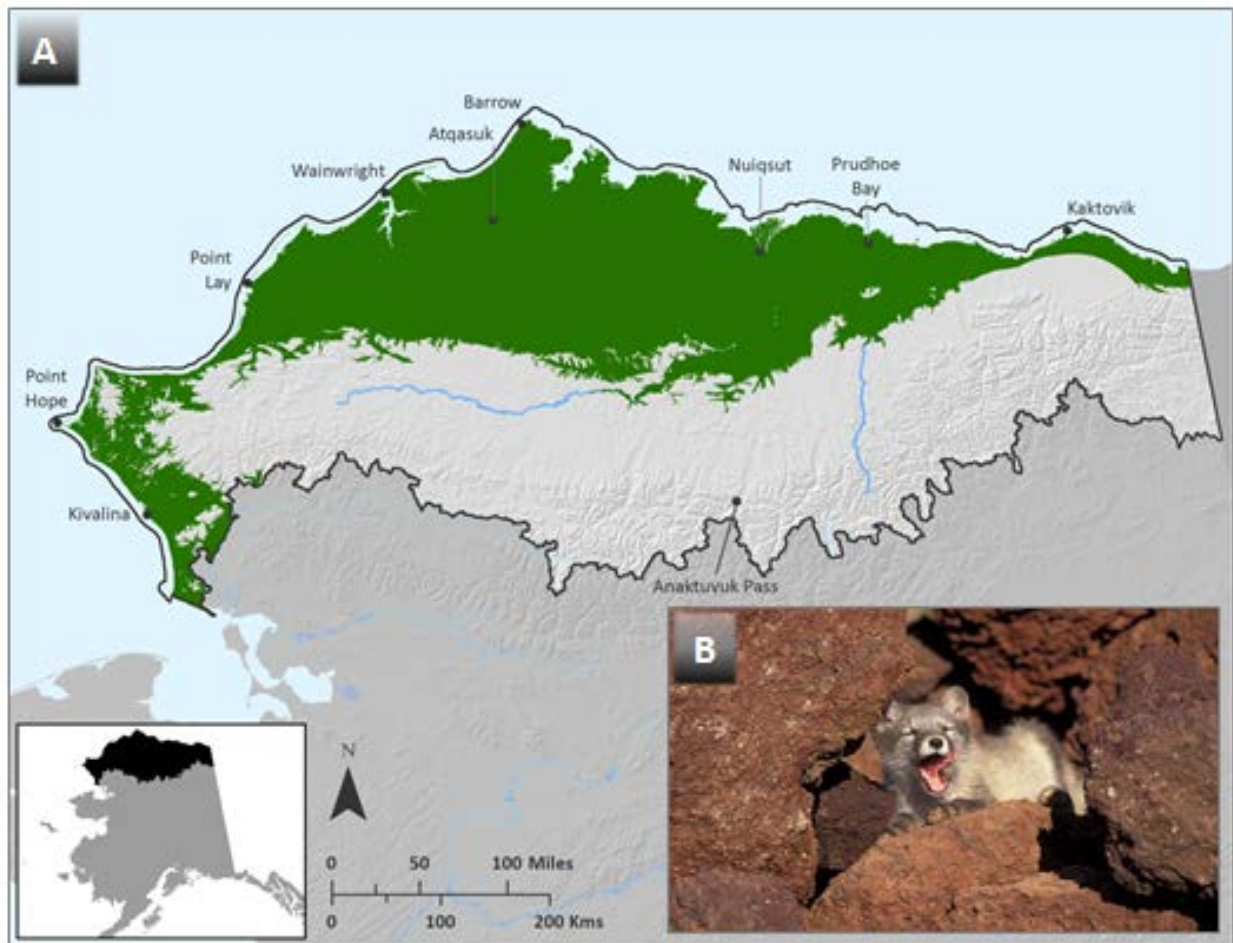


Figure H-9. Current modeled distribution of Arctic fox (*Vulpes lagopus*) in the North Slope study area (A) and juvenile Arctic fox, photo from Animal Diversity Web (B).

5.1. Introduction

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

The Arctic fox is a year-round resident of the Arctic Coastal Plain. It is highly adapted for survival in such a very cold, strongly seasonal environment (Burgess 2000), where it remains active throughout the 8-9

month Arctic winter. Some of its cold-tolerant adaptations include thick fur, large fat reserves, a specialized heat retaining circulatory systems in its feet, and the ability to lower its metabolic rate to endure periods of starvation.

In North America, the Arctic fox is abundant and the overall population probably ranges in the tens of thousands of individuals (Angerbjörn et al. 2012). An estimate of the size of the Arctic fox population across the North Slope ecoregion is unknown. Most populations fluctuate widely in numbers between years in response to varying lemming numbers (IUCN 2014). In most areas, however, population status is believed to be good. Density estimates within the North Slope study area range from 1/13 km² in the Prudhoe Bay Oil Field (Burgess et al. 1993) to 1/50 km² in the Outer Colville Delta (Truett and Johnson 2000).

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

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

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

5.2. Conceptual Model

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

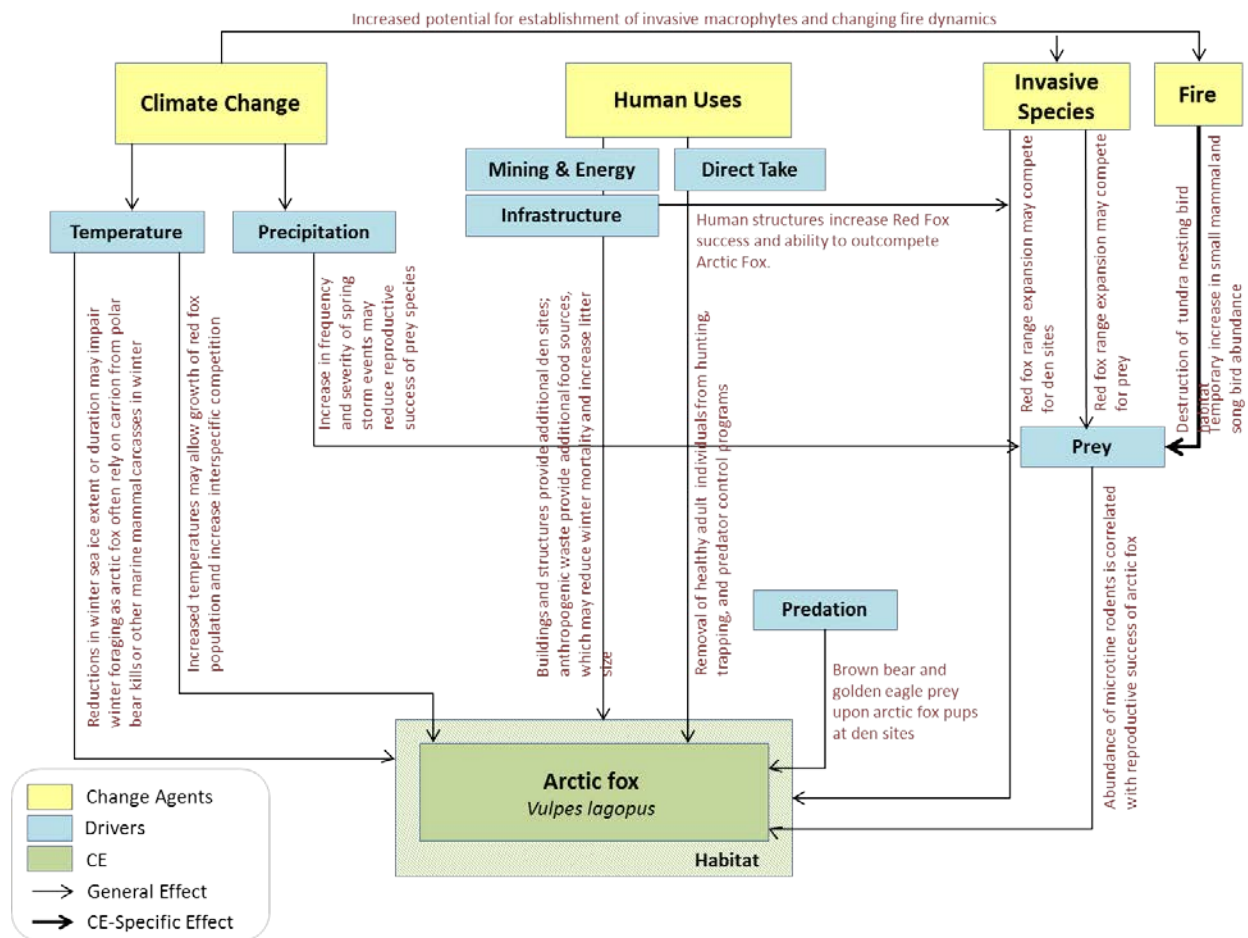


Figure H-10. Conceptual model for Arctic fox (*Vulpes lagopus*) in the North Slope study area.

5.3. Attributes and Indicators

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

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

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

⁶ Based on Hersteinsson and MacDonald 1992 and Pamperin et al. 2006.

⁷ Based on Martin et al. 2011.

⁸ Based on Tannerfeldt et al. 2003 and Szor et al. 2008.

⁹ Based on Duchesne et al. 2011.

¹⁰ Based on Burgess et al. 1993, Burgess 2000, Hammerson and Cannings 2004, and Bart et al. 2013.

5.4. Distribution Model

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

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

Table H-14. Datasets used for Arctic fox.

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

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

5.5. Abiotic Change Agents Analysis

Temperature

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

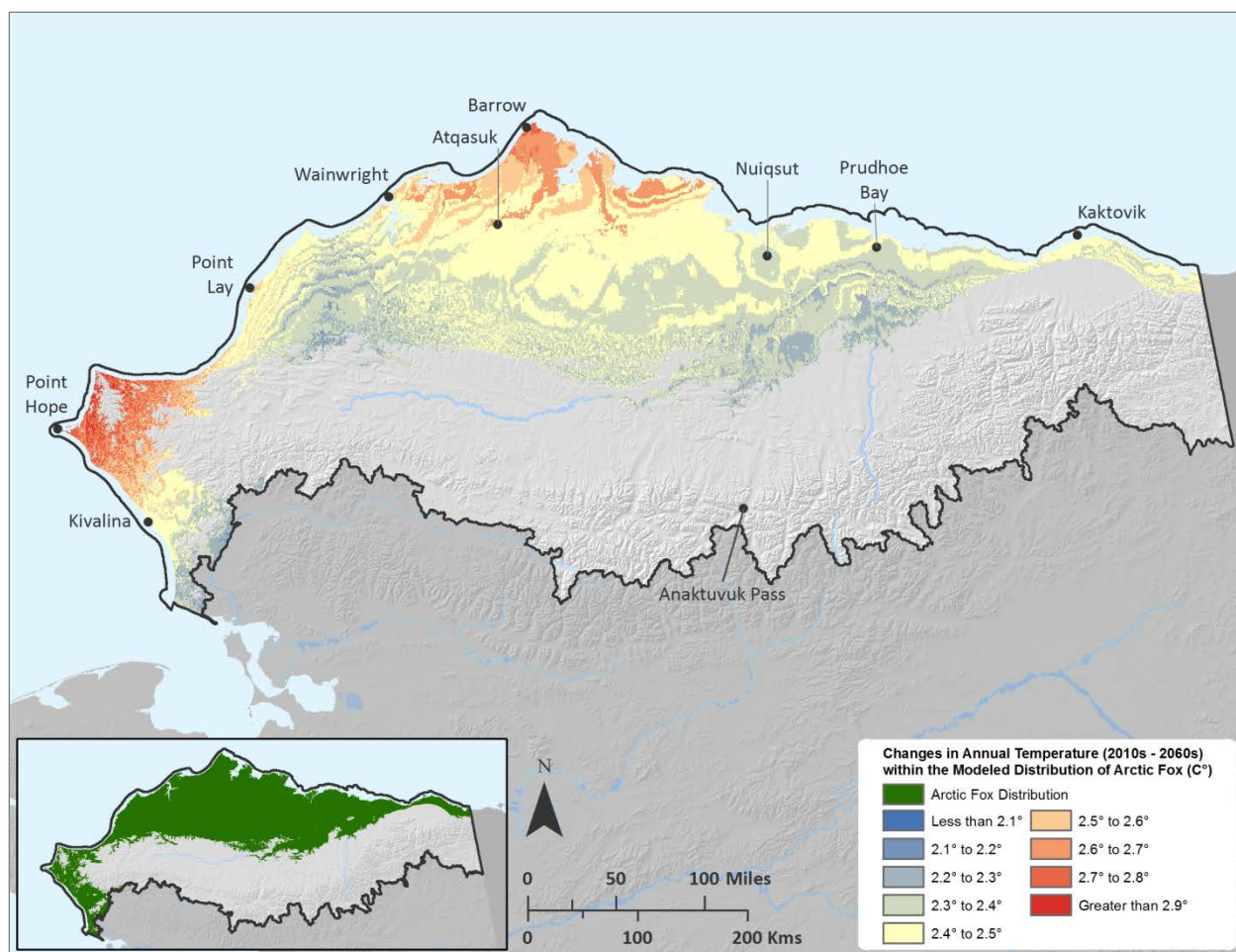


Figure H-11. Changes in mean annual temperature within the modeled distribution of the Arctic fox.

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

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

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

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

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

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

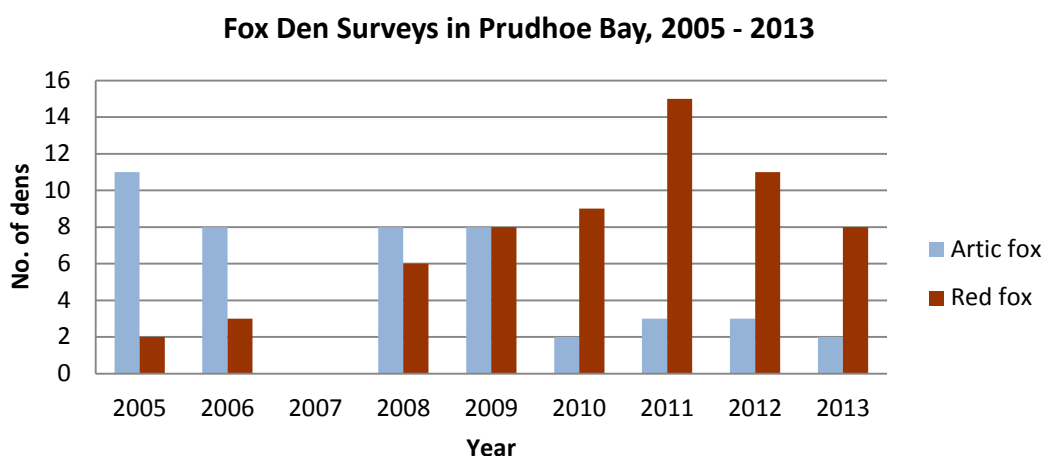


Figure H-12. Number of neonatal dens of Arctic and red foxes in the Prudhoe Bay area, 2005 – 2013 (adapted from Stickney 2014).

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

Snow Volume

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

the North Slope study area, there will likely be less snowfall during late winter and spring months (Figure H-13).

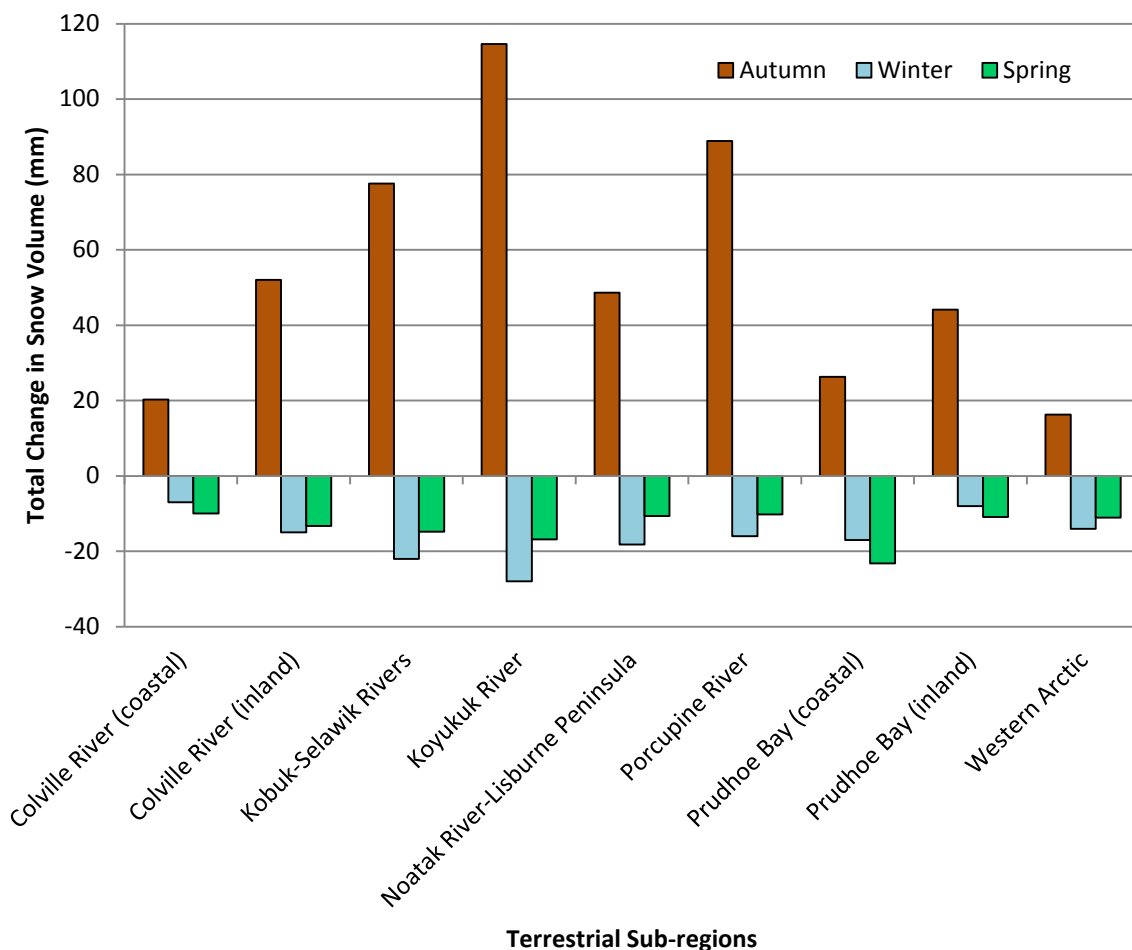


Figure H-13. Projected snowfall (mm rainwater equivalent) summarized by three-month period (SON, DJF, MAM) and ecological sub-region.

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

Growing Season Length

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

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

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

Active Layer Thickness

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

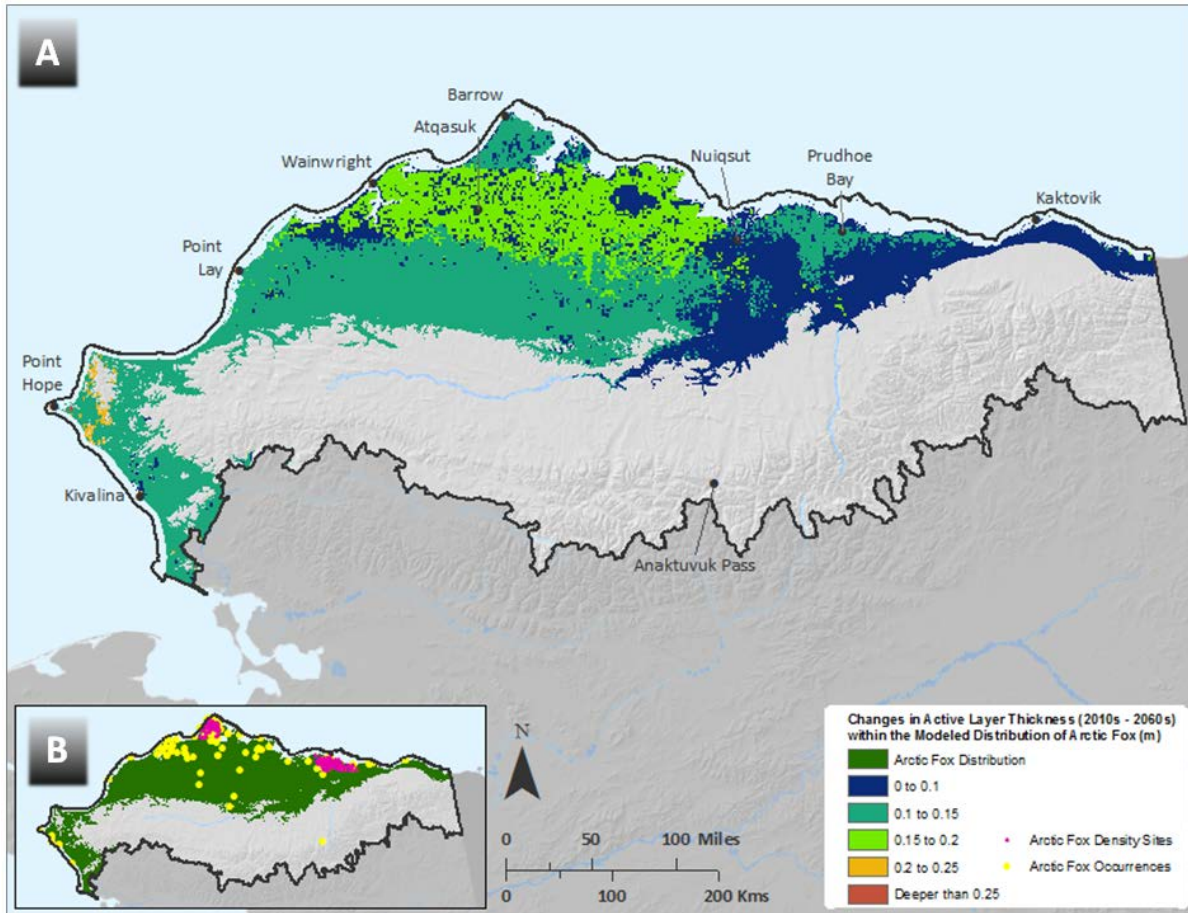


Figure H-14. Projected changes in active layer thickness within the modeled distribution of the Arctic fox (A), and distribution of fox den sites and known occurrences (B).

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

Climate Summary

Overall, our assessment of abiotic climate variables suggest the Arctic fox will be moderately vulnerable to climate change, with positive and negative impacts creating a complex overall picture. Denning sites

are likely to be more readily available, but competition with red foxes for these sites may be more intense and more widespread. Prey availability may increase, based on greater overall ecosystem productivity, but unreliable snow conditions may sometimes decimate sub-nivean prey, perhaps exacerbating the amplitude of existing predator-prey cycles (Table H-17).

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

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

5.6. Current Status and Future Landscape Condition

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

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

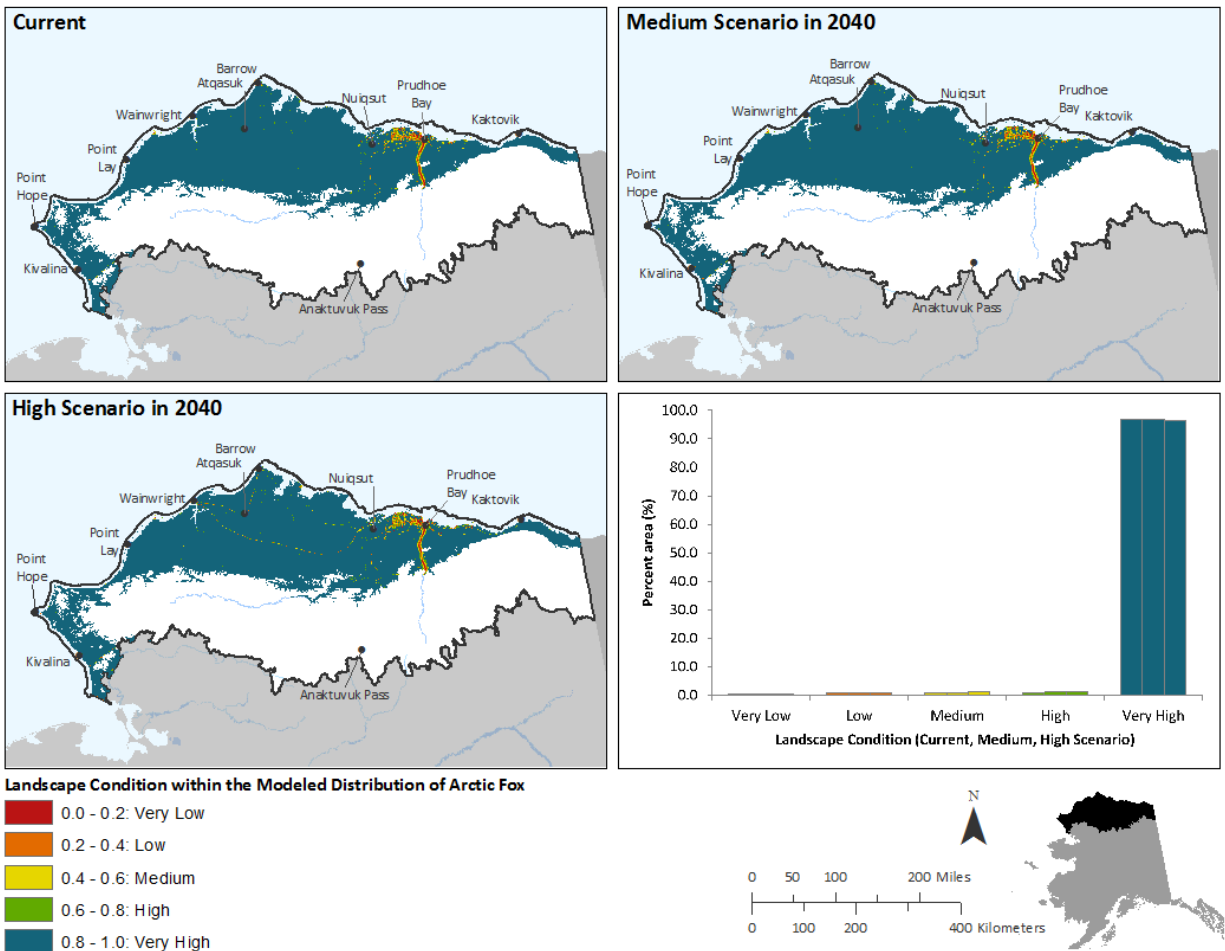


Figure H-15. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current distribution of Arctic fox in the North Slope study area.

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

Concern related to higher fox densities includes the possibility of transmission of diseases, especially rabies to humans (Burgess 2000). Recent studies indicate that the increasing ambient temperatures in Alaska and other regions of the Arctic may influence the incidence and distribution of zoonotic and parasitic infections in humans by changing the population density and range of wild and domestic animals and insect hosts. Arctic fox are a potential disease and parasite vector for humans. They are known to carry giardia, toxoplasmosis, and cryptosporidium, which can be transmitted to humans or human water supplies (or humans can transmit them to foxes). Furthermore, rabies is enzootic among the fox populations of northern and western Alaska, with periodic epizootics documented every 3–5 years (the last epizootic in Alaska was in 2006–07) (Hueffer et al. 2013). In early spring, Arctic foxes tend

to move inland off the sea ice, increasing the likelihood of coming into contact with domestic animals or humans. Dogs can readily serve as a transmission vehicle of the rabies virus from wildlife to humans (Hueffer et al. 2013). Reductions in sea ice (see data gaps) could force foxes inland much earlier in spring, increasing encounter rates with humans and domesticated pets. Long-term higher densities of foxes could result in reduced nesting success and smaller regional populations of some species of birds (Burgess 2000).

5.7. Limitations and Data Gaps

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

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

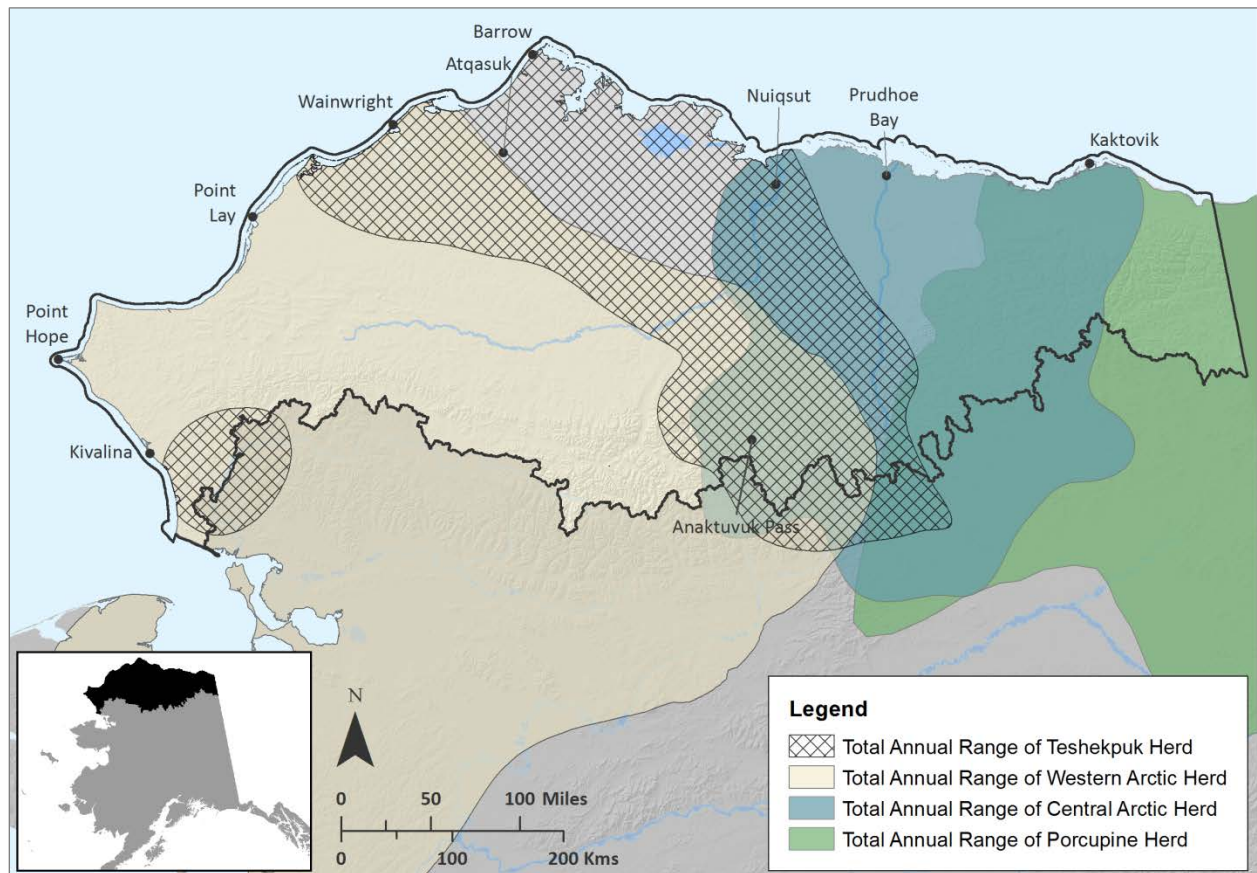


Figure H-16. Generalized range maps for the four barren ground caribou herds present in the North Slope study area: Western Arctic Herd, Teshekpuk Herd, Central Arctic Herd, and Porcupine Herd.

6.1. Introduction

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

Population size and trends are highly variable between the four herds (Table H-18). The Western Arctic Herd is the largest caribou herd in Alaska and one of the largest in the world, with a population estimate of 235,000 animals as of 2013 (Dau 2013). The population of this herd has been declining since 2003,

with a rapid decline since 2011. Similarly, the Teshekpuk Herd was estimated at 32,000 caribou in 2013, less than half of the highest count of 68,000 in 2008 (Parrett et al. 2014). Although the reasons behind the declines are not easily identifiable, poor calf production, poor calf survival, and spikes in adult female mortality are contributing to the declines in both herds. Poor nutrition appears to be playing a role in the Teshekpuk Herd declines whereas caribou of the Western Arctic Herd have maintained good body condition during the population decline (Parrett et al. 2014).

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

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

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

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

6.2. Methods

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

management with Canada. The 1983 to 2001 annual range of the herd reported in Griffith et al. (2002) was digitized for this assessment.

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

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

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

6.3. Conceptual Model

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

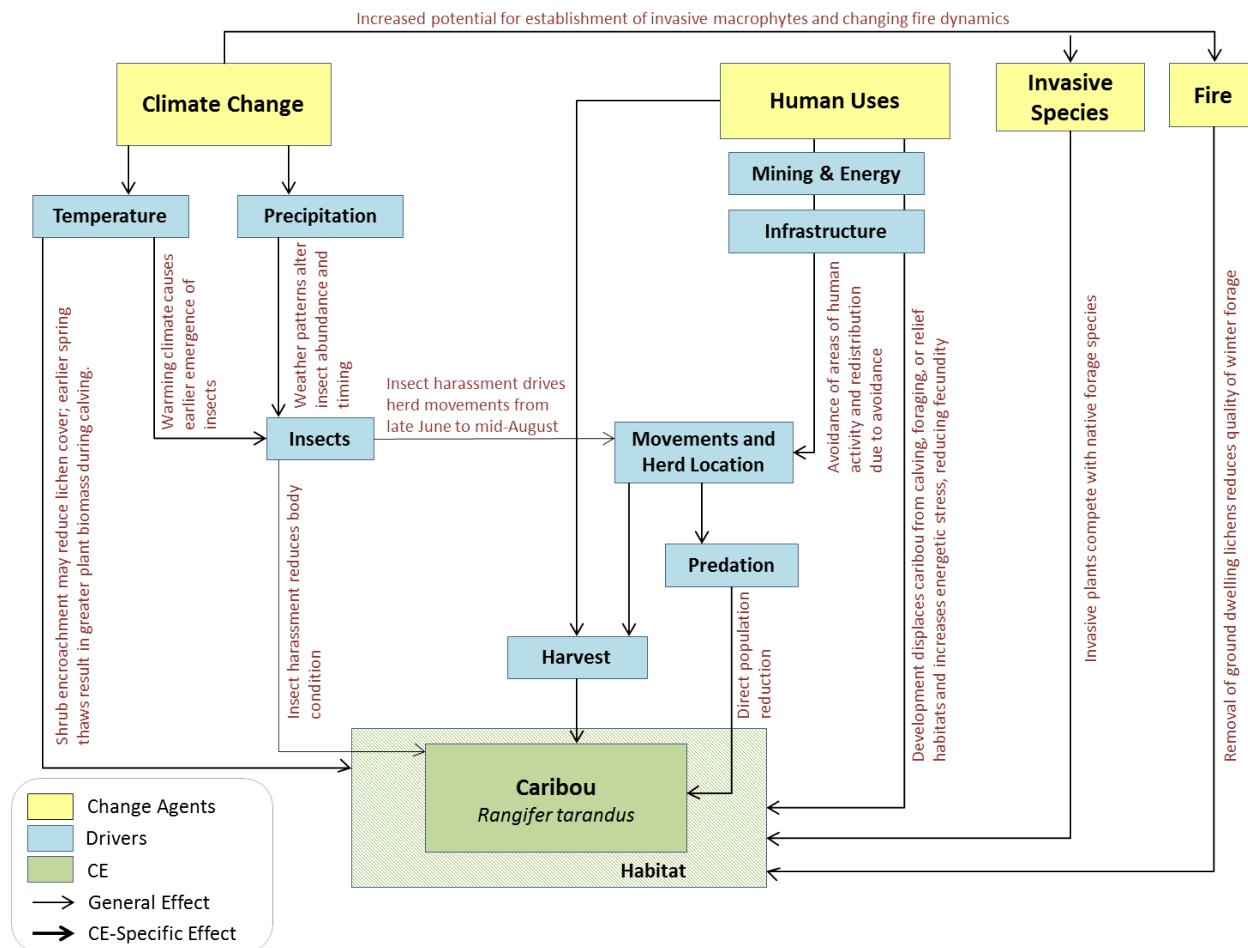


Figure H-17. Conceptual model for caribou in the North Slope study area.

6.4. Attributes and Indicators

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

Table H-20. Attributes and indicators for caribou.

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

¹¹ Based on Griffith et al. 2002, Sparks and Menzel 2002, Stone et al. 2002, and Post et al. 2003. However, see Section H.7. Caribou Seasonal Forage for discussion of possible reverse effect from trophic mismatch.

¹² Based on Hansel et al. 2011.

¹³ Based on Joly and Klein 2011.

¹⁴ Based on Bolduc et al. 2013.

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

¹⁵ Based on Downes et al. 1985, Witter et al. 2012, and Bolduc et al. 2013.

¹⁶ Based on Jandt et al. 2008.

¹⁷ Based on Cronin et al. 1994.

6.5. Seasonal Distribution and Movement Patterns

MQ TF 4	What are caribou seasonal distribution and movement patterns and how are they related to season and weather?
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Barren ground caribou cover large ranges and move long distances seasonally (Figure H-18). Although the exact patterns of movement vary between herds, the factors driving seasonal migrations are relatively constant across the North Slope. The current timing of annual cycle events and migrations, along with factors that drive both the timing and spatial distribution of the annual cycle, are reviewed with a focus on season and weather. The seasonal distributions and movements of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds are described in relation to current and potential future season and weather. Seasonal distribution of the four herds are assessed during calving, summer (insect relief), and winter. Movement patterns are assessed during spring migration to calving grounds and fall migration to winter ranges. The general life cycles of barren-ground caribou herds in the North Slope study area are summarized in Figure H-19. The historic (pre-2004) ranges of the four caribou herds vary, sometimes largely, from the ranges presented in this section.

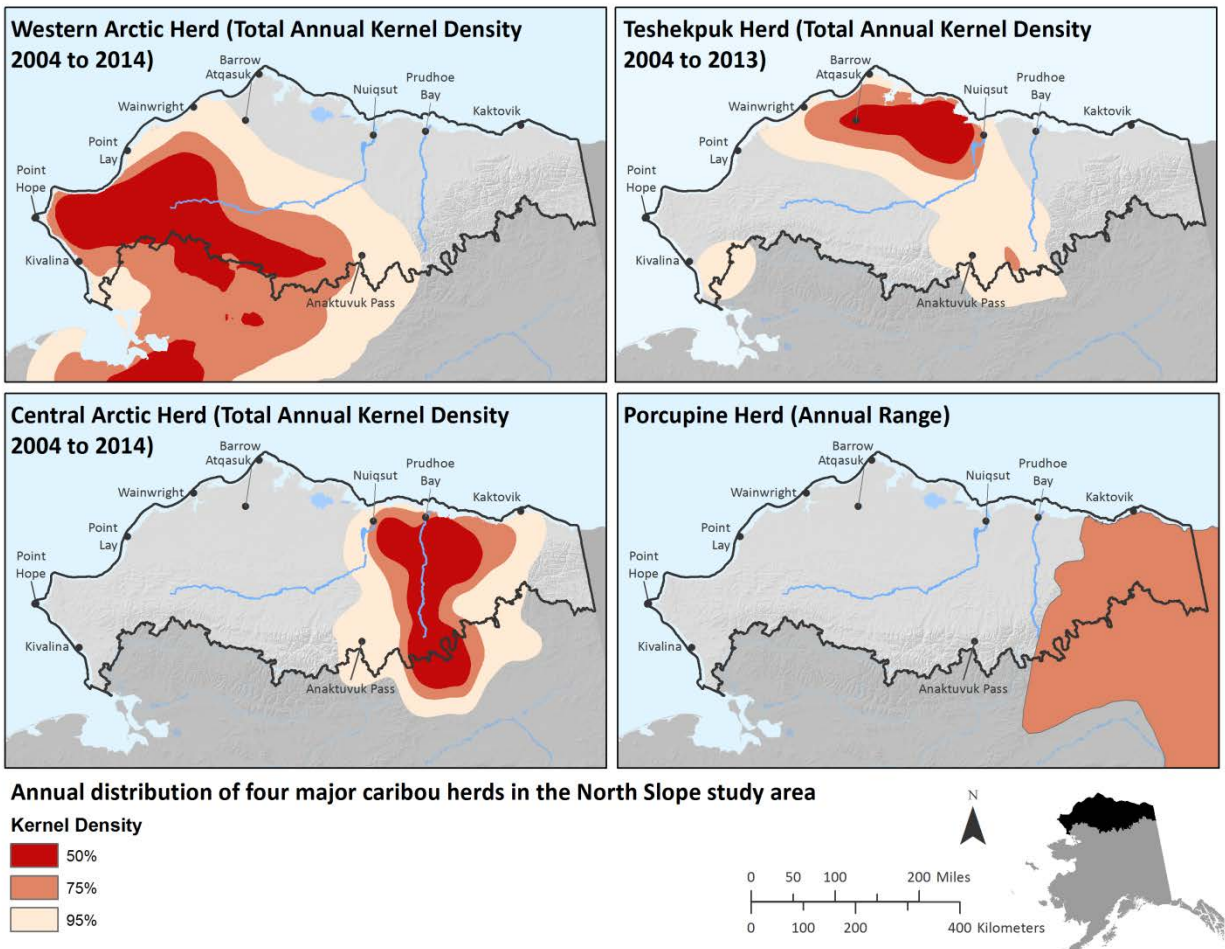


Figure H-18. Annual distribution of Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds.

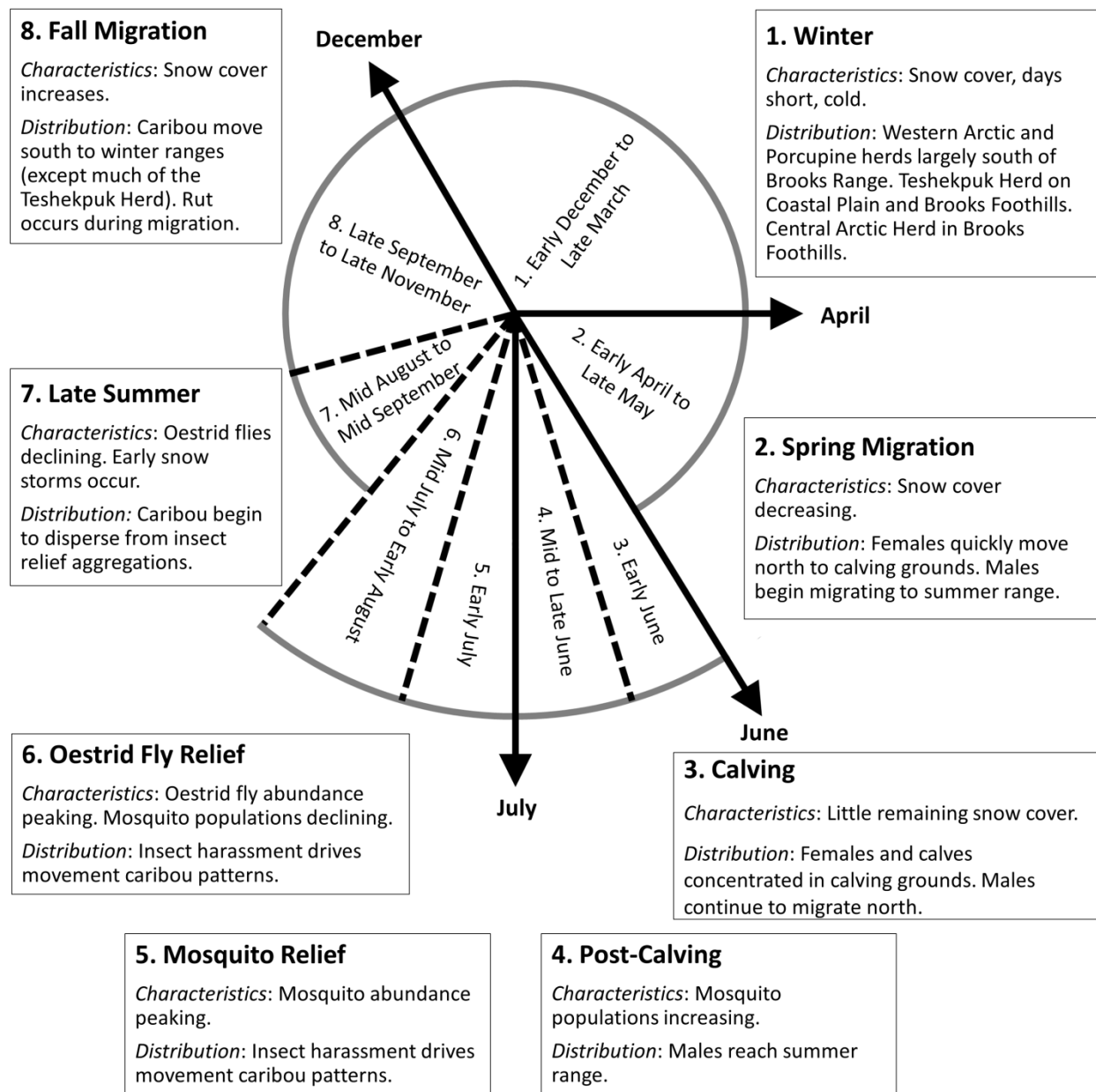


Figure H-19. Generalized movement patterns of North Slope caribou herds by approximate date range.

Calving

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

maternal protein reserves are low during calving season, calving habitats are especially important to female and calf protein budgets (Griffith et al. 2002). Males and non-parturient females continue their spring migration during the calving season (Dau 2013).

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

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

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

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

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

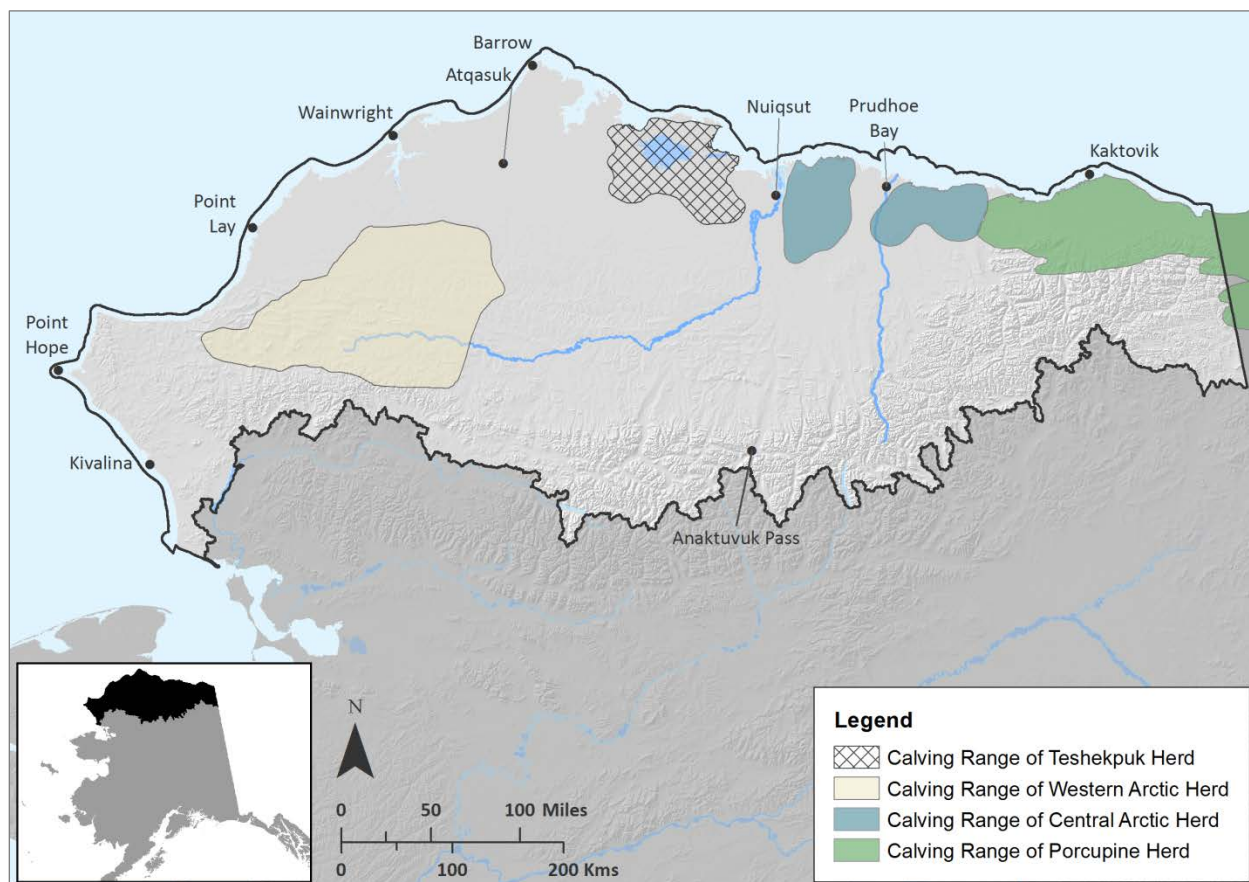


Figure H-20. Generalized calving distribution of parturient females and calves of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds.

Insect Relief

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

Caribou seek insect relief habitat: terrain where conditions are consistently unfavorable for flying insects. The movements of caribou during July and early August are driven by insect avoidance and the need to seek high quality forage. Therefore, caribou neither remain stationary at the highest quality

forage sites until available forage has been consumed nor do they access relatively insect-free zones such as alpine barrens in the Brooks Range. Instead, they constantly move among areas of good to moderate forage quality and nearby insect relief habitats or microhabitats. During July and early August, caribou spend a significant but variable portion of their time on energy-consuming avoidance behaviors such as standing, running, and walking rather than foraging or resting (Downes et al. 1985). Because of avoidance behaviors and movement to forage sites, daily rates of movement are highest in July (Fancy et al. 1989).

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

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

Late Summer

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

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

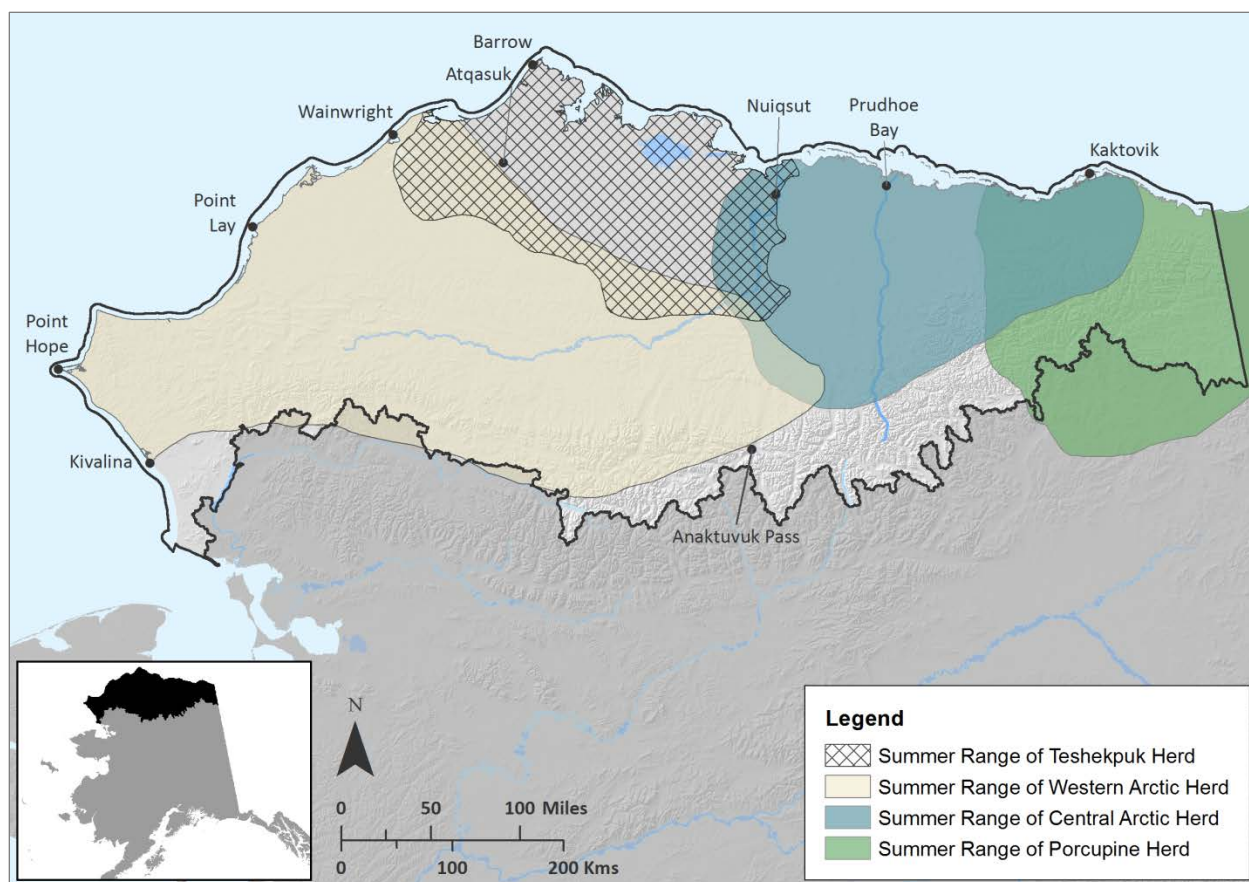


Figure H-21. Generalized summer (post-calving to late summer) distribution of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds.

Fall Migration

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

Winter

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

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

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

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

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

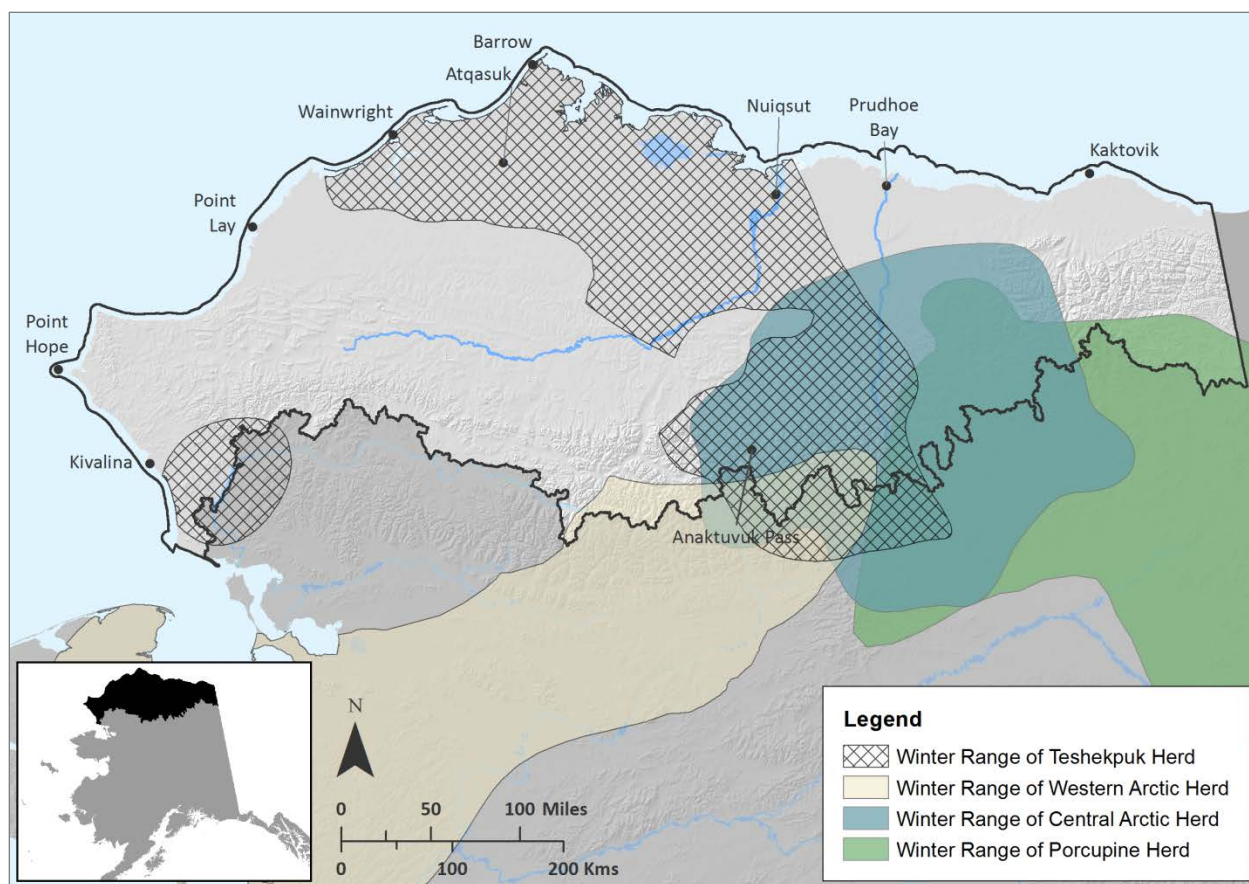


Figure H-22. Generalized winter distribution of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds.

Spring Migration

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

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

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

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

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

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

Sexual Segregation

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

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

Herd-Specific Factors

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

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

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

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

6.6. Abiotic Change Agents Analysis

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

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

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

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

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

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

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

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

6.7. Current Status and Future Landscape Condition

Resource extraction and infrastructure development have caused the fragmentation of caribou habitat throughout Alaska. Patch sizes are likely to decrease with increased development. While a previous study in Prudhoe Bay found that caribou cows and calves did not avoid drilling areas (Fancy 1983), more recent studies have found that caribou generally avoid areas of human activity (up to 50-95% reduced presence; Vistnes and Nellemann 2008) and can be displaced from preferred calving grounds by human disturbance (Joly and Klein 2011; Wolfe et al. 2000). In addition, human activities can result in increased

vigilance and avoidance behaviors which increase energy expenditure of individuals (Fancy 1983; Wolfe et al. 2000). Human activity may also cause a redistribution of animals on the landscape (Wolfe et al. 2000).

The Central Arctic Caribou herd has coexisted with oil field development around Prudhoe Bay for more than three decades. Construction of oil field infrastructure can displace caribou from the area. In the Milne Point Road area, caribou density decreased as road density increased, despite the overall concurrent population growth of the Central Arctic herd (Noel et al. 2004, Joly et al. 2006). While some caribou have occasionally used gravel pads and roads as insect relief areas (Fancy 1983), infrastructure can typically delay or redirect caribou moving towards coastal areas to seek mosquito relief. If displacement from breeding, foraging, and relief habitats causes energetic stress, then affected cows will likely respond with lower fecundity (Murphy and Lawhead 2000, Vistnes and Nellemann 2008). Birth rates for female caribou in the Central Arctic herd exposed to areas of oil development were 10-20% lower than those not exposed to oil development (Cameron et al. 2005). The Western Arctic Caribou herd currently has little contact with industrial infrastructure, except around the Red Dog Mine. The Teshekpuk Lake and Porcupine herds do not have significant contact with industrial infrastructure in Alaska, although the Porcupine herd does encounter road corridors in the Yukon Territory (Murphy and Lawhead 2000).

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

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

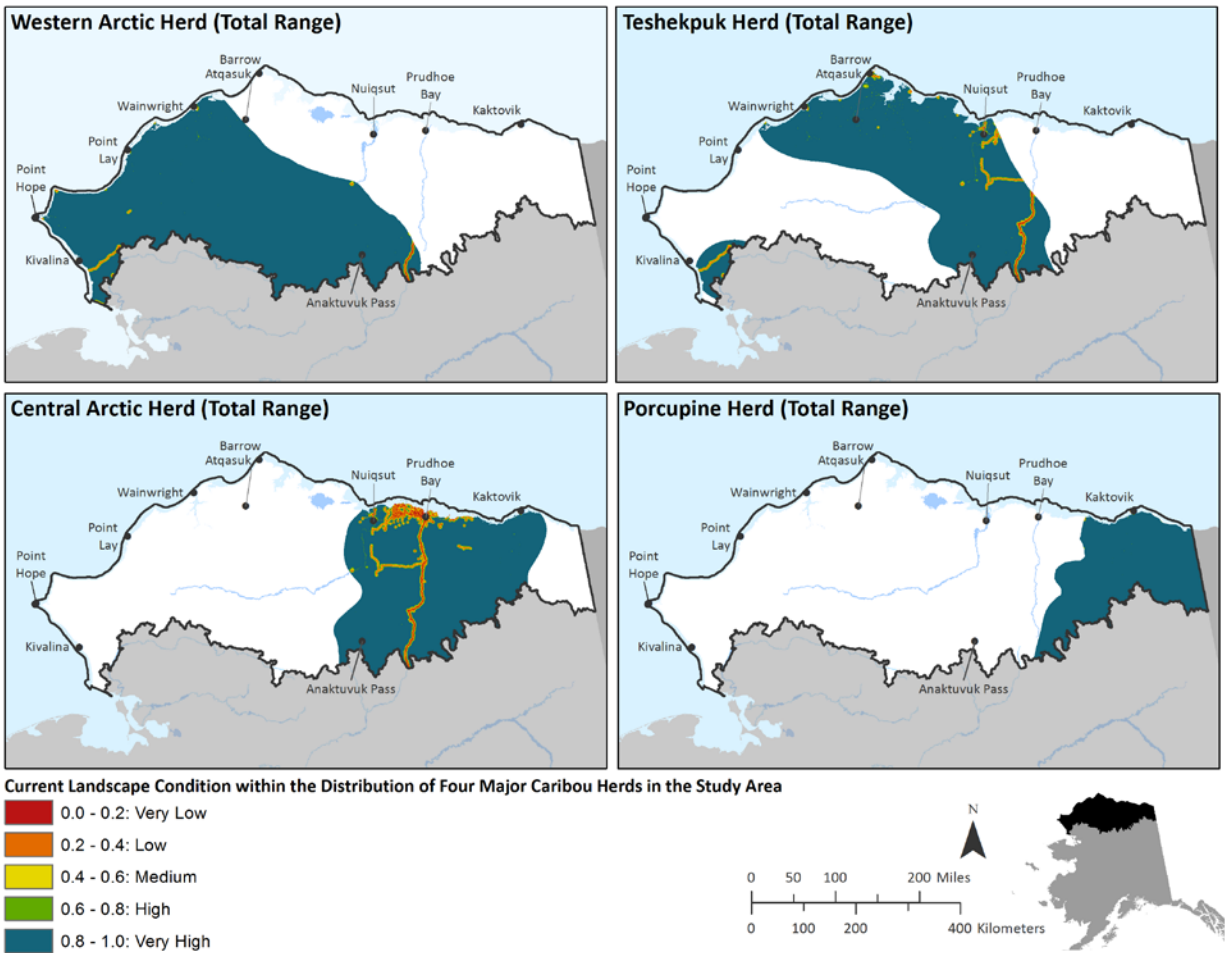


Figure H-23. Current landscape condition within the current total annual range of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds in the North Slope study area.

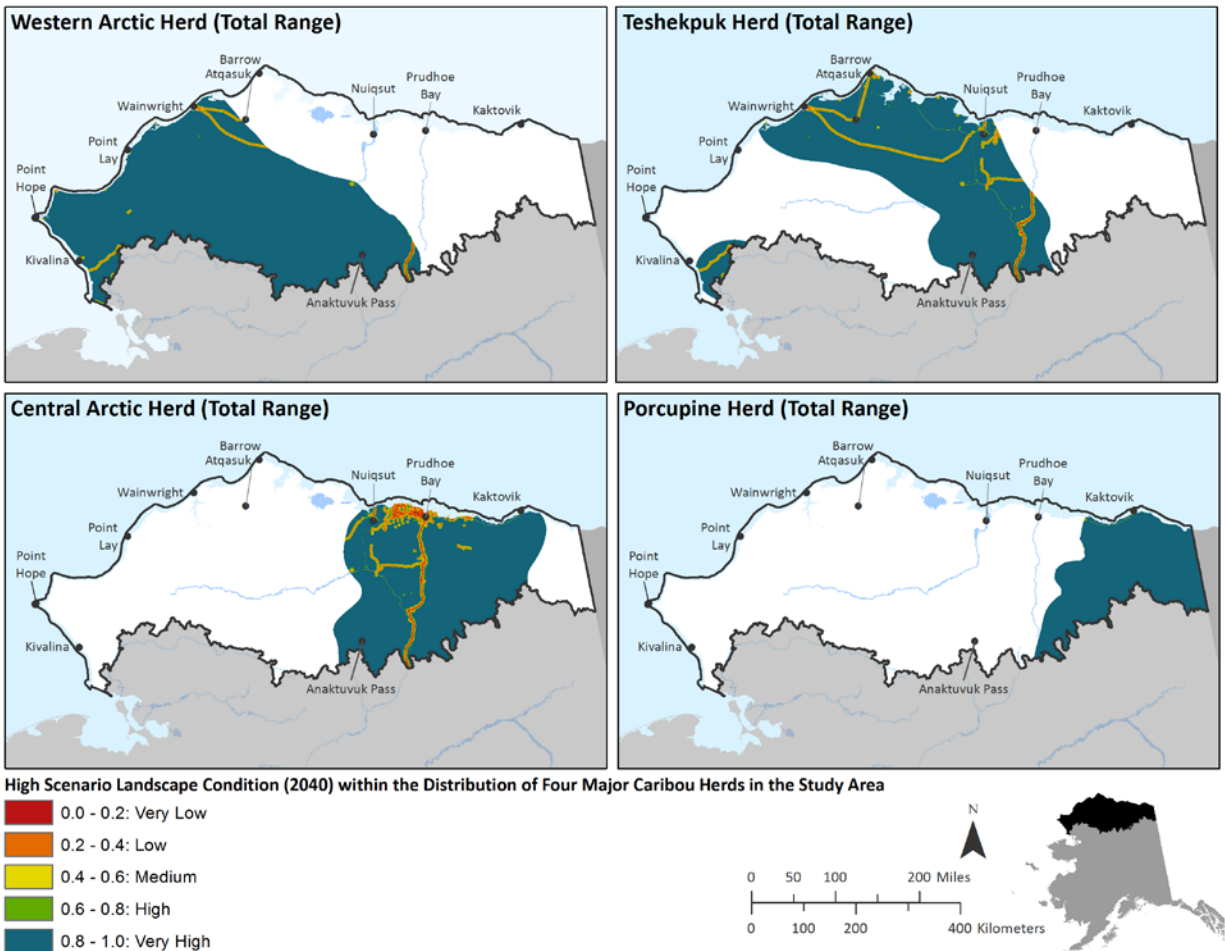


Figure H-24. 2040 high-development scenario landscape condition within the current total annual range of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine caribou herds in the North Slope study area.

6.8. Harvest and Predation

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

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

6.9. Limitations

The spatial representations of caribou seasonal distribution are based on the best available and obtainable information. This included kernel density polygons obtained through a data sharing

agreement with ADF&G for the Western Arctic, Central Arctic, and Teshekpuk herds. Such fine-scale data were not available in summary format for the Porcupine Herd. This herd is managed jointly between Alaska and the Yukon Territory, therefore a separate data request was necessary to obtain raw radio-collar data for that herd, which was deemed beyond the scope of the REA.

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

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

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

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

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

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7. Caribou Seasonal Forage

MQ TF 2

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

7.1. Introduction

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

Calving

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

The forage preferences of male and female caribou differ during calving season. Both males and females use *Eriophorum*- and *Carex*-rich habitats and consume emerging *Eriophorum* inflorescences. For male caribou, however, *Salix* leaves and inflorescences also contribute a large portion of the diet and are preferentially sought in floodplain and riparian habitats, in which *Salix* spp. are prevalent. *Salix alaxensis*, *S. glauca*, *S. pulchra*, and *S. richardsonii* are common forage species. *Salix reticulata* is also a preferred forage and occurs outside of riparian areas in tussock tundra and dwarf shrub tundra (White and Trudell 1980, Klein 1990). In the Central Arctic Herd, males were observed foraging more in riparian corridors than were the females. Females primarily foraged in *Eriophorum*- and *Carex*-rich habitats but avoided riparian habitats, likely because brown bears and wolves are more commonly encountered along the

riparian corridors (Jakimchuk et al. 1987). In other herds as well, young leaves and inflorescences of *Salix* spp. contribute a sizable component of caribou diet during calving season. Although males may consume more *Salix*, females also browse *Salix* preferentially (Thompson and McCourt 1981). In addition to *Eriophorum* and *Salix*, caribou also forage *Carex aquatilis* and other *Carex* spp., but not as a major component of the diet (White and Trudell 1980). Caribou consume relatively small amounts of *Equisetum* spp. in riparian habitats (Jakimchuk et al. 1987). In areas with low availability of *Eriophorum* and *Salix*, caribou have been observed consuming mosses and evergreen shrubs during calving season; however, these plants are not easily digestible and are not preferred forage (Griffith et al. 2002).

Summer

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

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

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

freshwater marshes, regardless of whether dominated by *Carex aquatilis* or *Arctophila fulva* (White and Trudell 1980, Wilson et al. 2012).

August and Autumn

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

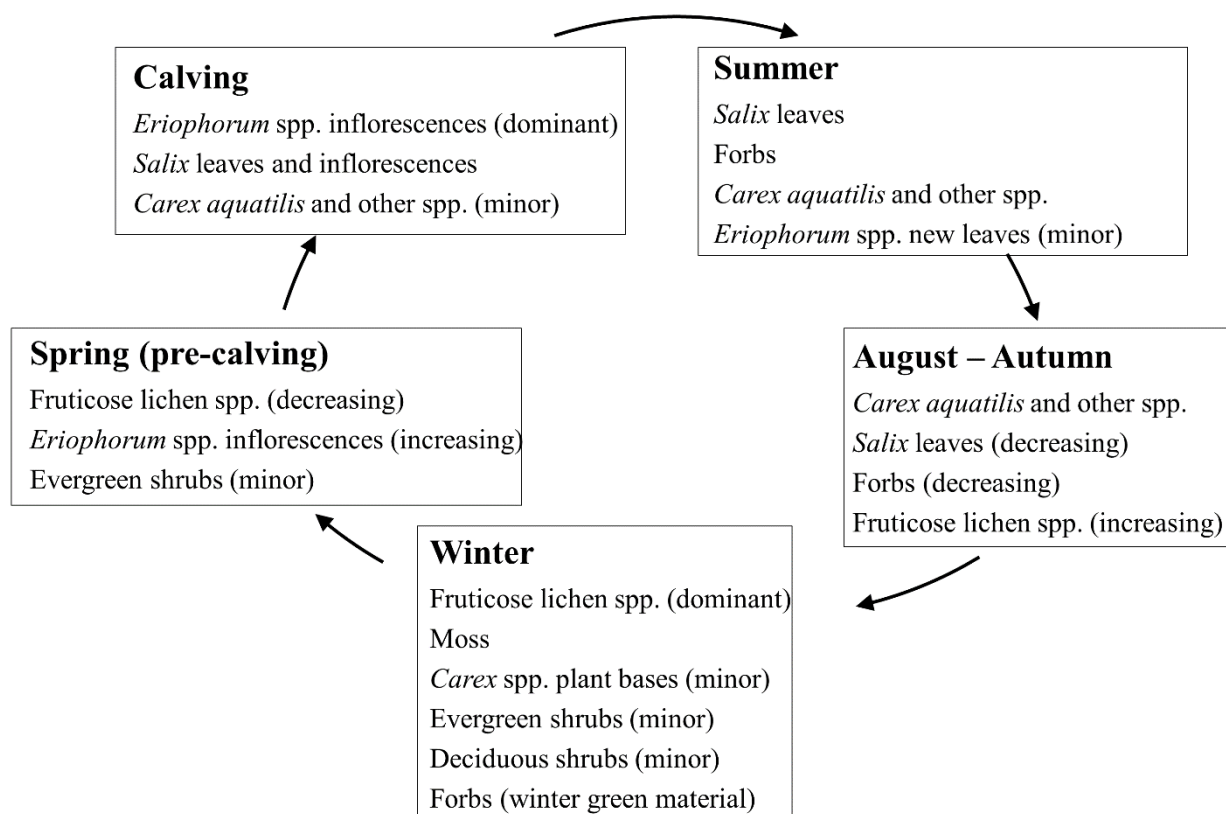


Figure H-25. Conceptual diagram of general caribou foraging preferences by season.

Winter

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

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

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

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

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

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

Spring (Pre-Calving)

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

7.2. Methods

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

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

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

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

7.3. Distribution

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

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

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

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

Calving Season Forage Quality

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

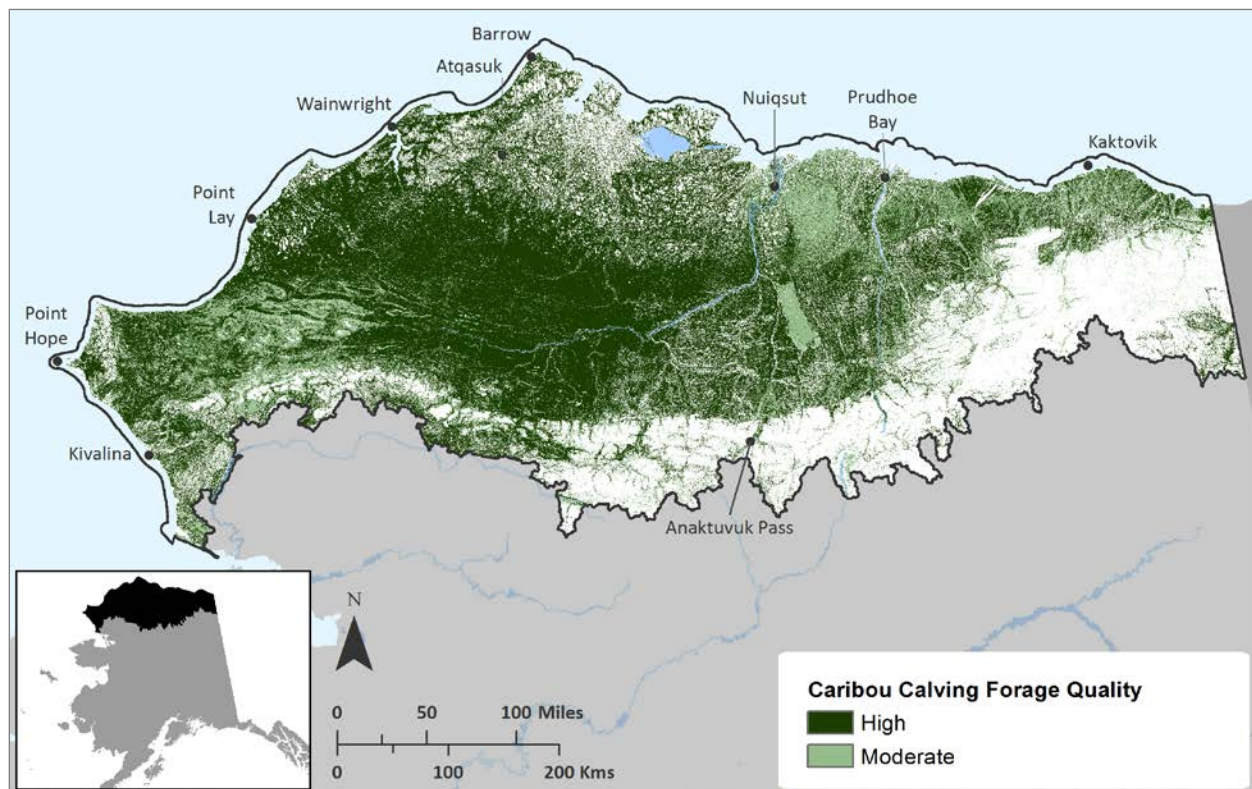


Figure H-26. Good and moderate quality caribou forage during calving season within the North Slope study area.

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

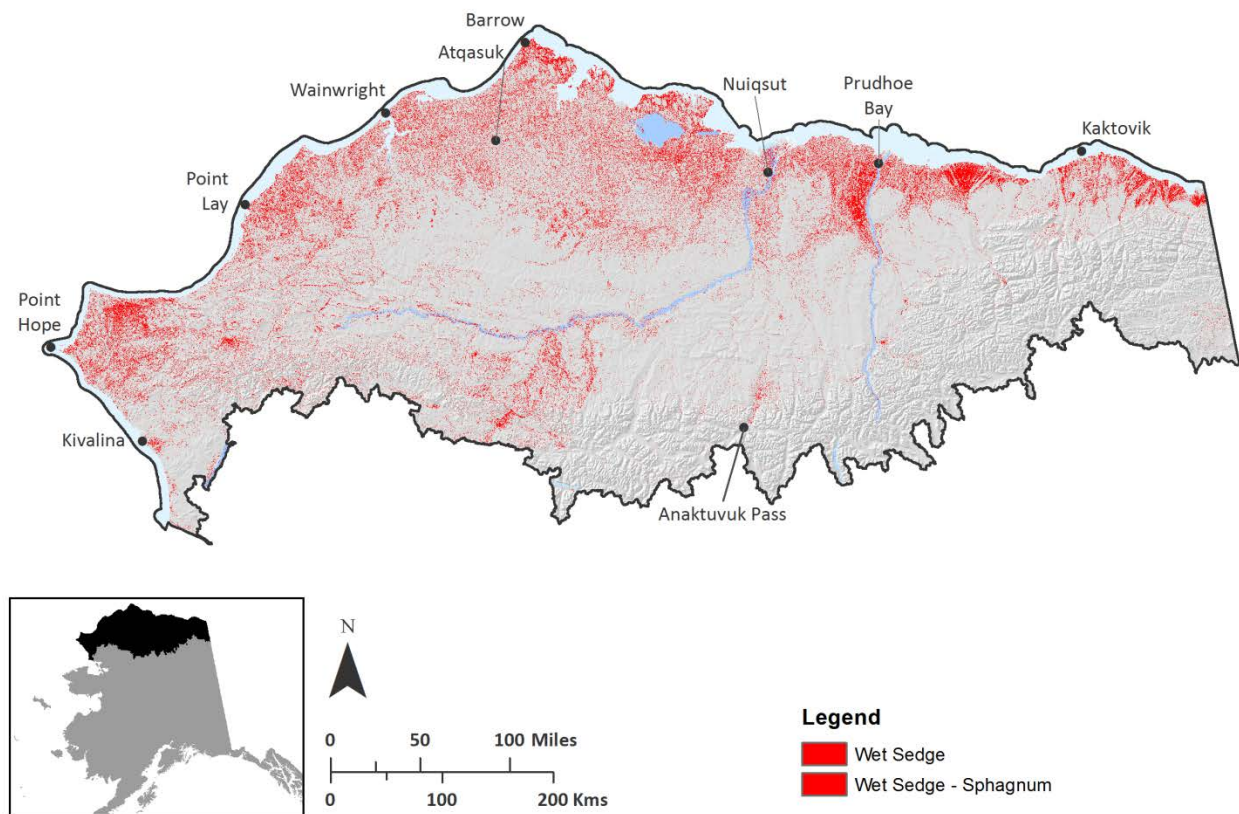


Figure H-27. Distribution of wet sedge and wet sedge – *Sphagnum* in the North Slope study area.

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

herds. However, this apparent regional distribution may be an artifact of differing regional mapping methodologies.

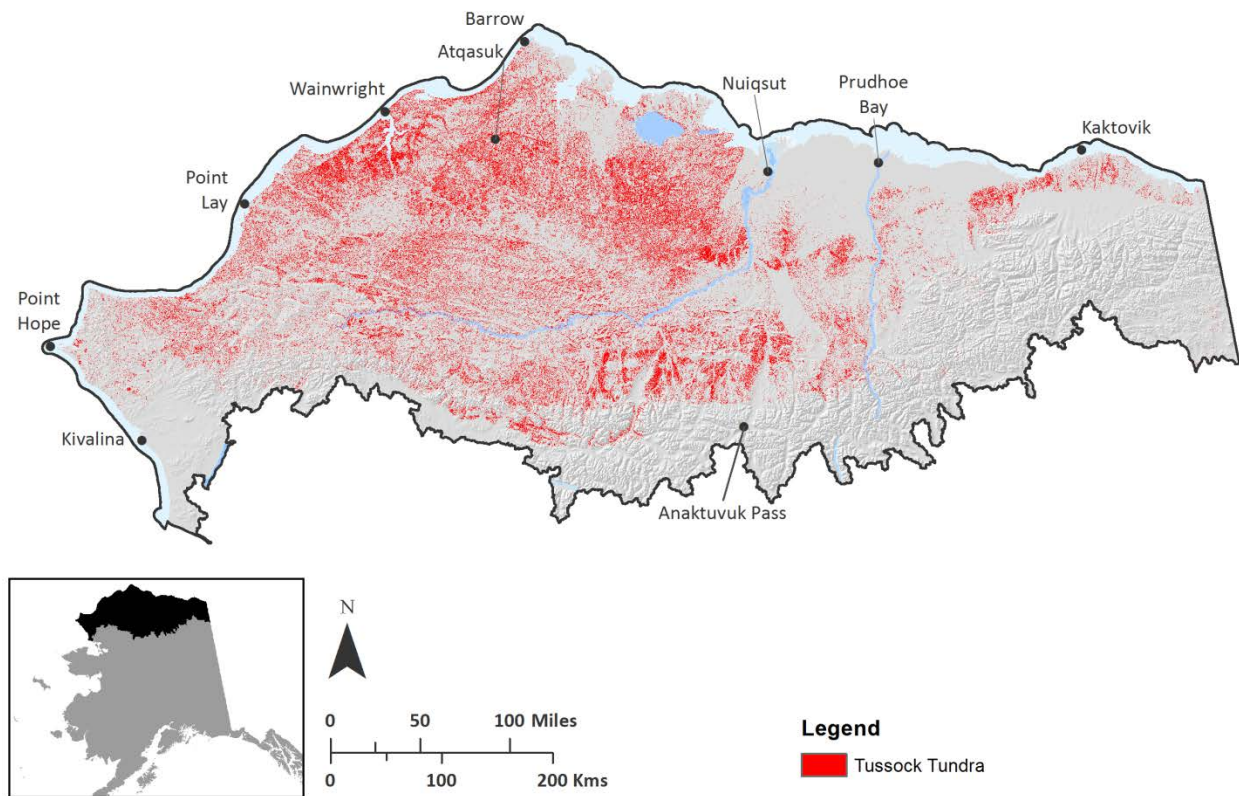


Figure H-28. Distribution of tussock tundra in the North Slope study area.

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

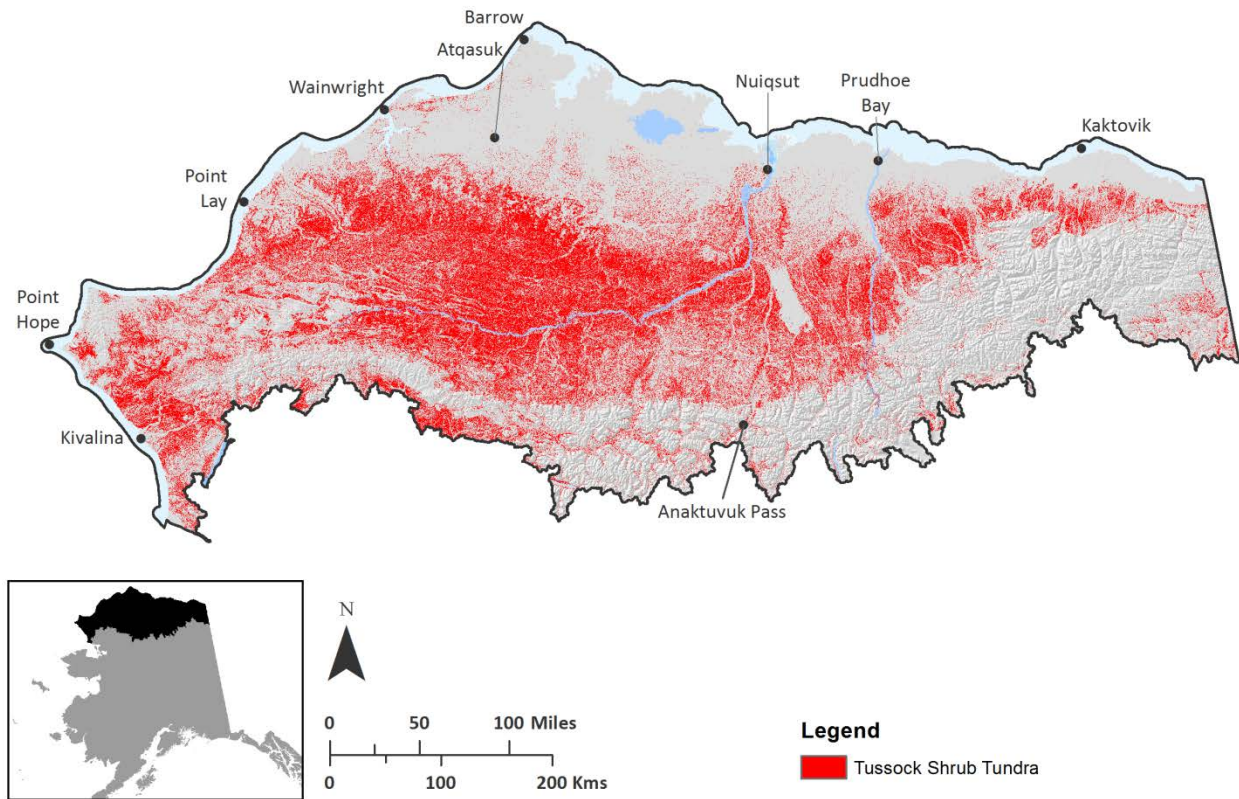


Figure H-29. Distribution of tussock shrub tundra in the North Slope study area.

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

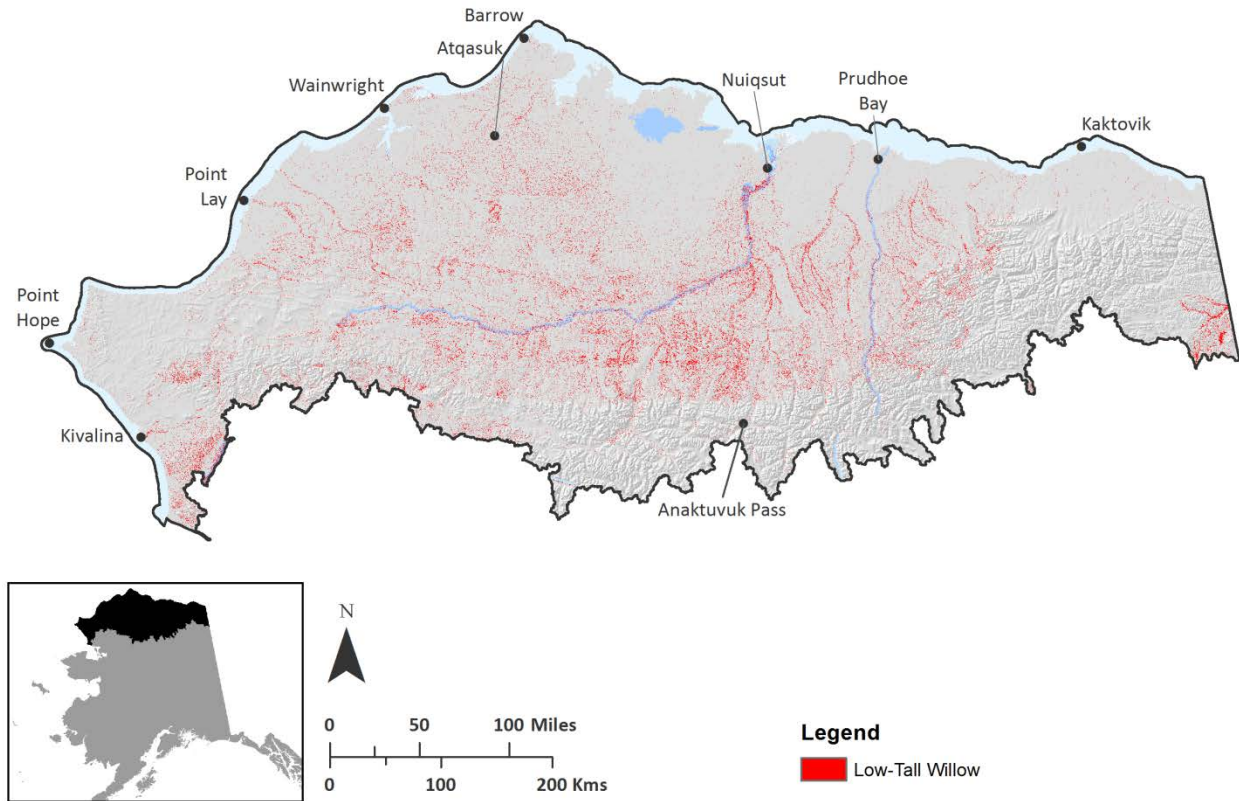


Figure H-30. Distribution of low – tall willow in the North Slope study area.

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

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

Summer Forage Quality

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

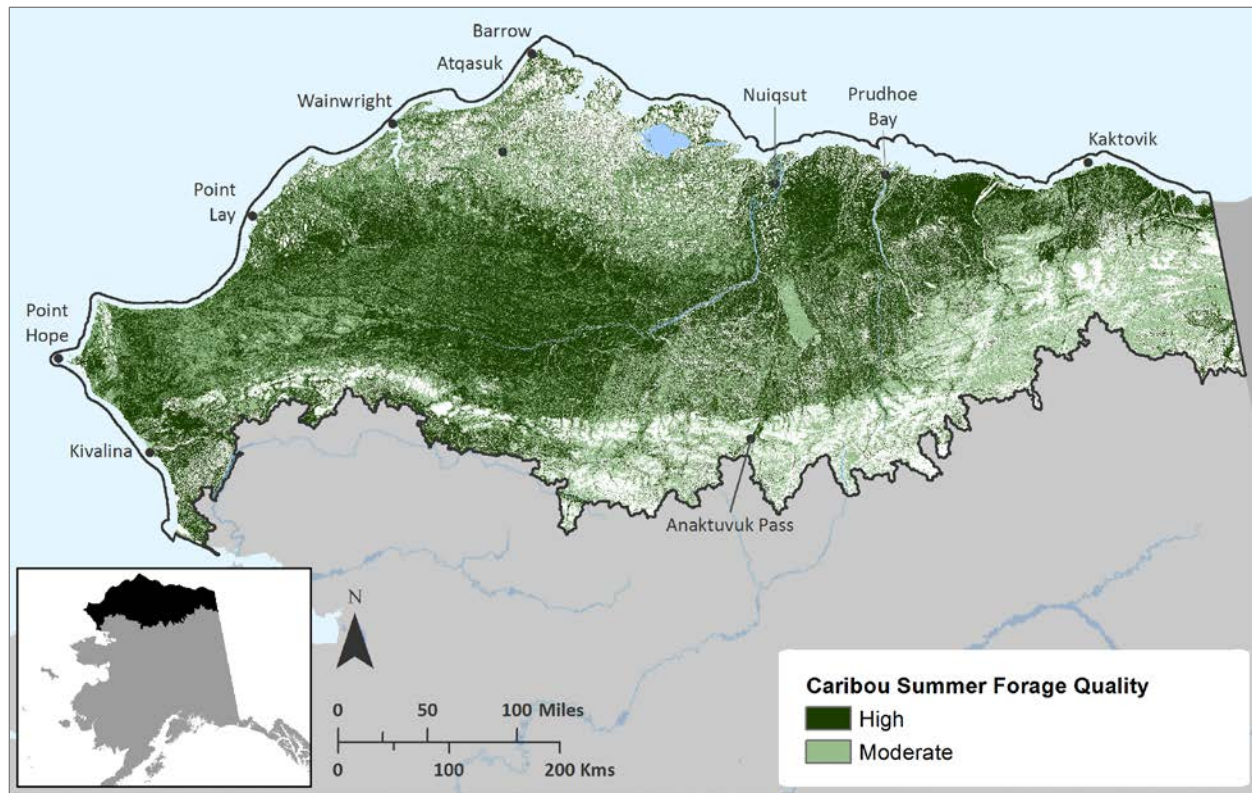


Figure H-31. Good and moderate quality caribou forage during summer (late June through early August) within the North Slope study area.

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

Mesic herbaceous and mesic sedge-dwarf shrub tundra provide high quality forage for caribou during summer. The mesic herbaceous landcover class is a minor component of the study area and contributes much less to the distribution shown in Figure H-32 than mesic shrub-dwarf shrub tundra. These two landcover classes often grade into one another and contain similar species composition. They are

therefore lumped together here. Mesic herbaceous and mesic sedge-dwarf shrub tundra may be more prevalent in Northeast Alaska than Northwest Alaska, and therefore it would likely be more important for the Central Arctic and Porcupine herds. However, this apparent regional distribution may be an artifact of differing regional mapping methodologies. Flat topped polygons are dominated by *Carex aquatilis* and *Salix pulchra* in the centers and *Carex aquatilis* in the troughs. *Salix pulchra*, *S. arctica*, *S. phlebophylla*, *S. reticulata*, and *S. rotundata* are common in these landcover classes. Species diversity is often high at these sites and many forbs consumed by caribou are present.

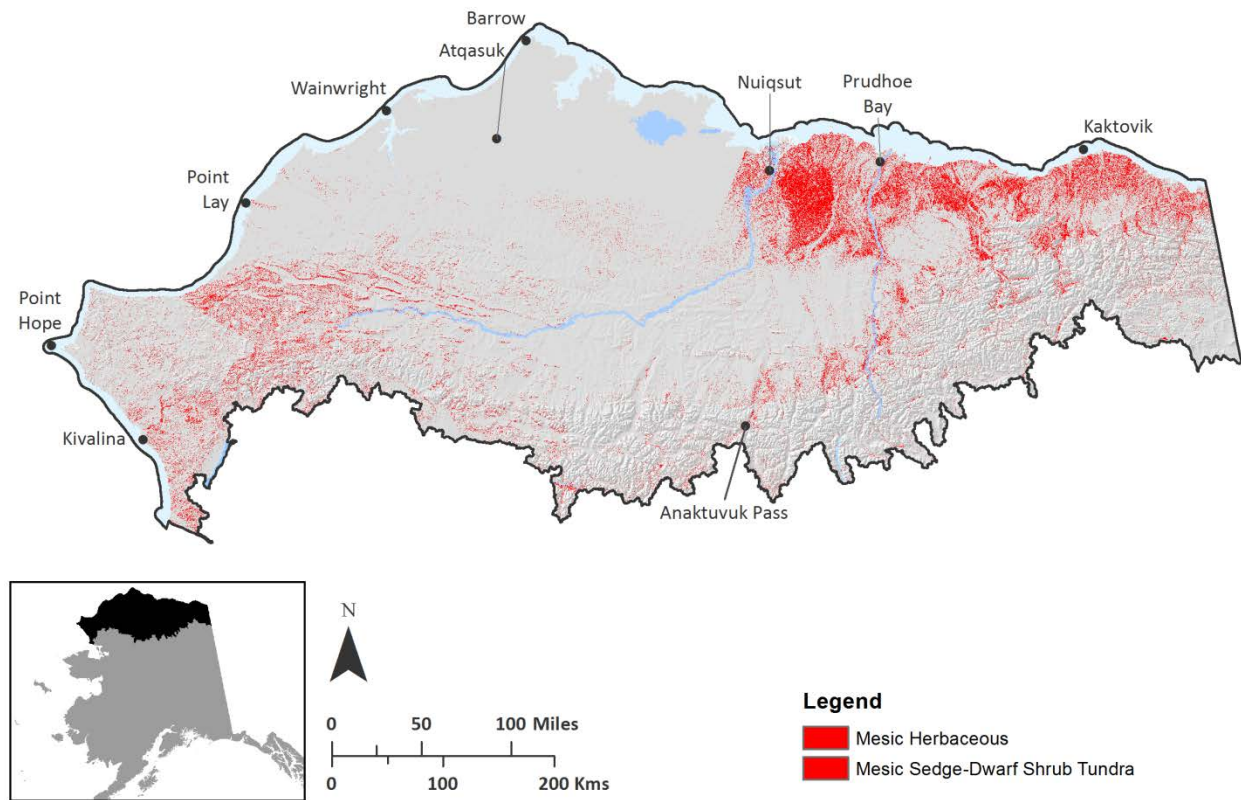


Figure H-32. Distribution of mesic sedge-dwarf shrub tundra and the mesic herbaceous landcover class in the North Slope study area.

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

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

Winter Forage Quality

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

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

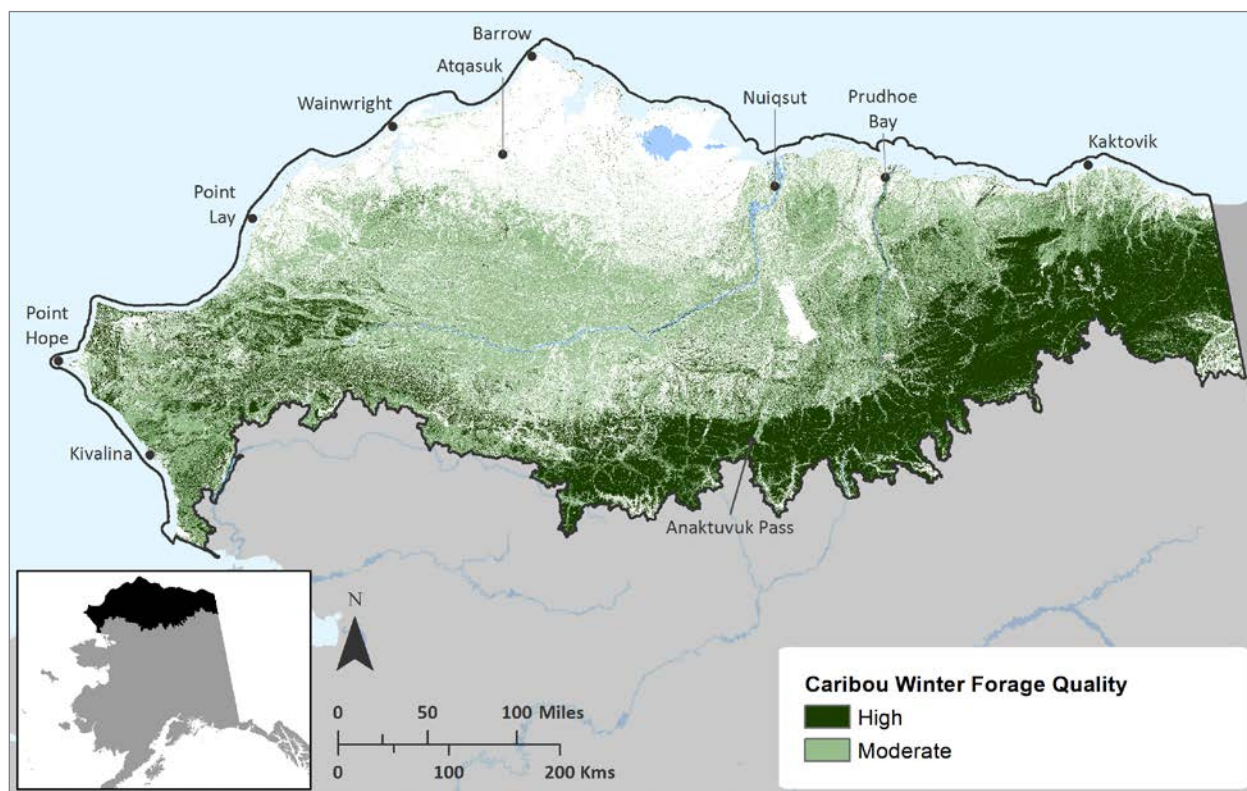


Figure H-33. Good and moderate quality caribou forage during winter within the North Slope study area.

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

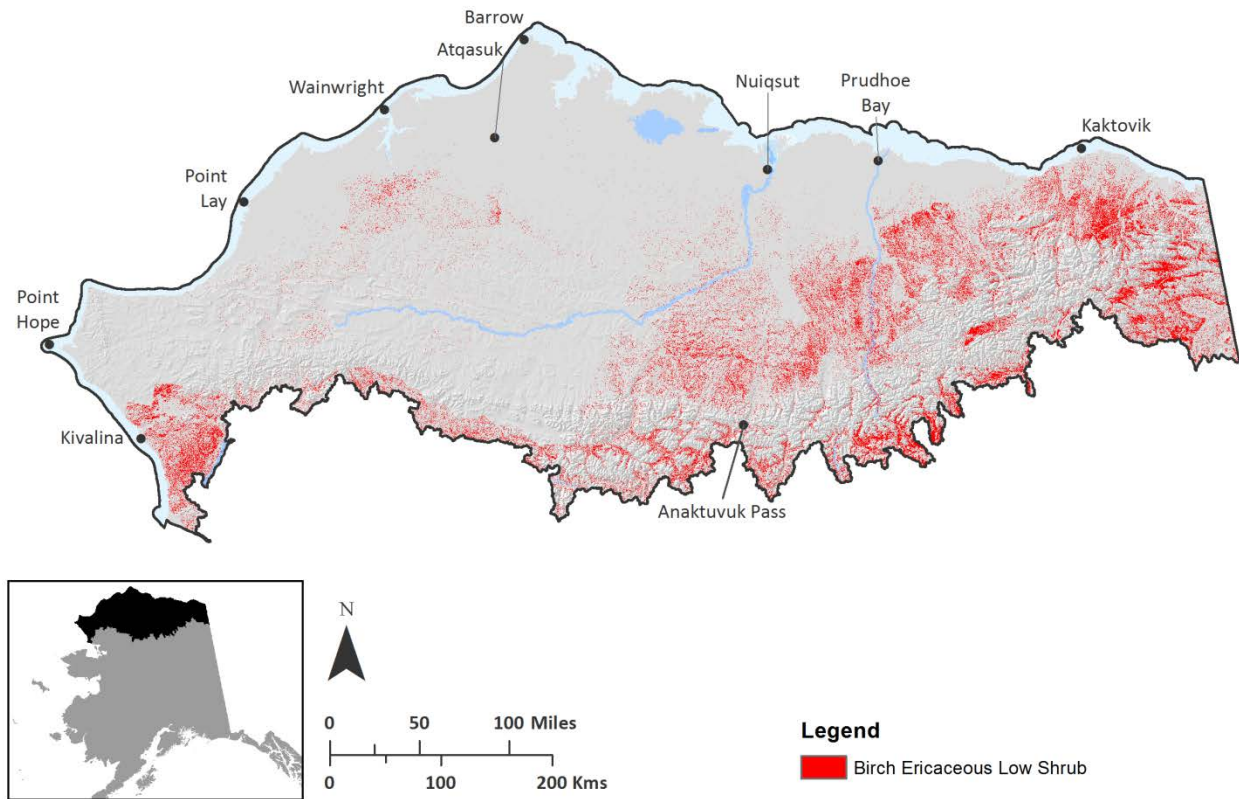


Figure H-34. Distribution of birch ericaceous low shrub in the North Slope study area.

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

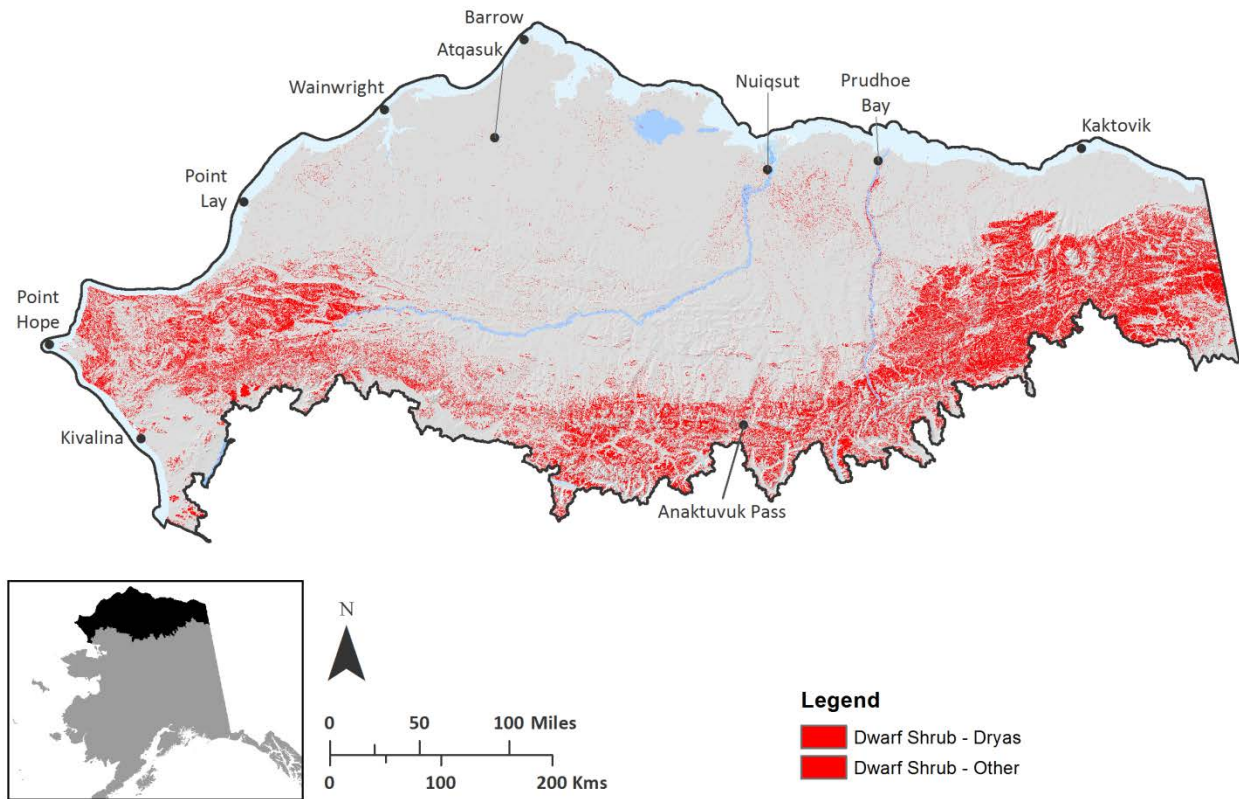


Figure H-35. Distribution of dwarf shrub – *Dryas* and dwarf shrub – other in the North Slope study area.

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

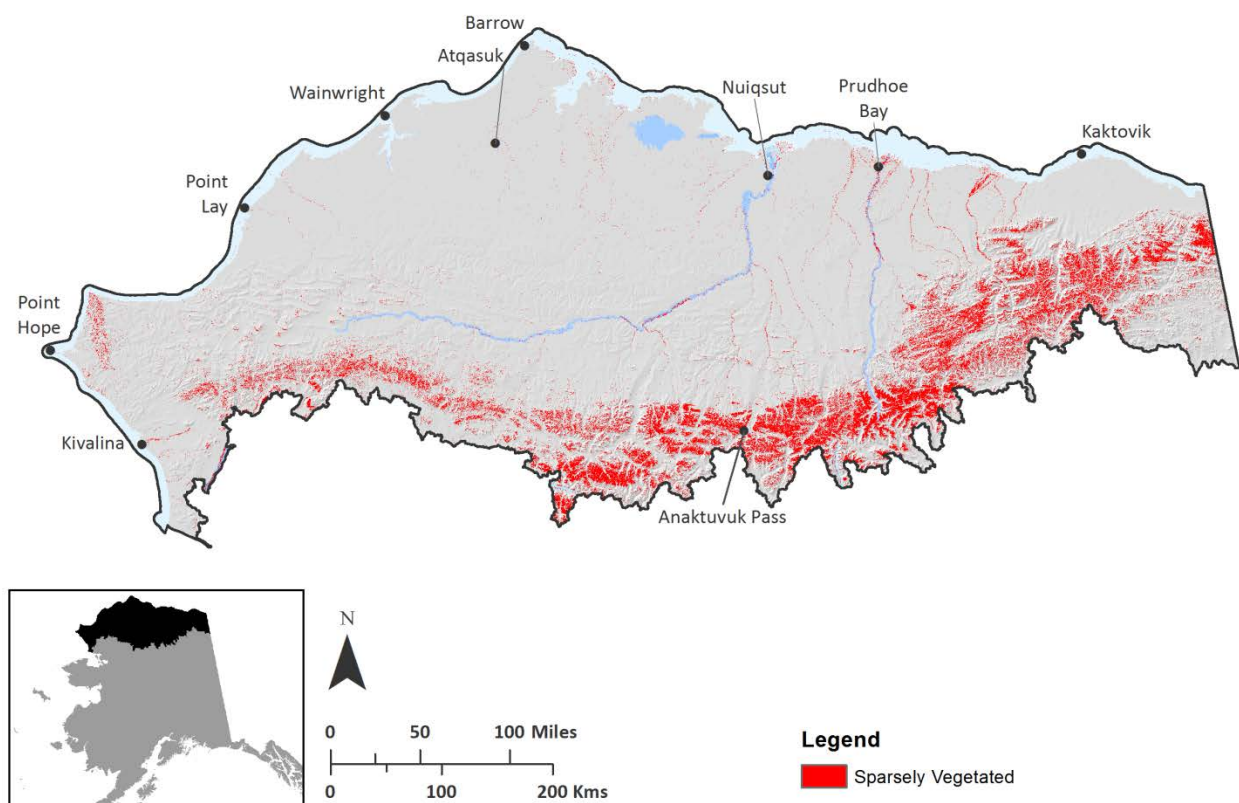


Figure H-36. Distribution of the sparsely vegetated landcover class in the North Slope study area.

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

7.4. Abiotic Change Agent Analysis

Date of Thaw

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

We intersected the calving range map for each of the four north slope caribou herds with modeled outputs for date of thaw (DOT), using DOT as a proxy for onset of snowmelt. DOT refers to the projected date on which the running mean temperature crosses the freezing point in spring. It can be expected to correlate with the condition of ice on rivers, streams, and wetlands, and could have implications for timing of changes in vegetation phenology, as described above. Modeled results indicate that by 2060, DOT is expected to occur between 1 to 5 days earlier across the North Slope study area. For the three

herds that calve on the Arctic Coastal Plain, DOT is only expected to be shifted by 1 to 2 days, while in the southwestern part of the study area, within the calving range of the Western Arctic Herd, DOT may shift from 3 to 5 days earlier (Figure H-37).

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

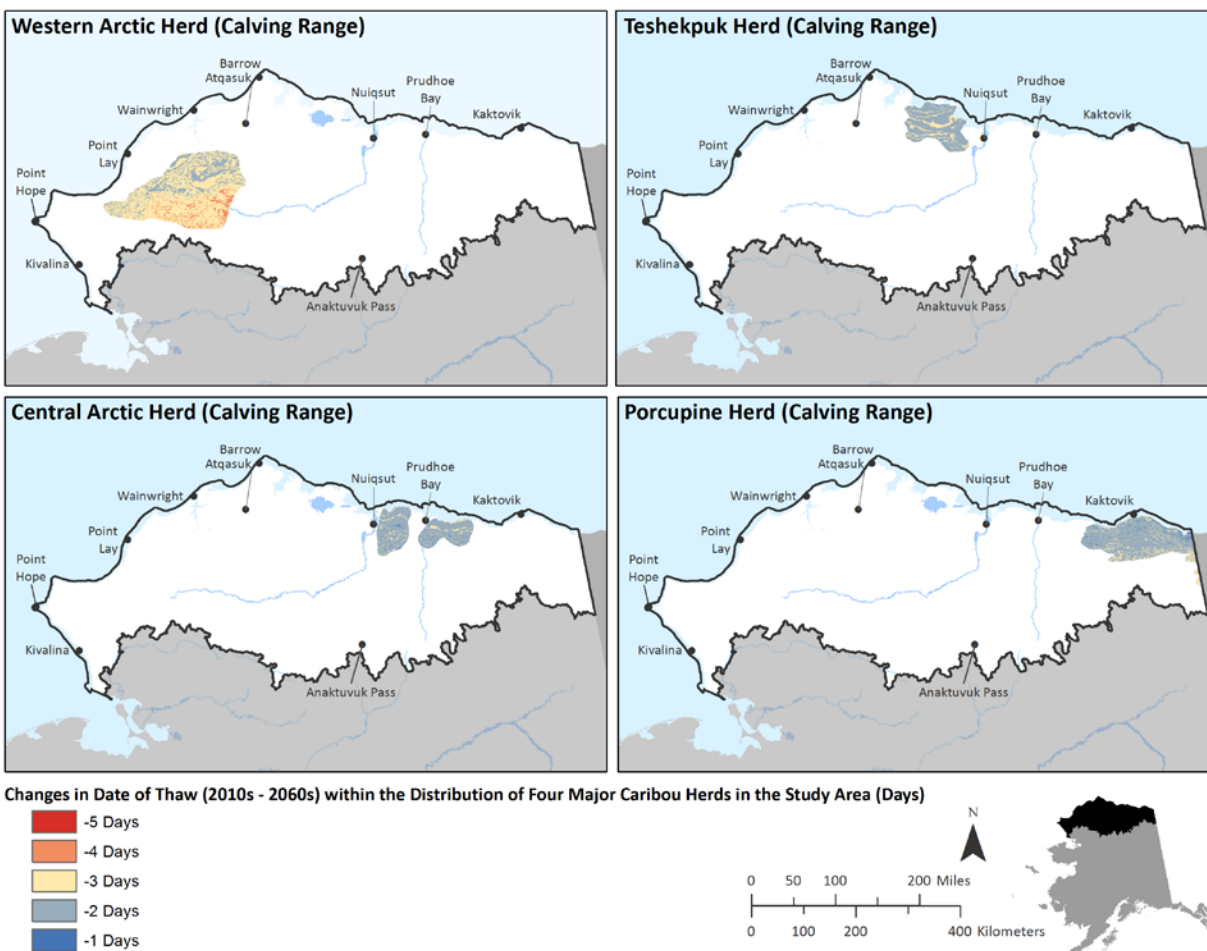


Figure H-37. Change in date of thaw from 2010s to 2060s within caribou calving habitat for the Western Arctic, Teshekpuk, Central Arctic, and Porcupine herds.

Growing Season Length

Climate models (see Section C. Abiotic Change Agents) indicate that warm season length (number of days between DOT and DOF) is projected to increase, on average, anywhere from 10 to 16 days across the North Slope study area, with the smallest increases seen in more southern and inland communities. A longer growing season may benefit caribou on their calving and summer ranges by promoting early onset of vegetation green-up, an increase in nutrient value of summer caribou forage, and an increase in

the duration of time for which summer forage is available. If an earlier availability of nutrients coincides with peak lactation, calf survival will likely increase (Griffith et al. 2002). Increases in growing season length are projected be the most pronounced within the summer range of the Western Arctic and Teshekpuk herds, where growing season in coastal areas is expected to increase by 10 to 14 days by 2060 (Figure H-38).

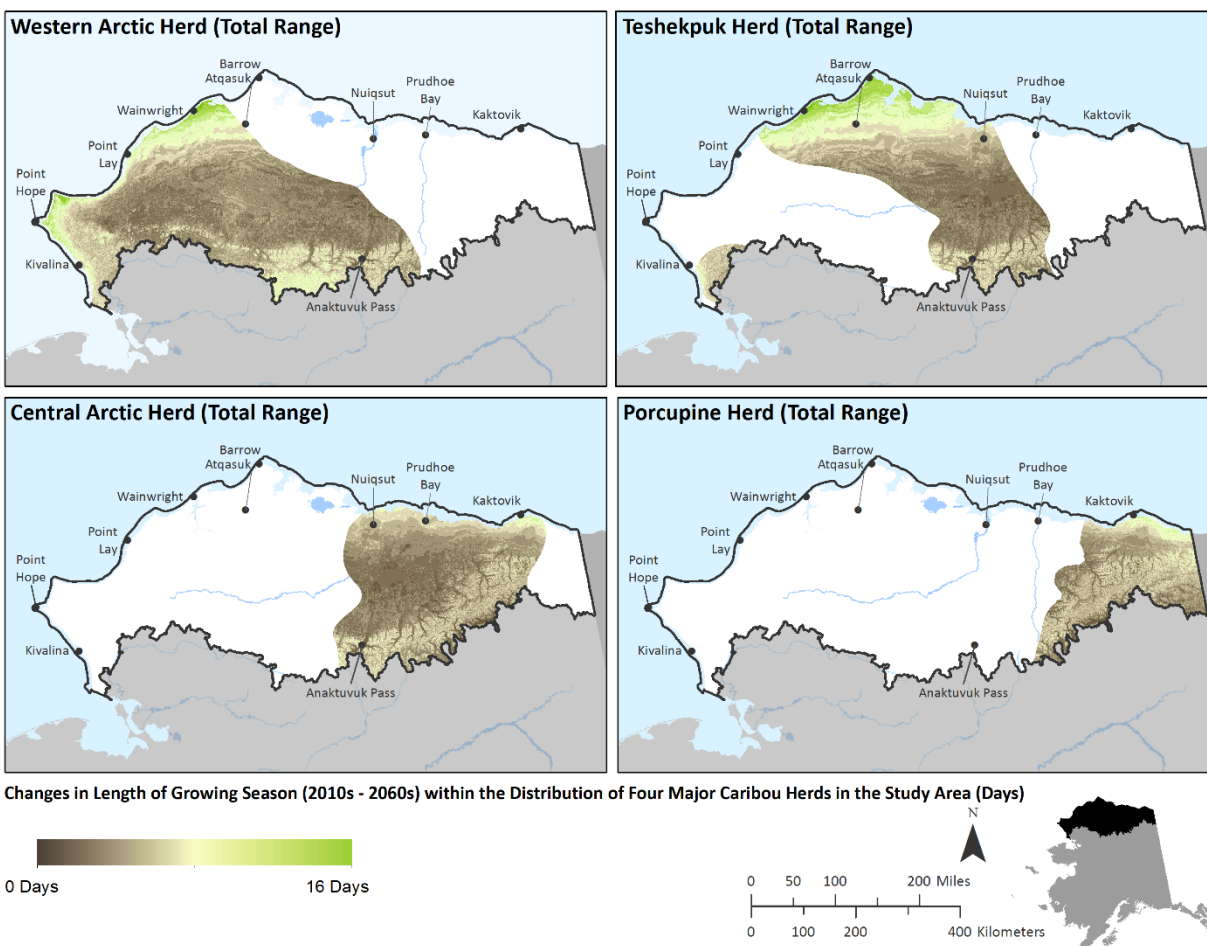


Figure H-38. Change in length of growing season from 2010s to 2060s for Western Arctic, Teshekpuk, Central Arctic, and Porcupine herds in the North Slope study area.

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

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

Snow Day Fraction

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

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

Wildfire

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

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

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

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

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

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

7.5. Limitations

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

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

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

may exist in some areas, high amounts of snow accumulation may make forage in those areas inaccessible for caribou.

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

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8. Lapland longspur (*Calcarius lapponicus*)

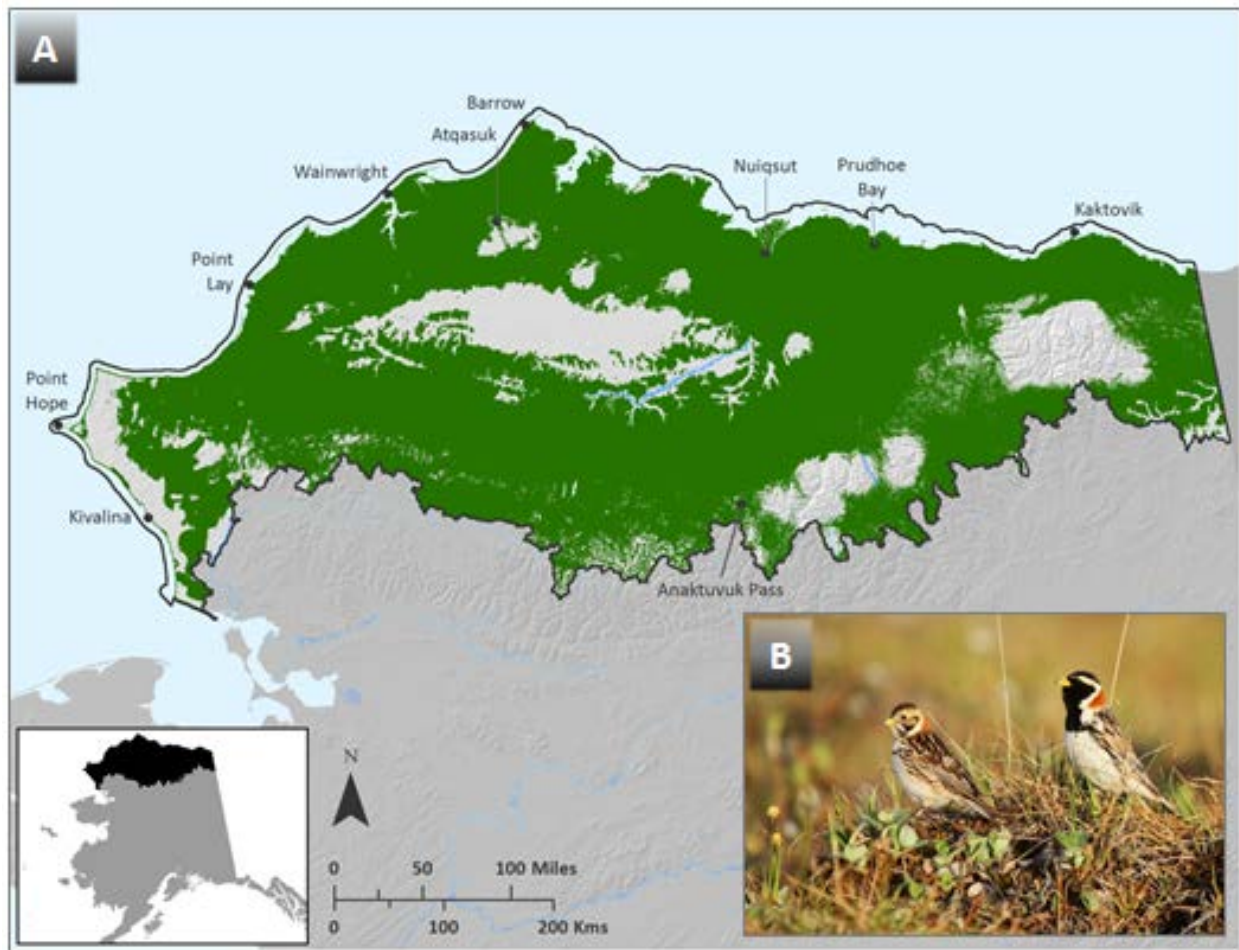


Figure H-39. Current modeled distribution of Lapland longspur (*Calcarius lapponicus*) in the North Slope study area (A) and Lapland longspur male and female at nest (B).

8.1. Introduction

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

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

Seeds, especially on exposed grasses, are a major component of Lapland longspur diets when snow still covers the ground. After snowmelt, Lapland longspurs primarily consume larval dipteran flies until July when adult dipteran flies emerge. During the breeding season, they typically forage in a wide range of habitats on a variety of invertebrates but also consume seeds and other vegetative matter (Hussell and Montgomerie 2002). Preferred foraging habitat often consists of drier upland sites but they will also forage in wet tundra. In August, saw-fly larvae are the most important food source (Custer and Pitelka 1978).

The Lapland longspur is considered a keystone species of arctic ecosystems because of its relation to vegetation stratigraphy, its abundance reflecting the height, nature and extent of willow scrub, and because of its dependence on the phenology and abundance of invertebrate prey and the effects that they have on prey and predator populations (avian and mammalian carnivores) (Christensen et al. 2013). This species is common throughout the Arctic wherever suitable habitat exists; thus, its disappearance from key areas would likely have ecosystem consequences, both as a consumer of arthropods and prey to generalist predators such as Arctic foxes, but also as prey to specialist predators, such as peregrine falcons (*Falco peregrinus*), where declines could have local consequences (ATBMP 2013).

8.2. Conceptual Model

The conceptual model below (Figure H-40) is based on literature review and describes the relationship between the various change agents and natural drivers for the Lapland longspur. The boxes and arrows represent the state of knowledge about the Lapland longspur and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and the Lapland longspur. Change agents selected for this REA and considered in this analysis include: climate change, fire, invasive species, and human use.

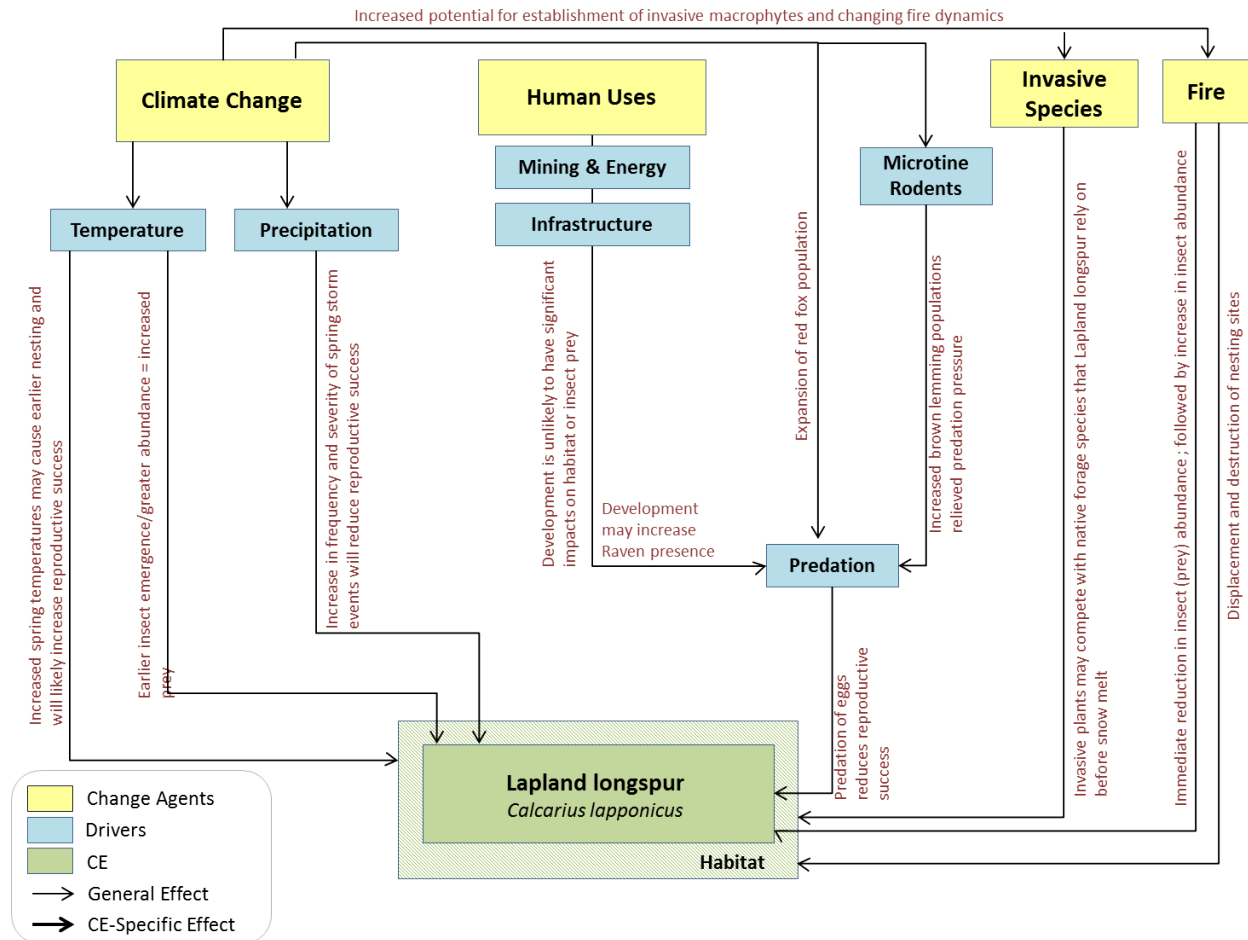


Figure H-40. Conceptual model for the Lapland longspur.

8.3. Attributes and Indicators

Attributes and indicators helped to define the relationships between conservation elements and change agents, and, where possible, the thresholds associated with these relationships. Based on the assessment of available indicators, spatial data used to assess the status of the Lapland longspur included: date of thaw, summer temperature, spring precipitation, and landscape condition (Table H-24).

Table H-24. Attributes and indicators for the Lapland longspur.

CA or Driver	Ecological Attribute	Indicator (unit of measure)	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Habitat availability ¹⁸	Date of thaw (proxy for timing of snowmelt)	Onset of nesting is timed with snowmelt.	Later than average			Earlier than average.
	Food availability ¹⁹	Mean temperature between DOT and DOF	Insect (primary prey) emergence and abundance are directly influenced by mean ambient temperature and number of frost-free days.	Below average			Above average
		Growing season length (#of days between DOT and DOF)		Below average			Above average
Fire	Prey availability; breeding habitat ²⁰	Fire return interval/relative flammability	Population reduced immediately after fire due to reduced insect (prey) abundance, displacement, damaged/burnt nest sites. Following a fire, new vegetation and insect abundance can increase bird diversity and abundance.	High fire return interval			Moderate fire return interval
Anthropogenic	Habitat quality / reproductive success ²¹	Landscape condition model	Risk of predation on passerine bird nests increases within 5 km of human infrastructure. Ravens, a common predator associated with human infrastructure, have a foraging range of 5-7 km.	Human development < 5 km from nesting habitat	Human development 5 - 10 km from nesting habitat		Human development sites > 10 km from nesting habitat

¹⁸ Based on Custer and Pitelka 1977 and Liebezeit et al. 2012.

¹⁹ Based on Bolduc et al. 2013.

²⁰ Based on Wright 1981, Luensmann 2010, and Liebezeit et al. 2012.

²¹ Based on Cannings and Hammerson 2004, Liebezeit et al. 2009, and Støen et al. 2010.

8.4. Distribution Model

We used predictive models generated by the Alaska Gap Analysis Project (AKGAP) to describe the distribution of the Lapland longspur across the North Slope study area (see Section H.1.1 for details relating to AKGAP models). A total of 4,329 occurrence records obtained from the AKGAP occurrence database and the BISON database were used to evaluate the model and generate a classification success statistic (Table H-25).

Lapland longspur are widely distributed throughout the entire study area in appropriate habitat (Figure H-39). Modeled outputs covered > 90% of the species range across the North Slope. Classification success values for the Lapland longspur AKGAP distribution model were 0.95%, indicating high model quality.

Table H-25. Datasets used for the Lapland longspur.

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

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

8.5. Abiotic Change Agents Analysis

We explored the relationship between Lapland longspur and three climatic change agents: date of thaw (DOT), growing season length, and mean summer temperature (JJA) at three time steps (current, near-term, and long-term). Current research indicates that years of late snowmelt could result in delayed breeding and that insect emergence and abundance are directly influenced by mean ambient temperature and number of frost-free days. We also compared the distribution of Lapland longspur to projected relative flammability to assess the effect that fire could have on habitat and forage availability.

Date of Thaw

The onset of nesting for Lapland longspur is timed with snowmelt (Custer and Pitelka 1977). Warmer spring temperatures can expedite snowmelt and create snow-free areas earlier, which could result in earlier nesting dates. The timing of insect emergence is also closely related to the timing of snowmelt, and might advance with warmer spring temperatures (Tulp and Schekkerman 2008). Earlier nesting dates may result in increased reproductive success for Lapland longspur (Liebezeit et al. 2012), as long as the shift in breeding season remains matched to the emergence of surface active insects.

We intersected the distribution map for Lapland longspur with modeled outputs for date of thaw (DOT), using DOT as a proxy for onset of snowmelt. DOT refers to the projected date on which the running mean temperature crosses the freezing point in spring. It can be expected to correlate with the condition of ice on rivers, streams, and wetlands, and could have implications for timing of breeding, breeding success, and changes in vegetation phenology. Modeled results indicate that by 2060, DOT is expected to occur between 1 to 6 days earlier within the current distribution of the Lapland longspur (Figure H-41). In areas of higher nesting densities like the Arctic Coastal Plain, DOT is only expected to be shifted by 1 to 2 days, while in the southern part of the study area, especially in the area adjacent to and west of Anaktuvuk Pass, DOT may be shifted from 4 to 6 days (Figure H-41).

Minimal changes in DOT are not expected to be drastic enough to be an issue for the Lapland longspur. The Lapland Longspur, appears to have adjusted nest initiation in response to climate warming over the last 10 years (J. Liebezeit and S. Zack, unpublished data in Liebezeit et al. 2012), but it is unknown whether this result can be generalized. Discussion of the potential for trophic mismatch in relation to earlier insect emergence is included with the discussion of growing season length and summer temperature, below.

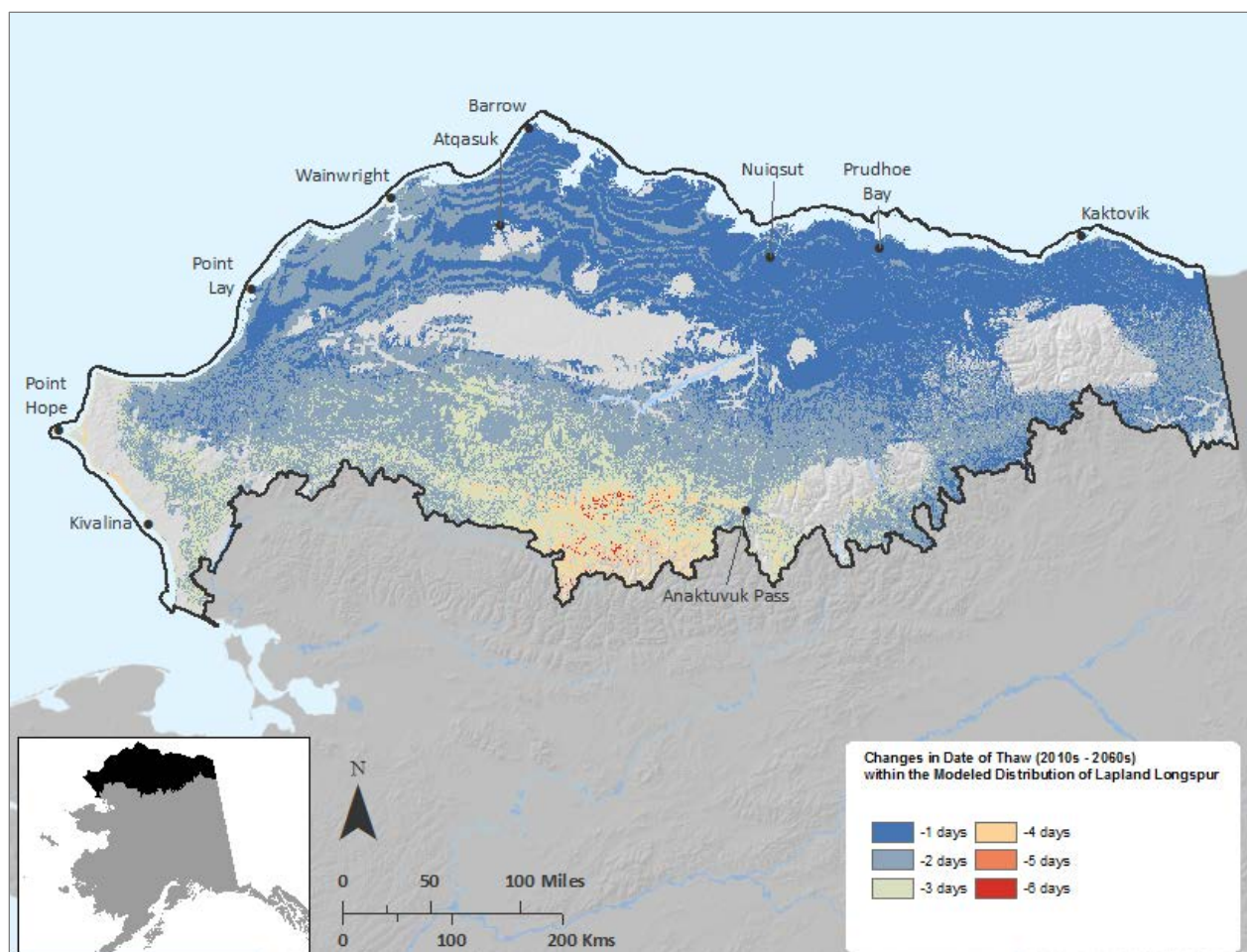


Figure H-41. Modeled decrease in date of thaw (DOT) between 2010s and 2060s within the current distribution of the Lapland longspur.

Length of Growing Season and Summer Temperature

Passerine breeding activity in the Arctic is closely linked with emergence of invertebrate prey (Fox et al. 1987), as described above. In addition to the timing of snowmelt, arthropod presence and abundance is directly influenced by mean ambient temperature and frost-free days (Bolduc et al. 2013). Because arthropods are highly sensitive to climate variation, climate change could affect prey abundance and/or shift the emergence date of insects. A longer growing season combined with warmer ambient temperatures could potentially result in increased insect abundance and more varied insect community composition (Danks 1992, Kittel et al. 2011), which could potentially benefit Lapland longspur by providing more abundant food sources.

Between the current (2010) and the near-term (2020), 100% of the area within the distribution of the Lapland longspur is expected to experience an increase of 0 - 1.3 °C in July temperature (Table H-26). By 2060, significant July temperature increases of > 1.3 °C are projected to occur in over half (57%) the species range (Table H-26). Geographically, warming will be more pronounced in the inland part of the Lapland longspurs distribution, with less change along the coast – similar to results for changes in DOT.

Table H-26. Predicted change over the near-term (2020) and long-term (2060) in abiotic change agents, mean July temperature and length of growing season, within the distribution of the Lapland longspur in the North Slope study area.

Lapland longspur	July Temperature		Length of Growing Season			
	0 - 1.3 °C	> 1.3 °C	< 0 Days	0 - 6 Days	7 - 14 Days	> 14 Days
Near-Term Future	100%	-	100%	-	-	-
Long-Term Future	43%	57%	-	-	98%	2%

Climate models (see Section C. Abiotic Change Agents) indicate that warm season length (number of days between DOT and DOF) is projected to increase, on average, anywhere from 10 to 16 days across the North Slope study area, with the smallest increases seen in more southern and inland communities. For the Lapland longspur, almost 98% of their current distribution is expected to see an increase of between one and two weeks in the growing season, and 2% will see an increase of greater than two weeks (Table H-26). Geographically, increases of > 14 days are only projected for the most northern part of the species range in the coastal margins between Wainwright and Barrow (Figure H-42).

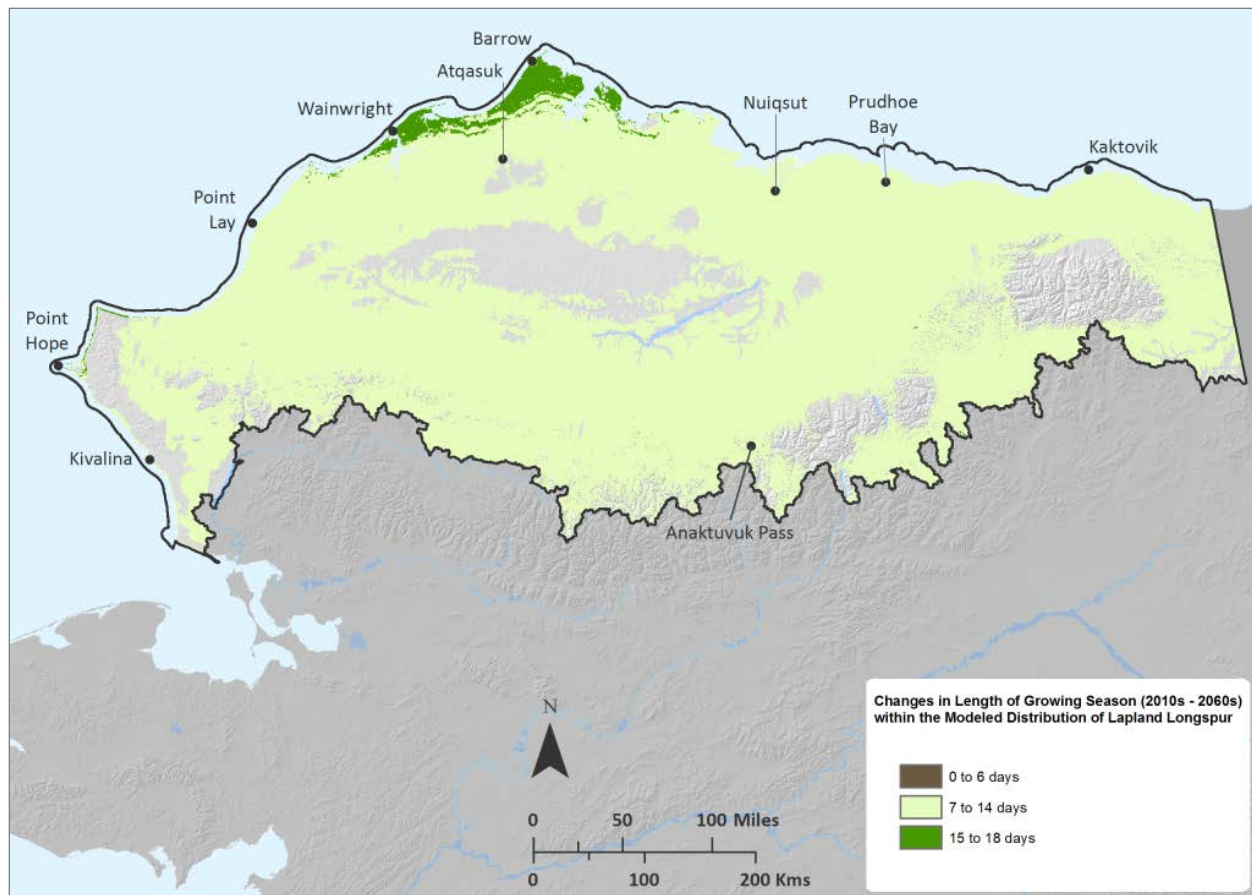


Figure H-42. Predicted change in length of growing season from 2010s to 2060s within the modeled distribution of the Lapland longspur.

A longer growing season, combined with warmer ambient temperatures could be beneficial to Lapland longspur nestling success. Longspurs may actually benefit from a warmer physiographical thermal niche, particularly during the nestling stage when thermo-regulatory capacity is compromised and cold snaps early in the breeding season can be frequent and potentially lethal (Barry 1962 in Liebezeit et al. 2012).

As the timing of seasonal events changes under the influence of climate change, corresponding adjustment in the timing of crucial life-history events for birds (e.g., breeding, migration) becomes an important issue. Although a longer growing season combined with warmer ambient temperatures could result in insect prey increases, shifts in the timing of insect emergence brought on by an earlier growing season could also be potentially deleterious to Lapland longspur survival if the insect outbreaks are not synchronous with migration and breeding events. Some evidence indicates that Lapland Longspurs are able to track phenological changes associated with a warming climate at least in terms of nest initiation (J. Liebezeit and S. Zack, unpublished data) suggesting they may be able to compensate for a warming climate, at least in terms of nest timing. However, their ability to cope with decoupling of nest initiation and other events is unknown (Liebezeit et al. 2012). At present, we lack information on changes in the timing of arrival of Lapland longspur to make determinations as to whether earlier insect emergence would result in a trophic mismatch.

Fire

Lapland longspurs are the dominant nesting bird within sedge tussock-shrub tundra, which covers more area than any other plant community in northwestern Alaska (Wright 1981). Historically, fire in sedge tussock-shrub tundra has resulted in a reduction of breeding Lapland longspurs the following year (Wright 1981). The following activities were indicated as factors and mechanisms for reduced bird abundance immediately following a fire: direct burning deterred settling of birds; males established larger breeding territories post fire; reduction of prey abundance; and elimination of nest sites from direct burning (Wright 1981). However, long-term post-fire effects are not reported.

Fire frequency across the North Slope study area is predicted to increase by the 2060s. However, most of the North Slope study area is likely to remain relatively free of fire, although sporadic tundra fires may occur in all sub-regions (see Section C. Abiotic Change Agents). Recent analyses suggest that changes in fire frequency on Alaska's landscapes may be driven at least as much by climate-induced changes in vegetation as they are by climate-induced changes in fire frequency (Starfield and Chapin 1996). The ALFRESCO model (described under the CA Fire Section) is directly linked to both climate and vegetation, and is also capable of modeling shifts in between-fire and post-fire trajectories of succession that are climate-derived. ALFRESCO outputs of projected vegetation change indicate that shrub habitats will increase by 2060 throughout much of the study area, with highest increases in the Brooks Range Ecoregion (Figure H-43). During the past 25 years (1988-2012), passerines associated with shrub habitats have increased across the tundra on the Seward Peninsula (McNew et al. 2013). It seems likely that increases in shrub habitats would be beneficial to Lapland longspur, although broad-scale expansion of shrub communities at the expense of wet sedge tundra and moist sedge-shrub tundra on the Coastal Plain could reduce preferred breeding habitat (Martin et al. 2009).

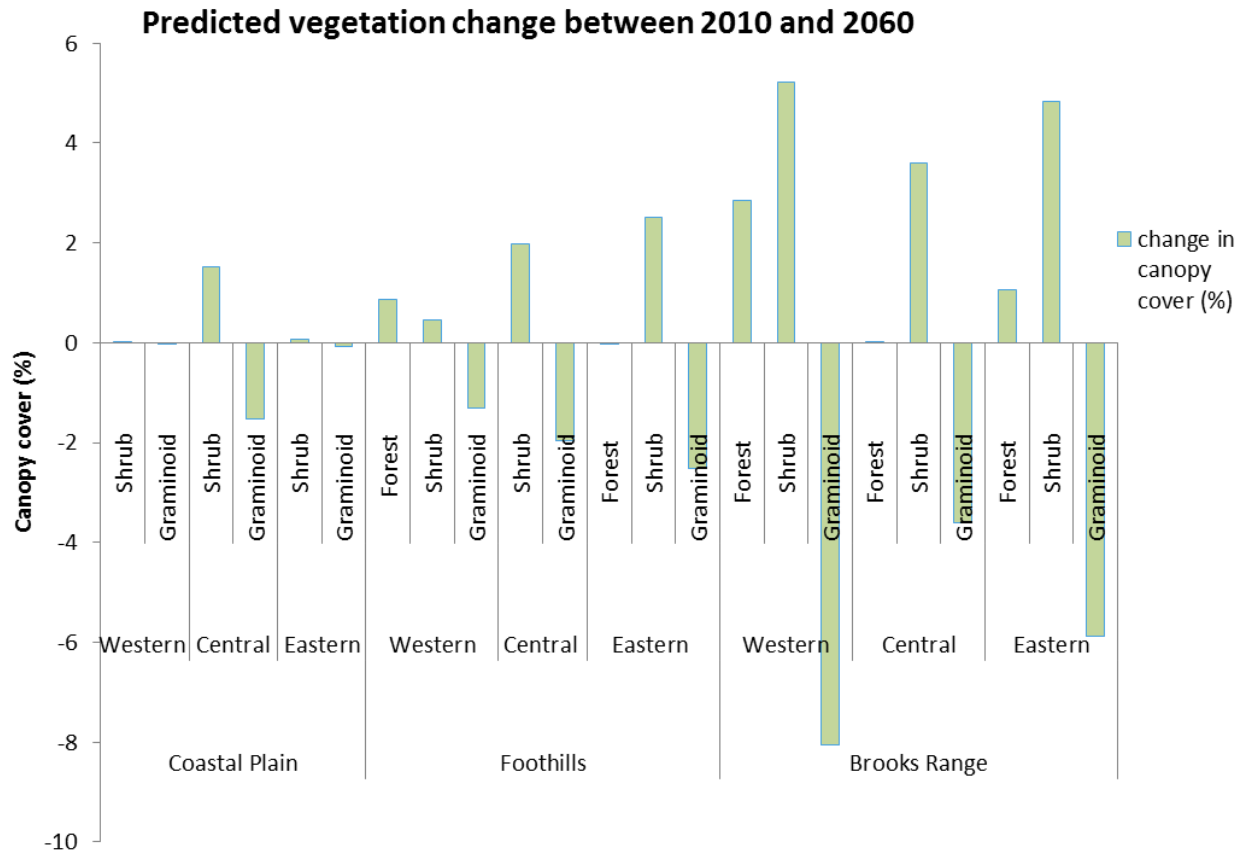


Figure H-43. Projected vegetation change (based on ALFRESCO modelling) by ecological sub-region in the North Slope study area.

Climate Summary

Overall, our assessment of abiotic climatic variables suggests that Lapland Longspurs could benefit and possibly increase under the current predictions of climate change during the 50-year timeframe of this assessment. Potential benefits include increased habitat due to climate-driven shrubification (both post-fire and without fire); decreased cold-related mortality early in the breeding season, due to warmer air temperatures; and more abundant and varied food sources, due to a longer and warmer growing season (Table H-27).

Table H-27. Summary of abiotic change agents used in the assessment for Lapland longspur and projected effects.

Indicator	Short-term (2020) trend	Long-term (2060) trend	Impact to	Effect
Date of thaw	No change	earlier	Earlier nesting, increased insect prey, increased reproductive success, potential for trophic mismatch	+
Growing season length	No change	+	Increases in insect prey, improved nestling success, potential for trophic mismatch	+/-
Summer temperature	Non-significant	+	Increases in insect prey	+
Fire	-	+	Short-term habitat loss, potential long-term gains	+/-

8.6. Current Status and Future Landscape Condition

The intersection of the Lapland longspur distribution map with the Landscape Condition Model indicates that the majority of habitat in the North Slope study area is classified as being in very high (intact) condition under all scenarios (Figure H-44). Potential threats as a result of increased development related to oil and gas infrastructure include potential increases in predation by ravens, as ravens are known to prey on Lapland longspur nestlings (Fox et al. 1987; Støen et al. 2010). Some evidence has suggested that ravens and foxes become more numerous in areas of human development because of the presence of additional food sources and artificial nesting/denning sites (Day 1998). While recent improvements to waste handling procedures associated with oil field infrastructure have likely dampened this effect in oil fields (Liebezeit et al. 2009), this may still be a concern in areas of other development.

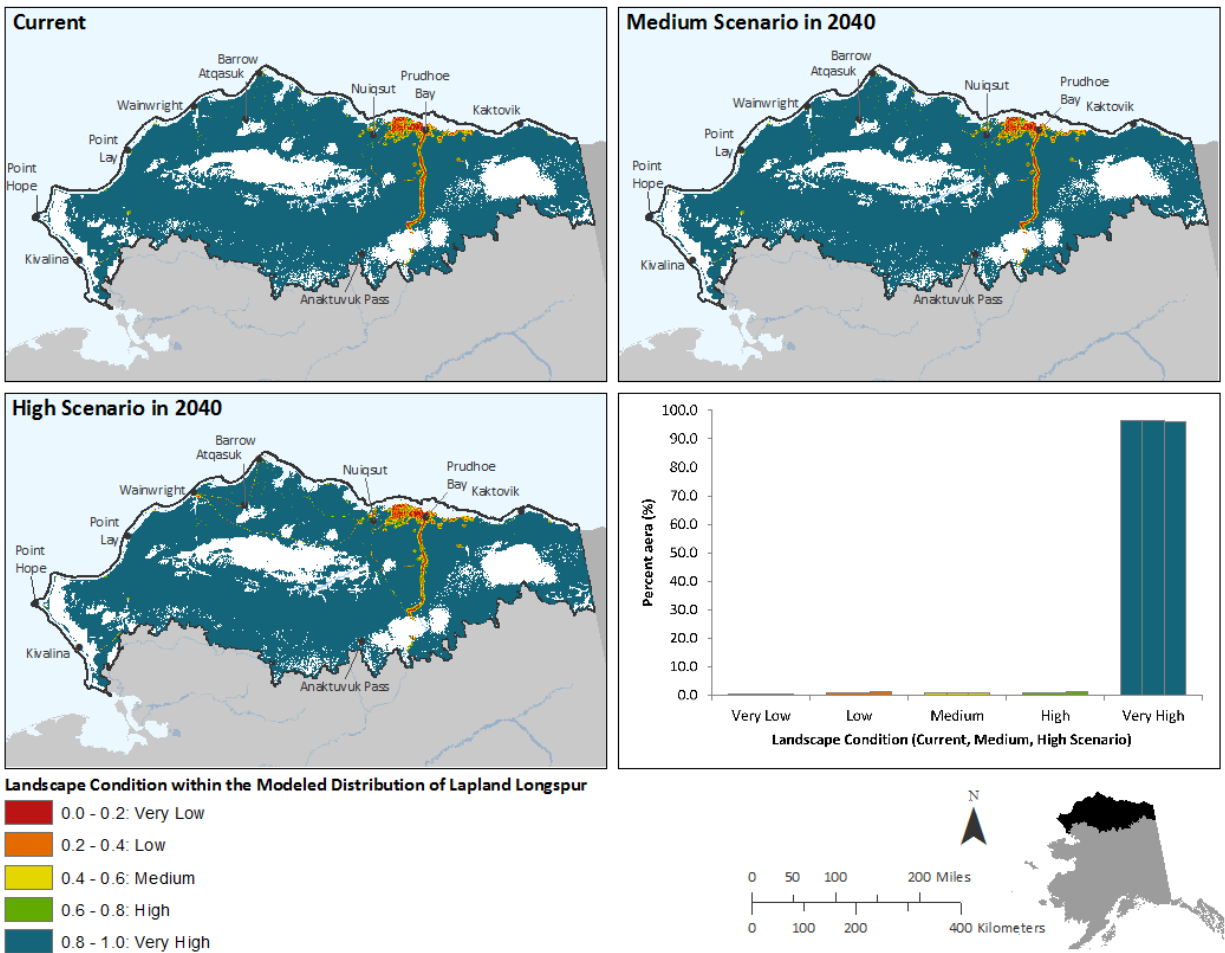


Figure H-44. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current distribution of Lapland longspur in the North Slope study area.

Currently, the degree of nest predation varies greatly from year to year. In years of low lemming abundance, predation by avian and mammalian predators on Lapland longspur increases, resulting in reduced reproductive success (Custer and Pitelka 1977). Breeding pairs that lose nests to predators rarely re-nest in the same season (Wingfield and Hunt 2002).

8.7. Limitations and Data Gaps

We lacked a suitable spatial layer to explore the relationship between spring storm events and Lapland longspur distribution. In West Greenland, Fox et al. (1987) reported that Lapland Bunting clutch size was depressed in years of climatic severity. Additionally, extreme weather events may change the activity patterns and availability of surface-active insects. A decrease in insect prey abundance during the Lapland longspurs reproductive period could have negative consequences.

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9. Baseline Data for Landbirds

MQ TF 1	What are the baseline data for the species composition, number of individuals, vegetation type used, and change in number/species composition of landbirds and their habitat over time?
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9.1. Introduction

The avifauna of arctic Alaska is dominated numerically by waterfowl and shorebirds for which there are numerous long-term region-wide datasets available to assess species composition, distribution, trends and habitat use. However, this is not the case for landbirds, whose distributions are often more dispersed than waterbirds and shorebirds, and survey data tend to be more localized and disparate. This management question required that we obtain and assemble baseline information from historical and contemporaneous avian surveys to produce a spatial data layer that identified the distribution and species composition of landbirds (passerines) across the North Slope study area. Because many of these studies utilized diverse survey methods, study areas, and target taxa, they were not directly comparable and did not allow us to assess changes in the number/species composition and habitats over time, as this would have required substantial effort to standardize the data and produce relative abundance or density estimates, which was beyond the scope of the REA. During the North Slope REA Methods Workshop, the AMT agreed that a compilation of existing occurrence data sources and production of an associated spatial data layer would fulfill the requirements for this MQ.

9.2. Methods

We gathered baseline data from numerous and disparate avian breeding surveys across the North Slope, many that utilized different observers, survey methods, and objectives. We then summarized the data into a common format, attributed with 39 common fields, and housed this information in a project specific geodatabase. We produced a spatial data layer depicting species distribution and species composition. We then compared avian distribution information to an existing map of vegetative classes and identified those vegetation types (NSSI landcover classes) that have been surveyed for passerines with the most frequency during the time period of the data collection. The general methods for developing spatial products for landbird distribution are shown in the process model below (Figure H-45).

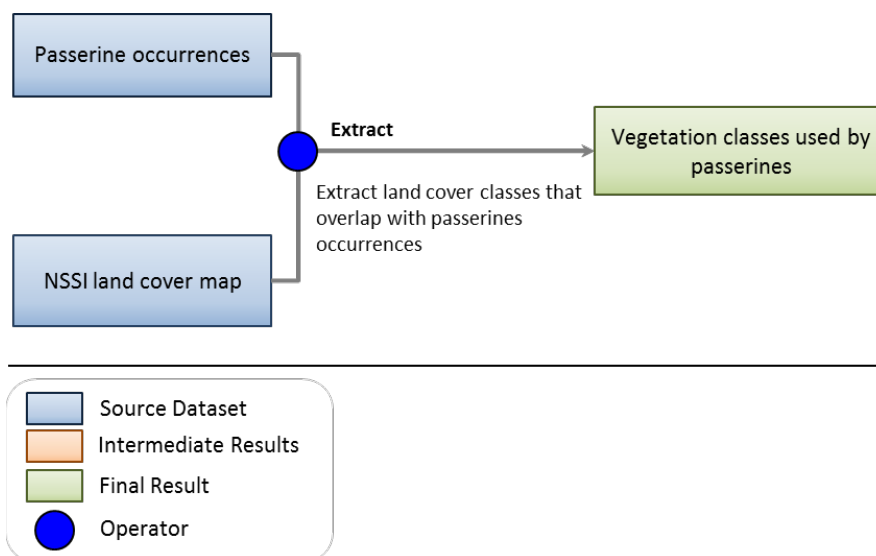


Figure H-45. Process model for MQ TF 1.

Table H-28. Data sources included in the development of the baseline landbird database for the North Slope REA.

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9.3. Results

All occurrence data used to answer this question were obtained from the [Alaska Gap Analysis Project](#). This included 14,508 occurrence records for 59 species from 40 unique data sources, spanning the time period 1948 to 2009 (Table H-28). Although the data spanned the time period 1948 to 2009, the majority of data (90%) were collected between 1990 and 2009. Although many avian surveys have occurred in the North Slope study area prior to 1990, the goal of this assessment was to obtain as much high quality information as was possible within the constraints of project resources. As such, we sought out digital datasets that were easy to manipulate and reproduce spatially. Much survey data collected prior to 1990 exist primarily in project reports and were not generally available in digital format.

Geographically, passerine survey data were available from throughout the North Slope study area (Figure H-46). The majority of surveys occurred along roads, in riparian areas, or adjacent to population centers of Barrow, Nuiqsut, and Prudhoe Bay, likely due to ease of accessibility. Survey data from the Brooks Foothills ecoregion was the most limited in scope.

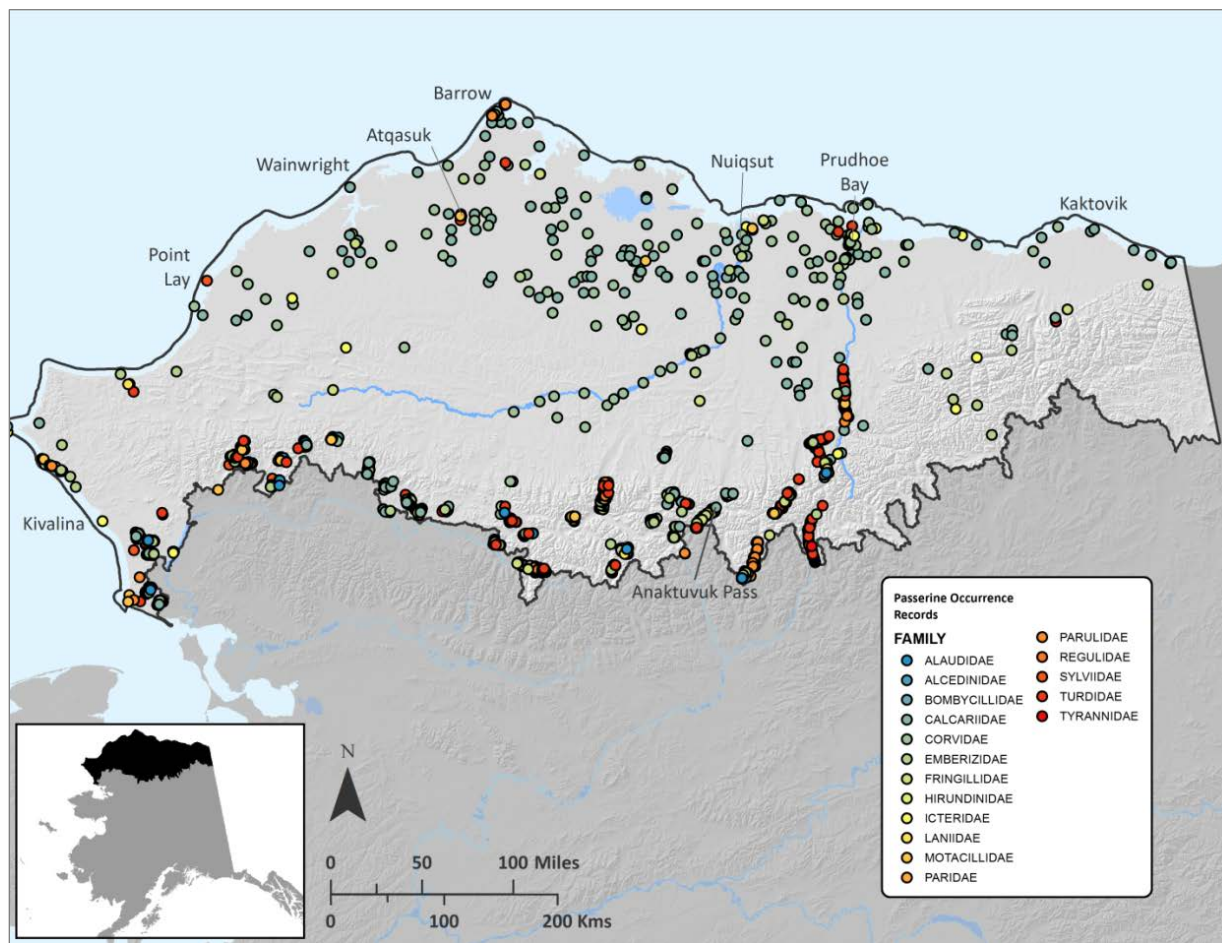


Figure H-46. Location of baseline passerine survey data for the time period 1948-2009. This dataset includes 14,508 occurrence records for 59 passerine species from 40 unique data sources.

Species composition

Because of the complexity involved with standardization of so many disparate datasets, we did not calculate relative abundance or provide density estimates for each species. Instead, we calculated species composition based solely on the total number of detections across all studies.

A total of 59 species from 17 families were detected in all surveys combined (Table H-29). Lapland longspur, savannah sparrow, American tree sparrow, and white-crowned sparrow were the most commonly detected species, all having > 1500 detections (Figure H-47). Common redpoll and American robin had between 100 and 1500 detections. Twenty-two of the 59 species had fewer than 20 detections (denoted by * in Table H-29). These species are likely uncommon to rare on the North Slope or detection probability may be low.

Table H-29. Passerine species composition by family (in bold) for all survey data combined for the time period 1948 – 2009. An asterisk* denotes species with fewer than 20 detections.

ALAUDIDAE	LANIIDAE
Horned lark	Northern shrike*
ALCEDINIDAE	MOTACILLIDAE
Belted kingfisher*	American pipit
BOMBYCILLIDAE	Eastern yellow wagtail
Bohemian waxwing*	Red-throated pipit*
CALCARIIDAE	PARIDAE
Lapland longspur	Black-capped chickadee*
Smith's longspur	Boreal chickadee
Snow bunting	Gray-headed chickadee*
CORVIDAE	PARULIDAE
Blackbilled magpie*	Blackpoll warbler
Common raven	Northern waterthrush
Gray jay	Orange-crowned warbler
Northwestern crow*	Townsend's warbler*
EMBERIZIDAE	Wilson's warbler
American tree sparrow	Yellow warbler
Dark-eyed junco	Yellow-rumped warbler
Fox sparrow	REGULIDAE
Golden-crowned sparrow	Ruby-crowned kinglet
Lincoln's sparrow	SYLVIIDAE
Savannah sparrow	Arctic warbler
White-crowned sparrow	TURDIDAE
FRINGILLIDAE	American robin
Common redpoll	Bluethroat
Gray-crowned rosyfinch	Gray-cheeked thrush
Hoary redpoll	Hermit thrush*
Pine grosbeak*	Mountain bluebird*
Pine siskin*	Northern wheatear
White-winged crossbill	Swainson's thrush
HIRUNDINIDAE	Townsend's solitaire*
Bank swallow*	Varied thrush
Barn swallow*	TYRANNIDAE
Cliff swallow*	Alder flycatcher
Tree swallow*	Olive-sided flycatcher
Violet-green swallow*	Says phoebe*
ICTERIDAE	
Brown-headed cowbird*	
Red-winged blackbird*	
Rusty blackbird	

Passerine Detections, 1948 - 2009

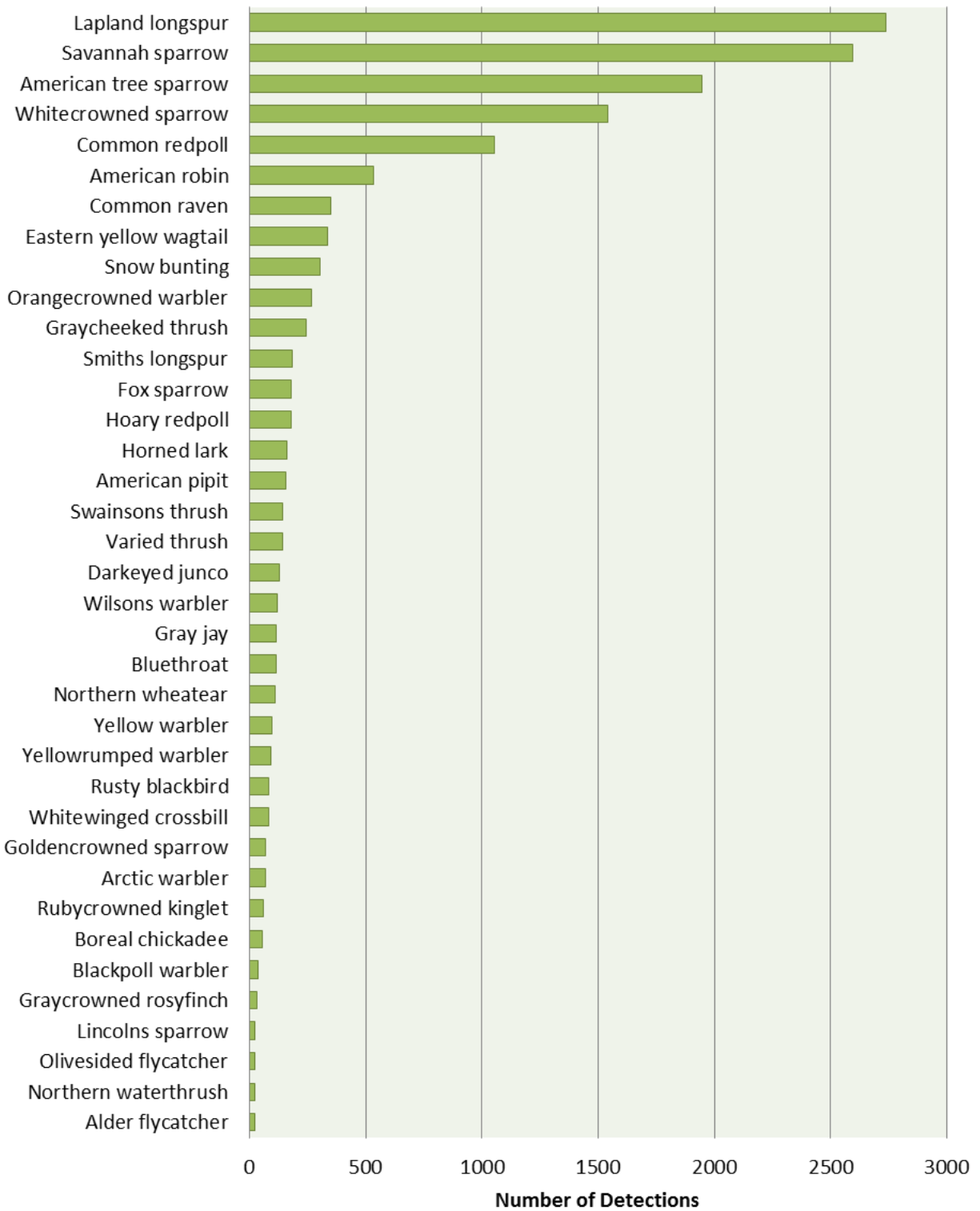


Figure H-47. Species composition and number of detections by species for all survey locations combined, 1948 – 2009.

Vegetation type used

Habitat information associated with the avian occurrence data was inconsistent, as many different techniques and multiple vegetation classification systems were used to quantify habitats in the various surveys. As a mechanism to assess “vegetation type used” by each of the passerine species in a systematic way, we intersected the passerine occurrence data layer with the NSSI landcover map and summarized landcover classes by avian occurrence. Shrub habitats, including tussock shrub tundra, mesic sedge-dwarf shrub tundra, birch ericaceous low shrub, and low and tall willow habitats had the greatest number of landbird occurrences associated with them (Figure H-48), which is consistent with general knowledge of passerine habitat use on the north slope (Martin et al. 2009).

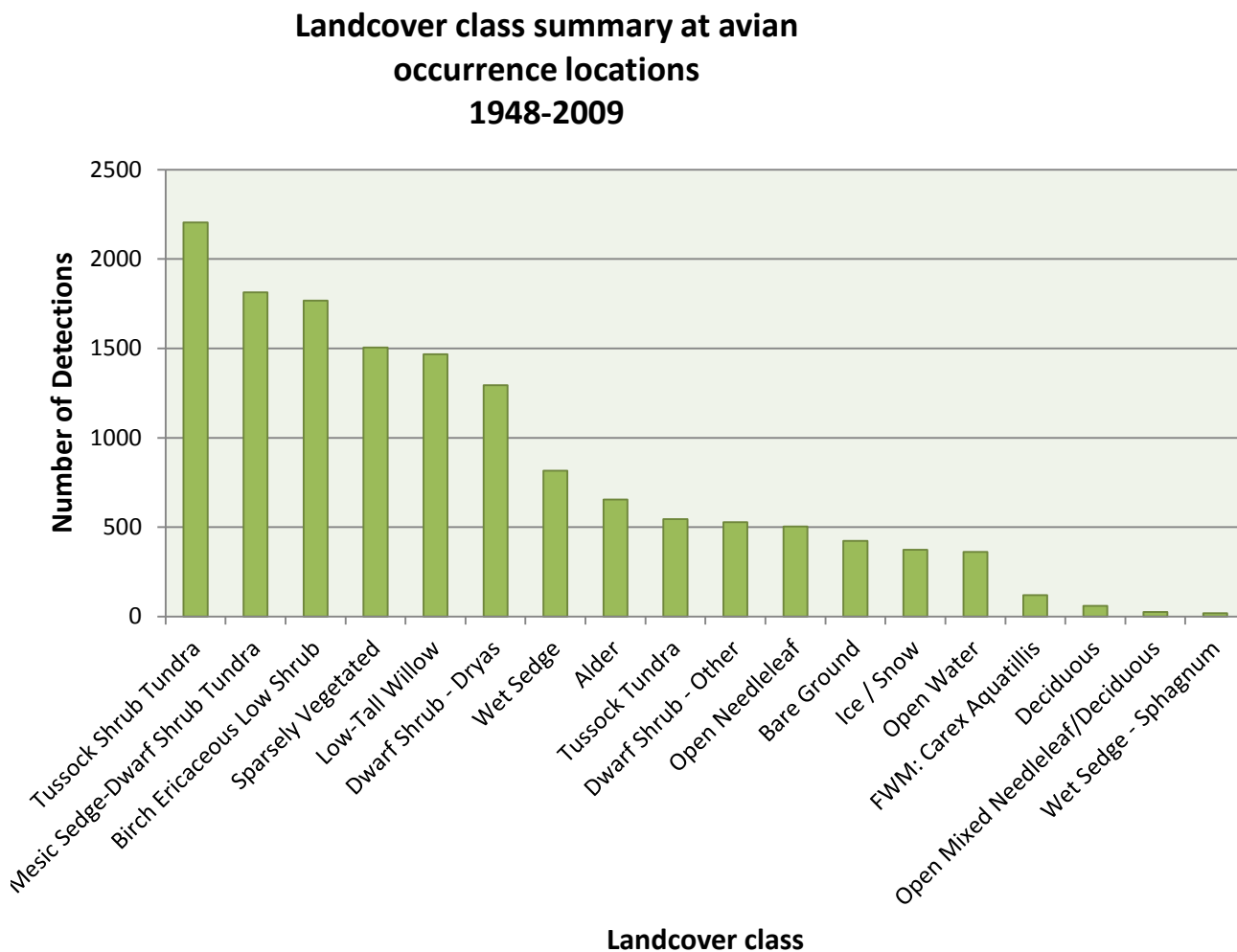


Figure H-48. NSSI landcover class summary at avian occurrence locations.

ALFRESCO outputs of projected vegetation change indicate that shrub habitats will increase by 2060 throughout much of the North Slope study area, with highest increases in the Brooks Range Ecoregion. During the past 25 years (1988-2012), passerines associated with shrub habitats have increased across

the tundra on the Seward Peninsula (McNew et al. 2013). It seems likely that increases in shrub habitats would be beneficial to passerines on the North Slope as well, although broad-scale expansion of shrub communities at the expense of wet sedge tundra and moist sedge-shrub tundra on the Coastal Plain could reduce preferred breeding habitat for some species (Martin et al. 2009).

9.4. Limitations

The data presented here provide a baseline of information on passerine distribution and species composition on the North Slope, but are likely far from complete. As described above, much of the avian survey data collected prior to 1990 exists primarily in project reports and was not available in digital format for this analysis. This is an obvious limitation in using this data to address changes in species composition over time, as it is highly biased toward more contemporary conditions.

Datasets that were not available in digital format but would have greatly improved this assessment include:

- Andersson, M. 1973. Birds of Nuvagapak Point, northeastern Alaska. *Arctic* 26:186-197.
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Additionally, spatial data from the Alaska Landbird Monitoring Survey (<http://alaska.usgs.gov/science/biology/bpif/monitor/alms.php>) was not included in our mapping for sensitivity reasons, which would have filled in many gaps in areas not accessible by river or road.

9.5. Literature Cited

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10. Willow Ptarmigan (*Lagopus lagopus*)

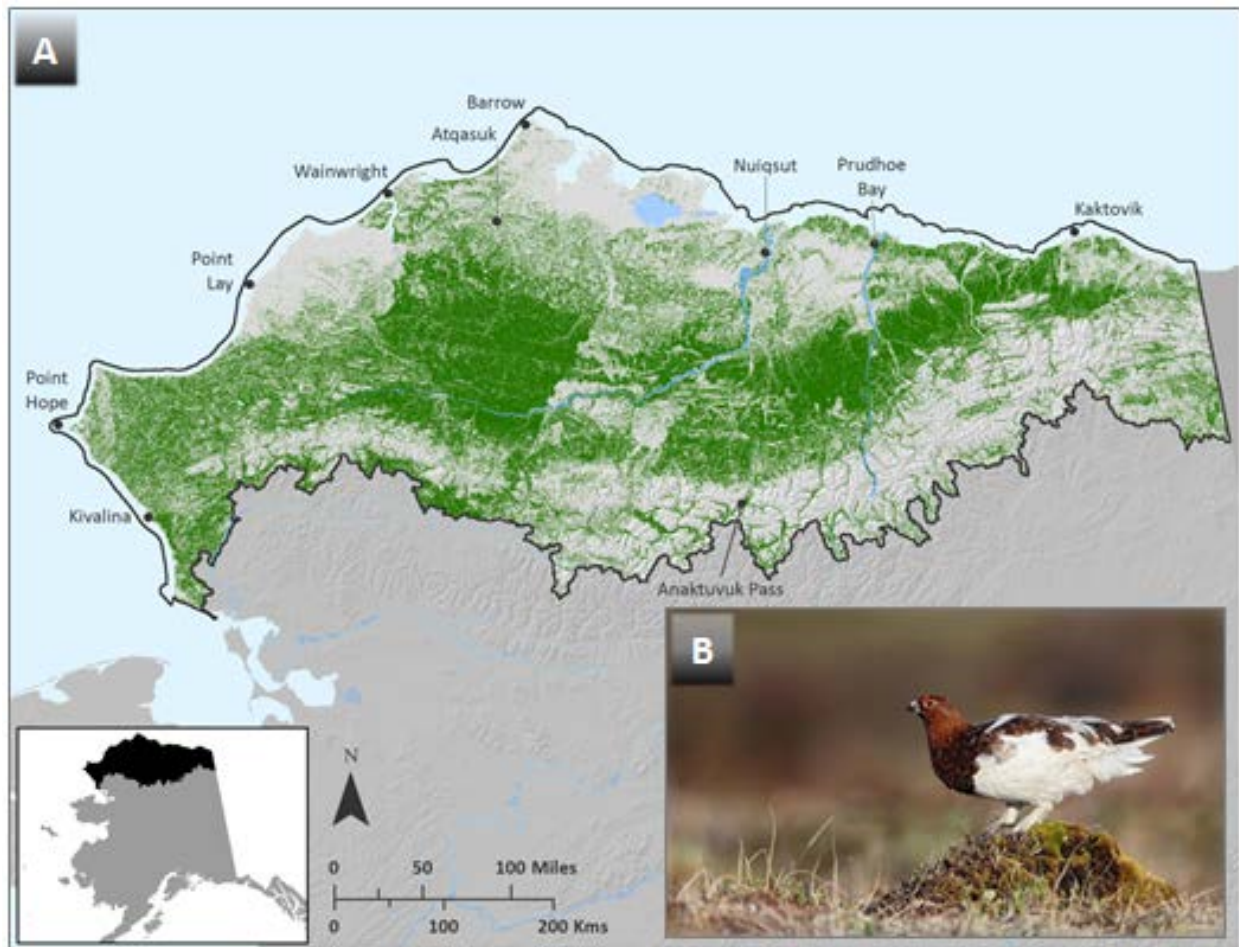


Figure H-49. Current modeled distribution of willow ptarmigan (*Lagopus lagopus*) in the North Slope study area (A) and willow ptarmigan (B).

10.1. Introduction

Willow ptarmigan (*Lagopus lagopus*) occupy the boreal and arctic northern hemisphere, and are one of the few bird species that remain in the Arctic year-round. In Alaska and northern Canada, willow ptarmigan are common in areas with patches of dense vegetation, especially where willow (*Salix*) or birch (*Betula*) shrubs are abundant. They are also found in sedge-willow (*Carex-Salix*) marshes, in meadows, along road and forest edges, and on open tundra. Unlike Rock Ptarmigan (*L. muta*), the species avoids dry, rocky areas. After chicks hatch, birds move to wetter areas, such as marshes and along streams (Hannon et al. 1998).

Ptarmigan nest on the ground after snow melt in willow and alder brush along major river corridors (Irving et al. 1967). Average clutch size is 6–10 eggs and chicks hatch in late June to early July. In the Yukon Territory, willow ptarmigan populations fluctuate in regular ten year patterns, although

population cycles have recently been disrupted (Mossop 2011).

Willow ptarmigan forage changes throughout the year. In late September, willow ptarmigan in Arctic Alaska form flocks and migrate south to mountain passes in the Brooks Range or the boreal forest of the southern Brooks Range where they primarily forage on willow buds and twigs for the winter. In April and May, ptarmigan return to Arctic nesting grounds (Irving et al. 1967, Tape et al. 2010). When they arrive at breeding grounds in spring, snow still covers the ground restricting access to forage. Thus, they are forced to feed almost exclusively on taller shrub species, particularly *Salix alaxensis* (which constitutes up to 80% of their diet) (Tape et al. 2010). This level of intensive browsing reduces the number of catkins on tall, but not short willows, because the short shrubs are still buried by snow (Tape et al. 2010). Browsing of this severity slows the growth of willow shrubs and could affect shrub architecture to such an extent as to retard the greening trend or alter the snow regime—these direct effects and feedbacks are only recently being explored (Tape et al. 2010, Christie et al. 2014).

In June, prior to nesting, males spend much of their time defending nesting territories while females spend more time foraging. Willow catkins often remain the primary forage at this time of year. In July, adult ptarmigan forage on young willow leaves and maturing seeds. In August, *Arctous* berries become important in addition to willow leaves. Chicks feed on a variety of flowers, fruits, seeds, insects, and willow leaves (Williams et al. 1980).

Willow ptarmigan were selected as a Terrestrial Fine-Filter CE for this assessment because they are an important prey species for gyrfalcon (*Falco rusticolus*) and are considered a keystone species for tundra environments (Mossop 2011); they are an important subsistence resource, especially in the spring; and because of the marked impact they can have on shrub structure and productivity.

10.2. Conceptual Model

The conceptual model below (Figure H-50) is based on literature review and describes the relationship between the various change agents and natural drivers for the willow ptarmigan. The boxes and arrows represent the state of knowledge about the willow ptarmigan and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and the willow ptarmigan. Change agents selected for this REA and considered in this analysis include: climate change, fire, invasive species, and human use.

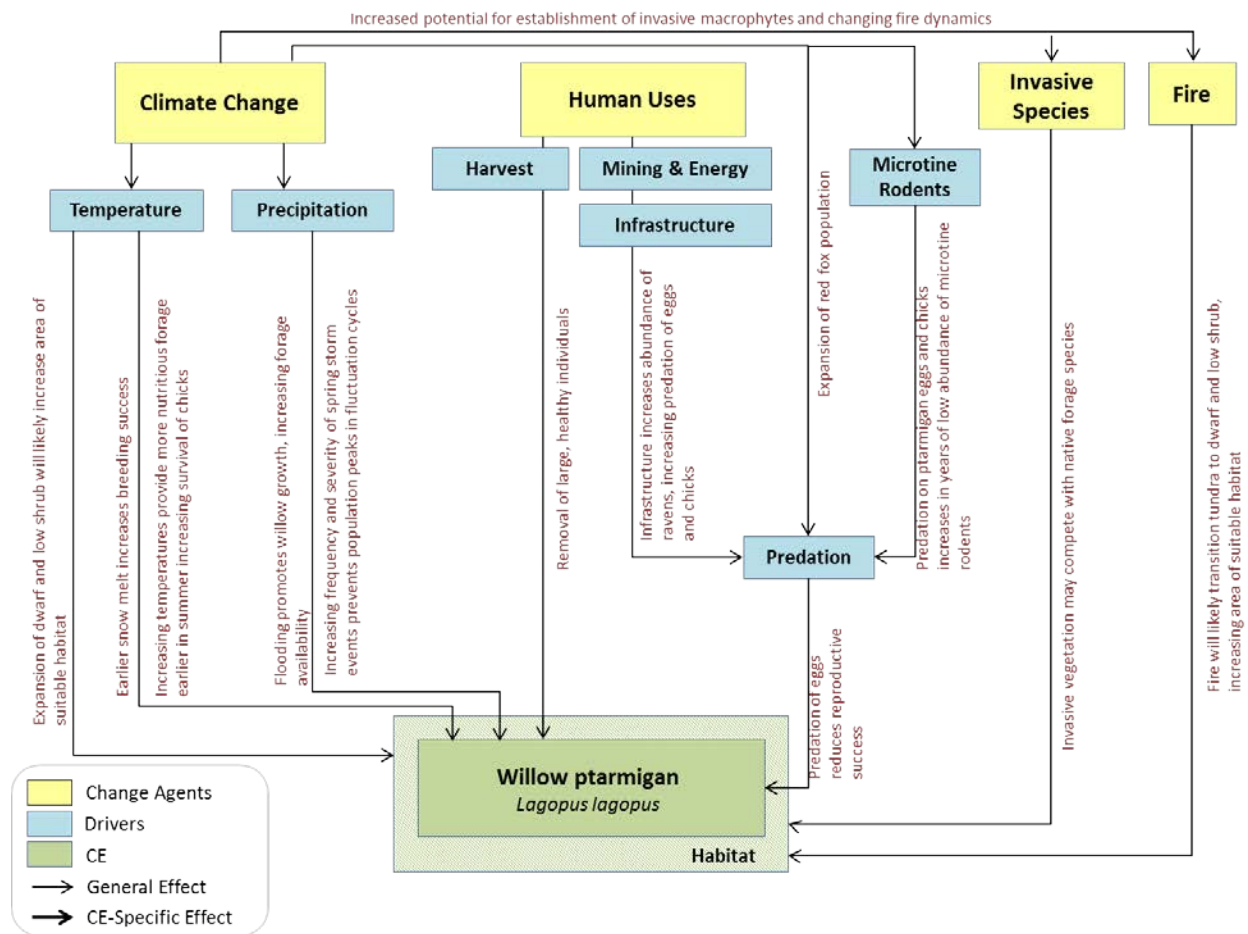


Figure H-50. Conceptual model for the willow ptarmigan.

10.3. Attributes and Indicators

Based on the assessment of available indicators, spatial data used to assess the status of the willow ptarmigan included: date of thaw (DOT), mean May temperature, June precipitation, mean July temperature, growing season length, fire return interval /ALFRESCO, and landscape condition (Table H-30).

Table H-30. Attributes and indicators for the willow ptarmigan.

CA or Driver	Ecological Attribute	Indicator (unit of measure)	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Habitat availability ²²	Date of thaw (timing of snowmelt)	Earlier snowmelt can increase consistency of breeding success. Ptarmigan begin breeding shortly after snow cover declines to 50%.	Later than average			Earlier than average
	Reproductive success ²³	May temperature	Earlier clutches are typically larger than clutches laid later in the spring. Earlier egg laying has been correlated with warmer temperatures the month prior to breeding.	Below average		Above average	Average
	Reproductive success ²⁴	June precipitation	Increased precipitation during incubation can decrease chick production/survival (clutch initiation begins late May/early June and chicks hatch late June).	Above average		Below average	Average
	Forage availability ²⁵	Summer temperature	Increased temperatures can provide more nutritious forage.	Below average		Average	Above average
Fire	Habitat availability	Fire frequency/ALFRESCO	Fire will likely transition tundra to dwarf and low shrub, increasing area of suitable habitat and forage.	Low return interval	Avg. return interval	High return interval	Moderate return interval

²² Based on Cotter 1999, Martin and Weibe 2004, and Wilson 2008.

²³ Based on Wilson 2008 and Wilson and Martin 2010.

²⁴ Based on Steen et al. 1988 and Hannon et al. 1998 (a review of incubation timing from late May through late June).

²⁵ Based on Williams et al. 1980.

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

²⁶ Based on Støen et al. 2010.

10.4. Distribution Model

We used predictive models generated by the Alaska Gap Analysis Project (AKGAP) to describe the distribution of the willow ptarmigan across the North Slope study area (see Section H.1.1 for details relating to AKGAP models). Willow ptarmigan are widely distributed across the North Slope in all three ecoregions (Figure H-49). Preferred habitats appear to be the more abundant inland, with the exception of the western part of the study area. In the southern part of the study area, ptarmigan distribution appears to be more tightly constrained to riparian areas.

A total of 2,827 occurrence records for the willow ptarmigan were obtained from various sources (Table H-31). Occurrence/survey data available to test the models were largely restricted to the Arctic Coastal Plain and Dalton Highway corridor (Figure H-51). Because so many of the records were densely clustered, we randomly selected 30% ($n = 940$) of the records for model evaluation. Classification success (CS) values for the willow ptarmigan AKGAP distribution model were 0.95, indicating high model quality.

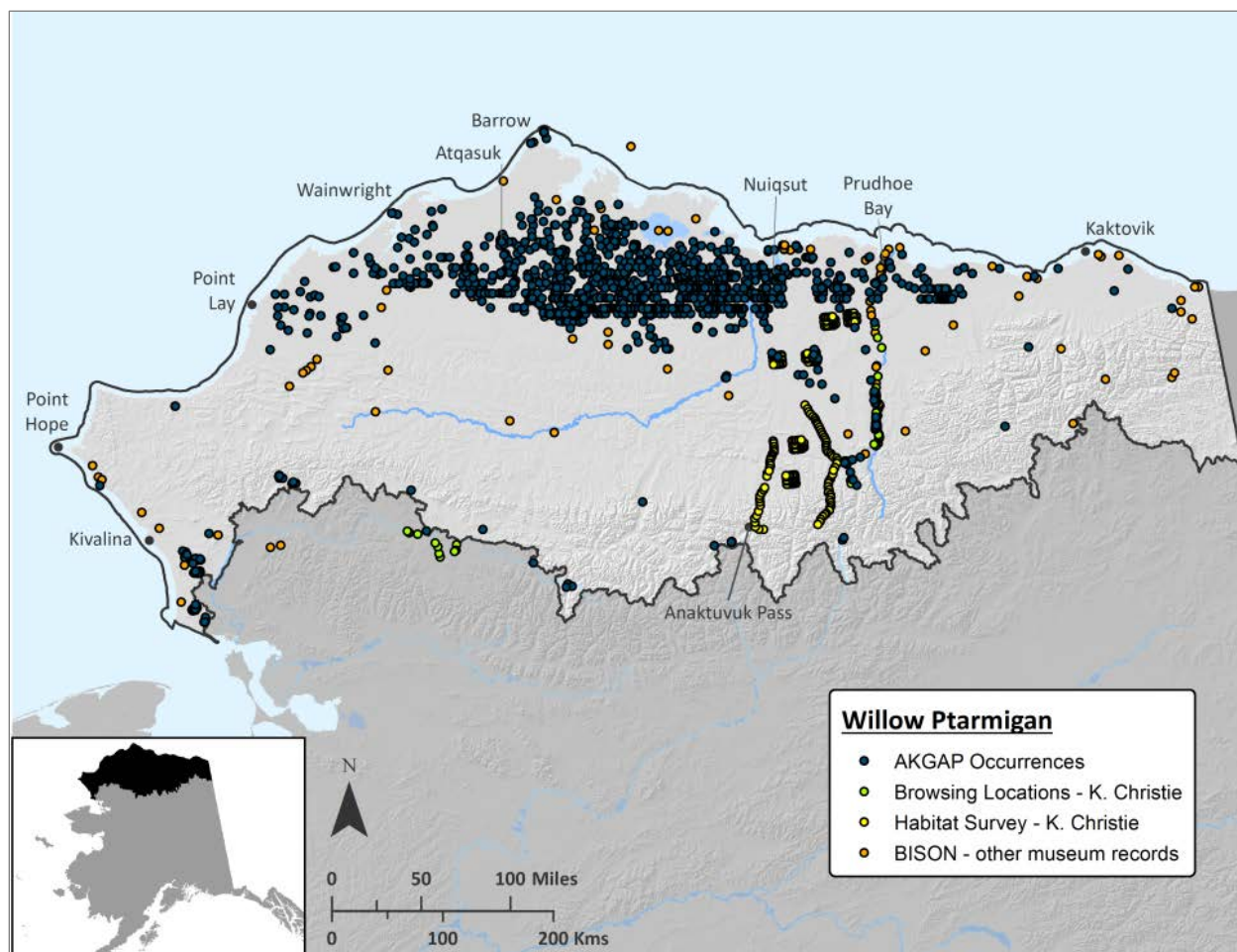


Figure H-51. Distribution of occurrence records for the willow ptarmigan in the North Slope study area.

Table H-31. Datasets used for willow ptarmigan.

Dataset Name	Data source
Gap Analysis distribution model for the willow ptarmigan	Alaska Gap Analysis Project, AKNHP
Gap Analysis terrestrial vertebrate occurrence geodatabase database records for willow ptarmigan *	Alaska Gap Analysis Project, AKNHP
BISON occurrence records for willow ptarmigan	BISON (http://bison.usgs.ornl.gov/#home)
Willow ptarmigan habitat survey, central Brooks Range	Katie Christie, UAF
Willow ptarmigan browsing study locations, Dalton Highway and Noatak River	Katie Christie, UAF

10.5. Abiotic Change Agents Analysis

We explored the relationship between willow ptarmigan and five climatic change agents: mean May temperature, date of thaw (DOT), June precipitation, mean July temperature, and growing season length at three time steps (current, near-term, and long-term). Current research indicates that warmer springs and earlier onset of snowmelt may improve breeding success (larger clutches and earlier date of first egg), while increases in precipitation during incubation (early summer) may be detrimental to chick growth and survival. Warmer summer temperatures and a longer growing season are expected to be beneficial to ptarmigan via more abundant forage and a longer period to successfully fledge young. We also explored the potential for expansion of favored dwarf and low shrub habitats through comparison with ALFRESCO model outputs.

Spring Temperature and Date of Thaw

Willow ptarmigan appear to adjust their lay dates according to snow cover, which varies annually and is dependent on spring ambient temperatures (Wilson 2008). A recent studies of rock ptarmigan (*L. muta*) and white-tailed ptarmigan (*L. leucura*) in the Yukon Territory reported that onset of egg-laying occurred earlier when spring temperatures in the month prior to breeding were warmer (Wilson and Martin 2010). Ptarmigan begin breeding shortly after snow cover declines to 50% (Hannon et al. 2008). The timing of snowmelt was correlated with the timing of egg laying in willow ptarmigan in Norway (Myrberget 1986). Females may be encouraged to lay eggs earlier if warmer temperatures advance snowmelt, which could results in increases in nesting habitat, and stimulate vegetative growth (Wilson and Martin 2010). In years with cold springs and late snowmelt, egg-laying is delayed (Hannon et al. 1988). Despite strong resilience in fecundity parameters, when snowmelt is extremely delayed, breeding success is greatly reduced (Martin and Weibe 2004).

Clutch initiation for willow ptarmigan begins in late May/early June and chicks generally hatch in late June (Hannon et al 1998). We compared the distribution of willow ptarmigan to May temperature and suggested that warmer spring weather could result in advances in snowmelt, which would encourage birds to lay earlier. This would have a positive effect on chick production, since earlier clutches have

been shown to be larger than clutches laid later in the spring (Wilson 2008). We also intersected the distribution map for willow ptarmigan with modeled outputs for date of thaw (DOT), the day on which the running mean temperature is projected to cross the freezing point, using DOT as a proxy for onset of snowmelt. DOT can be expected to correlate, in general, with spring temperatures, and would also have implications for timing of egg laying in ptarmigan.

Modeled May temperature is expected to increase by 0.6 to 1.4 °C throughout the range of the willow ptarmigan by 2060 (Figure H-52a). May temperature increases in the near term, however, are likely to be minor, but by 2060, modeled temperature increases are significant in some areas (see Section C. Abiotic Change Agents). Significant increases of > 0.8 °C in May temperature are predicted for inland areas in the western half of the North Slope. Modeled DOT is expected to occur between 1 to 3 days earlier throughout the current distribution of the willow ptarmigan by 2060 (Figure H-52b). Currently, mean DOT within the range of willow ptarmigan occurs between May 17 and May 21. The warming trend predicted for May temperature across the North Slope, and the associated slight advance in DOT, suggests that future conditions may be advantageous for ptarmigan productivity, especially for birds nesting in the central and western Brooks Range.

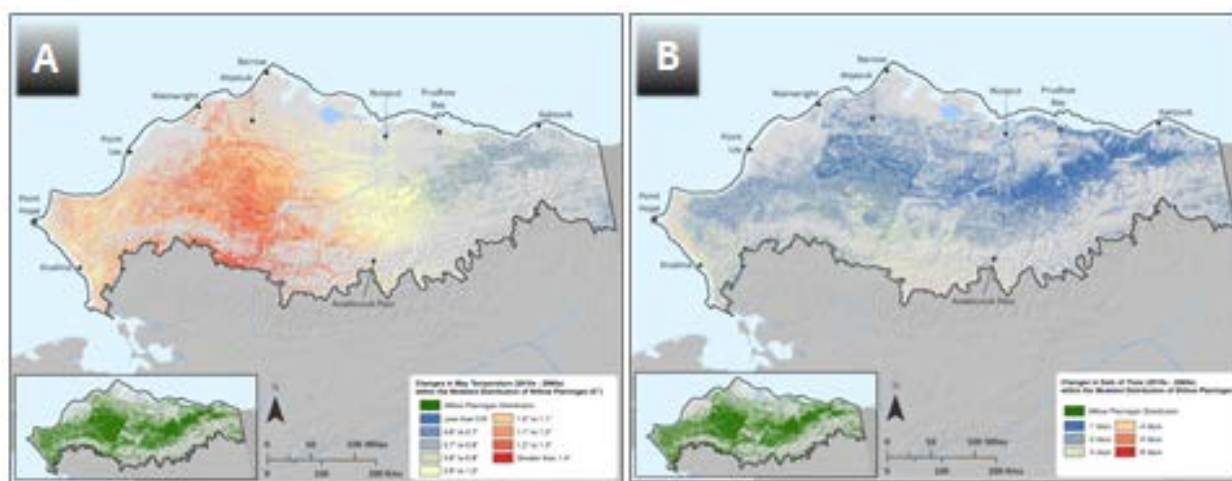


Figure H-52. Modeled change in May temperature (A) and date of thaw (B) from the 2010s to the 2060s within the current distribution of the willow ptarmigan.

Spring precipitation

Weather conditions during incubation may affect willow ptarmigan chick production both directly and indirectly. Chick production has been negatively correlated with both cold spring temperatures (discussed above) and the number of spring rain events prior to hatching (Wilson et al. 2008, Steen et al. 1988). Frequent precipitation and low air temperature during incubation may affect the hen's energy balance (Gabrielsen and Unander 1987) and also cause poor incubation conditions and weaker chicks (Steen et al. 1988). After hatching, poor weather conditions may affect chick survival indirectly by limiting access to food, since chicks are reluctant to feed in wet vegetation (Erikstad and Anderson 1983). We compared the distribution of willow ptarmigan with June precipitation and considered that

wetter than average conditions would have a negative effect during incubation and on post-breeding success.

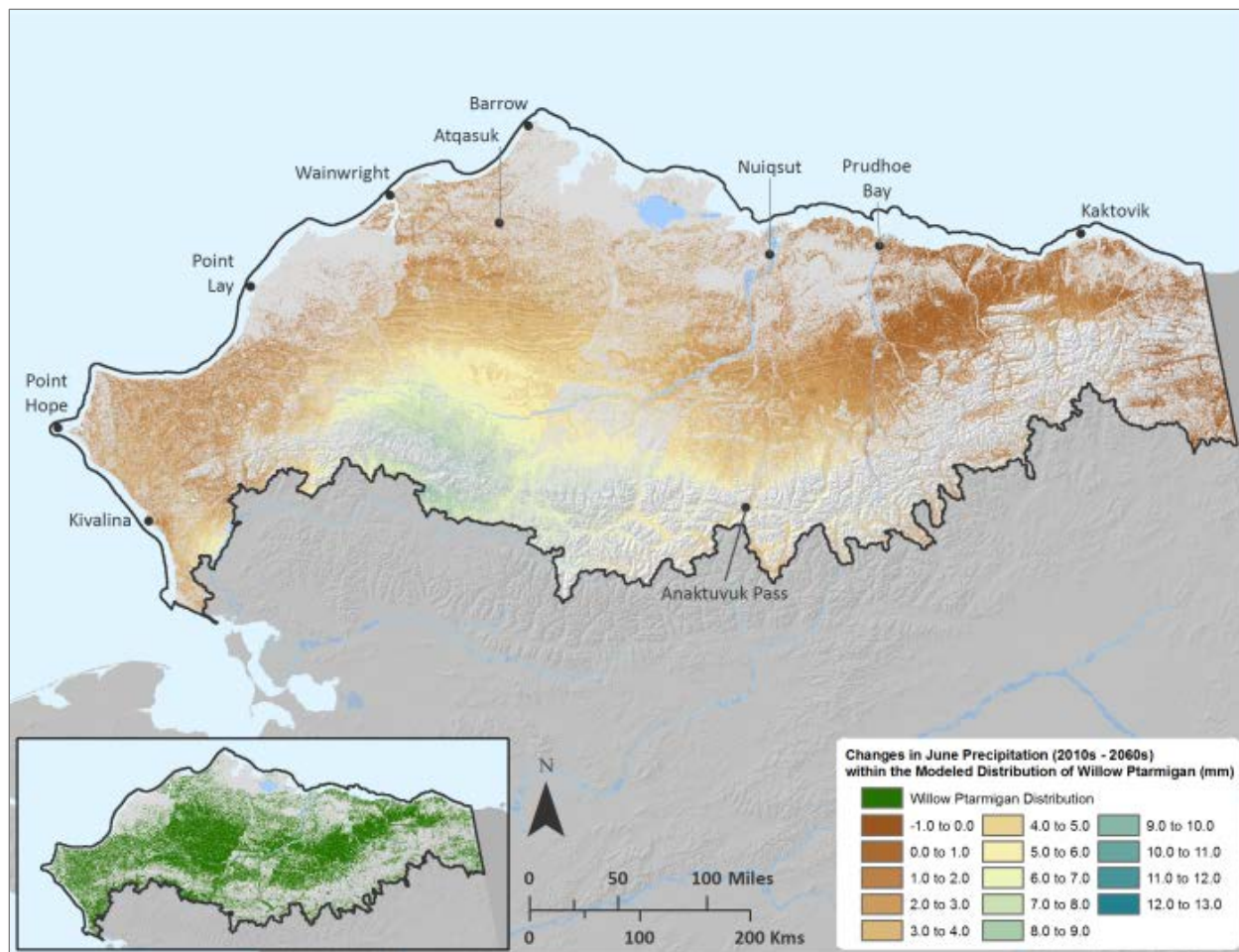


Figure H-53. Modeled change in June precipitation from the 2010s to the 2060s within the current distribution of the willow ptarmigan.

By 2060, slight to moderate increases of 1 to 9 mm in June precipitation are projected within the range of willow ptarmigan (Figure H-53). Significant increases (> 6.2 mm) in June precipitation are only projected to occur in the central and western Brooks Range, where ptarmigan distribution is largely limited to riparian areas. Little to no change is expected in more northerly inland areas, to the east, or along the coast.

Annual temperature and growing season length

Increases in ambient temperature and a longer growing season in the Arctic will result in increased photosynthetic activity and growth of willows and other shrubs (Christies et al. 2014). During the summer, expansion of dwarf and low shrub vegetation communities will likely increase the area of suitable breeding habitat available to willow ptarmigan. Additionally, increased temperatures can

provide more nutritious forage, such as inflorescences of *Bistorta vivipara*, for ptarmigan chicks earlier in summer (Williams et al. 1980).

Timing of reproductive events within the breeding season may affect individual fitness and the number of young produced in the population. Birds that breed in northern environments are considered to be constrained by the time available to reproduce successfully (Hannon et al. 1988). A longer breeding season will promote a longer breeding window and allow young more time to forage before fall migration.

We compared the distribution of willow ptarmigan with mean July temperature (warmest month) and growing season length (estimated number of days with mean temperatures above freezing) and suggested that ptarmigan would benefit under warmer conditions through availability to more abundant or higher quality forage, and a longer growing season would allow for additional time to successfully fledge young. Modeled results indicate that between the current (2010) and the near term (2020), 100% of the area within the distribution of the willow ptarmigan will experience a non-significant increase of 0 - 1.3 °C in July temperature (Table H-32). By the 2060s, significant July temperature increases of > 1.3 °C are projected to occur in over 64% of the species range. By 2060, growing season increases of 7 to 14 days are projected to occur in 99% of the species range (Table H-32).

Table H-32. Predicted change over the near-term (2020) and long-term (2060) in abiotic change agents, mean July temperature and length of growing season, within the distribution of the Lapland longspur within the North Slope study area.

Willow ptarmigan	Δ July Temperature		Δ Length of Growing Season		
	0 - 1.3°C	> 1.3°C	0 - 6 Days	7 - 14 Days	> 14 Days
Near Term	100%	-	100%	-	-
Long Term	36%	64%	-	99%	1%

Fire – ALRESCO model

In the winter and spring when snow cover is extensive, willow ptarmigan on the North Slope of Alaska depend primarily on one willow species, *Salix alaxensis*, for food and cover (Christie et al. 2014). Any changes in the distribution of this one plant species could have a significant impact on willow ptarmigan. Fire will likely transition the tundra to dwarf and low shrub, potentially increasing the area of suitable habitat and forage for willow ptarmigan.

Fire frequency across the North Slope study area is predicted to increase. However, most of the region is likely to remain relatively free of fire although sporadic tundra fires may occur in all sub-regions (see Section C). Thus, changes in fire frequency will likely not have much of a direct impact on willow shrubs favored by willow ptarmigan. However, recent analyses suggest that changes in fire frequency on Alaska's landscapes may be driven at least as much by climate-induced changes in vegetation as they are by climate-induced changes in fire frequency (Starfield and Chapin 1996). The ALFRESCO model (described in the CA Fire Section) is directly linked to both climate and vegetation, and is also capable of modeling shifts in between-fire and post-fire trajectories of succession that are climate-derived.

ALFRESCO outputs of projected vegetation change indicate that shrub habitats will increase by 2060 throughout much of the study area, with highest increases in the Brooks Range Ecoregion (Figure H-54).

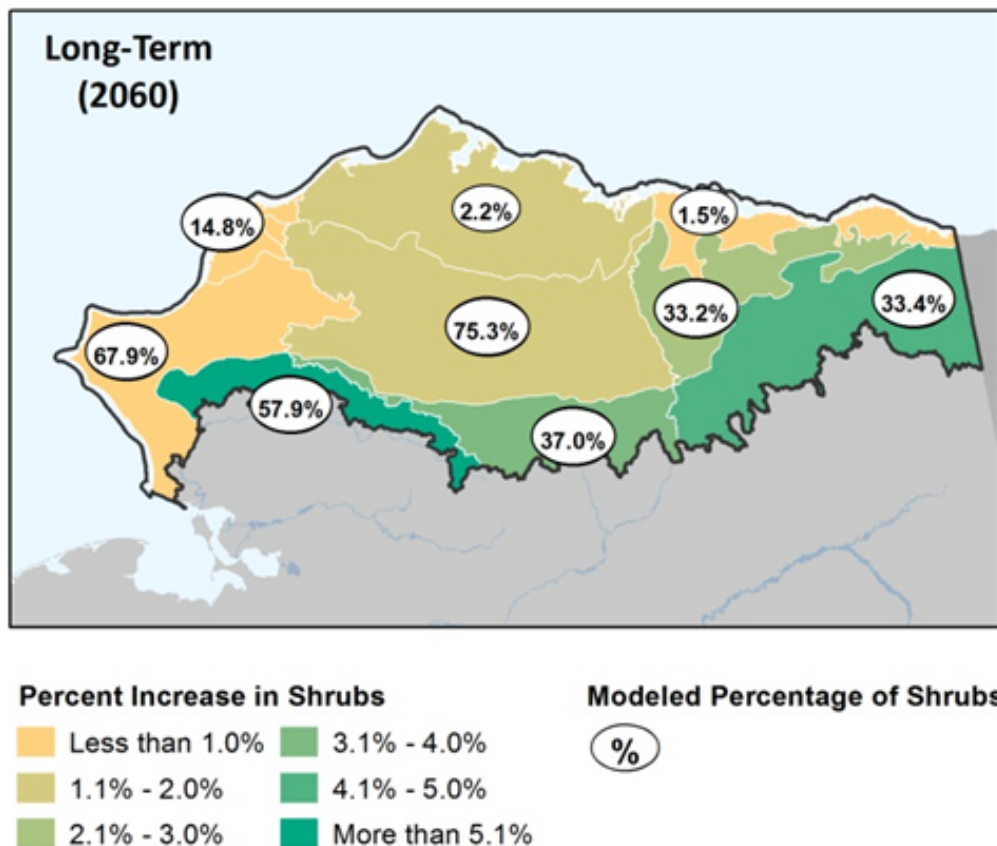


Figure H-54. Projected long-term (2060) change in shrub tundra by ecological sub-region (adapted from Fresco et al. 2014, this study).

With shrub expansion projected for the North Slope, it could provide expanded breeding habitat opportunities for this species. Willow ptarmigan are such extensive browsers on willow shrubs that they are able to influence their architecture, growth and reproduction. Furthermore, this species is capable of altering forage plants in such a way that it creates a broomed structure, which increases the quantity and availability of their own food source (Christie et al. 2014). Increased bud production, in combination with broomed architecture, may be beneficial for future ptarmigan browsing because the two processes result in higher concentrations of buds within easy reach of ptarmigan, thereby increasing the carrying capacity of their own habitat. It should also be noted, however, that spruce and deciduous forests are projected to expand into shrub-dominated areas. If this occurs, willow ptarmigan habitat will likely be reduced (Liebezeit et al. 2012).

Climate Summary

Overall, our assessment of abiotic climate variables suggests that willow ptarmigan will likely benefit from expected changes in environmental conditions (Table H-33), and that they have enough flexibility in life history to allow them to remain stable with regard to climate change, at least within the

timeframe of this assessment. This species has such a marked impact on shrub structure and productivity that browsing by these herbivores needs to be considered in future models of shrub expansion in the Arctic.

Table H-33. Summary of abiotic CAs used in the core analysis assessment for willow ptarmigan and projected effects.

Indicator	Short-term (2020) trend	Long-term (2060) trend	Impact to	Effect
Spring temperature	+ or -	+	chick production	+
Date of thaw	+	+	chick production	+
Spring precipitation	+	+	chick survival	-
Annual temperature	+	+	forage availability	+
Growing season length	+	+	fledgling survival	+
Fire/ALFRESCO	n/a	+	habitat (shrub) expansion	+ or -

10.6. Current Status and Future Landscape Condition

The majority of current willow ptarmigan habitat is in areas with very high (intact) landscape condition (Figure H-55). Future scenarios of landscape condition do not indicate any significant changes in both medium and high scenarios.

Predation is the largest direct cause of nest failure for willow ptarmigan (Wilson 2008). Potential threats as a result of increased development related to oil and gas infrastructure include potential increases in predation by ravens, as ravens are known to prey on willow ptarmigan eggs and chicks. Some evidence has suggested that ravens become more numerous in areas of human development because of the presence of additional food sources and artificial nesting/denning sites. While recent improvements to waste handling procedures associated with oil field infrastructure have likely dampened this effect in oil fields (Liebezeit et al. 2009), this may still be a concern in areas of other development. Increased raven abundance could potentially reduce the reproductive success of willow ptarmigan (Støen et al. 2010).

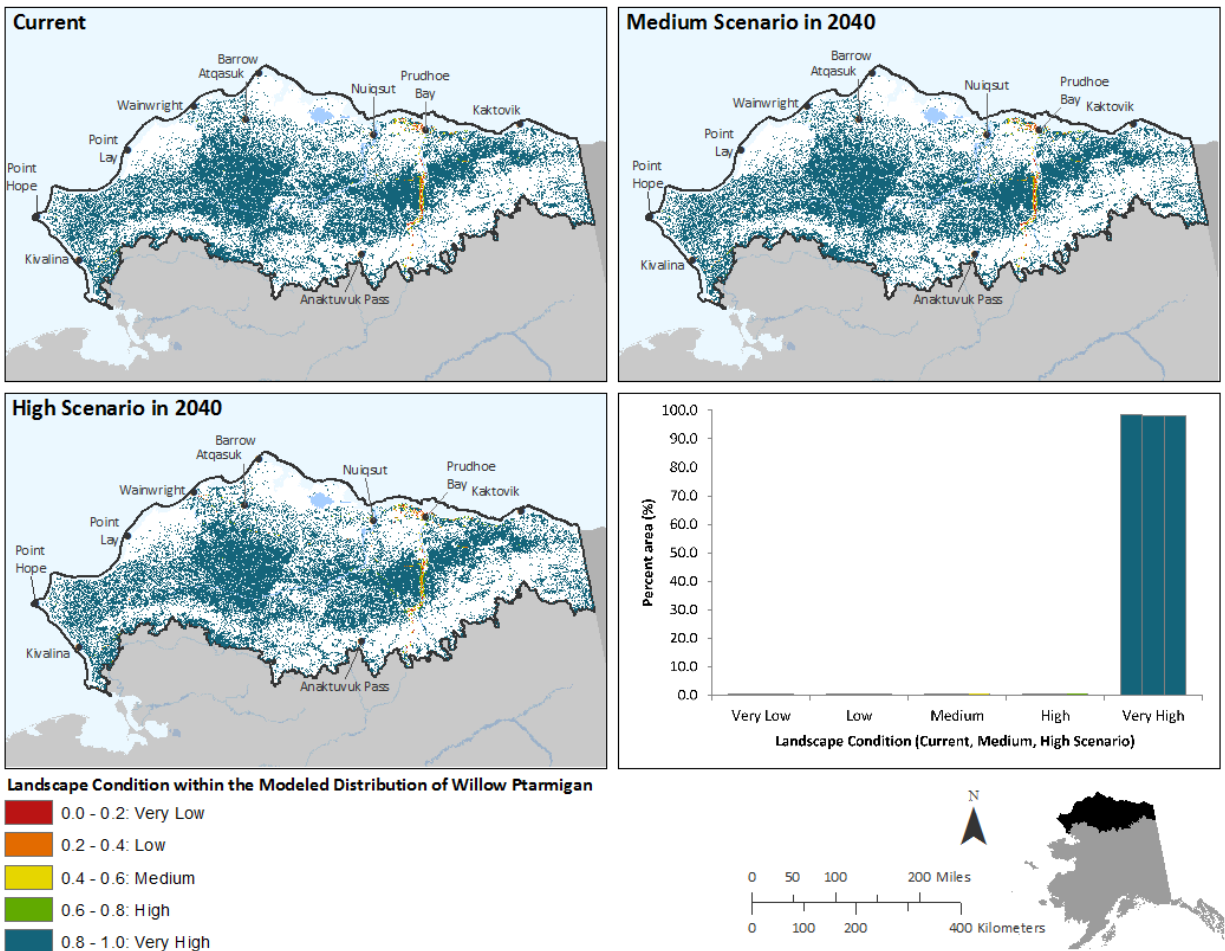


Figure H-55. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current distribution of Willow Ptarmigan in the North Slope study area.

10.7. Limitations and Data Gaps

The presence of large flocks of ptarmigan, combined with their exclusive preference for willow buds in the spring when first arriving at Arctic breeding grounds, results in substantial influence on the growth and architecture of willows that exceed snow level (Christie et al. 2011). After several years or ptarmigan browsing, willows become “hedged” just above average snow level, providing optimal food accessibility for future average snow years. In years of higher than average snowfall, willows may become buried and protected from browsing, whereas in years of lower than average snowfall, more willow branches are available for browsing. Food availability for ptarmigan is therefore strongly related to snow conditions in a given year (Christie et al. 2014). We lacked a suitable snow-depth layer for the REA that precluded examining the relationship of snow and its role in conjunction with ptarmigan herbivory.

Since limited spatial data were available on fire, most potential changes related to ptarmigan habitat were qualitatively described based on literature review and ALFRESCO model outputs.

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11. Greater White-fronted Goose (*Anser albifrons*)

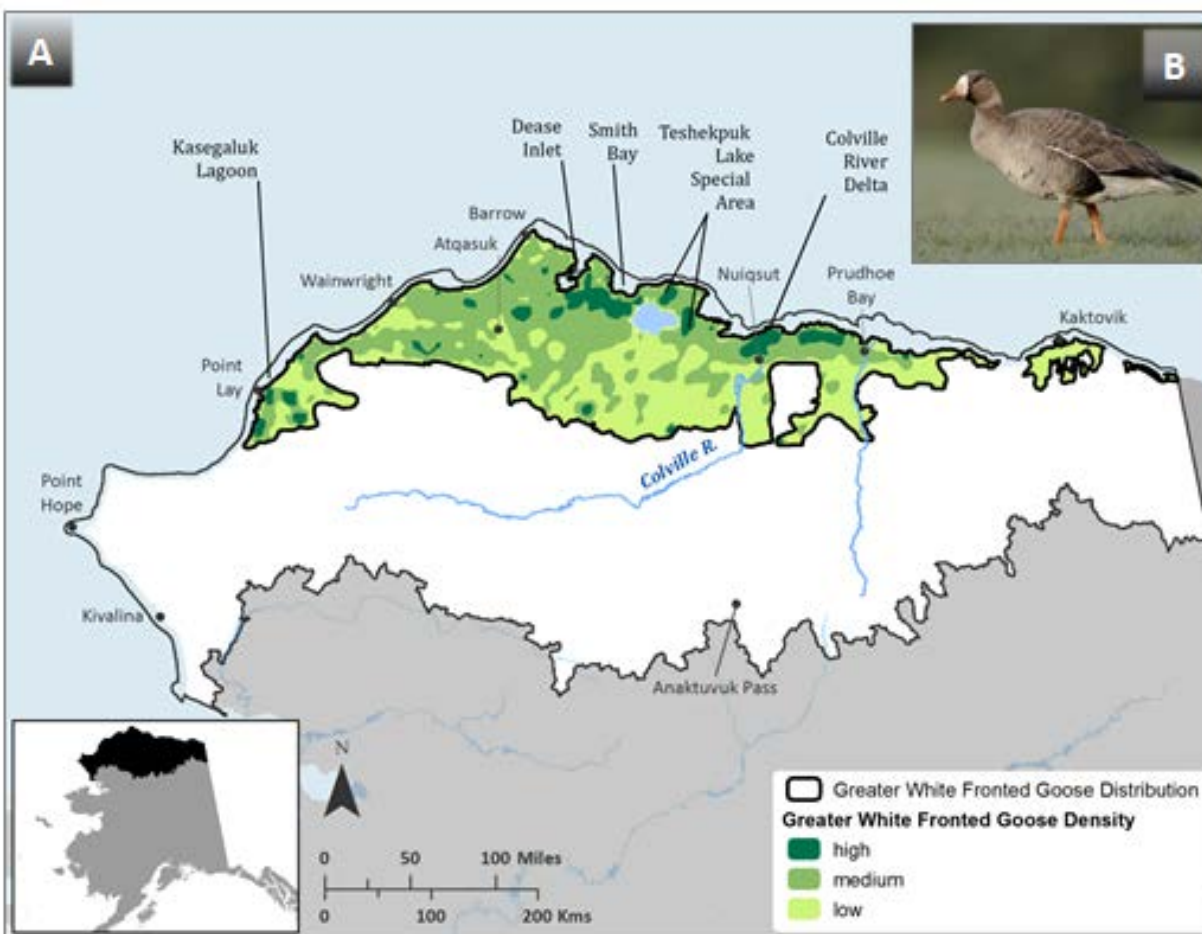


Figure H-56. Current modeled distribution of greater white-fronted goose (*Anser albifrons*) in the North Slope study area from density estimates provided by Platte, unpubl. data (A) and greater white-fronted goose (B).

11.1. Introduction

The greater white-fronted goose (*Anser albifrons*) has a nearly circumpolar distribution and is highly valued for sport hunting and as a subsistence food. In western North America, summer breeding occurs in arctic and boreal habitats from eastern Hudson Bay to western Alaska. Geese that breed in tundra habitats differ from those that breed in boreal habitats, and interchange between the two groups is small (Marks 2013). Geese that spend summers in the arctic of Alaska and Canada, winter in Texas, Louisiana, and Mexico. Individuals live up to 26 years with late maturation and produce a small number of offspring per year compared to other geese (Schoen and Senner 2002).

Between 2005 and 2009, the breeding population of greater white-fronted geese in the northern Arctic Coastal Plain grew rapidly but appeared to have leveled off in 2010-2011 (Larned et al. 2012). In 2012, population estimates were much higher than any previous year recorded, with population estimates as

high as 329,792. In 2013, indices were again similar to the preceding five years and in 2014 indices were the lowest since 2007 (Marks and Fisher 2014).

Within the North Slope study area, greater white-fronted geese nest primarily within a strip that extends to approximately 30 km from the coast (King 1970). White-fronted geese have been noted on their Alaska Beaufort Sea breeding grounds from the second or third week of May to the first week of June (Johnson and Herter 1987). Arrival is about two to three weeks before incubation, during which time they feed intensively. Primary forage consists of *Arctophila fulva* shoots and *Triglochin palustris* bulbs (Budeau et al. 1991). Breeding pairs occupy much of the central Coastal Plain in open tundra with nest sites in dense grass, sedges, and shrubs, and commonly on slough banks, lake shores, pingos, and polygon ridges within 400 m of water (Rothe et al. 1983, Ely and Dzubin 1994).

Molting typically begins in early July. Geese select areas near lakes or river deltas that provide forage access and predator escape during this time. During the molting period, many geese aggregate around Teshekpuk Lake where their primary forage consists of *Arctophila fulva* and *Carex* species.

11.2. Conceptual Model

The conceptual model below (Figure H-57) is based on literature review and describes the relationship between the various change agents and natural drivers for the greater white-fronted goose. The boxes and arrows represent the state of knowledge about the greater white-fronted goose and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and the greater white-fronted goose. Change agents selected for this REA and considered in this analysis include: climate change, fire, invasive species, and human use.

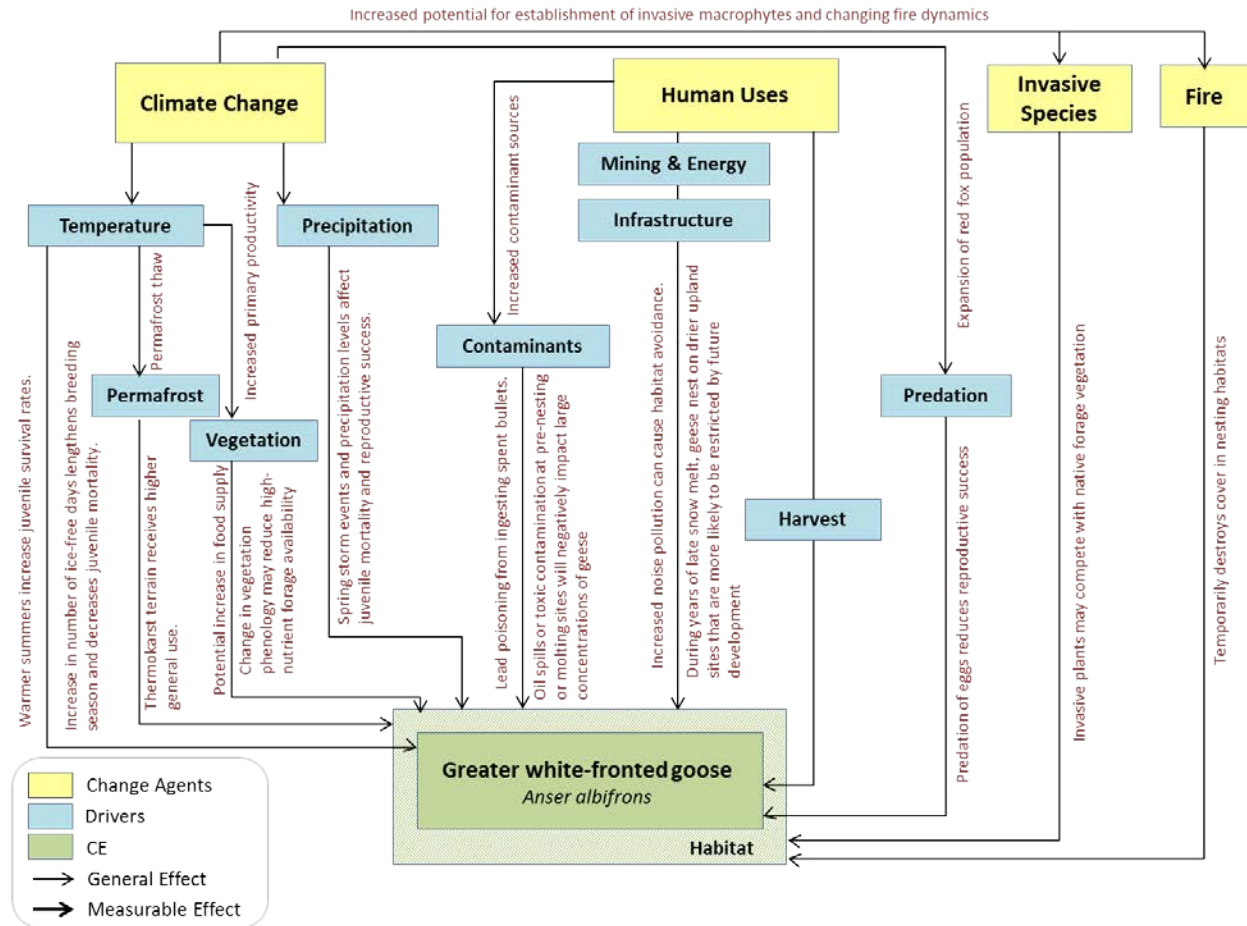


Figure H-57. Conceptual model for greater white-fronted goose.

11.3. Attributes and Indicators

Based on the assessment of available indicators, spatial data used to assess the status of the greater white-fronted goose included: date of thaw, summer temperature, spring precipitation, permafrost predisposition, and landscape condition (Table H-34).

Table H-34. Attributes and indicators for the greater white-fronted goose.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Food and habitat availability ²⁷	Date of thaw	Later than average snowmelt can result in delayed breeding; change in vegetation phenology may reduce availability of high-quality forage.	Later than average		Average	Earlier than average
	Reproductive success ²⁸	Spring precipitation - March, April, May	Increased precipitation results in decreased reproductive success.	Above average		Average	Below average
	Food availability ²⁹	Mean Summer Temperature - June, July, August	Warmer than average summers result in increased juvenile survival rates and increased forage production (biomass), but diminished forage quality.	Cooler than average		Average	Warmer than average
	Habitat quality ³⁰	Thermokarst predisposition	Habitat heterogeneity characteristic of thermokarst terrain receives higher general use by geese during the breeding season.	< 50%	50-75%	> 75%	> 90%
Fire	Habitat quality ³¹	Fire return interval	Increased fire may temporarily reduce breeding habitat quality by destroying cover in nesting habitats.	High return interval			Low return interval

²⁷ Based on Ely and Dzubin 1994 and USFWS 2008.

²⁸ Based on Boyd and Fox 2008.

²⁹ Based on Boyd and Fox 2008 and Martin et al. 2009.

³⁰ Based on Martin et al. 2009.

³¹ Based on Hoffpauier 1968.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Anthropogenic	Habitat quality ³²	Landscape condition model	White-fronts are sensitive to machine noise (within 5km of nesting) which can result in habitat avoidance. Aircraft disturbance can lead to habitat avoidance at breeding/nesting sites.	< 5km		> 5km	
	Predation pressure ³³	Landscape condition model	Risk of nest predation (by Arctic fox for example) increases within 5km of human infrastructure.	< 5km		> 5km	
	Habitat quality/reproductive success ³⁴	Landscape condition model	Geese have a foraging range of 3-10km during nesting. Contaminant leaks within this vicinity could have a negative effect on individual health and reproductive success.	< 3km		>10km	
	Habitat quality ³⁵	Subsistence use area	Lead poisoning from ingesting spent shotgun pellets.	High	Medium	Low	Zero

³² Based on Barry and Spencer 1976 in Ely and Dzubin 1994, and Derksen et al. 1979.

³³ Based on Liebezeit et al. 2009.

³⁴ Based on Schoen and Senner 2002.

³⁵ Based on Frierabend 1983.

11.4. Distribution Model

We used predictive models generated by the Alaska Gap Analysis Project (AKGAP) to describe the distribution of the greater white-fronted goose across the North Slope study area (see Section H.1.1 for details relating to AKGAP models). We also obtained a breeding density distribution map for the greater white-fronted geese for the Arctic Coastal Plain from the USFWS (Platte, unpubl. data). For a final distribution model, we clipped the AKGAP model to the extent of the density distribution map, as it more closely defined the distribution of the greater white-fronted goose in the North Slope study area (Figure H-56). The clipped AKGAP model was then used for intersections with the CAs as part of the core analysis.

During the breeding season, greater white-fronted geese are distributed across the entire Arctic Coastal Plain, with densities being the highest within 30 km of the coast. Areas of high breeding density include the Colville River Delta, Teshekpuk Lake Special Area, Dease Inlet and Smith Bay, west of Atkasuk, and Kasegaluk Lagoon (Schoen and Senner 2002) (Figure H-56).

A total of 31,636 occurrence records for the greater white-fronted goose were obtained from various sources (Table H-35). Occurrence records were densely clustered on the Arctic Coastal Plain, so we subsampled them to obtain an accuracy assessment data set of 1,081 records. Classification success (CS) values for the greater white-fronted goose AKGAP distribution model were 0.95%, indicating high model quality.

Table H-35. Datasets used for greater white-fronted goose.

Dataset Name	Data source
Gap Analysis distribution model for the greater white-fronted goose	Alaska Gap Analysis Project, AKNHP
Gap Analysis terrestrial vertebrate occurrence geodatabase database records for greater white-fronted goose *	Alaska Gap Analysis Project, AKNHP
Greater white-fronted goose density map for the Arctic Coastal Plain	Migratory Bird Management, USFWS

*Sources for Gap Analysis Vertebrate Occurrence records for greater white-fronted goose are comprised of field survey data obtained from various agencies and researchers. A full bibliography of all data sources for this species is included in the North Slope Data Discovery Memo.

11.5. Abiotic Change Agents Analysis

We explored the relationship between the greater white-fronted goose and four climatic change agents: date of thaw, summer temperature, spring precipitation, and thermokarst predisposition at three time steps (current, near-term, and long-term). Earlier snowmelt as a result of warming temperatures could be beneficial to breeding geese by extending breeding season length, while changes in vegetation phenology could reduce availability of high-quality forage; we also speculated that warmer than average summer temperatures could affect juvenile survival rates as a result of a trophic mismatch; that higher

than average spring precipitation could negatively affect reproductive success; and that expansion of thermokarst terrain could result in increases in higher quality habitats.

Date of Thaw and Summer Temperature

We intersected the distribution map for greater white-fronted goose with modeled outputs for date of thaw (DOT), as DOT can be expected to correlate in general with the condition of ice on rivers, streams, and wetlands, and could have implications for timing of breeding, breeding success, and changes in vegetation phenology. Results of our analysis indicate within the current North Slope breeding distribution of greater white-fronted goose, projected changes in DOT between present day and 2060 will be minimal (Figure H-58). In areas of highest geese densities, near the coastal communities of Nuiqsut, Prudhoe Bay, and Point Lay, DOT is only expected to occur 2 to 3 days earlier than current conditions (see Section C. Abiotic Change Agents).

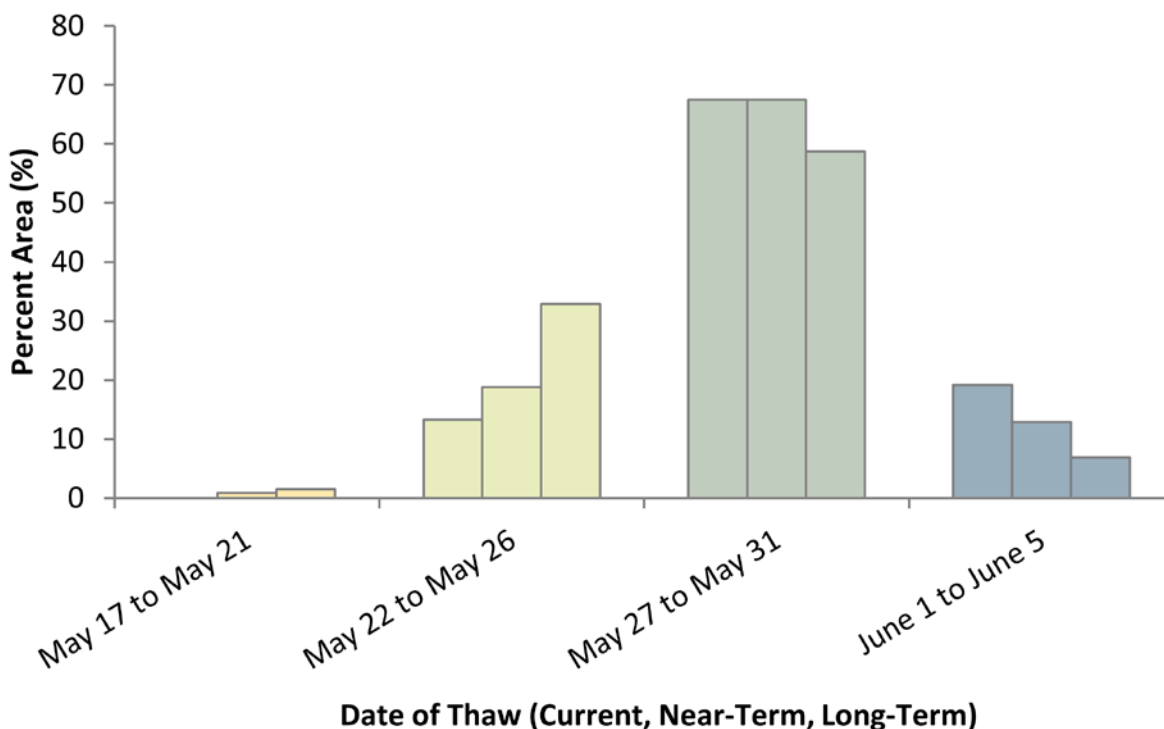


Figure H-58. Current, near-term future, and long-term future (left to right bars within clusters, respectively) date of thaw within the current modeled distribution of the greater white-fronted goose.

Warming temperatures will alter the overall phenology of the North Slope study area, including earlier snowmelt and plant growth (Sparks and Menzel 2002, Stone et al. 2002). An increase in the number of ice-free days and earlier spring thaw could result in earlier goose arrival and lengthened breeding season duration, potentially decreasing juvenile mortality rates (Sargeant and Raveling 1992, Ely and Dzubin 1994, Boyd and Fox 2008).

Increased primary production from earlier spring thaw and warmer temperatures will benefit geese as long as the shift in breeding season remains matched to the emergence of forage vegetation (USFWS 2008). Preliminary studies near Teshekpuk Lake (Schmutz et al. unpublished in Martin et al. 2009) suggest that warmer temperatures during the growing season result in greater plant biomass but diminished forage quality. For herbivorous geese such as white-fronts, forage quality rather than quantity is thought to be limiting and can affect gosling growth rates and survival. There is evidence suggesting that gosling size in years of higher spring temperature may be attributed to a mismatch between hatching dates of goslings and timing of peak forage quality (Martin et al. 2009).

To assess potential changes in growing season temperatures in relation to goose forage quality and abundance, we intersected the distribution map for greater white-fronted goose with modeled outputs for mean summer (June, July, August) temperature. Possible significant summer warming is expected by the 2060s for the North Slope study area, with the greatest changes expected in the inland part of the North Slope and less change along coastal areas (see Section C) favored by white-fronted geese. Similar to results for DOT, summer temperatures within the range of the greater white-fronted goose show only slight increases by 2060, but generally by not more than 0.8°C, and near-term summer warming is non-significant (Figure H-59).

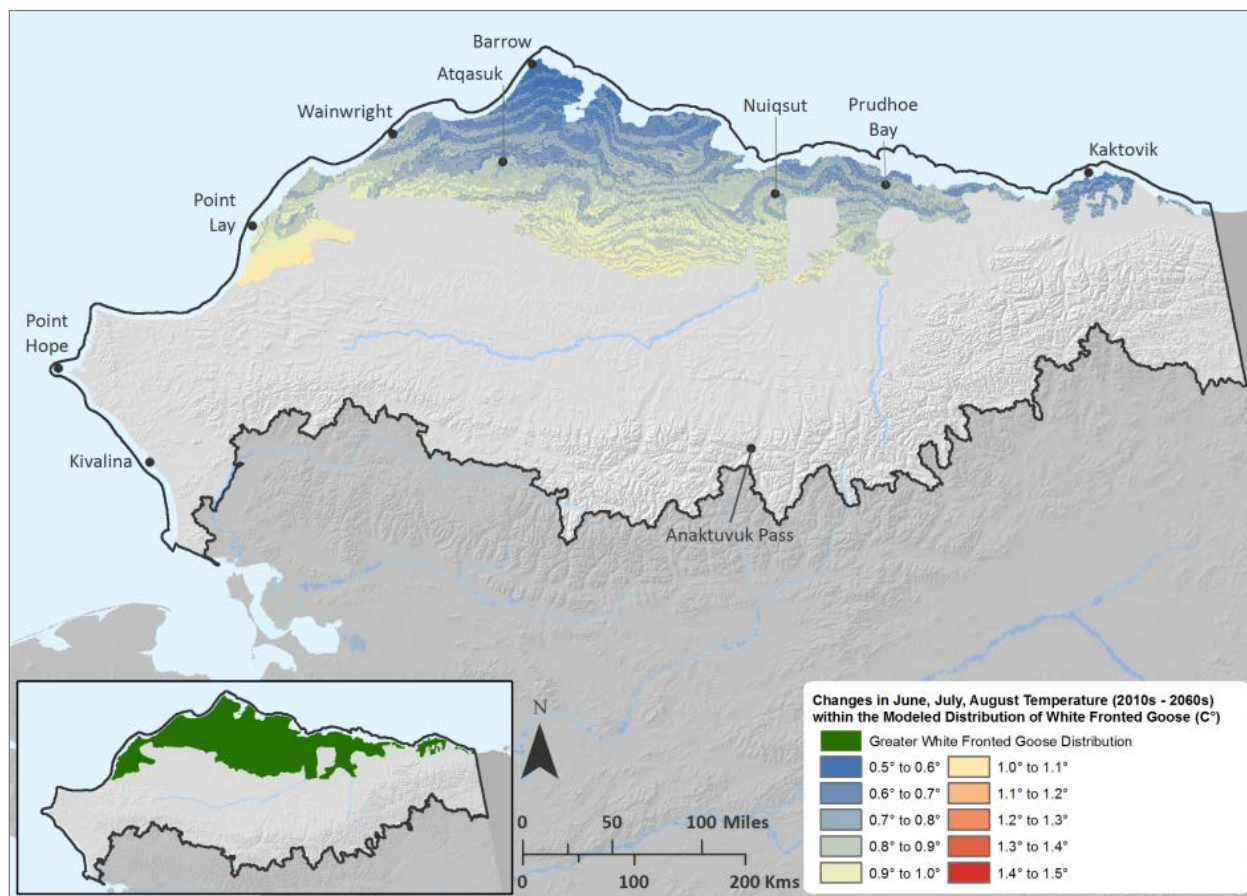


Figure H-59. Change in summer temperature (JJA) within the current modeled distribution of the greater white-fronted goose.

The timing of nesting for this species has advanced by 10 days since the 1970s, likely in response to increasing spring and summer temperatures (D. Ward, pers. comm. *in* Liebezeit et al. 2012). The slight increases projected in DOT and summer temperature for the North Slope study area will likely have little impact on this species breeding on the Arctic Coastal Plain. Because this species experiences much warmer conditions at interior Alaska breeding sites, they should be able to adapt physiologically to a warmer arctic environment. However, it is unknown if they can synchronize timing to changing schedules of other species and processes they depend on (e.g. timing of spring green up) (Liebezeit et al. 2012).

Spring Precipitation

Increases in spring precipitation as a result of climate change could lead to greater likelihood of flooding events. Flooding has been associated with greater white-fronted goose nest failure. On the Yukon-Kuskokwim Delta in 1978, 13 of 25 white-fronted goose nests flooded were destroyed, while only 3 out of 19 nests that had not been flooded were destroyed (Ely and Raveling 1984).

The overall pattern of change in summer precipitation across the North Slope study area shows greater increases to the south and east, and little or no change to the west, particularly on the coast. Results of our analysis indicate that within the range of the greater white-fronted goose there will be little change in spring precipitation between current conditions and 2060 (Figure H-60).

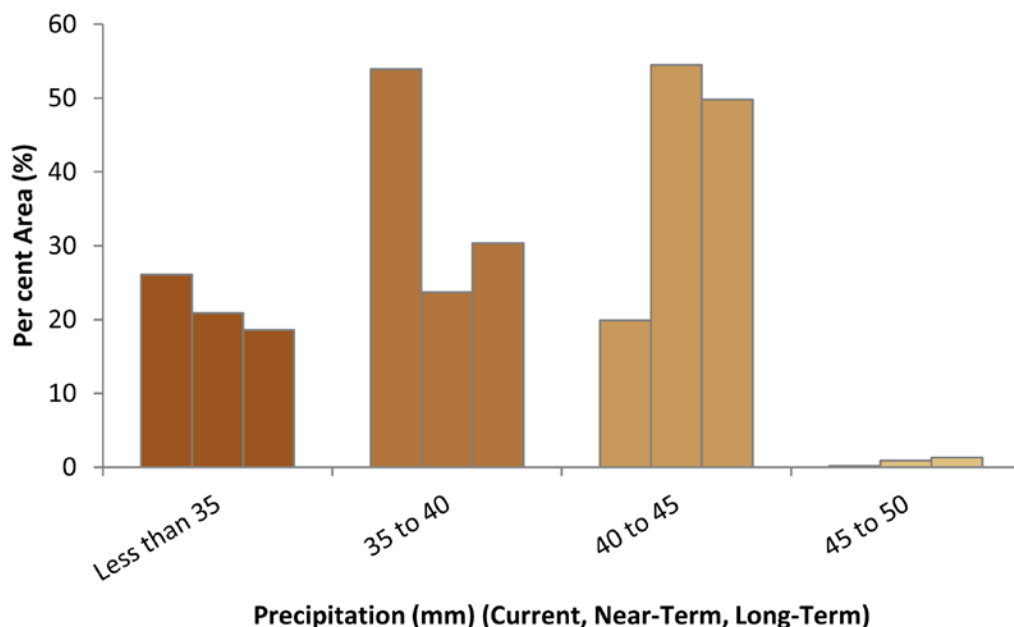


Figure H-60. Change in precipitation (mm) within the current modeled distribution of the greater white-fronted goose at current (left bars), near-term (2020; center bars), and long-term (2060; right bars) time steps.

Thermokarst Predisposition

Climate-mediated disturbance processes, such as thermokarst, could both create and destroy nesting and foraging habitats through both ice wedge degradation and draining of thaw lakes (Martin et al.

2009). Loss of productivity in drying polygon centers as a result of permafrost degradation could be compensated for by increased productivity of expanding thermokarst pits (Martin et al. 2009). Habitat heterogeneity characteristic of thermokarst terrain has been linked to higher general use by some waterfowl such as greater white-fronted goose (Troy 1991).

The thermokarst predisposition module developed for the North Slope determines how much area is predisposed to thermokarst disturbance, based on the occurrence and the ice content of permafrost, histels, and local drainage conditions (Zhang et al. 2014). We compared areas of thermokarst disposition to the current distribution of greater white-fronted goose to explore the association that increases in thermokarst terrain as a result of permafrost thaw could result in additional preferable habitat for geese and other waterfowl species.

With the exception of one small cluster, all mapped high density goose nesting areas are underlain by areas with 95% thermokarst predisposition, while medium density polygons are within both predisposed and non-predisposed areas (Figure H-61). However, since these areas are not likely to undergo a great deal of permafrost thaw in either the near term or long term, thermokarst effects may be limited.

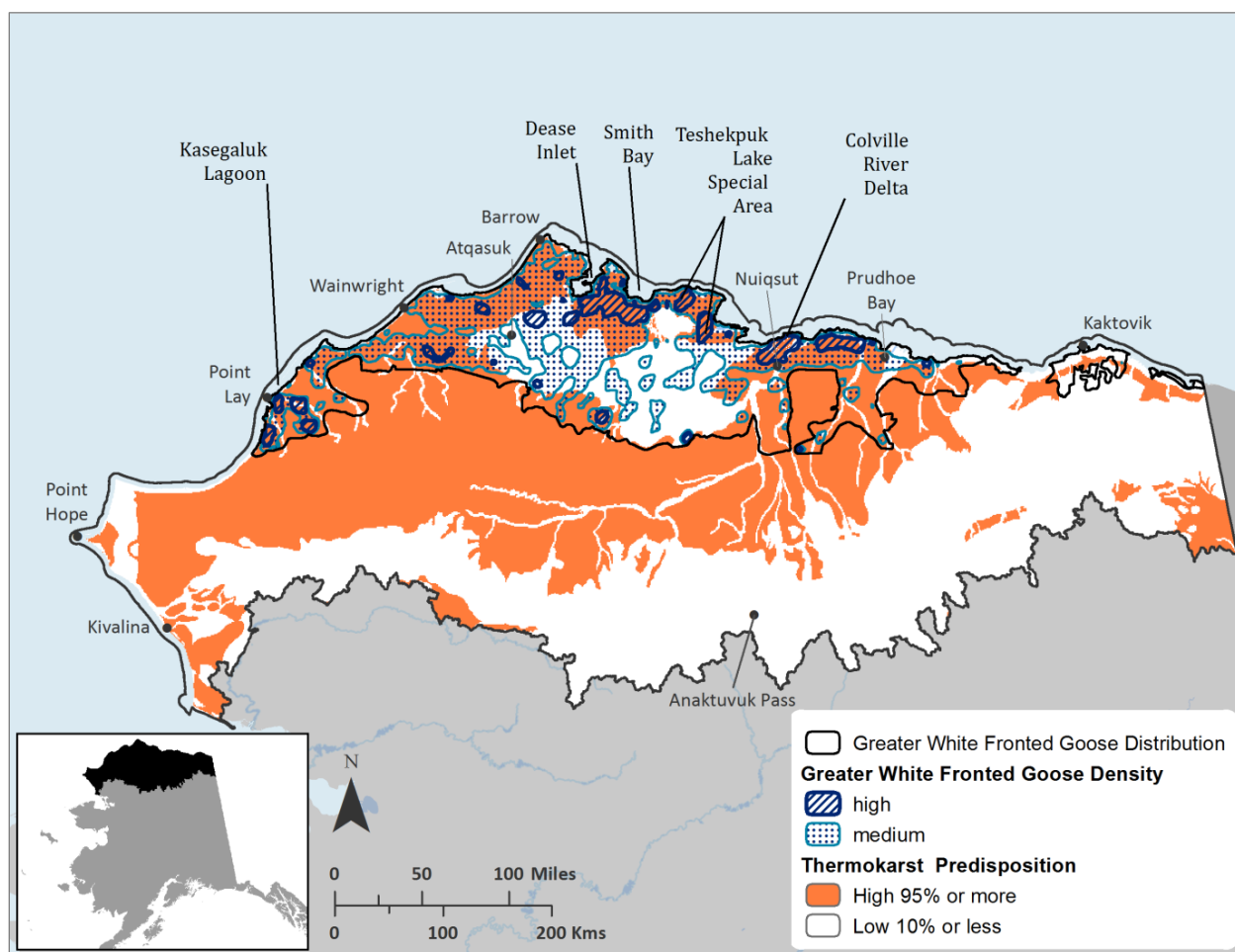


Figure H-61. Distribution of greater white-fronted goose intersected with modeled distribution of thermokarst predisposition in the North Slope study area.

Climate Summary

Overall, greater white-fronted geese appear to be prospering under recent climate-change-induced habitat modifications on both coastal and interior portions of the Arctic Coastal Plain. Population size of the greater white-fronted goose has increased seven-fold in northern Alaska since 1980 (Flint et al. 2008). Results of climatic comparisons here indicate that modeled changes in date of thaw, summer temperature, and spring precipitation will have minimal impacts on this species and that greater white-fronted geese will likely be adaptable enough to cope with the climate changes predicted to occur, at least during the timeline of this assessment (Table H-36).

Table H-36. Summary of abiotic change agents used in the assessment greater white-fronted goose and projected effects.

Indicator	Short-term (2020) trend	Long-term (2060) trend	Impact to	Effect
Date of thaw	Negligible	earlier	Earlier arrival and nesting, increased reproductive success, potential for trophic mismatch	+/-
Summer temperature	+	+	Earlier arrival and nesting, potential for trophic mismatch	+/-
Spring precipitation	No change	Negligible	Increases in flooding events and nest failure	?
Thermokarst predisposition	-	+	Potential gain in habitat availability	+

11.6. Current Status and Future Landscape Condition

The majority of current greater white-fronted goose habitat is in areas with very high (intact) landscape condition (Figure H-62). However, very low condition is indicated in high density nesting areas around Prudhoe Bay and Nuiqsut. Future scenarios of landscape condition do not indicate any significant changes in both medium and high scenarios.

Greater white-fronted geese are loyal to breeding and molting sites, which may hinder a population's ability to relocate if breeding or molting sites are negatively impacted or destroyed by development. Because geese concentrate at pre-nesting and molting sites, the effects of severe but rare local disturbance events, such as oil spills or toxic contamination, will likely have large negative impacts on populations (Schoen and Senner 2002). During years of late snowmelt, geese nest on drier upland sites (Ely and Raveling 1984) that are more likely to be restricted by future development. Greater white-fronted geese are sensitive to machine noise (Barry and Spencer 1976 *in* Ely and Dzubin 1994) and aircraft disturbance (Derksen et al. 1979) which can result in habitat avoidance.

All-weather roads (necessitated by a warming climate and shortened ice road season) associated with energy extraction activities could impact greater white-fronted geese, especially near important molting areas around Teshekpuk Lake (Liebezeit et al. 2012).

Jaegers (*Stercorarius* spp.), large gulls (*Larus* spp.), and ravens (*Corvus corax*) prey upon nests of greater white-fronted geese. Gyrfalcon (*Falco rusticolus*), mink (*Mustela vison*) and large carnivorous mammals predate both eggs and geese (Schoen and Senner 2002). Arctic foxes are present in high densities in the northern portion of the NPRA (Bart et al. 2013) and exert high predation pressure on tundra nests during nesting season, including those of the greater white-fronted goose (Stickney 1991). Some evidence has suggested that predators such as ravens and Arctic fox become more numerous in areas of human development because of the presence of additional food sources and artificial nesting/denning sites. While recent improvements to waste handling procedures associated with oil field infrastructure have likely dampened this effect in oil fields (Liebezeit et al. 2009), this may still be a concern in areas of other development. Furthermore, predation by red foxes (*Vulpes vulpes*) may increase if the climate becomes more suitable for the expansion of the red fox population (Liebezeit et al. 2012).

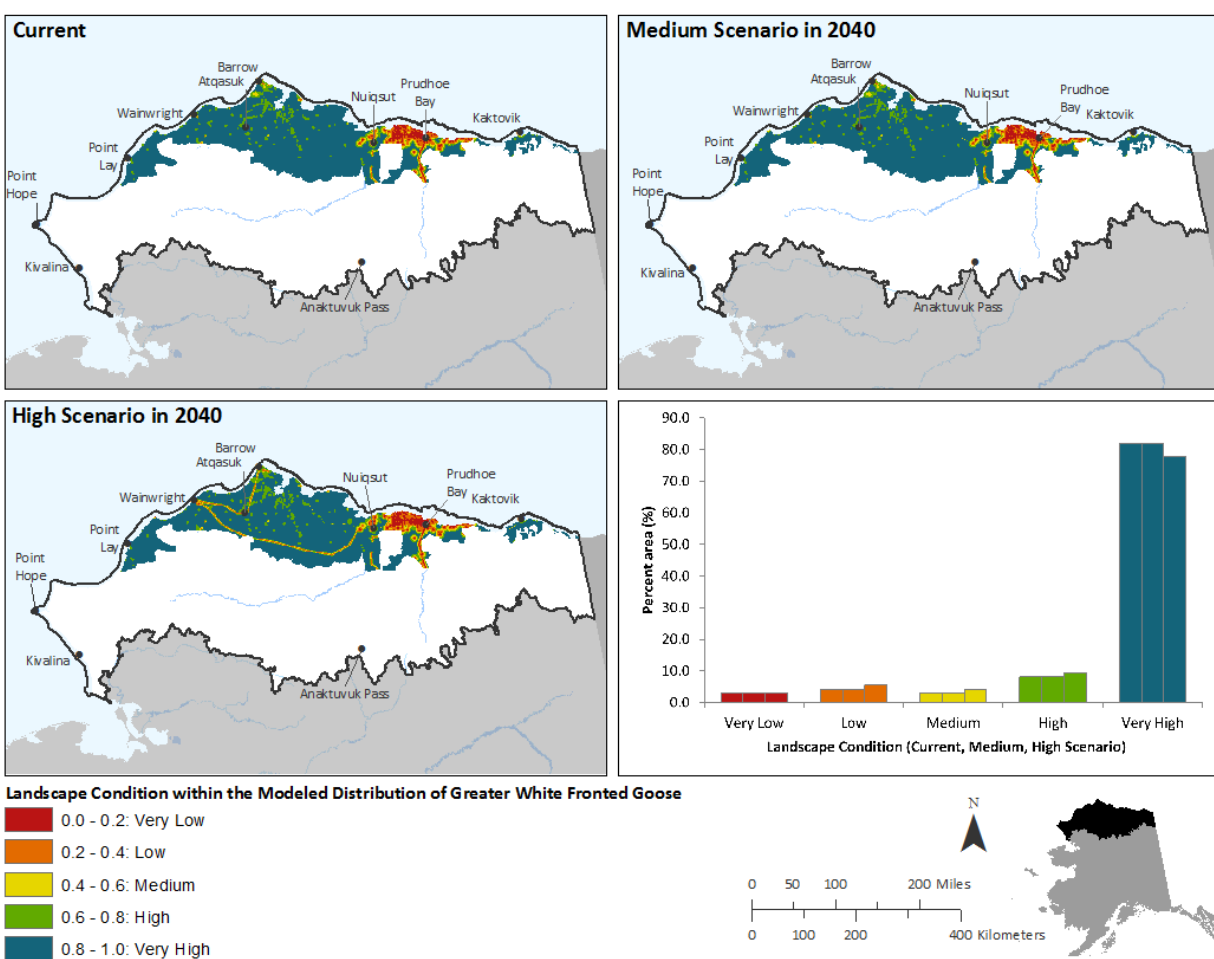


Figure H-62. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current distribution of greater white-fronted goose in the North Slope study area.

Greater white-fronted geese are harvested by subsistence users on the North Slope. Because greater white-fronted geese arrive relatively early in spring compared to other geese, they may receive greater subsistence hunting pressure prior to breeding. Roads associated with energy extraction activities could

provide increased accessibility to goose nesting areas, thereby increasing potential for greater hunting pressure.

11.7. Limitations and Data Gaps

We did not directly explore the relationship between coastal erosion and salinization and the potential affects to post-breeding aggregations foraging/molting habitats, as this was beyond the scope of this assessment. However, MQ TF 4 does provide an overview of expected changes to habitat as a result of coastal erosion and salinization and could be referred to for comparison.

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12. Raptor Concentration Areas

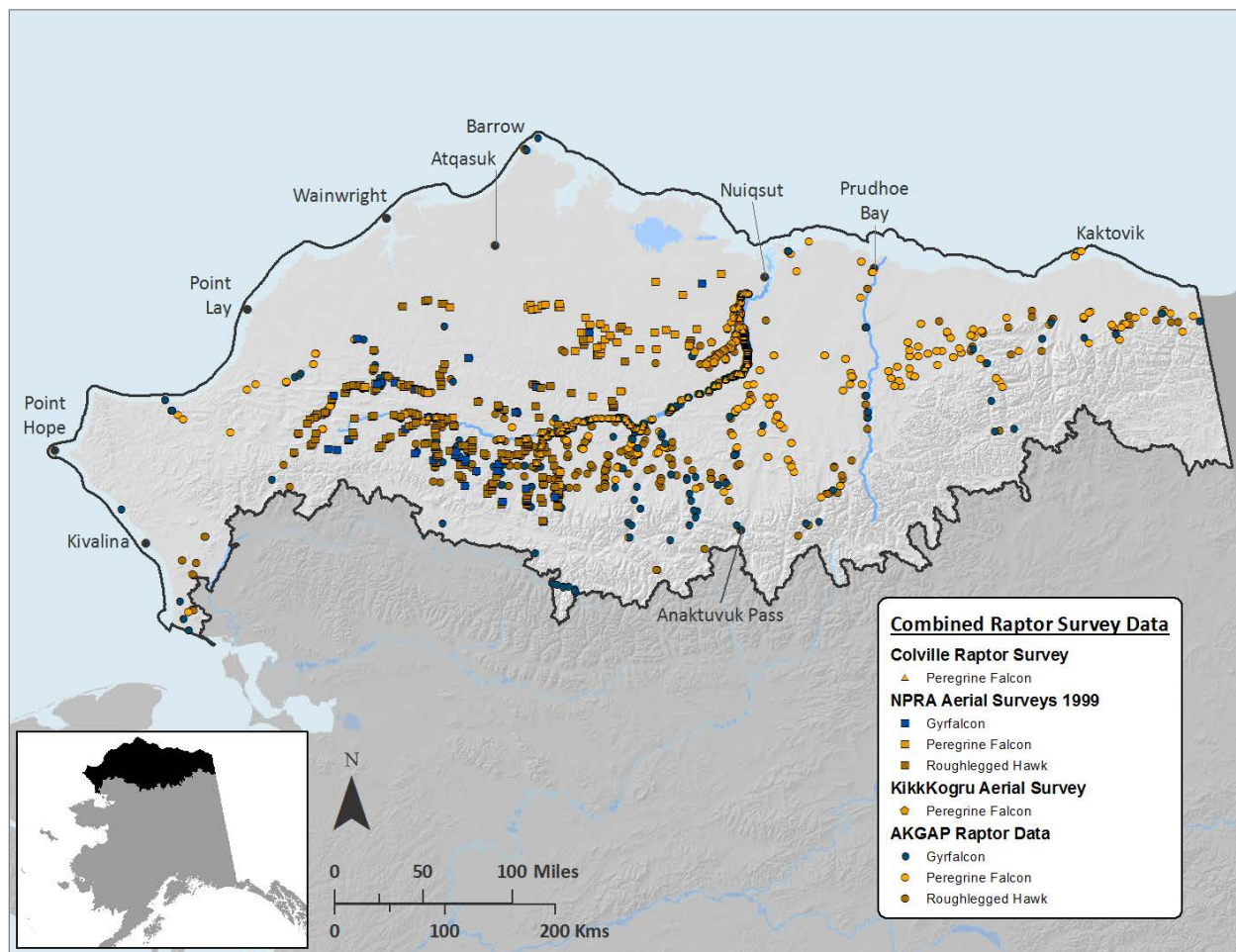


Figure H-63. Documented occurrences for peregrine falcon, gyrfalcon, and rough-legged hawk in the North Slope study area.

12.1. Introduction

Species selected to represent the “Raptor Concentration Areas” assemblage for the North Slope study area include gyrfalcon (*Falco rusticolus*), peregrine falcon (*Falco peregrinus tundrius*), and rough-legged hawk (*Buteo lagopus*). These three species share similar habitats in arctic Alaska, but differ in seasonal distribution and prey preferences. Primary habitats include cliffs in riparian areas along river drainages and major tributaries, shale banks, mud or sand banks, scree and talus slopes, and steep escarpment faces. This species assemblage was nominated as a Terrestrial Fine-Filter CE because of the role raptors play as top trophic-level predators and that changes in their status could be indicative of large-scale ecosystem changes.

The gyrfalcon is the largest falcon species, the most northern diurnal raptor, and an arctic specialist. It is migratory with a circumpolar distribution, including summer breeding sites in Alaska. Gyrfalcons are

most common on the arctic slope east of the Sagavanirktok River and west of the Anaktuvuk River, with relatively low numbers along the Sagavanirktok River. The Colville River and adjacent drainages support a substantial proportion of the North Slope population (Johnson and Herter 1989). Gyrfalcons are also common east of the Canning River in the Arctic National Wildlife Refuge. Individuals are typically present on their breeding grounds from March to September (see Booms et al. 2008 for review); however, there is evidence for winter occupation of nest sites in Alaska (Cade 1960) and other northern regions (Platt 1976, Kuyt 1980, Norment 1985). Current population on the North Slope (*tundrius* subspecies) is estimated at 250 breeding pairs (USFWS 2001). This species nests primarily on precipitous cliff faces and typically utilizes nests built by other species (particularly common raven, golden eagle, and rough-legged hawk) (Booms et al. 2008). They lay one clutch (averaging 3.7 eggs; Booms et al. 2008) per year which is incubated for approximately 35 days (Platt 1977). Pairs may not breed every year, depending on prey availability (Cade 1960, Nielsen and Cade 1990). Ptarmigan are the preferred prey species, but they will also take birds ranging in size from passerines to geese (Poole and Boag 1988, Booms et al. 2008). Foraging range during breeding is approximately 12–15 km from the nest site (Palmer 1988).

The peregrine falcon ranges throughout much of the world as either a seasonal migrant or resident. Peregrine falcons that breed in arctic Alaska spend winters in Central and South America (Liebezeit et al. 2012). The principle nesting area in the North Slope study area occurs along the Colville River drainage (including major tributaries such as the Etivluk, Oolamnagavik, Killik, and Chandler rivers) and the Sagavanirktok River (APFRT 1982). Individuals are typically present on their breeding grounds from mid-April/mid-May to mid/late-August (APFRT 1982). They lay one clutch (averaging 3 eggs) per year (Cade et al. 1968, Wright and Bente 2001), which is incubated for 33 to 35 days (White et al. 2002). Peregrine falcons prey primarily on bird species including passerines, shorebirds, and ducks (Mindell and Craighead 1981, *reviewed in* White et al. 2002). Foraging range during breeding is approximately 8 km (Brown and Amadon 1968).

The rough-legged hawk is a migratory species that breeds in the circumpolar arctic and subarctic, and winters in the temperate northern hemisphere. It is the most abundant and wide-spread cliff-nesting raptor in the North Slope study area (Ritchie et al. 2003). Distribution and densities are enhanced during years of high microtine populations and appear to be limited to the north by lack of preferred nesting sites (Zarn 1975). They lay one clutch (averaging 3–4 eggs) per year (Swem 1996, Kessel 1989), which is incubated for a minimum of 32 days (Parmelee et al. 1967, Cramp and Simmons 1980). On the coastal plain of Alaska, they typically forage for small mammal prey in open tundra and low-brush habitats (e.g. river floodplains) (Bechard and Swem 2002). Foraging range during breeding is approximately 3–7 km (Cannings 2002).

The diversity of food habits vary annually for the three raptor species. Annual fluctuations in the population sizes of gyrfalcon and rough-legged hawk in Arctic Alaska are linked to the abundance of primary prey species (ptarmigan and lemmings, respectively), which are residents of the arctic environment (Mindell et al. 1987). Synchronous population cycles have been documented between willow ptarmigan (*L. lagopus*) and gyrfalcon, although the regularity of willow ptarmigan cycles may be faltering (Mossop 2011). Peregrine falcon populations appear to be more stable from year to year, likely

because peregrines primarily consume migratory bird species, whose populations are less affected by local conditions, and therefore less volatile than populations of resident species (Mindell et al. 1987).

12.2. Conceptual Model

The conceptual model below (Figure H-64) is based on literature review and describes the relationship between the various change agents and natural drivers for the three raptor species included in this assemblage; peregrine falcon, gyrfalcon, and rough-legged hawk. The boxes and arrows represent the state of knowledge about the raptor assemblage and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and the raptor assemblage. Change agents selected for this REA and considered in this analysis include: climate change, fire, invasive species, and land use change (i.e. human development).

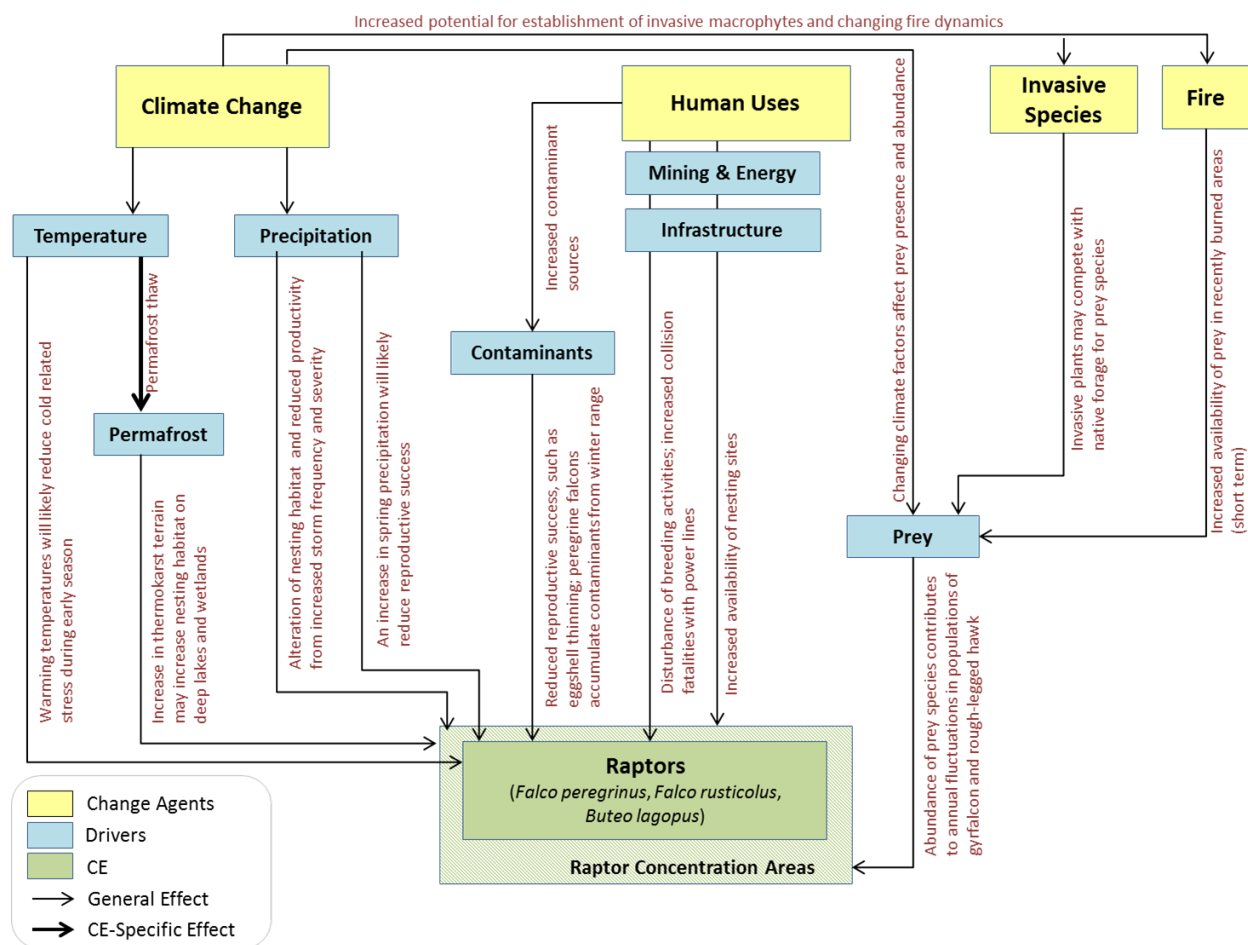


Figure H-64. Conceptual model for raptor concentration areas.

12.3. Attributes and Indicators

Attributes and indicators helped to define the relationships between conservation elements and change agents, and, where possible, the thresholds associated with these relationships. Based on the assessment of available indicators, spatial data used to assess the status of raptor concentration areas included: mean summer temperature, growing season length, spring precipitation, and landscape condition (Table H-37).

Table H-37. Attributes and indicators for raptor concentration areas.

CA or Driver	Ecological Attribute	Indicator (unit of measure)	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Prey availability ³⁶	Mean Temperature - June, July, August	Warmer temperatures associated with increases in prey availability, chick survival and reproductive success.	Below average		Average	Above average
	Prey availability ³⁶	Growing season length		Below average		Average	Above average
	Habitat availability ³⁷	Spring precipitation - March, April, May	Cold, wet springs can increase nestling mortality.		Above average	Average	
Anthropogenic	Habitat condition ³⁸	Landscape condition model (human footprint)	Disturbance at breeding sites may lead to abandonment and nest failure.	0-3 km	3 - 6 km	6 - 10 km	> 10 km

³⁶ Based on Cade et al. 1971, Bale et al. 2002, Liebezeit et al. 2012, and Bolduc et al. 2013.

³⁷ Based on Cade et al. 1971, Liebezeit et al. 2012.

³⁸ Based on Brown and Amadon 1968, Palmer 1988, Cannings 2002, and Oregon Department of Transportation 2007.

12.4. Distribution Model

For most of the Terrestrial Fine-Filter CEs, we used predictive models generated by the Alaska Gap Analysis Project (AKGAP) to describe the species distribution across the North Slope study area. However, the AKGAP distribution models for raptors were of generally of poor quality, as cliff nesting features were not mapped well in the land cover base maps used to generate the distribution models (Gotthardt et al. 2014). Therefore, we opted not to include them in this analysis. Instead, we compiled 5,166 existing occurrence records for peregrine falcon (n = 2752), gyrfalcon (n = 413), and rough-legged hawk (n = 2001) for the North Slope study area from a variety of data sources (Table H-38; Figure H-63). We standardized the data into a common format, projected it in ArcGIS, and buffered records that were clustered along river drainages and major tributaries. We selected a 5 km buffer distance based on previous work by Audubon Alaska, who identified important raptor habitat within a 5 km swath along the Lower Colville River (Alaska Audubon 2008). The bare rock cliffs along these rivers are critical habitat for nesting. The riparian areas along the rivers, including the gravel bars and shrubs within the river bottoms, are important raptor hunting habitat, as are the lakes and ponds and adjacent tundra.

Table H-38. Datasets used for raptor concentration areas.

Dataset Name	Data source
Alaska Gap Analysis terrestrial vertebrate occurrence database - peregrine falcon, gyrfalcon, and rough-legged hawk*	Alaska Gap Analysis Project, AKNHP
Peregrine falcon surveys in interior and northern Alaska, 1990	Bureau of Ocean Energy Management
Site occupancy of cliff nesting raptors in Arctic NWR	USFWS, Arctic NWR
Peregrine falcon locations in NPR-A	BLM, NPRA EIS

*23 unique datasets are included in the Alaska Gap Analysis occurrence database. A full list of citations is provided in the North Slope Data Discovery Memo.

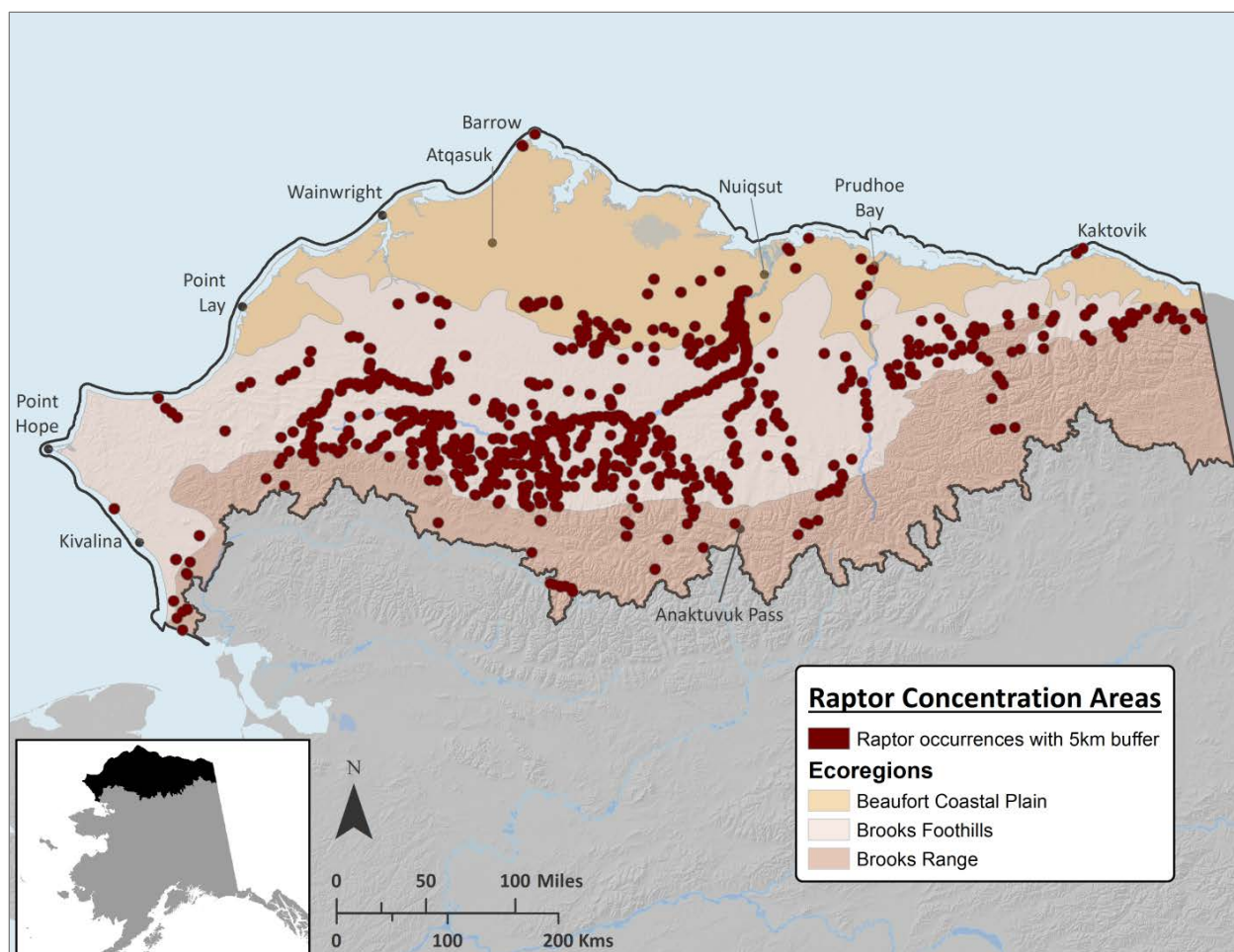


Figure H-65. Current distribution of raptor concentration areas in the North Slope study area.

Figure H-65 depicts important nesting concentration areas for the three raptor species included in this assemblage. Nesting sites, and therefore raptors, are most common in the Brooks Foothills, with less suitable habitat in the Brooks Range and the Beaufort Coastal Plain. Raptors nesting in the Brooks Range are primarily gyrfalcons. Gyrfalcons are rare to uncommon along the Beaufort Coastal Plain.

12.5. Abiotic Change Agents Analysis

We explored the relationship between arctic raptors and three abiotic climatic change agents: summer temperature, growing season length, and spring precipitation at three time steps (current, near-term, and long-term). We hypothesized that warmer than average summer temperatures and a longer growing season would be beneficial for raptors, by reducing cold related stress during early season, and potentially resulting in increases in prey availability, chick survival and reproductive success, while wetter than average springs (increase in frequency and severity of spring storms) could reduce raptor reproductive success.

Temperature and Growing Season Length

The results of our analysis indicate that within the current modeled distribution of raptor concentration areas, both summer temperature and growing season will increase by 2060. Summer temperatures increases will be significant, by as much as 1.3 °C, with the warmest temperatures occurring in the Brooks Foothills (Figure H-66). Growing season length (estimated days with mean temperatures above freezing) across the North Slope study area is currently between 110 to 130 days, but by 2060 will increase by 7 to 14 days throughout the entire raptor concentration area range (Figure H-67).

Warmer temperatures may be favorable for some arctic nesting raptors, as they are expected to result in increased insect abundance and more varied insect community composition (Danks 1992), providing energy dense diets for insectivorous passerines, which are primary prey items for peregrine falcon (Bale et al. 2002, Bolduc et al. 2013). Warming temperatures may also reduce cold related stress during early season nesting (Cade et al. 1971, Liebezeit et al. 2012, Ontario Peregrine Falcon Recovery Team 2010).

A longer growing season should promote a longer breeding window and allow fledglings more time to forage before fall migration (Kittel et al. 2010). This could be especially beneficial to gyrfalcon, which has the longest reproductive cycle of the three raptors (ca. 160-180 days from establishment of nesting territory to independently fledging young) and is the first raptor to arrive on arctic breeding grounds in the spring (Cade 2011). Breeding is currently timed so that young nestlings fledge during the period of peak availability of young, inexperienced prey (especially ptarmigan). In addition, a longer growing season may allow for earlier arrival of prey species (Murphy-Klassen et al. 2005) providing raptors with more abundant prey resources in the spring. It is unclear how raptor breeding phenology will be influenced by a lengthening Arctic summer, but it could be advantageous in spring and autumn by allowing for new trophic relationships (Cade 2011).

Currently, gyrfalcons are the most common raptor nesting in the Brooks Range and uncommon to rare along the Coastal Plain, where the current length of growing season may limit their ability to be successful reproductively. A longer growing season could allow gyrfalcons to expand their range northward, allowing for increased competitive interactions with peregrine falcons and rough-legged hawks. However, recent modeling efforts indicate that the future gyrfalcon range in Alaska could decrease substantially (Booms et al. 2011).

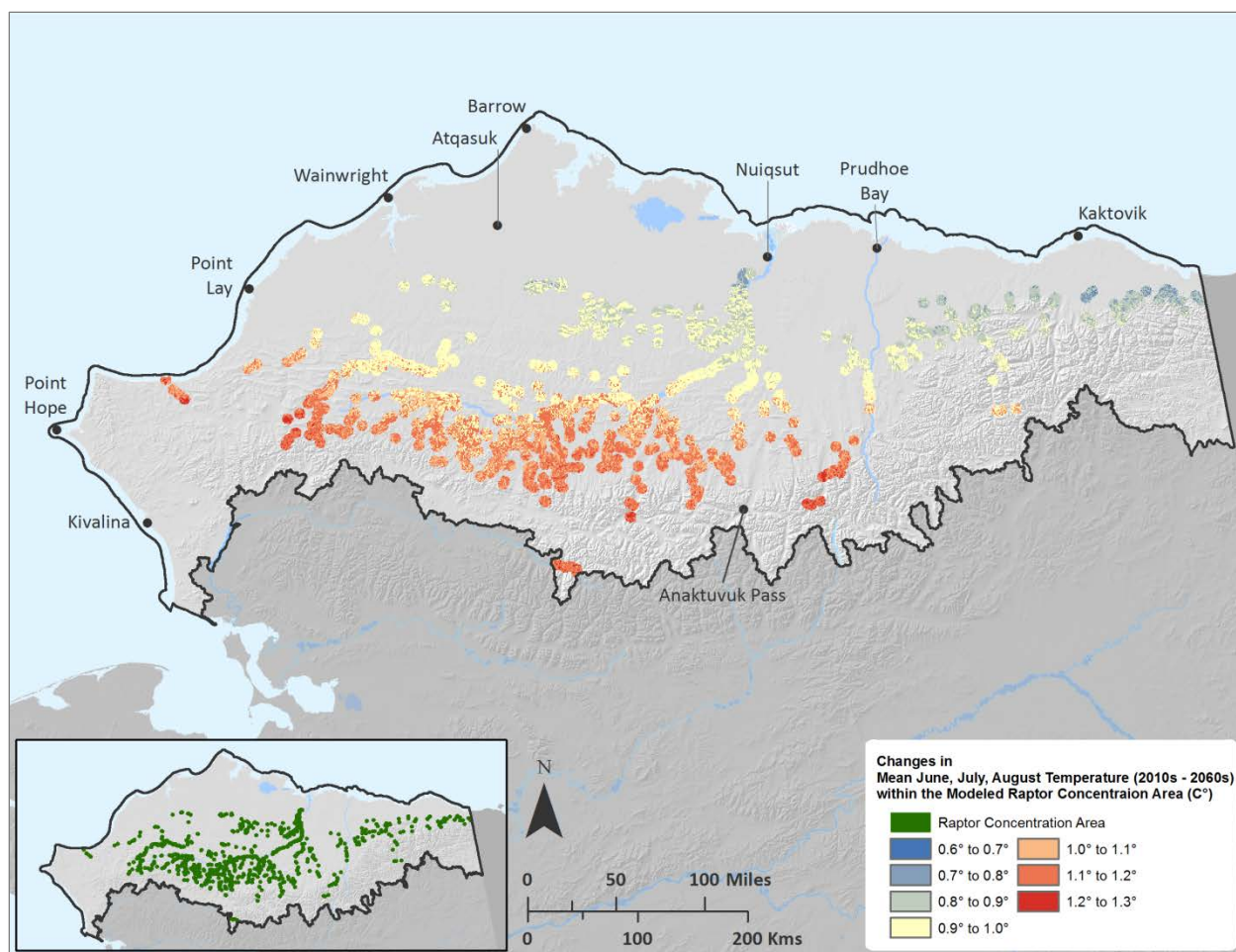


Figure H-66. Changes in mean summer (June, July, and August) temperature (2010s to 2060s) within the modeled raptor concentration area in the North Slope study area.

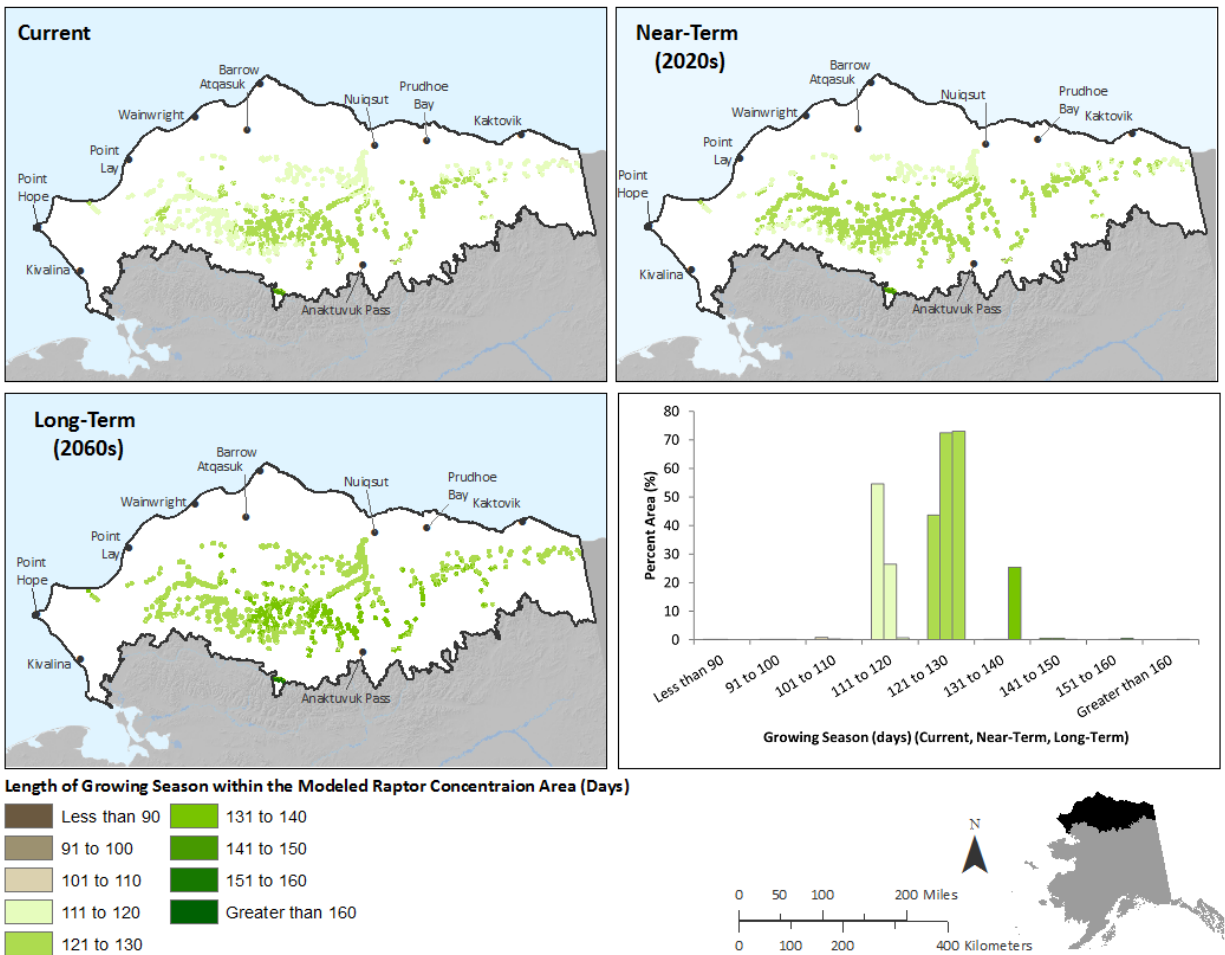


Figure H-67. Length of growing season at current, near-term future (2020s), and long-term future (2060s) time intervals within the modeled raptor concentration area in the North Slope study area.

Spring precipitation

An increase in the frequency and severity of erratic weather events has the potential to cause heavy rains that may negatively affect raptor productivity during incubation and brood rearing (Cade et al. 1971, Liebezeit et al. 2012, Ontario Peregrine Falcon Recovery Team 2010). Recently, researchers in the Canadian Arctic have linked an increase in the frequency of heavy rain over the last three decades to the recent decline of peregrine falcon nestling survival rates, and subsequent decreases in annual breeding productivity (Ancil et al. 2013). This direct linkage between rainfall and survival in wild birds indicates that top level avian predators may be significantly impacted by changes in precipitation regimes (Ancil et al. 2013).

We used precipitation as a surrogate for “increased storminess” in our comparison with raptor concentration areas. Results indicate that total precipitation may increase slightly between current conditions and 2060, but geographic patterns of precipitation are likely to remain relatively unchanged across the raptor concentration area range (Figure H-68). While the potential for increased storminess

during the arctic spring is highly uncertain, total precipitation models indicate that impacts to raptors will likely be minimal.

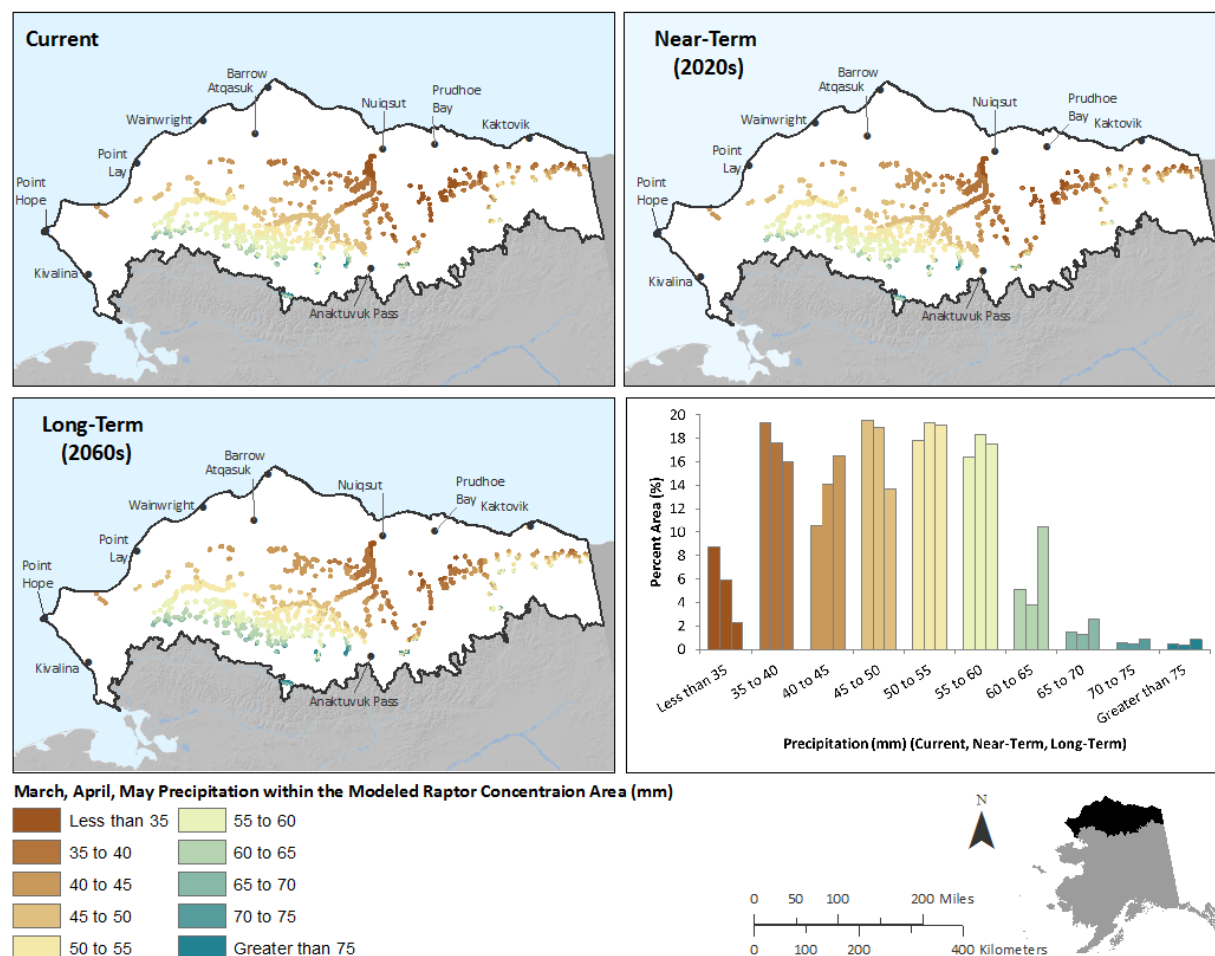


Figure H-68. Spring precipitation (March, April, and May) in mm within the modeled distribution of raptor concentration areas.

The 10-year population cycles of ptarmigan and hares and the 3-4 year cycles of microtine rodents are expected to exhibit lower peaks and less regularity under climate change. In the Yukon Territory, regular population cycles of willow ptarmigan (a major prey item for gyrfalcon) have faltered in recent years, likely a consequence of climatic changes (see Section H.8). Concurrent with observed changes in the population cycling of willow ptarmigan, the timing of gyrfalcon nesting has moved later in spring and fewer nest sites have been observed (Mossop 2011). The lack of recent peaks in ptarmigan population cycles, possibly caused by the increasing frequency and severity of spring storm events, has likely removed peaks in gyrfalcon reproduction that have historically boosted gyrfalcon populations during ptarmigan population troughs (Mossop 2011). Whether these population changes will persist and what they portend for predators needs study (Cade 2011).

Climate change, including warmer temperatures and increased precipitation, are expected to affect infectious disease prevalence and proliferation in arctic and subarctic regions (Kutz et al. 2009). An

increased prevalence of disease may reduce these species' capacity to adapt to rapid climate change (Boom et al. 2011). For example, the northward expansion or ecological shift of diseases and parasites facilitated by warming climates (e.g., Hueffer et al. 2011) likely poses significant confounding risks to gyrfalcons in particular, which are known for their susceptibility to numerous diseases in lower latitudes (Booms et al. 2011).

Fire

The impact of fire and its potential increase in frequency and severity with a warming climate could affect raptor habitat. Although ALFRESCO predicts increased fire frequency in the foothills and Brooks Range sub-regions, and are where the majority of raptors are concentrated, total area burned is expected to remain relatively low and will likely not be a significant driver affecting raptor habitat.

Due to their high mobility, fire-related mortality of adult raptors is likely low. Nestling mortality is potentially higher because nestlings are unable to flee approaching fire (Luensmann 2010). Because these birds nest on cliff faces, rock outcrops, and similar sites, the potential for damage to nesting sites or nestling mortality is low but possible if vegetation on the nest ledge catches fire. Fire may threaten nests at the ground level amongst dense vegetation (Luensmann 2010).

Increased fire frequency may both create and destroy favorable hunting habitat (Racine and Jandt 2008). Bird diversity and small mammal populations will likely temporarily increase in recently burned areas, as these prey species are attracted to abundant new vegetative growth in the months following fire (Luensmann 2010, Liebezeit et al. 2012). In New Mexico and southern California, abundant prey species attracted golden eagles (*Aquila chrysaetos*) and peregrine falcons to recently burned areas (Lehman and Allendorf 1989).

Climate Summary

Of the three raptor species considered in this assessment, gyrfalcon are considered to be quite vulnerable to climate change due to factors mostly related to their narrow ecological niche that includes a specialized diet (ptarmigan) and nesting requirements, while rough-legged hawk and peregrine falcon are more likely be able to adjust to associated habitat changes predicted to occur on the North Slope over the time period of this assessment (Liebezeit et al. 2012). Overall, raptors could benefit from warmer temperatures by reducing cold related stress during nesting; a longer growing season provides a longer time period to fledge young; projected changes in spring precipitation related to decreases in nestling survival are expected to be negligible, as will affects from fire on nesting habitat (Table H-39).

Table H-39. Summary of abiotic change agents used in the assessment of raptor concentration areas and projected effects.

Indicator	Short-term (2020) trend	Long-term (2060) trend	Impact to	Effect
Summer temperature	+	+	Earlier food for prey, reduced cold related stress	+
Growing season length	+	+	Longer breeding window, more abundant spring prey	+
Spring precipitation	No change	Negligible	Decreases in nestling survival rates; decreases in annual breeding productivity	-
Fire	Negligible	Negligible	Loss of ground level nests; short-term increases in prey species	?

12.6. Current Status and Future Landscape Condition

The majority of current raptor concentration distribution locations are in areas with very high (intact) landscape condition (Figure H-69). Future projections of landscape condition suggest very little change in landscape condition in the vicinity of riparian corridors and areas occupied by these species.

Although landscape condition appears to be high in the general vicinity of nesting concentrations, these birds are highly sensitive and vulnerable to disturbance, especially at the nest site. Nest habitat is limited, so disturbed birds are unable to simply move elsewhere. Development will bring a general increase of human activities, including aircraft traffic, which will create additional disturbance to the birds. Threats associated with development as a result of oil and gas activities could include direct loss of habitat from the development footprint, including roads, pipelines, drilling pads, and residential facilities. Human activity (including noise, recreational activities, and vehicle traffic) and development near nesting sites can deter and disturb breeding activities, cause nest abandonment, and destroy potential nesting habitat (Oregon Department of Transportation 2007), although studies are not conclusive (Ritchie et al. 1997, Palmer et al. 2003). Peregrine falcons have shown greater negative response to animate (human) than to inanimate (aircraft) activity, and more to boats than to airplane (Windoor 1977, Nordmeyer 1999). Aircraft have been shown to disturb peregrines at distances less than 150 m during the fledgling period (Windoor 1977). Human presence has elicited higher levels of disturbance as far as 150 m from a cliff base (Windoor 1977).

Recreational users use boats for access and floating rivers in the area. Since the river is the agent of erosion which creates the cliffs so critical to the nesting raptors, recreational floaters pass directly under almost all nests. Increased recreational activity could disturb nesting birds. The Colville River is used for travel between subsistence hunting and fishing opportunities. Umiat is a camp along the Colville which supports oil and mineral exploration activities. It also serves as a landing field and refueling stop for aircraft (Alaska Audubon 2008). The high scenario LCM indicates potential for a pipeline connecting

Umiat to other oil and gas infrastructure, which could have negative implications for birds nesting in this area.

The Bureau of Land Management requires that permitted activities across the entire National Petroleum Reserve-Alaska adhere to a series of restrictions and required conduct around potential raptor nesting habitats, all of which are designed to minimize disturbance and nest abandonment (Audubon Alaska 2008). Recreational boating, wildlife viewing, and wilderness tours are all activities now conducted within the Colville corridor. Since the 1950s, the Colville River corridor has been used as a research area for monitoring Peregrine Falcons (Alaska Audubon 2008).

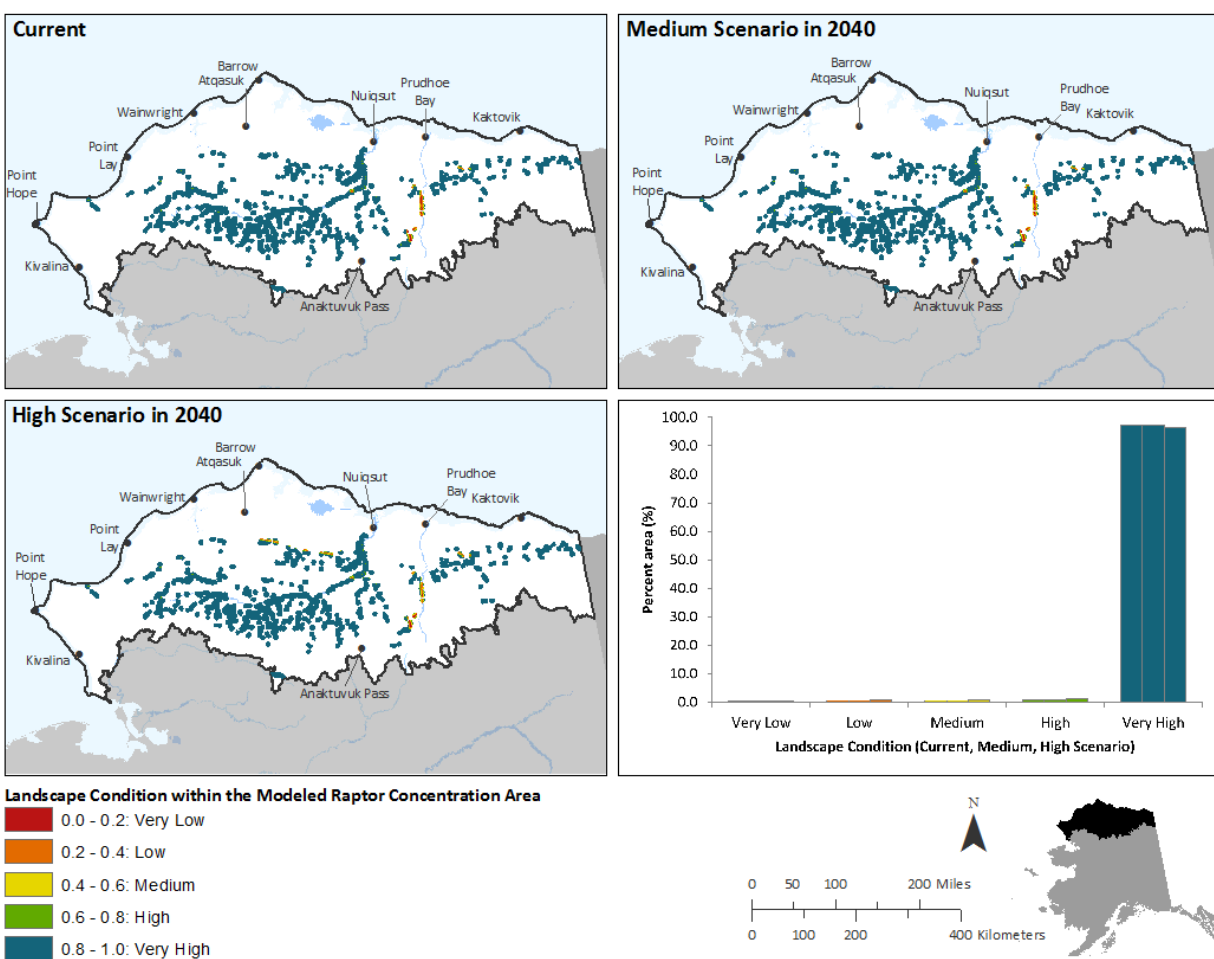


Figure H-69. Current, 2040 medium-development scenario, and 2040 high-development scenario landscape condition within the current raptor concentration areas in the North Slope study area.

Disturbances that may have contributed to the peregrine falcon decline which resulted in their listing status in 1970 include destruction of wetlands, construction of roads and other structures, poaching, removal of eggs and nestlings from nests, disturbance from recreational activities, and climate change (Kiff 1988). Because peregrine falcons use a wide range of habitats and landscapes, the effects of habitat degradation are difficult to assess. The greatest effects are likely due to losses of nesting sites, which may be limited.

Frequent interruptions during nesting can lengthen the incubation period and delay hatching (White et al. 2002). The timing of disturbance at nest sites also seems to be critical to nesting success (Ratcliffe 1993). Nesting peregrine falcons are intolerant of excessive human disturbance; they may abandon a nest site during courtship and move to another ledge or cliff. Breeding pairs may attempt to continue nesting if eggs or nestlings are being brooded, but often, the nest is deserted (Ratcliffe 1993). Peregrine falcon young can perish in harsh environments if the parents, panicked by disturbance, are away from the nest for long periods (White 1969). Ellis (1982) recommended that recreational activities and human development be minimized whenever peregrine falcons occupy an area, and concluded that protecting nesting sites from human disturbance is critical for peregrine falcon conservation (Stephenson and Calcarone 1999).

12.7. Limitations and Data Gaps

We did not address the potential impacts to raptor concentration areas as a result of fire frequency. Although ALFRESCO predicts increased fire frequency in the foothills and Brooks Range sub-regions, total area burned is expected to remain relatively low and will likely not be a significant driver affecting raptor habitat. Furthermore, we did not explore the relationship of raptor habitat with permafrost and thermokarst disposition. Thermokarst, through both ice wedge degradation and draining of thaw lakes (Martin et al. 2009) could both create and reduce nesting sites on deep lakes and wetland foraging sites. However, we felt we lacked suitable raptor distribution models to explore these potential relationships.

Although we sought to compile a comprehensive raptor dataset for the North Slope study area for this analysis, it is likely that there are numerous data sets that are lacking from this synthesis of observations that we were simply unaware of. We developed a database structure for this project that includes 5,166 records, which can easily be added to and updated over time as new information becomes available.

12.8. Literature Cited

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