# D. Conservation Elements



**Subsections:**

1. Terrestrial Coarse-Filter CEs
2. Terrestrial Fine-Filter CEs
3. Aquatic Coarse-Filter CEs
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# 1. Terrestrial Coarse-Filter Conservation Elements

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**Summary**

Section D-1. *Terrestrial Coarse-Filter Conservation Elements* provides the detailed descriptions, methods, datasets, results, and limitations for the assessments of selected vegetation classes considered to be of high ecological importance in the region and potential impacts of CAs.

## 1.1. Introduction

Terrestrial Coarse-Filter CEs are regionally important vegetation classes that represent the characteristic vegetation assemblages and encompass many of the dominant ecological processes and patterns of the YKL study area. Together the Coarse-Filter CEs address the habitat requirements of most native species and the majority of ecosystem functions and services. After several iterations of review by the AMT and Tech Team, six aggregated vegetation classes and one biophysical setting were selected for analysis as CEs because of their representation of ecosystem functions and their overall representation on the landscape (covering 89% of the entire study area, Table D-1). Permafrost was initially selected as a Coarse-Filter CE due to its regional importance for maintaining soil, sediment, and water retention; however, because permafrost functions as a significant CA in the region, it is considered as such for this REA.

**Table D-1.** Total area of Terrestrial Coarse-Filter CEs in the YKL study area and their ecosystem functions.

| Terrestrial Coarse-Filter CEs | Ecosystem Function | Area (km$^2$) | Percent of Study Area |
|---|---|---|---|
| Deciduous forest | Early to mid seral forest habitat for birds, mammals, and invertebrates | 36,652 | 16% |
| Dwarf-shrub (mesic) | Habitat for birds, mammals, and invertebrates; stabilizes scree slopes | 15,790 | 7% |
| Large floodplains[1] | High quality habitat for moose and beaver; aquatic-terrestrial exchange | 17,464 | 8% |
| Herbaceous wetlands | Nutrient inputs from soil resources to freshwater resources; important habitat for waterfowl and beavers in addition to other birds, mammals, and invertebrates | 11,507 | 5% |
| Low shrub | Habitat for birds, mammals, and invertebrates | 26,827 | 12% |
| Tall shrub | Alder is an important source of nitrogen in Interior Alaska, and willow is important moose browse | 13,975 | 6% |
| White spruce or black spruce forest | Habitat for birds, mammals, and invertebrates; impacts fire regime | 98,210 | 43% |
| **Total** | | **206,366** | **89%** |

The Coarse-Filter CEs section is organized by first describing the methods used to develop the distribution models for all the CEs. We then describe the characteristics, spatial distribution, and relationship of Terrestrial Coarse-Filter CEs to the current, near-term (2025), and long-term (2060) landscape condition, as well as selected climate and CA variables understood to be critical. Following this section, a MQ that encompasses a synthesis of

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[1] Because floodplains are a biophysical setting and not an aggregation of vegetation classes, they partially overlap with the other Terrestrial Coarse-Filter CEs. The total area of floodplains is 17,464 km$^2$, covering 8% of the study area. For the purpose of calculating the total area of Coarse-Filter CEs in the study area, we only included the area of floodplains that do not overlap with other Terrestrial Coarse-Filter CEs (3,405 km$^2$ and 1% of the total project area).

the distribution of current vegetation classes is answered. Potential applications and limitations of the results are then addressed.

## 1.2. Methods

**Vegetation Mapping and Classification**

Prerequisite to the delineation of the Terrestrial Coarse-Filter CEs was the production of a single land cover map with adequate resolution of vegetation cover classes at the best available accuracies. At project initiation, there was not a single vegetation map available with the attributes needed to define Coarse-Filter CEs. During the course of the project, we combined various regional maps (Figure D-1) to create a vegetation map (Boggs et al. 2012) that covered the YKL study area in its entirety (Figure D-2). We reclassified vegetation classifications from the regional maps across the entire study area based on a variation of levels III and IV of the Viereck et al. (1992) classification. To develop Coarse-Filter CEs, we selected either a single vegetation class or an aggregate of vegetation classes from the Boggs et al. 2012 vegetation map (Table D-2), with the exception of the floodplains CE, which we delineated separately.
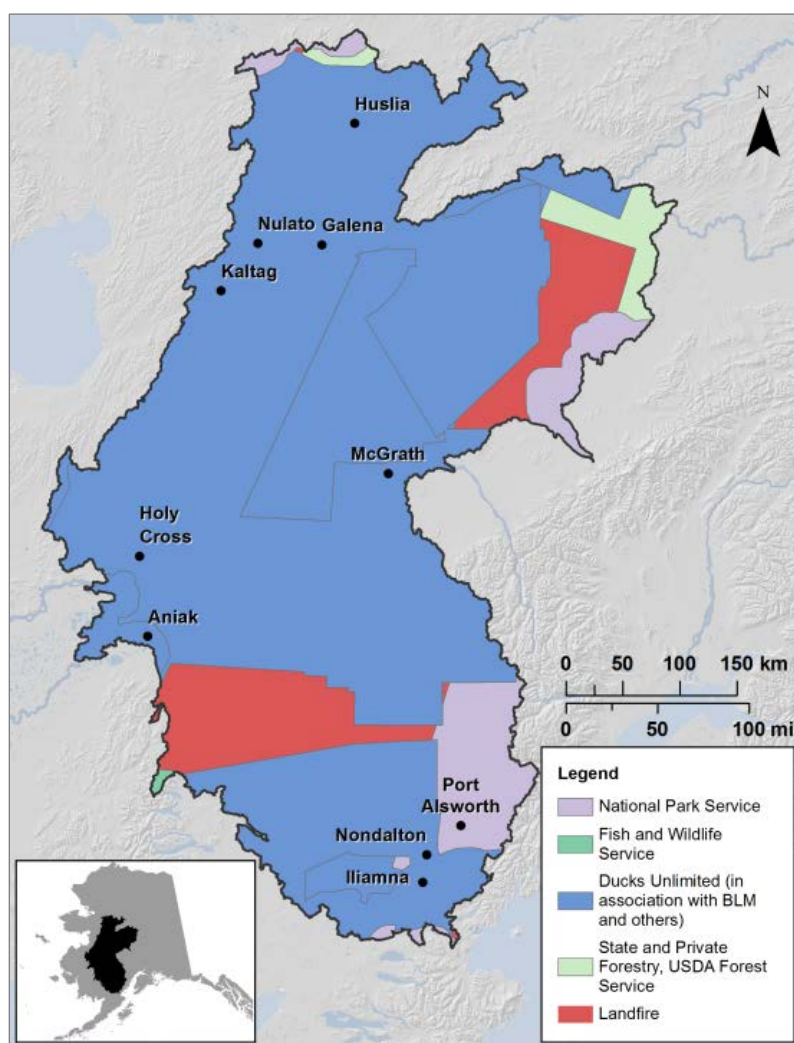


**Figure D-1.** Source data coverage for Vegetation Map and Classification – Northern, Western, and Interior Alaska (Boggs et al. 2012) within the YKL study area.

**Legend**

**Vegetation Map of Northern, Western, and Interior Alaska**

Coarse Vegetation Class

- Bareground
- Deciduous Forest (Open-Closed)
- Dwarf Shrub
- Dwarf shrub-Lichen
- Fire Scar
- Freshwater or Saltwater
- Herbaceous (Aquatic)
- Herbaceous (Marsh) (Interior Alaska, Cook Inlet Basin)
- Herbaceous (Marsh) (Northern and Western Alaska)
- Herbaceous (Mesic) (Interior Alaska, Cook Inlet Basin)
- Herbaceous (Mesic) (Northern and Western Alaska)
- Herbaceous (Wet) (Interior Alaska, Cook Inlet Basin)
- Herbaceous (Wet) (Northern and Western Alaska)
- Herbaceous (Wet-Marsh) (Tidal) (Western Alaska, Cook Inlet Basin)

- Ice-Snow
- Lichen
- Low Shrub
- Low Shrub/Lichen
- Moss
- Sitka Spruce (Open-Closed)
- Sparse Vegetation (Interior Alaska, Cook Inlet Basin)
- Sparse Vegetation (Northern and Western Alaska)
- Tall Shrub (Open-Closed)
- Tussock Tundra (Low shrub or Herbaceous)
- Urban, Agriculture, Road
- White Spruce or Black Spruce (Open-Closed)
- White Spruce or Black Spruce (Woodland)
- White Spruce or Black Spruce (Woodland-Closed)
- White Spruce or Black Spruce-Deciduous (Open-Closed)
- White Spruce or Black Spruce/Lichen (Woodland-Open)

**Figure D-2.** Vegetation Map and Classification – Northern, Western, and Interior Alaska (Boggs et al. 2012) within the YKL study area.

**Table D-2.** A crosswalk of all the vegetation classes from the Vegetation Map and Classification – Northern, Western, and Interior Alaska (Boggs et al. 2012) selected to develop the Terrestrial Coarse-Filter CEs.

| Terrestrial Coarse-Filter CE | Vegetation Classes Aggregated from Boggs et al. (2012) |
|---|---|
| Deciduous forest | 1. Deciduous forest (open-closed)<br>2. White spruce or black spruce – deciduous (open-closed) |
| Dwarf-shrub (mesic) | 1. Dwarf-shrub<br>2. Dwarf-shrub – lichen |
| Herbaceous wetlands | 1. Herbaceous (aquatic)<br>2. Herbaceous (marsh) (Interior Alaska, Cook Inlet Basin)<br>3. Herbaceous (marsh) (northern and western Alaska)<br>4. Herbaceous (wet) (Interior Alaska, Cook Inlet Basin)<br>5. Herbaceous (wet) (northern and western Alaska) |
| Low shrub | 1. Low shrub<br>2. Low shrub/lichen |
| Tall shrub | 1. Tall shrub (open-closed) |
| White spruce or black spruce forest | 1. White spruce or black spruce (open-closed)<br>2. White spruce or black spruce (woodland)<br>3. White spruce or black spruce/lichen (woodland-open)<br>4. White spruce or black spruce (woodland-closed) |

We delineated floodplains using soils data for the United States derived from NRCS State Soil Geographic (STATSGO) database. The STATSGO soils map already defined several different floodplain classes. We reviewed each of these floodplain classes using current imagery and retained classes that contained enough detail and represented current conditions. Floodplain classes were either retained, redrawn using heads-up digitization of the best available current imagery, or removed because they were no longer the dominant process on the landscape.

**Accuracy Assessment**

Because each of the regional maps combined to form the Boggs et al. (2012) map was developed using different methodology and base imagery, and because there was not an accuracy assessment associated with the Boggs et al. (2012), we developed an accuracy assessment of the Coarse-Filter CEs. Some of the regional maps had associated reports outlining methodologies and map accuracies; however, accuracy assessments were not comprehensively completed, methodologies varied significantly, and measurements were often taken per Landsat scene rather than as collective measures of overall accuracy. Because the maps varied significantly in approaches, we determined that reporting the accuracy per Terrestrial Coarse-Filter CE would be inappropriate. We do, however, report an overall measure of accuracy, with associated imagery dates, and a relative contribution (based on area) for each regional map (Table D-3).

**Table D-3.** Imagery dates, accuracy assessment statistics, and percentage of the total study area for regional maps used to develop the Vegetation Map and Classification – Northern, Western, and Interior Alaska (Boggs et al. 2012).

| Regional Map Name | Imagery Dates | Accuracy Assessment | % of Map |
|---|---|---|---|
| Spatial Solutions Inc. 2005. 2005 Alaska BAER Earth Cover Classification. Bend OR. 45 pp. | 1985-2003 | Between 86% and 89% | 0.04 |
| Collins, G. 2003.Togiak National Wildlife Refuge Earth Cover Accuracy Assessment. Togiak National Wildlife Refuge | 1989-2000 | Between 80% and 90% | 0.08 |
| Stumpf, K., K. Boggs, and J. Grunblatt. 2003. Land Cover Map of Katmai National Park and Preserve-2000. National Park Service Alaska Regional Office. | 1987, 1991, 1995, 2000 | None | 0.18 |
| Jorgenson, M. T., J. E. Roth, P. F. Miller, M. J. Macander, M. S. Duffy, A. F. Wells, G. V. Frost, and E. R. Pullman. 2009. An ecological land survey and landcover map of the Arctic Network. Natural Resource Technical Report NPS/ARCN/NRTR—2009/270. National Park Service, Fort Collins, Colorado. | 2002 | Between 65% and 80% | 0.52 |
| U.S.G.S. EROS Alaska Field Office. 1999. Bristol Bay Mapping Project – Iliamna. Alaska Department of Natural Resources, Anchorage AK | 1991 | None | 1.15 |
| Ducks Unlimited, Inc. April 2011. Yukon Delta National Wildlife Refuge Earth Cover Classification User's Guide. Ducks Unlimited, Inc., Western Regional Office, Rancho Cordova, California. Prepared for U.S. Fish and Wildlife Service. pp 93. | 2000, 2002, 2005 | None | 1.60 |
| Stevens, J.L., K. Boggs, A. Garibaldi, J. Grunblatt and T. Helt. 2001. Land Cover Map of Denali National Park and Preserve. National Park Service - Alaska Regional Office. | 1985, 1988, 1991, 1994, 1996, 1999 | Between 82% and 85% | 1.95 |
| Fleming, M. 2012. Alaska Statewide Land cover classification – part 1- 4. Images Unlimited, Anchorage, Alaska | 2000 | None | 2.42 |
| Golden, M., and P. Spencer. 1998. Lake Clark National Park and Preserve land cover mapping project user's guide. Natural Resource Technical Report NPS/LACL/NRTR—1998/001. National Park Service, Fort Collins, Colorado | 1995 | 83% | 4.07 |
| LANDFIRE. 2004. The existing vegetation type (EVT) spatial data layer. The Wildland Fire Leadership Council. | 2000 | None | 11.68 |
| Ducks Unlimited, Inc. 2007. ak_earthcov_mosaic _feb2007.img. USDI Bureau of Land Management, the USDI Fish and Wildlife Service. | 1986-2000 | See Table D-4 for individual map assessments | 76.32 |

**Table D-4.** Imagery dates and accuracy assessments for regional maps used to develop the Ducks Unlimited, Inc. 2007 mosaic map.

| Regional Map Name | Imagery Dates | Accuracy Assessment |
|---|---|---|
| Bristol Bay Mapping Project | 1991 | None |
| Naknek MOA Earth Cover Mapping Project | 1989, 1999 | Between76% and 84% |
| Innoko Earth Cover Mapping Project | 1991, 1995 | Between 72% and 86% |
| Galena MOA / Nowitna NWR Earth Cover Mapping Project | 1999 | Between 72% and 87% |
| Melozitna River and Koyukuk NWR Earth Cover Mapping Project | 1999, 2000 | Between 76% and 86% |
| Northern Innoko Earth Cover Mapping Project | 1995, 2000 | Between 66% and 94% |
| Kanuti NWR/Ray Mountains/ Hogatza River Earth Cover Mapping Project | 1992, 1999 | Between 33% and 85% |
| Kvichak Earth Cover Mapping Project | 1999, 2000 | Between 62% and 87% |
| Stony River MOA Earth Cover Mapping Project | 1986, 1989 | Between 74% and 91% |

### Core Analysis

For each Terrestrial Coarse-Filter CE, we extracted and overlaid current CE distributions with the current, near-term (2025), and long-term (2060) status of relevant CA variables. The relevant CA variables are those considered to be most critical in structuring the Coarse-Filter CEs and include: Temperature, Precipitation, Change in Length of Growing Season, Permafrost, Fire, Invasive Plants, and Insect and Disease.

#### *Cliomes*

Abiotic change agents were also combined into climate-linked clusters or "cliomes" using temperature and precipitation variables (see Change Agents: Climate Change for methods). These cliomes were used to make future projections for six of the terrestrial coarse filter CEs; deciduous forest (open-closed), white spruce and black spruce (woodland-closed), tall shrub (open-closed), low shrub, dwarf-shrub (mesic), and herbaceous wetlands.

#### *Conceptual Models*

These analyses are further aided by the development of CE-specific conceptual models. The CE-specific conceptual models represent a general review of the relationship between the CE, CAs and natural drivers in graphical formats.

*Landscape Condition Model*

The overall status of each CE was assessed by intersecting the Landscape Condition Model (LCM) with the CE specific distribution model at current, near-term (2025) and long-term (2060) time steps. In the long-term (2060) we present a hypothetical scenario of a road along the Kuskokwim River, which should be noted is a distant possibility based on the construction of a natural gas pipeline adjacent to the Kuskokwim River. The LCM is a way to measure the potential impact of the human footprint on a landscape (see Section C for a detailed description of LCM methods).

## 1.3.  Core Analysis Results

Climate change agents intersected with CEs are summarized below (Table D-5 and Table D-6). The relevant CA variables are those considered to be most critical in structuring the Terrestrial Coarse-Filter CEs: temperature, precipitation, change in length of growing season, permafrost, fire, invasive plants, and insect and disease.

**Effects of Climate Change on Vegetation Communities**

| MQ 1 | What are the possible impacts on vegetation communities from climate change? |
|------|------|

We used climate clusters (cliomes) to address the impact of the temperature, precipitation, and change in length of growing season on the Terrestrial Coarse-Filter CEs (see Section B.1. for detailed cliome methods).

### *Temperature*

In the near-term (2025), climate models project a slight decrease in July temperature for some habitat areas, and about an equal number of sites show a slight increase (less than 1°C); however estimated changes are still less than model uncertainty. Thus any changes in July temperatures are likely to be relatively minor and unlikely to cause significant impacts at the species or landscape level. However, by 2060, warming is expected to accelerate. Thus 100% of habitat is expected to see summer temperatures more than 1°C warmer than current averages and 89% to 98% of habitat is expected to be at least 1°C warmer for the month of July alone.

### *Precipitation*

In the next decade, projected changes in precipitation are slight, with most habitat areas seeing a change of less than 50 mm, and a small percentage experiencing an increase of 50-100 mm. Given that precipitation is so variable both spatially (ranges from 350 mm to 900 mm) and temporally, model uncertainty is higher than it is for temperature variables, and the near-term change demonstrated here is likely to be insignificant in terms of clear impacts to CEs.

In the longer term, more marked increases in precipitation are expected, with most habitat areas experiencing an increase of 50-100 mm annually, and some areas experiencing an increase of over 100 mm – a relatively high percentage increase, when compared to the modest totals for this area. It should be noted that precipitation may be, overall, less important in terms of impacts to CEs than hydrologic change driven indirectly by climate, including snow-day fractions (discussed under climate change) and permafrost (discussed under permafrost).

### *Change in Length of Growing Season*

Growing season length is not expected to see much change in the near term. As with summer temperature, the fact that some pixels or cells experience small amounts of cooling can be attributed to the stochastic nature of the model.  Indeed, about half of all habitat areas are projected to see marginally shorter summer seasons, while half are projected to see summers that are 0-6 days longer.

In the longer term, however (as represented by the change between the current decade and 2060), growing season is expected to increase by at least a week for every habitat in the REA. For some habitats, almost 50% of habitat area is expected to see an increase of more than two weeks in growing season.

**Table D-5.** Predicted change in climate change variables from current to near-term (2025) and current to long term (2060) as percent of total CE area.

| Terrestrial Coarse-Filter CE | | Mean July Temperature Difference | | | Total Annual Precipitation Difference | | | Change in Length of Growing Season | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | < 0°C | 0 - 0.999°C | ≥ 1°C | ≤ 50 mm | 51 - 100 mm | > 100 mm | < 0 Days | 0 - 6 Days | 7 - 14 Days | > 14 Days |
| Deciduous forest | Near Term | 47% | 53% | -- | 97% | 3% | 0% | 40% | 60% | -- | -- |
| | Long Term | -- | 1% | 99% | 19% | 78% | 2% | -- | -- | 83% | 17% |
| Dwarf-shrub (mesic) | Near Term | 85% | 15% | -- | 79% | 20% | 1% | 54% | 46% | -- | -- |
| | Long Term | -- | 4% | 96% | 1% | 78% | 21% | -- | -- | 63% | 37% |
| Large floodplains | Near Term | 46% | 54% | -- | 97% | 3% | -- | 30% | 70% | -- | -- |
| | Long Term | -- | -- | 100% | 16% | 81% | 3% | -- | -- | 80% | 20% |
| Herbaceous wetlands | Near Term | 73% | 27% | -- | 84% | 16% | 0% | 45% | 55% | -- | -- |
| | Long Term | -- | 1% | 99% | 7% | 78% | 15% | -- | -- | 68% | 32% |
| Low shrub | Near Term | 67% | 33% | -- | 90% | 10% | 0% | 52% | 48% | -- | -- |
| | Long Term | -- | 1% | 99% | 6% | 84% | 10% | -- | -- | 69% | 31% |
| White spruce or black spruce forest | Near Term | 45% | 55% | -- | 99% | 1% | 0% | 50% | 50% | -- | -- |
| | Long Term | -- | 0% | 100% | 21% | 78% | 1% | -- | -- | 92% | 8% |
| Tall shrub | Near Term | 72% | 28% | -- | 91% | 9% | 0% | 53% | 47% | -- | -- |
| | Long Term | -- | 4% | 96% | 6% | 84% | 10% | -- | -- | 67% | 33% |

*Climate Clusters (Cliomes)*

As plant communities are determined in part by patterns in temperature and precipitation, we compared units of climatic similarity (i.e., cliomes, see Section B.1.) with the Terrestrial Coarse-Filter CEs (Figure D-3). We also collapsed the remaining land cover classes from the Boggs et al. (2012) map (Urban, Agriculture, Fire Scar, Tussock Tundra, Lichen, Sparse Vegetation) into a single "sparse / other" class and the Ice-Snow and Bareground classes into the "Unvegetated" class. The projection does not include floodplains because floodplains are restricted to areas where streams occur and will not migrate independently.

While there is not a one-to-one correspondence between cliomes and CEs, some patterns are present. Five cliomes are dominated by spruce forests (8, 9, 10, 12, and 15) with similar proportions of other vegetation classes. Cliomes 11, 14, 16 encompass some spruce forests, but are composed of greater proportions of shrub habitats. Cliomes 13 and 17 represent largely unvegetated habitats.

While the assumption that a projected shift from one cliome to another results in a shift from the vegetative patterns of the former cliome to the vegetative patterns of the latter is likely not appropriate, we do see a value in exploring the potential for vegetation change associated with alterations to climatic patterns. One should also keep in mind that even if climate is the overriding factor ultimately determining vegetation composition, vegetation patterns may be dissimilar due to a lag time in dispersal and establishment. This lag time can be shortened somewhat if disturbance takes place, such as fire, but change is still slow when viewed at the time scale under consideration.
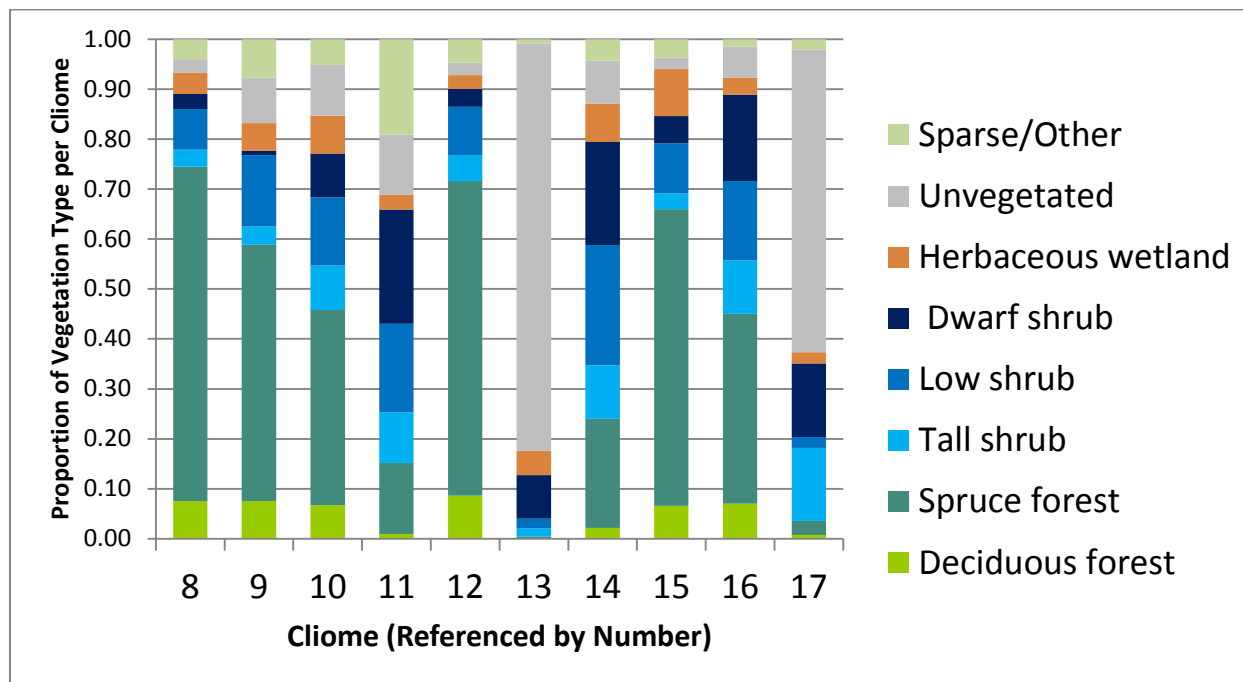


**Figure D-3.** Cliomes by CEs, plus the sparse/other class and unvegetated class.

To understand possible shifts in vegetation communities we cross-tabbed the cliomes in the near-term (2025) and long-term (2060) future with corresponding changes in CEs (Figure D-4). Results suggest an overall decline in

the white spruce and black spruce CE and deciduous forest CE. All of the remaining CEs and land cover classes increase. This result is largely due to a predicted loss of area for cliomes 8 and 12, and a gain in cliome 14. While these projections are based on robust climate data, the linkage between cliomes and CE distribution are speculative.
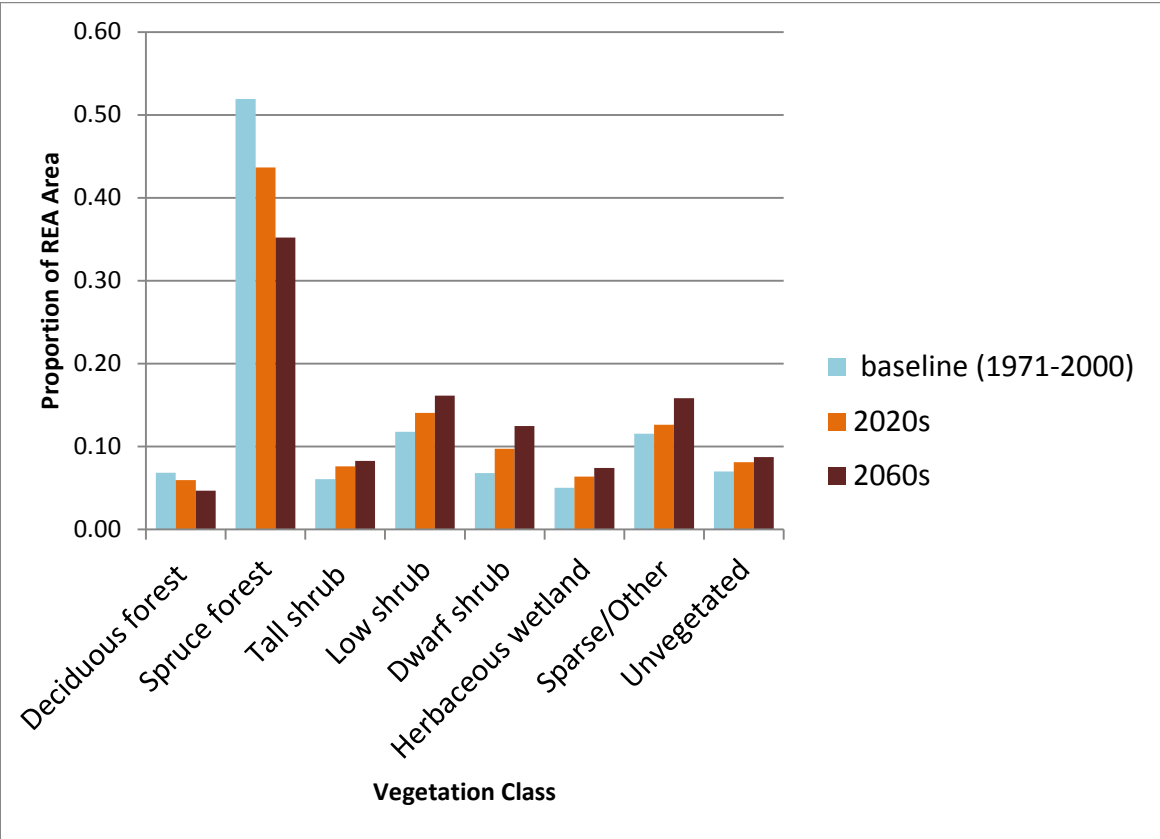


**Figure D-4.** Projected change in CEs, plus the sparse/other and unvegetated land cover classes based on projected cliome shifts.

## Impacts of Permafrost on Vegetation

| MQ 3 | How and where will changes in permafrost impact vegetation? |
|------|-------------------------------------------------------------|

See Table D-6 for percentages of the total CE area that will change from continuous permafrost to discontinuous permafrost in the near-term and long-term futures. In the near term, a small but likely insignificant proportion of habitat (1-3%) is projected to shift across this threshold. However, by 2060, much more sweeping change is expected, with up to 1/3 of habitat thawing or partially thawing for some CEs. We anticipate that the black spruce woodland and forest component of the spruce CE will decline with decreasing area of permafrost and transition to mixed white spruce and deciduous forest communities. As permafrost is lost we expect a range of vegetation responses to erosion, reduced soil moisture, increased nutrient availability, among other changes. We currently cannot predict the response of the tall shrub CE, low shrub CE, dwarf shrub CE or the herbaceous wetlands CE to changes in permafrost.

**Fire**

In the near-term and long-term future, all forested habitats are expected to see a decrease in mean fire return interval by at least 30 years (Table D-6).  With probability of fire increasing in the area, it is likely that the white spruce and black spruce forest CE will be less common, with more of the deciduous forest CE regenerating after fire. We currently cannot predict the response of the tall shrub CE, low shrub CE, dwarf shrub CE, or the herbaceous wetlands CE to changes in fire using the ALFRESCO model.

**Table D-6.** Predicted change in permafrost as percent of total CE area and the mean reduction in fire return interval in years from current to near-term (2025) and current to long term (2060).

| Terrestrial Coarse-Filter CE | | Current continuous permafrost that changes to future discontinuous permafrost | Mean Reduction in Fire Return Interval (Years) |
|---|---|---|---|
| Deciduous forest | Near Term | 1% | 33.7 (s = 5.7) |
| | Long Term | 20% | 31.2 (s = 8.5) |
| Dwarf-shrub (mesic) | Near Term | 1% | N/A |
| | Long Term | 8% | N/A |
| Large floodplains | Near Term | 2% | 34.7 (s = 5.0) |
| | Long Term | 29% | 30.3 (s = 6.8) |
| Herbaceous wetlands | Near Term | 1% | N/A |
| | Long Term | 13% | N/A |
| Low shrub | Near Term | 1% | N/A |
| | Long Term | 16% | N/A |
| White spruce or black spruce forest | Near Term | 1% | 34.4 (s = 5.1) |
| | Long Term | 17% | 31.8 (s = 7.7) |
| Tall shrub | Near Term | 1% | N/A |
| | Long Term | 16% | N/A |

**Invasive Plants**

Currently invasive plants are largely restricted to the anthropogenic footprint in the REA area and compose a very minor element in the Terrestrial Coarse-Filter CEs. Invasive tree species are present in the Deciduous forest CE in McGrath and could expand further in this forest type in the future. Less invasive, non-native plant populations are established on large floodplains in the REA area, while the large floodplains species present currently are unlikely to cause major ecological disruption, this CE is susceptible to invasion by more threatening species such as *Melilotus albus* that is established in villages and towns in the region. Regional vulnerability to non-native plant invasion is treated in Section B.4.

**Insect and Disease**

Insect and Disease damage (including mortality/dieback and defoliation/discoloration) by area has been highest within the White spruce or black spruce and Deciduous forest CEs (Table D-7). The Floodplains CE, because it includes a subset of the White spruce or black spruce and Deciduous forest CEs, encompasses the third largest area of damage and has the highest relative rate of forest damage. Although the aerial forest damage surveys are biased by preferentially sampling along major riparian corridors, it is still significant to note that over 20% of the floodplains have shown evidence of forest mortality, defoliation, or discoloration caused by insect or disease agents within the past 25 years. Within the past 5 years, annual forest damage within floodplains has decreased compared to the past 25 years (compare Table D-7 and Table D-8). Defoliation within deciduous forest, on the other hand, has increased in the past 5 years (Table D-8), although it has been significant over the entire past 25 years as well. The other Terrestrial Coarse-Filter CEs individually have less than 700 km$^2$ of damaged area from the past 25 years, equating to 5% or less of the total area for each CE. Spruce beetles are a major damage agent in *Picea glauca* and *P. mariana* forests and have caused the most tree mortality of any insect or disease agent in the YKL study area overall over the past 25 years (Table D-9). Spruce beetles have also caused the majority of acres of mortality observed within each CE in both the past 25 years and the past 5 years with the exception of floodplains in the past 5 years. In recent decades, warmer temperatures contributed to spruce beetle outbreaks in southern Interior Alaska and Kenai Peninsula forests (Werner 1996), in part due to a reduction of the beetle life cycle from 2 years to 1 year (Holsten 1984, Berg et al. 2006).

Insect and disease agents commonly defoliate or kill stands of alder and willow. Five percent of the tall shrub CE has been defoliated or impacted by insect and disease agents over the past 25 years. If the prevalence of insect and disease agents increases in the study area, it might result in rapid conversion of tall-shrub habitat to mesic-herbaceous or low shrub habitats.

We currently cannot predict the response of the low shrub CE, dwarf shrub CE or herbaceous wetland CE to future changes in insects and disease.

**Table D-7.** Area in km$^2$ and percent of total CE area of tree and shrub mortality and defoliation for the past 25 years (1989 to 2013) within the YKL study area.

| Terrestrial Coarse-Filter CE | | Area of Forest Damage (km$^2$) | Percent Total CE Area |
|---|---|---|---|
| Deciduous forest | Mortality/Dieback | 1284 | 4% |
| | Defoliation/Discoloration | 2720 | 7% |
| | **Total** | **3851** | **11%** |
| Dwarf-shrub (mesic) | Mortality/Dieback | 70 | 0.4% |
| | Defoliation/Discoloration | 183 | 1% |
| | **Total** | **247** | **2%** |
| Large floodplains | Mortality/Dieback | 1482 | 8% |
| | Defoliation/Discoloration | 2353 | 13% |
| | **Total** | **3647** | **21%** |
| Herbaceous wetlands | Mortality/Dieback | 116 | 1% |
| | Defoliation/Discoloration | 366 | 3% |
| | **Total** | **464** | **4%** |
| Low shrub | Mortality/Dieback | 131 | 0.5% |
| | Defoliation/Discoloration | 513 | 2% |
| | **Total** | **631** | **2%** |
| White spruce or black spruce forest | Mortality/Dieback | 732 | 0.7% |
| | Defoliation/Discoloration | 3494 | 4% |
| | **Total** | **4112** | **4%** |
| Tall shrub | Mortality/Dieback | 368 | 3% |
| | Defoliation/Discoloration | 402 | 3% |
| | **Total** | **698** | **5%** |

**Table D-8.** Area in km$^2$ and percent of total CE area of tree and shrub mortality and defoliation for the past 5 years (2009 to 2013) within the YKL study area.

| Terrestrial Coarse-Filter CE | | Area of Forest Damage (km$^2$) | Percent Total CE Area |
|---|---|---|---|
| Deciduous forest | Mortality/Dieback | 240 | 0.7% |
| | Defoliation/Discoloration | 804 | 2% |
| | **Total** | **1022** | **3%** |
| Dwarf-shrub (mesic) | Mortality/Dieback | 21 | 0.1% |
| | Defoliation/Discoloration | 115 | 0.7% |
| | **Total** | **135** | **0.9%** |
| Large floodplains | Mortality/Dieback | 90 | 0.5% |
| | Defoliation/Discoloration | 307 | 2% |
| | **Total** | **395** | **2%** |
| Herbaceous wetlands | Mortality/Dieback | 21 | 0.2% |
| | Defoliation/Discoloration | 57 | 0.5% |
| | **Total** | **76** | **0.7%** |
| Low shrub | Mortality/Dieback | 30 | 0.1% |
| | Defoliation/Discoloration | 156 | 0.6% |
| | **Total** | **184** | **0.7%** |
| White spruce or black spruce forest | Mortality/Dieback | 134 | 0.1% |
| | Defoliation/Discoloration | 527 | 0.5% |
| | **Total** | **655** | **0.7%** |
| Tall shrub | Mortality/Dieback | 95 | 0.7% |
| | Defoliation/Discoloration | 172 | 1% |
| | **Total** | **251** | **2%** |

**Table D-9.** Area in km$^2$ and percent of total CE area of spruce mortality caused by spruce beetle for the past 25 years (1989 to 2013) and the past 5 years (2009 to 2013) within the YKL study area.

| Terrestrial Coarse-Filter CE | | Area of Forest Damage (km$^2$) | Percent Total CE Area |
|---|---|---|---|
| Deciduous forest | 1989 to 2013 | 1182 | 3% |
| | 2009 to 2013 | 187 | 0.5% |
| Large floodplains | 1989 to 2013 | 1246 | 7% |
| | 2009 to 2013 | 7 | 0.04% |
| White spruce or black spruce forest | 1989 to 2013 | 535 | 0.5% |
| | 2009 to 2013 | 92 | 0.1% |

## Anthropogenic Change Agents (LCM)

The current anthropogenically disturbed area (defined as the area occupied by LCM scores of very low, low, or medium) of the combined Terrestrial Coarse-Filter CEs relative to the total area is currently minimal (2%) (Table D-10). The most obvious human impacts are those related to villages, roads, and airstrips. Village infrastructure

includes broadband communication and cellular service towers. Diesel generators are the main source of electricity in communities within the YKL study area, and power transmission requires short distance lines or cables.

Commercial timber harvesting is minimal in the region, although wood is harvested throughout the YKL study area for individual household fuel. Most villages are located within or adjacent to the floodplains CE and likely obtain much of their fuel there.

Hunting and recreational fishing and other forms of recreation are also common. Harvesting of game animal species can have cascading effects on vegetation. For example, moose and snowshoe hares intensively use *Salix* and *Populus balsamifera* seedlings, sharply reducing the density of both (Kielland and Bryant 1998). Consequently, changes in moose and snowshoe hare populations may have significant effects on vegetation.

The anthropogenically disturbed area of the combined Terrestrial Coarse-Filter CEs relative to the total area for the near-term (3%) and long-term (4%) suggests that they will remain relatively intact within the timeframe considered for this REA. The only major reductions in status are along the potential Kuskokwim Road south of McGrath, and the two planned mines: Pebble Mine, an open-pit copper mine site north of Iliamna Lake; and Donlin Creek Mine, an open-pit gold mine site about 10 miles north of the village Crooked Creek. Either mining project could potentially increase population size in the YKL study area. Large scale mining operations could alter stream channels and lake connectivity, remove or impair vegetation, and increase sedimentation to important aquatic habitats. Both mines are potential sources of contamination in rivers, groundwater, and the ground surface.

Many of the villages on floodplains will be subject to river erosion and flooding, and will likely need to migrate inland. In addition, if commercial timber harvesting starts in the future, it will likely be on the floodplains (Adams 1999).

**Table D-10.** Percent of total CE area of current, near-term (2025), and long-term status (2060), represented by Landscape Condition Model in five condition classes, for Terrestrial Coarse-Filter CEs.

| Terrestrial Coarse-Filter CE | | Landscape Condition (% of Area) | | | | |
|---|---|---|---|---|---|---|
| | | Very Low | Low | Medium | High | Very High |
| Deciduous forest | Current | 0.9% | 1% | 2% | 4% | 92% |
| | Near Term | 0.9% | 2% | 2% | 4% | 91% |
| | Long Term | 0.9% | 3% | 3% | 5% | 89% |
| Dwarf-shrub (mesic) | Current | 0.2% | 0% | 1% | 1% | 98% |
| | Near Term | 0.3% | 0% | 1% | 1% | 97% |
| | Long Term | 0.4% | 1% | 1% | 2% | 96% |
| Large floodplains | Current | 0.6% | 1% | 2% | 16% | 80% |
| | Near Term | 0.6% | 1% | 2% | 16% | 79% |
| | Long Term | 0.6% | 5% | 4% | 16% | 74% |
| Herbaceous wetlands | Current | 0.2% | 0% | 1% | 2% | 97% |
| | Near Term | 0.2% | 0% | 1% | 3% | 96% |
| | Long Term | 0.2% | 1% | 1% | 3% | 96% |
| Low shrub | Current | 0.2% | 0% | 1% | 2% | 97% |
| | Near Term | 0.2% | 0% | 1% | 2% | 97% |
| | Long Term | 0.3% | 1% | 1% | 2% | 96% |
| White spruce or black spruce forest | Current | 0.5% | 1% | 1% | 2% | 96% |
| | Near Term | 0.5% | 1% | 1% | 2% | 95% |
| | Long Term | 0.5% | 1% | 2% | 3% | 94% |
| Tall shrub | Current | 0.3% | 0% | 1% | 3% | 96% |
| | Near Term | 0.4% | 1% | 1% | 3% | 95% |
| | Long Term | 0.4% | 1% | 1% | 3% | 94% |

## 1.4.  Deciduous Forest
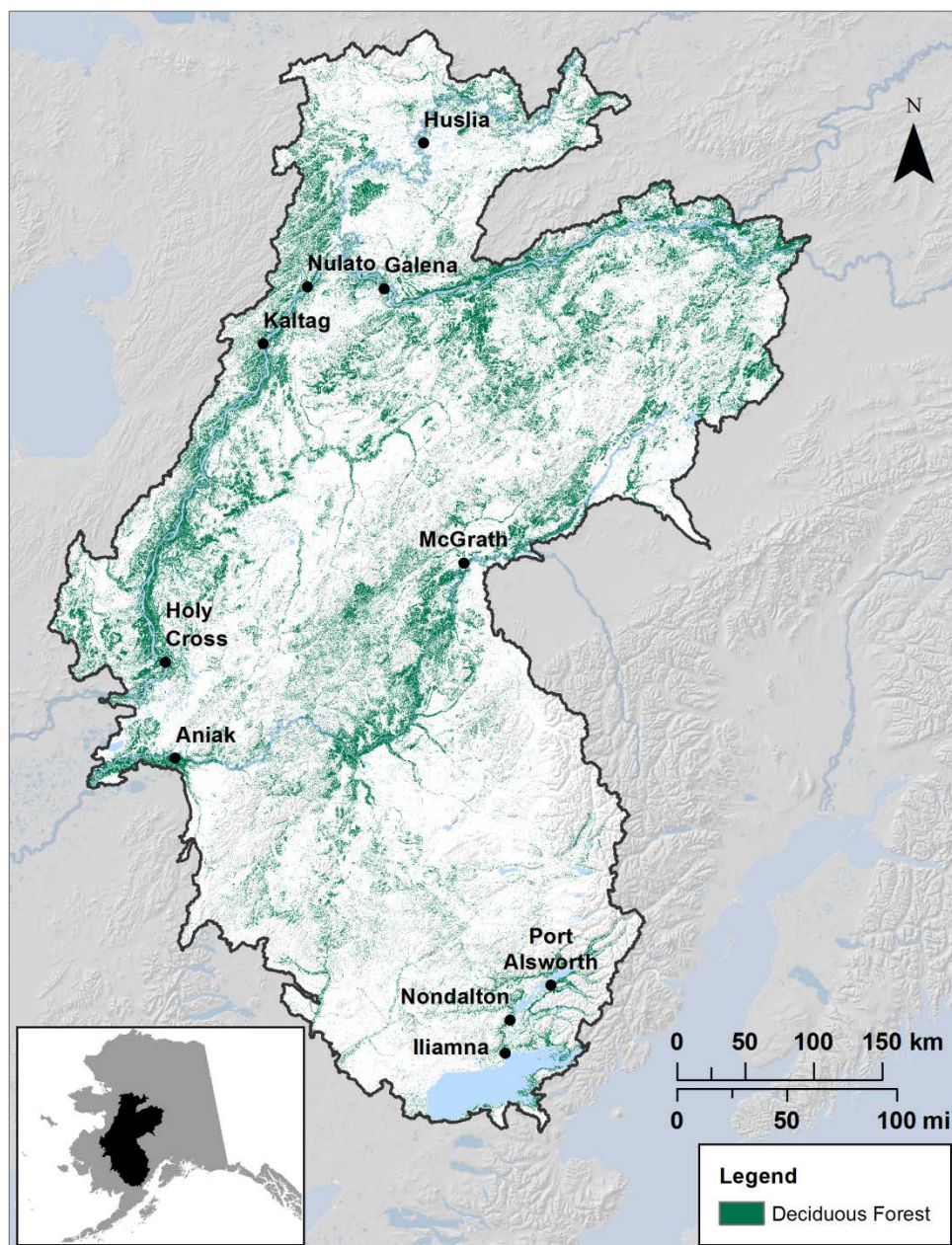


**Figure D-5.** Current distribution of the deciduous forest CE in the YKL study area.

The deciduous forest Coarse-Filter CE covers 16% of the YKL study area (Figure D-5). This CE includes open to closed subclasses. Dominant trees of the deciduous forest include quaking aspen, paper birch, and balsam poplar (Figure D-6). Each species may occur as solid stands or may co-dominate the canopy. In some areas white spruce or black spruce are present, but do not dominate the canopy. The deciduous forest CE commonly occurs on well-drained, flat to gently sloping, dry sites and on upland terrain slopes with south, west, or east aspects. Deciduous forest currently occurs at elevations from 18 to 5,614 ft. in the YKL study area. In its upper elevation range, deciduous forest can occur in the subalpine zone above the coniferous treeline, especially along riparian areas.

**Figure D-6.** Deciduous forest (open-closed) can be co-dominated by quaking aspen, paper birch, or balsam poplar (A). In some areas, white spruce or black spruce may co-dominate with quaking aspen, paper birch, or balsam poplar (B).

Soils are typically well-drained and can be shallow, developing on bedrock, residual material, or re-transported deposits including glacial till, loess, and colluvium. Permafrost is rare on most sites. Stands are often closed-canopied, with an open shrub or herbaceous understory. Common understory shrub species include *Alnus* spp., *Vaccinium vitis-idaea, Betula nana, Rosa acicularis, Shepherdia canadensis, Viburnum edule, Salix* spp., and *Ribes triste.* A wide variety of herbaceous species may occur, including *Calamagrostis canadensis, Pyrola* spp., *Aconitum delphiniifolium, Chamerion angustifolium, Gymnocarpium dryopteris*, *Cornus canadensis*, *Equisetum*

spp., and *Mertensia paniculata* (Viereck 1979, Jorgenson et al. 2003). Moss and lichen cover ranges from common to low. If mosses are present, feather mosses such as *Hylocomium splendens* and *Pleurozium schreberi* are common (Boggs and Sturdy 2005, Jorgenson et al. 2001).

## Conceptual Model

The deciduous forest class will likely be impacted by climate change in direct and indirect ways (see Figure D-7). Increased fire probability may dramatically increase fire's role in driving ecosystem succession. Post-fire early seral sites are generally herbaceous or aspen-paper birch (Duchesne and Hawkes 2000). This is followed by *Picea glauca*-deciduous tree dominated sites, and over long periods, *Picea glauca* (Viereck 1975, Foote 1983b, Payette 1992, Boucher 2003). In general, with fire increasing significantly in the area, it is likely that deciduous forest will expand in the YKL study area with paper birch and quaking aspen commonly establishing as early or mid-seral species in burned areas.

Few non-native plant infestations have been recorded in the study area in this vegetation class (AKEPIC 2012); however weed populations are found on roadsides and other disturbed habitats proximal to deciduous forests, representing a threat for future invasion. Bird vetch (*Vicia cracca*) has been recorded on imported fill in Shageluk and this species is capable of forming dense populations in deciduous forests of the interior, particularly of more open forests and south-facing slopes (Conn et al. 2007, Seefeldt et al. 2007). Of particular concern are bird cherries (*Prunus padus* and *P. virginanus*) that are recorded from mixed deciduous forests in McGrath. These are shade-tolerant trees that are expanding rapidly in deciduous forests in Southcentral Alaska and have the potential of replacing birch and other tree species (Cortés-Burns and Flagstad 2009, Flagstad et al. 2010a, Flagstad et al. 2010b, Flagstad et al. submitted). Additionally, Siberian pea shrub (*Caragana arborescens*) is planted as an ornamental in McGrath and this species has established dense thickets in natural and semi-natural deciduous forests in Interior and Southcentral Alaska.

Currently approximately 11% of the deciduous forest CE has been mapped to have some form of damage caused by insect and disease agents over the past 25 years (see Table D-7). We do not speculate on how this will affect the future distribution of deciduous forests.

Mortality caused by bark beetles to spruce increases deciduous species representation in the deciduous forest class. Bark beetle-caused mortality has affected 3% of this CE for the past 25 years (Table D-9). Spruce beetle damage (by area) over the past 25 years has been largest in the deciduous forest and floodplain CEs. Spruce beetles are a major damage agent in *Picea glauca* and *Picea mariana* forests and have caused the most tree mortality of any insect or disease agent in the YKL study area overall over the past 25 years (Table D-9). In recent decades, warmer temperatures contributed to spruce beetle outbreaks in southern Interior Alaska and Kenai Peninsula forests (Werner 1996), in part due to a reduction of the beetle life cycle from 2 years to 1 year (Holsten 1984, Berg et al. 2006). During spruce beetle outbreaks, the older *Picea glauca* can be largely eliminated. *Calamagrostis canadensis* often dominates following the elimination of the *Picea glauca* overstory, and *Picea glauca* eventually recolonizes the sites (Boggs et al. 2008).
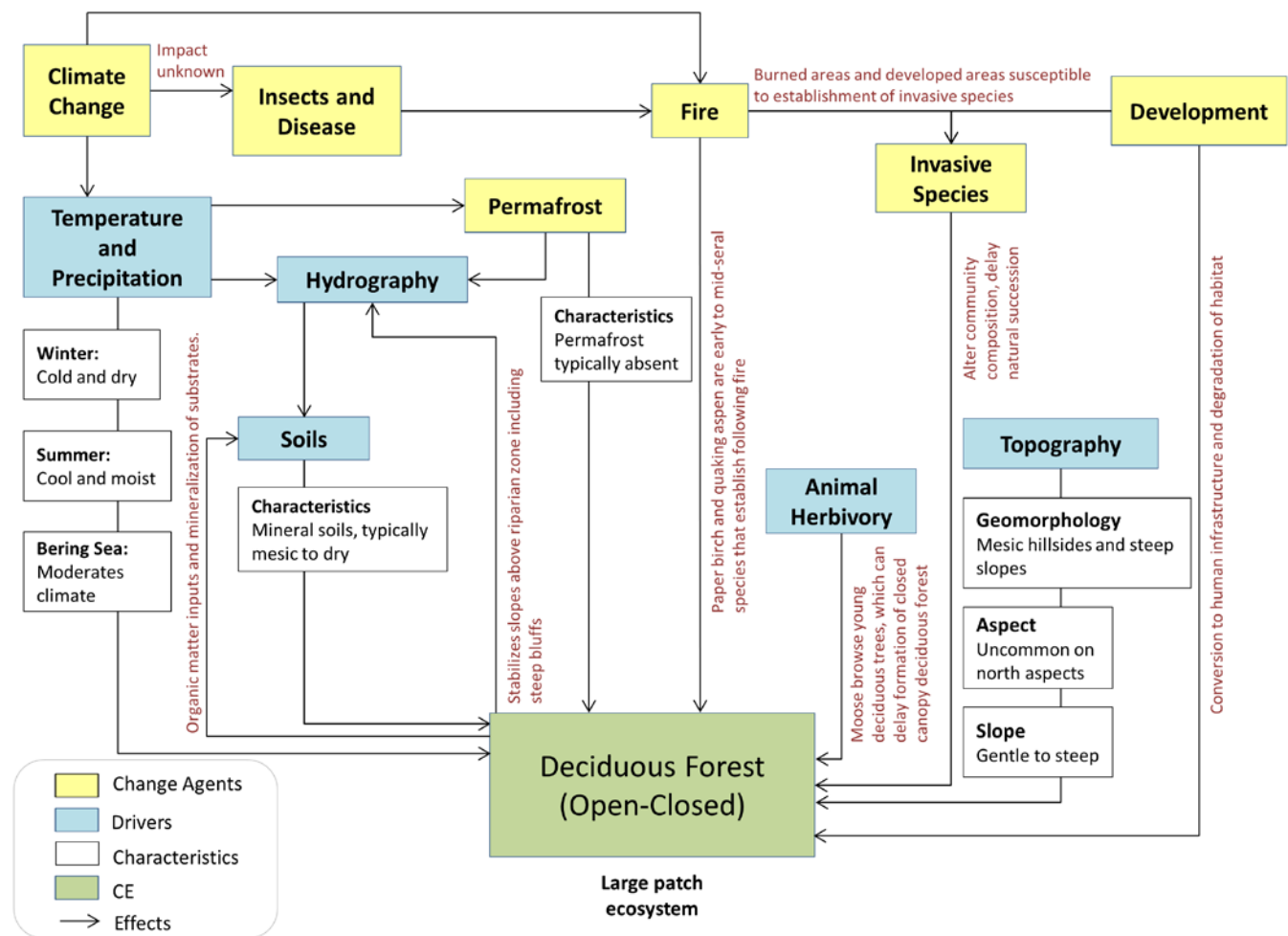
**Figure D-7.** Conceptual model for deciduous forest.

## Current Status and Future Landscape Condition

The intersection of the deciduous forest distribution with the LCM indicates that over 89% of the total CE area is very high (intact) condition for the current, near-term, and long-term projections (Figure D-8). The long-term landscape condition suggests a slight decrease (4% of the total CE area) in very high quality condition and a slight increase (2% of the total CE area) in low condition, particularly around the villages of Galena and McGrath, as well as along both the Yukon and Kuskokwim river corridors.
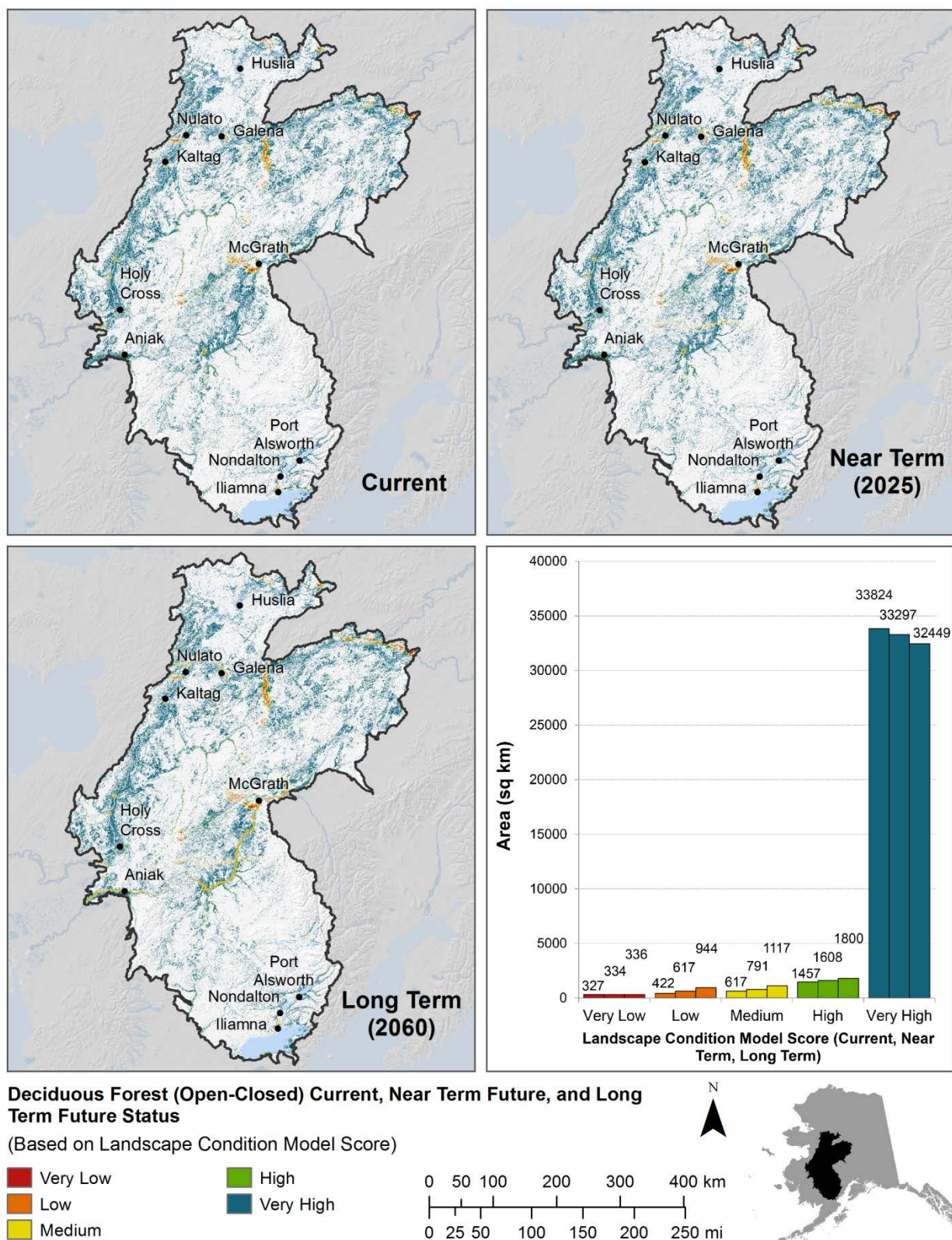
**Figure D-8.** Current, near-term (2025), and long-term (2060) status of deciduous forest (open-closed) in the YKL study area.

## 1.5. White Spruce and Black Spruce
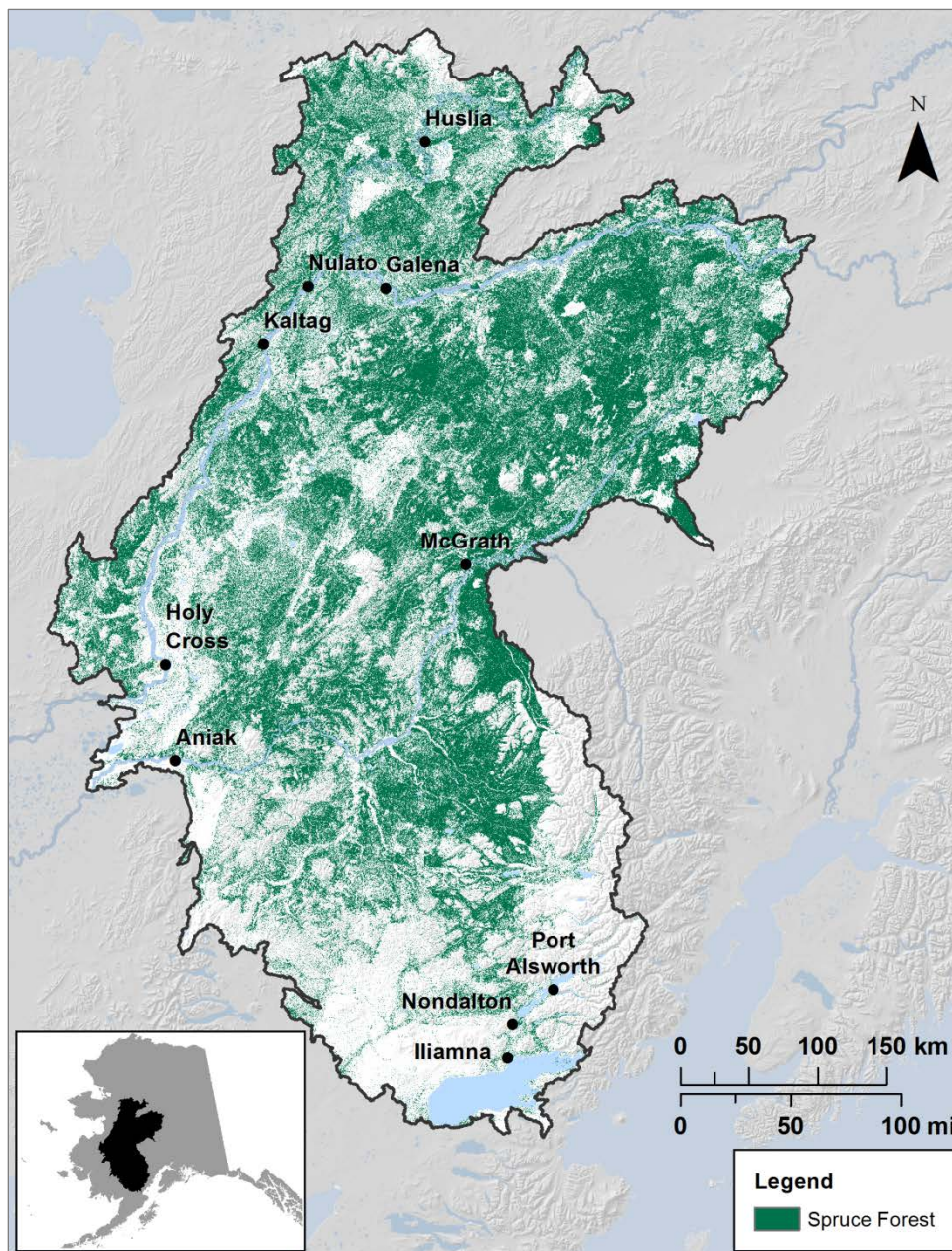


**Figure D-9.** Distribution of the white spruce or black spruce CE in the YKL study area.

The white spruce or black spruce CE covers 43% of the study area (Figure D-9). This CE varies significantly in tree cover, landform, soil saturation, aspect, permafrost, peat development, and vegetation composition. White spruce (Figure D-10) and black spruce (Figure D-12) either occur as co-dominant or dominant species in the canopy. Tree cover ranges from 10% to 100%, with 75% or more of the trees being needleleaf. White spruce or black spruce occurs on a variety of landforms including floodplains, valley bottoms, benches, side slopes, and ridges. Treed bogs and treed fens are included within the white spruce or black spruce CE. Elevations range from 20 to 5,308 ft. The white spruce or black spruce CE is common on all aspects with slopes ranging from generally flat to steep. Peat development ranges from absent to well-developed. Permafrost typically underlays black spruce sites, but may be absent from white spruce sites.

**Figure D-10.** Upland forest dominated by white spruce (A). Black spruce woodland forest (B).

Other sub-dominant trees include *Betula neoalaskana, Larix laricina,* and *Populus tremuloides*. Common understory shrubs may include *Rosa acicularis, Vaccinium vitis-idaea, Betula nana*, *Vaccinium uliginosum*, *Empetrum nigrum, Rhododendron tomentosum* ssp. *decumbens*, *Rhododendron groenlandicum*, *Andromeda polifolia, Chamaedaphne calyculata, Salix pulchra*, *Alnus* spp., *Shepherdia canadensis,* and *Linnaea borealis*. Common herbaceous species include *Pyrola* spp., *Equisetum* spp., *Calamagrostis canadensis, Carex* spp., *Eriophorum angustifolium, Eriophorum vaginatum, Carex bigelowii,* and *Mertensia paniculata*. Common bryophytes may include *Sphagnum* spp., *Hylocomium splendens,* and *Pleurozium schreberi*. Lichens, such as *Cladina* spp., may be abundant (Figure D-11).

**Figure D-11.** White spruce or black spruce woodland with significant lichen cover.

## Conceptual Model

The white spruce or black spruce CE will be impacted by climate change and the related direct impacts from fire regime, permafrost, and possibly insect and disease agents in the YKL study area (Figure D-12). The probability of fires occurring is predicted to increase for this CE. Following fire, sites transition from herbaceous or aspen-paper birch to *Picea glauca*-deciduous tree dominated sites, and over long periods, *P. glauca* (Viereck 1975, Foote 1983, Payette 1992, Boucher 2003). However, succession to pure *P. glauca* stands may be truncated due to the shorter fire return interval.

In interior *P. mariana* stands shifts towards more deciduous dominated forests post fire has been proposed due to increase in mineral soil seed beds (Johnstone and Kasischke 2005, Kasischke and Johnstone 2005, Johnstone and Chapin 2006) and reduction in fire return interval (Johnstone et al. 2010a, b, Bernhardt et al. 2011).

17% of the total CE area is projected to change from continuous permafrost to discontinuous permafrost by 2060. Reductions in black spruce dominated woodlands and forests are anticipated in areas loosing permafrost, however, more specific or quantitative predictions are not possible.

No non-native plant infestations have been recorded in the study area in this vegetation class (AKEPIC 2012); and while weed populations are found on roadsides and other disturbed habitats proximal to spruce forests, few non-native plant species have invaded white and black spruce forests elsewhere in Alaska.

Spruce mortality caused by bark beetles has affected <1% of this CE for the past 25 years (Table D-9). See the Deciduous Forest CE for a description of the response of this CE to bark beetles.
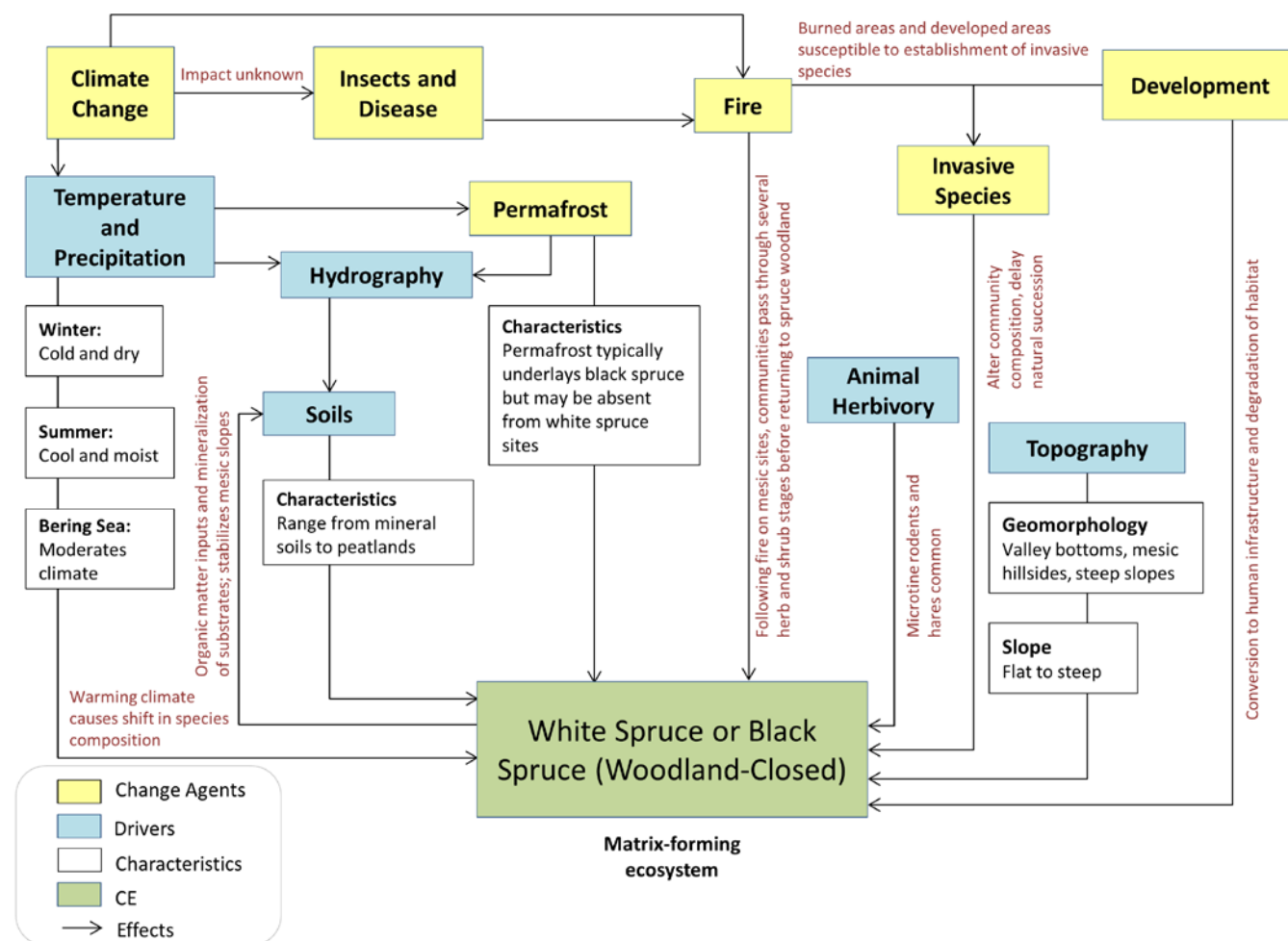
**Figure D-12.** Conceptual model for white spruce or black spruce.

## Current Status and Future Landscape Condition

The intersection of the white spruce or black spruce CE distribution with the LCM suggests that over 94% of the total CE area is in very high (intact) condition for the current, near-term, and long-term projections (Figure D-13). The long-term (2060) landscape condition suggests a very slight decrease (2% of the total CE area) in very high quality condition and no change in the very low or low condition classes (0.5% and 1% of the total CE area, respectively).
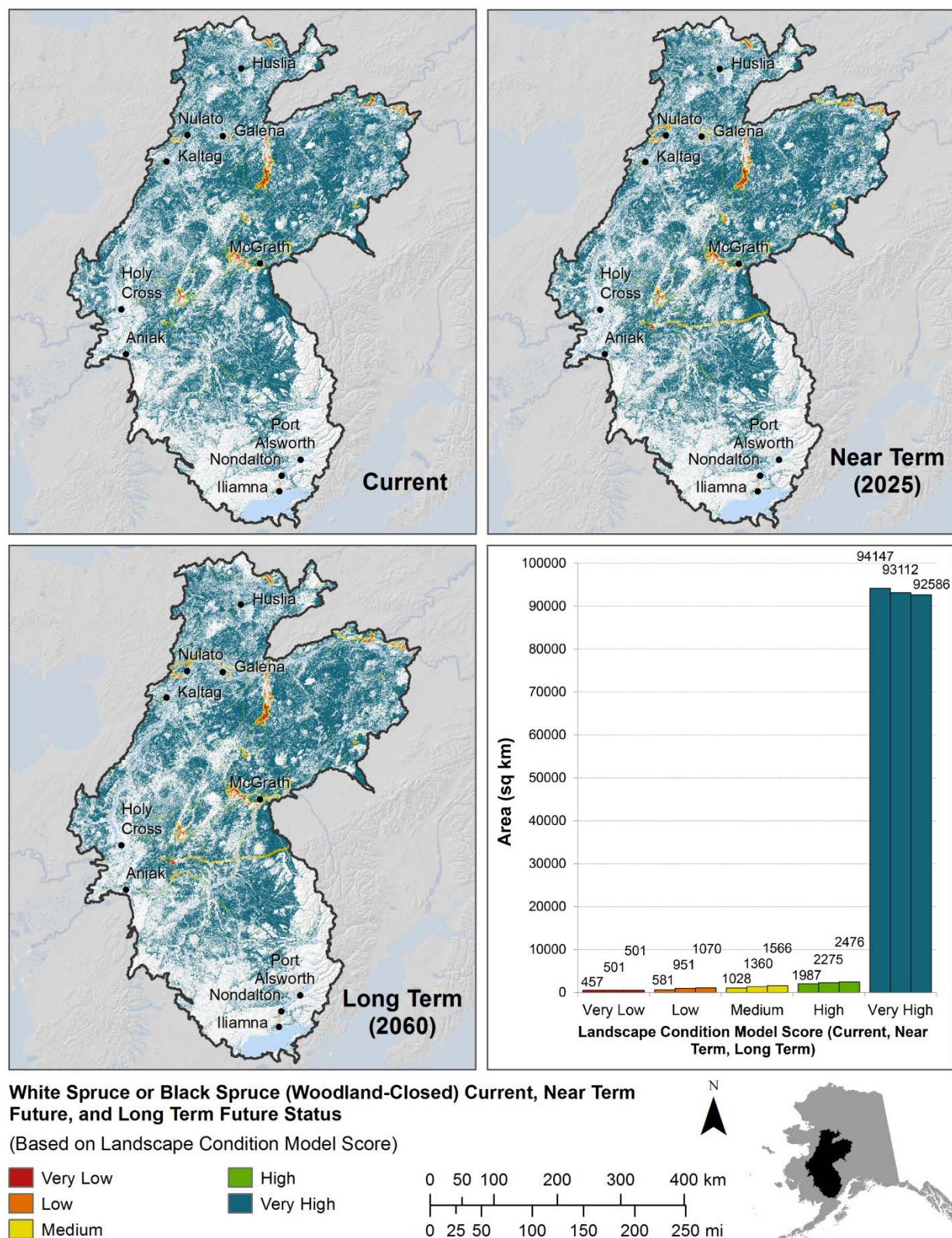
**Figure D-13.** Current, near-term (2025), and long-term (2060) status of white spruce or black spruce in the YKL study area.

## 1.6. Tall Shrub
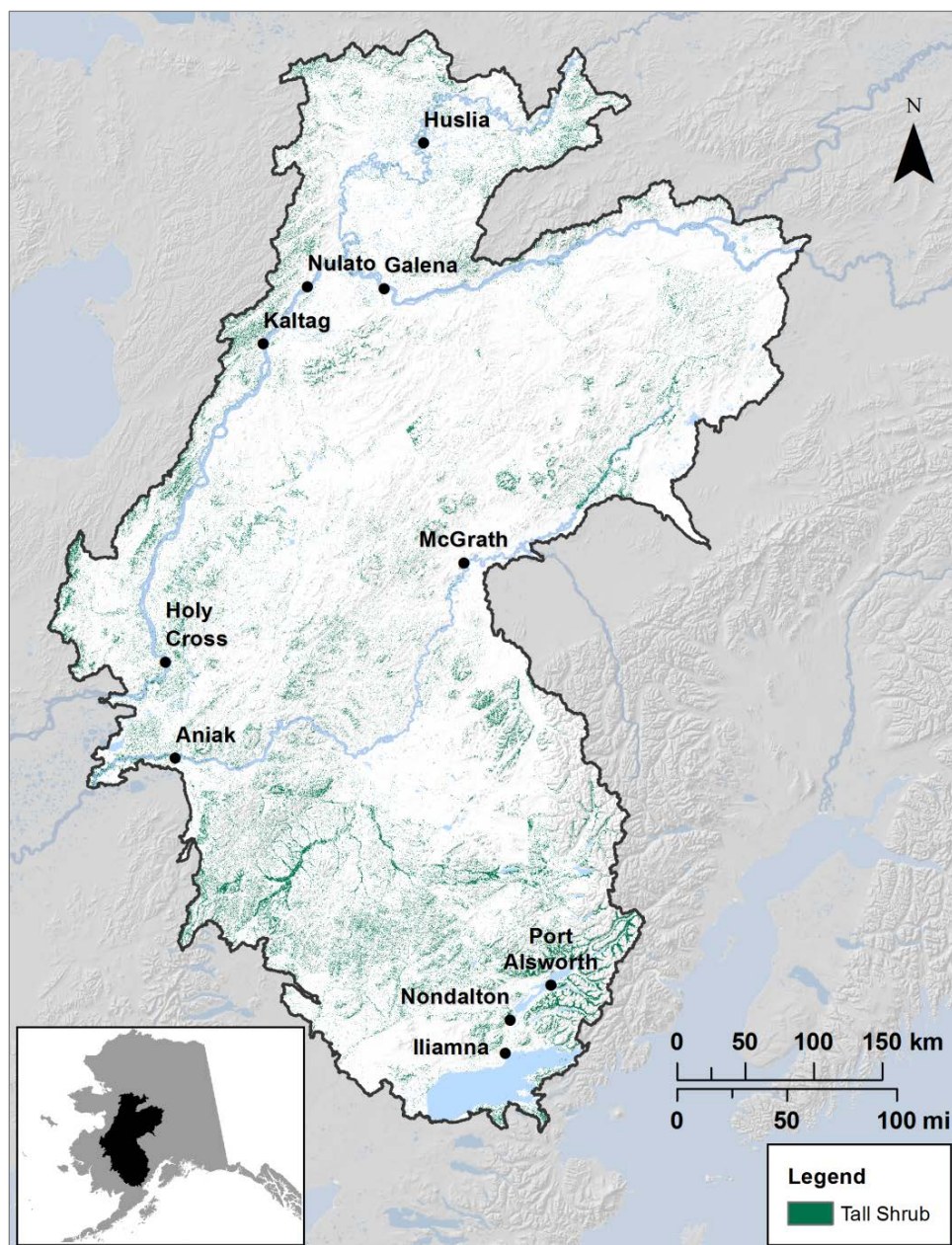


**Figure D-14.** Current distribution of the tall shrub CE in the YKL study area.

The tall shrub CE occurs across the entire study area, although it covers only 6% of the area (Figure D-14). Shrubs contribute 25% to 100% of the vegetation cover, and the shrub layer is comprised primarily of alder and/or willow. At least 25% of the site consists of shrubs greater than 1.3 m in height. Tall shrub is widespread on mountains and hill slopes (Figure D-15), and elevations range from 22 to 4,875 ft. Soils are typically mesic.

Common tall shrubs include *Alnus viridis* ssp. *fruiticosa*, *A. viridis* ssp. *sinuata, Salix glauca, S. barclayi*, and *S. pulchra*. Additional species include *Sambucus racemosa, Vaccinium uliginosum, Vaccinium vitis-idaea, Betula nana, Rhododendron tomentosum* ssp. *decumbens, Empetrum nigrum, Spiraea stevenii, Dryas* spp., and *Cassiope*

*tetragona*. Mosses include *Hylocomium splendens* and *Dicranum* spp. This class is often mosaicked with low shrub tundra and dwarf-shrubs.



**Figure D-15.** Tall shrub CE on mountain slopes.

## Conceptual Model

The tall shrub CE will be impacted by climate change and the related direct impacts from fire regime, permafrost, and possibly insect and disease agents in the YKL study area (Figure D-12). The probability of fires occurring is predicted to increase for this CE. In some tall shrub sites, *Salix* spp. will likely increase as it regenerates quickly post-fire (Boggs, personal observation).

16% of the total CE area is projected to change from continuous permafrost to discontinuous permafrost by 2060. We currently cannot predict the response of this CE to these changes in permafrost.

A total of 21 non-native plant infestations have been recorded in tall shrub vegetation in the YKL study area. Many of these non-native plant populations are associated with population centers (such as Galena) or occur adjacent to trails, roads, or boat launches. Of the 11 species associated with tall shrub vegetation, most are ruderal species and not expected to persist without disturbance. *Linaria vulgaris*, *Bromus inermis* ssp. *inermis*, *Hordeum jubatum*, *Taraxacum officinale*, and *Trifolium hybridum* are species considered to have greater ecological impacts (see Carlson et al. 2008, Nawrocki et al. 2011). Overall however, non-native plants are not recognized as having a major impact on this CE.

Insect and disease agents commonly defoliate or kill stands of alder and willow. Five percent of the tall shrub CE has been defoliated or impacted by insect and disease agents over the past 25 years (see Table D-7). If the prevalence of insect and disease agents increases in the study area, it might result in rapid conversion of tall-shrub habitat to mesic-herbaceous or low shrub habitats (Boucher et al. 2012).

We also speculate that a warming climate may increase the available habitat for tall shrub vegetation at higher elevations in the Kuskokwim Mountains and Lime Hills but may also increase the conversion of tall shrub to spruce woodland at lower elevations.
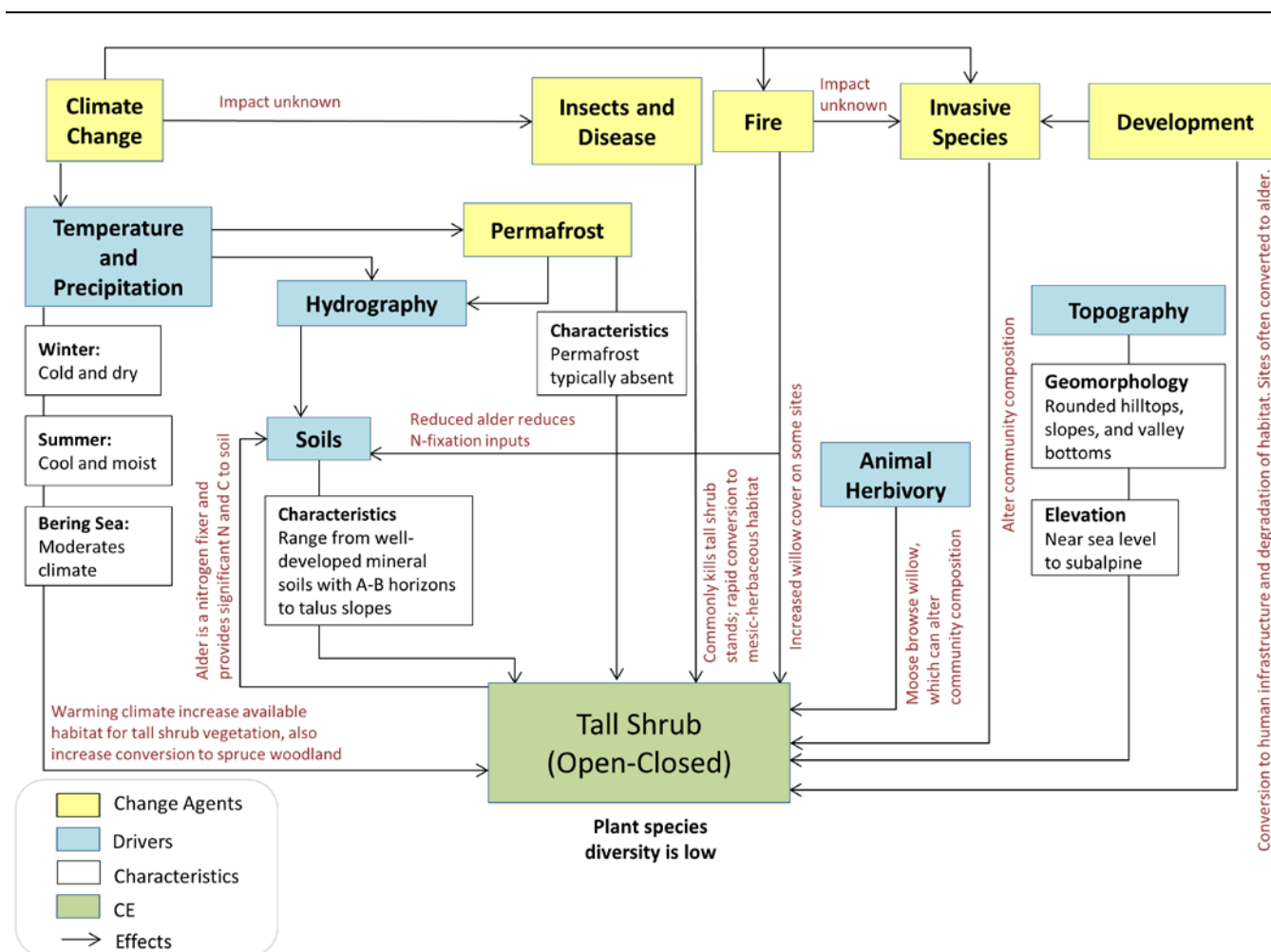


**Figure D-16.** Conceptual model for tall shrub (open-closed) in the YKL study area.

## Current Status and Future Landscape Condition

The intersection of the tall shrub CE distribution with the LCM indicates that over 94% of the total CE area is very high (intact) condition for the current, near-term, and long-term projections (Figure D-17). The long-term (2060) landscape condition suggests almost no change in any landscape condition class, with less than 2% change in total CE area for all landscape condition classes.
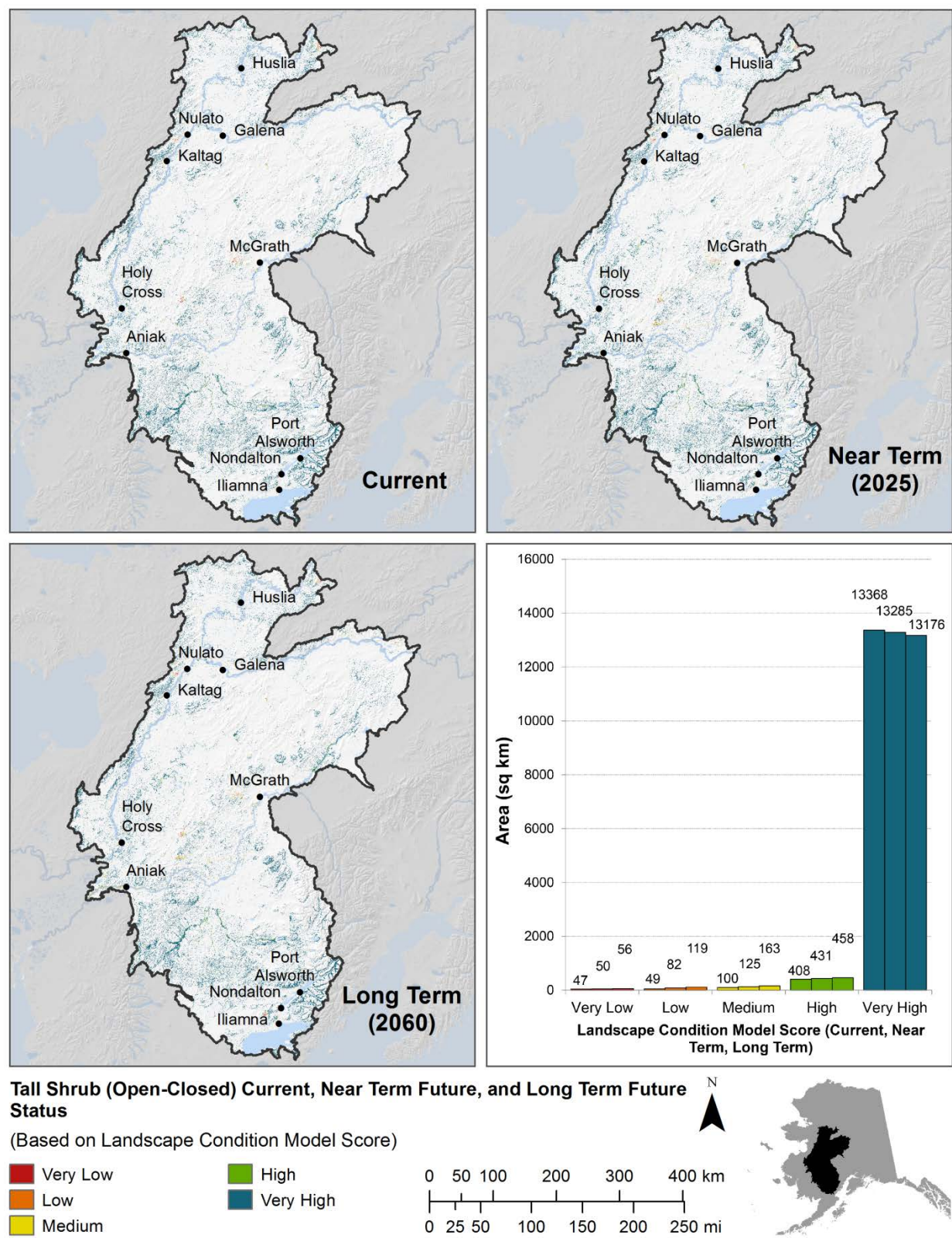
**Figure D-17.** Current, near-term (2025), and long-term (2060) status of tall shrub (open-closed) in the YKL study area.

## 1.7. Low Shrub
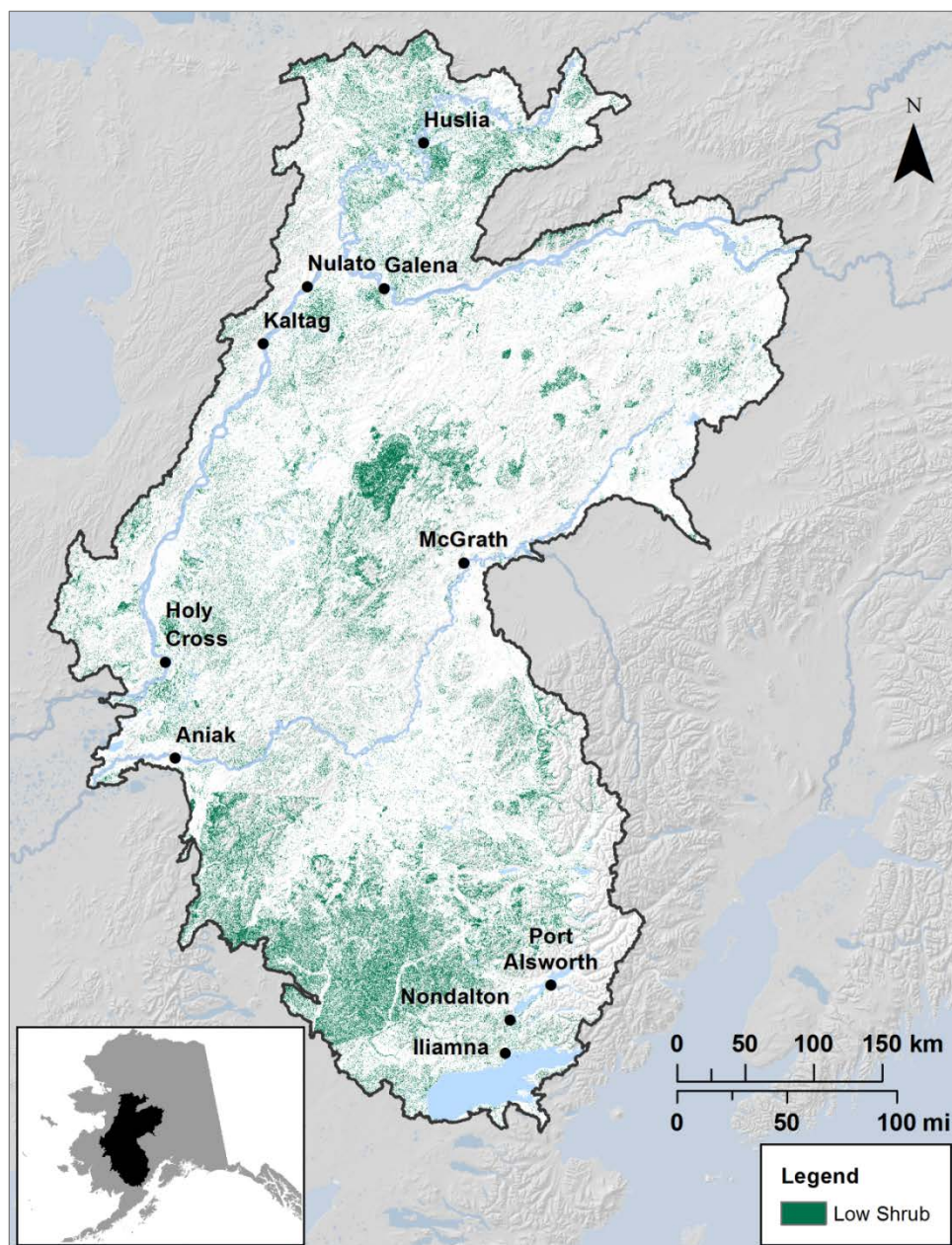


**Figure D-18.** Distribution of the low shrub CE in the YKL study area.

The Low Shrub CE covers 12% of the YKL study area and occurs throughout the study area (Figure D-18). This CE is defined as shrubs with 25% to 100% vegetation cover, shrubs greater than 1.3 m in height contribute less than 25% of vegetation cover of the site, and either more than 25% of the site consists of shrubs between 0.2 and 1.3 m in height, or shrubs between 0.2 and 1.3 m in height are the most common shrubs.

The low shrub CE is common on wet and mesic mountain slopes, hill slopes, flats, and stream banks and also occurs in lowlands and wetlands. Low shrub sites occur from 20 ft. to 6,255 ft. within the YKL study area. Patch size is small to large and often linear along small streams, and low shrub can be matrix-forming. Soils range from mesic to wet, and mineral to organic peat. Permafrost is often present.

Common shrubs include *Betula nana, Rhododendron tomentosum, S. pulchra, S. glauca*, *S. niphoclada, S. chamissonis*, *S. bebbiana, S. barclayi, Empetrum nigrum, Chamaedaphne calyculata, Vaccinium uliginosum,* and *Myrica gale.* Other shrubs include *Alnus viridis* ssp. *fruiticosa, Therorhodion glandulosum, Oxycoccos microcarpus, Comarum palustre,* and *Salix fuscescens.* Additional species include *Calamagrostis canadensis, Carex aquatilis,* and *Sphagnum* spp. Lichen cover (primarily *Cladina* spp.) can be greater than 20% and occur in large patches between shrubs.

**Conceptual Model**

The low shrub CE will likely be impacted by climate change and the related direct impacts from fire regime, permafrost, and possibly insect and disease agents in the YKL study area (Figure D-20). The probability of fires occurring is predicted to increase for this CE. In addition, 16% of the total CE area is projected to change from continuous permafrost to discontinuous permafrost by 2060. We currently cannot predict the response of this CE to changes in fire or permafrost.

Only two non-native plant records list low shrub as the associated habitat. Both infestations are of the disturbance related species *Plantago major*, which is not considered a species likely to cause significant ecological disruption. Invasive species are not perceived to cause major impacts to this CE.

Only 2% of the low shrub CE has been defoliated or impacted by insect and disease agents over the past 25 years. We currently cannot predict the response of this CE to future changes in insects and disease.

We speculate that a warming climate may increase the available habitat for low shrub vegetation at higher elevations in the Kuskokwim Mountains and Lime Hills but may also increase the conversion of low shrub to other vegetation classes at lower elevations.
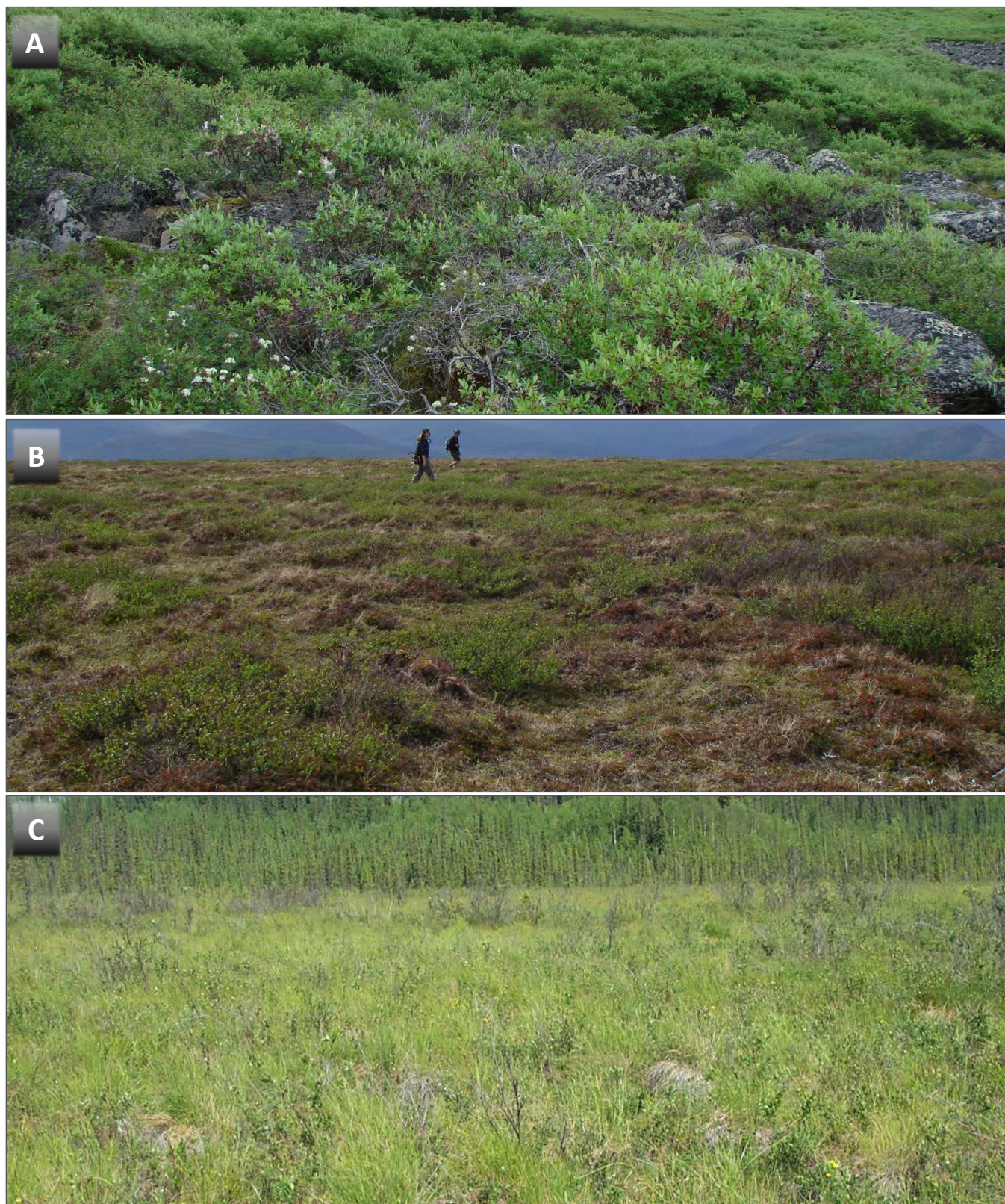
**Figure D-19.** The low shrub CE can occur as primarily willow (A), dwarf birch and ericaceous shrubs (B), or dwarf birch and bog blueberry peatlands (C).
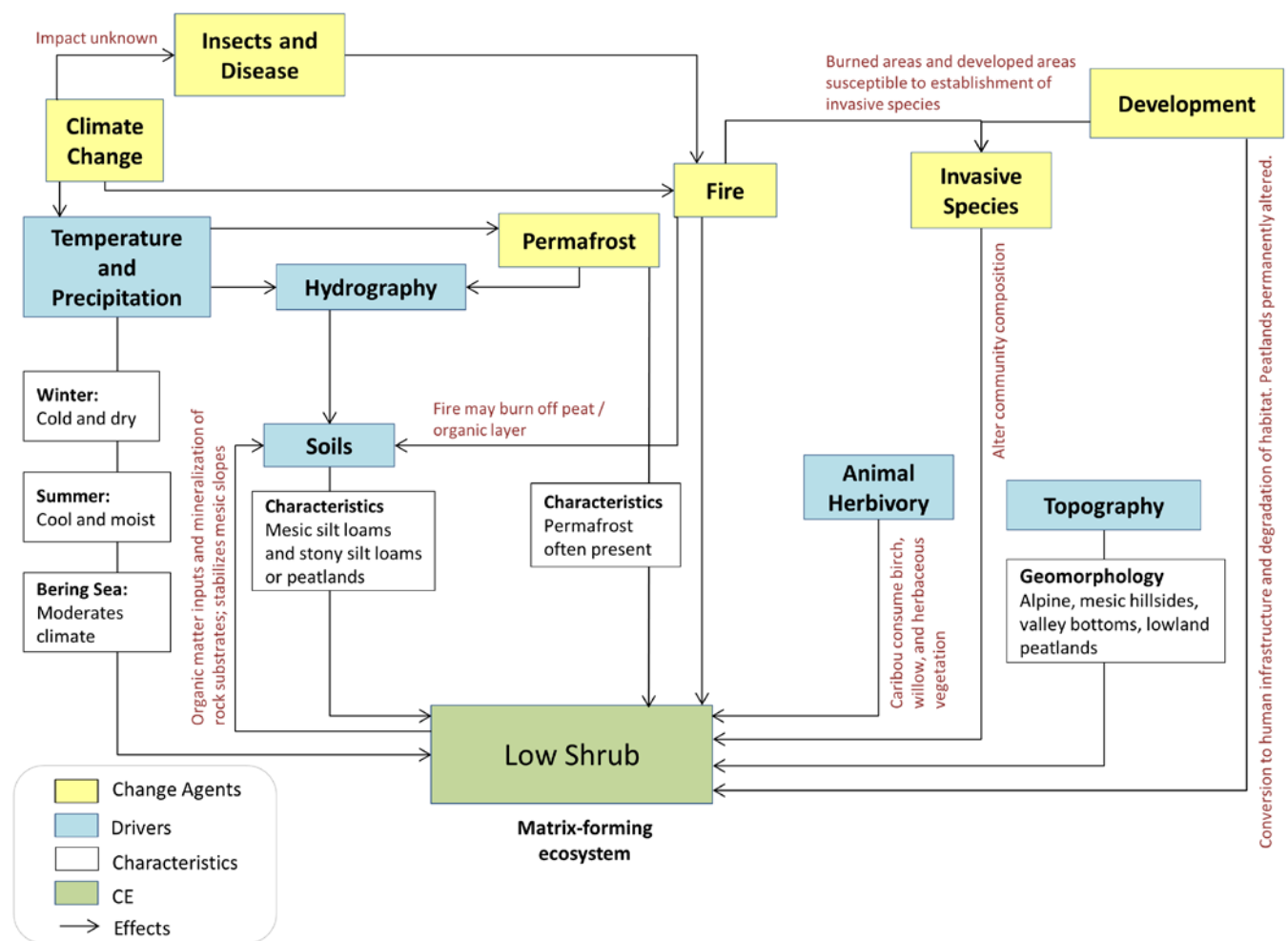
**Figure D-20.** Conceptual model for low shrub in the YKL study area.

## Current Status and Future Landscape Condition

The intersection of the low shrub CE distribution with the LCM indicates that over 96% of the total CE area is very high (intact) condition for current, near-term, and long-term projections (Figure D-21). The long-term (2060) landscape condition suggests almost no change in any landscape condition class, with less than 1% increase in the total CE area occupied by the low and very low condition classes.
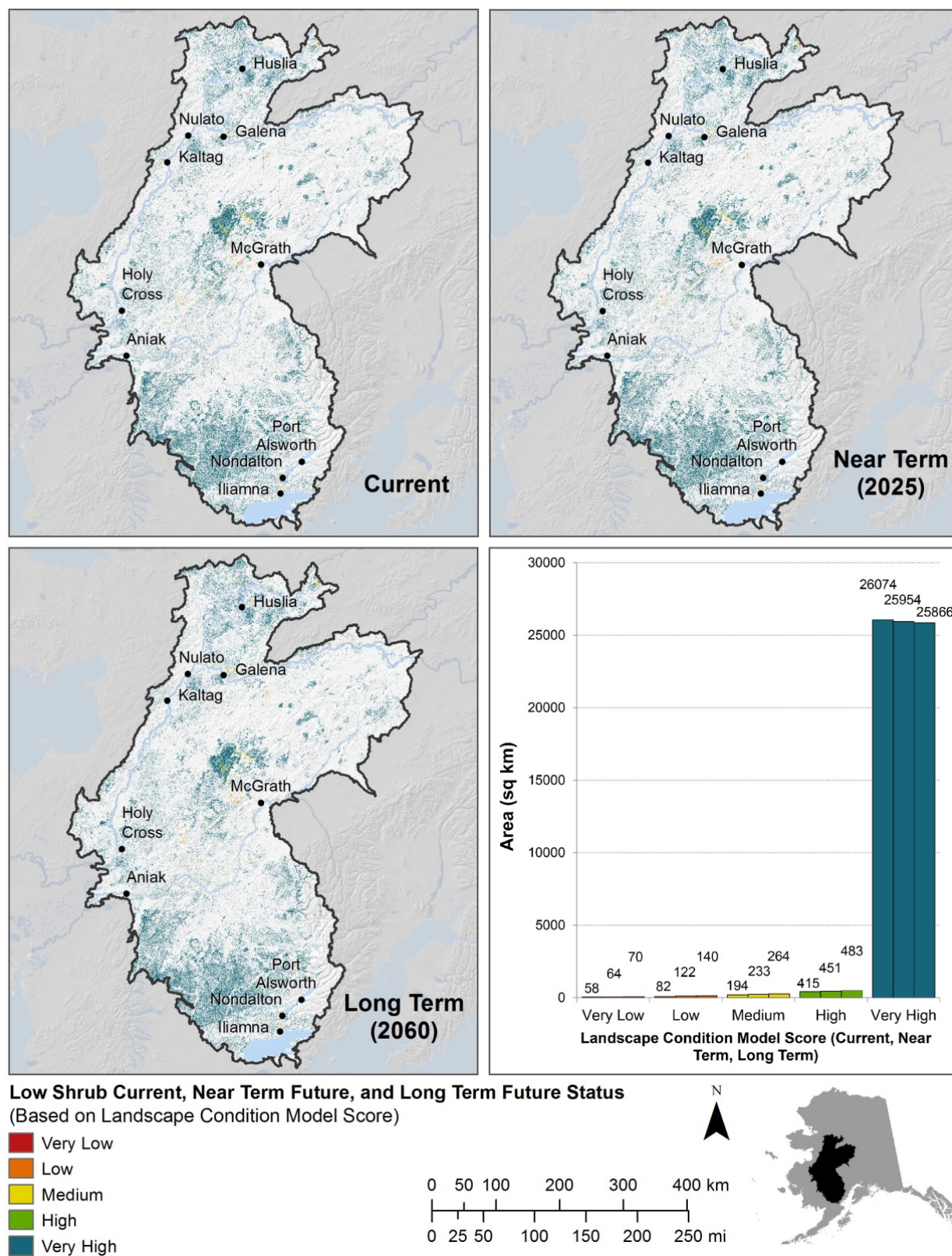
**Figure D-21.** Current, near-term (2025), and long-term (2060) status of low shrub in the YKL study area.

## 1.8.  Dwarf-Shrub (Mesic)
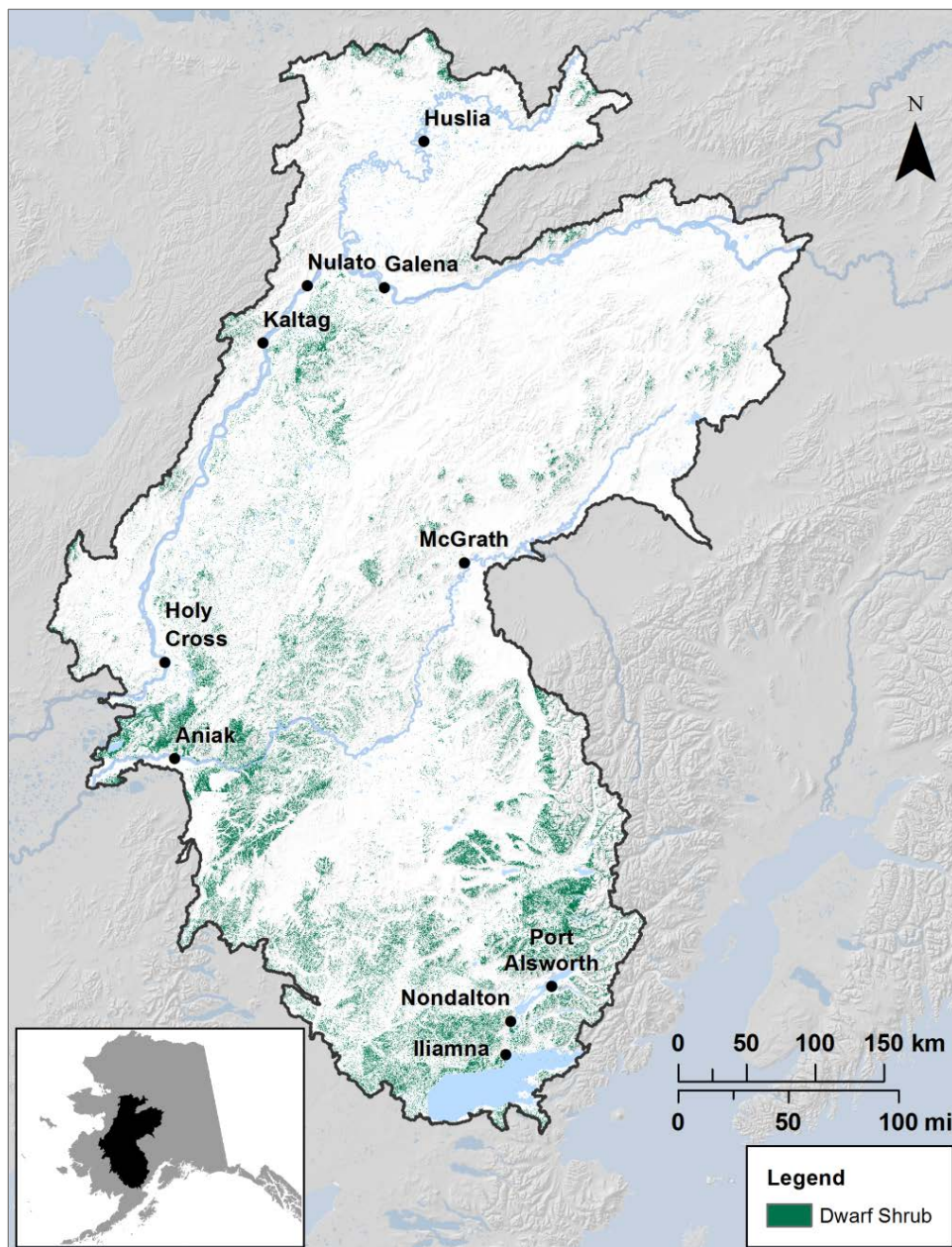


**Figure D-22.** Distribution of the dwarf-shrub (mesic) CE in the YKL study area.

The dwarf-shrub (mesic) CE covers 7% of the YKL study area and is primarily distributed throughout the southern region (Figure D-22). The shrub layer is composed of *Dryas*, ericaceous, and/or *Salix* species (Figure D-23). Either at least 25% of the site consists of shrubs less than 0.2 m in height or shrubs less than 0.2 m in height.

The dwarf-shrub CE commonly occurs on sideslopes, ridges, summits, floodplains, valleys, late-lying snow beds, and bluffs. Elevations range from 20 to 7,449 ft.  Sites are typically dry to mesic with lithosols common. Permafrost ranges from present to absent (according to the permafrost model approximately 11% of the dwarf-shrub CE is currently underlain by continuous permafrost). Patch size ranges from small to large. The dwarf shrub CE does not include peatland plateaus or wetlands.

Plant species diversity is high in dwarf-shrub sites. Common dwarf-shrub species include *Dryas integrifolia*, D. *octopetala*, *Betula nana, Cassiope tetragona, Salix arctica, S. phlebophylla, S. reticulata, S. rotundifolia, Vaccinium uliginosum, V. vitis-idaea, Empetrum nigrum, Rhododendron tomentosum* ssp. *decumbens, Diapensia lapponica, Harrimanella stelleriana, Kalmia procumbens,* and *Arctous* spp. Common herbaceous species may include *Boykinia richardsonii, Geum glaciale, Pedicularis lanata, Eriophorum angustifolium* ssp. *triste, Senecio lugens, Anemone* spp., *Hierochloe alpina, Arnica lessingii, Carex scirpoidea, C. bigelowii, C. microchaeta, C. scirpoidea, Festuca* spp., *Lupinus arcticus, Artemisia globularia, Bistorta officinalis, Luzula* spp., *Antennaria alpina*, and *Equisetum* spp. Common mosses may include *Rhytidium rugosum, Aulacomnium turgidum, A. palustre, Distichium capillaceum, Hylocomium splendens, Racomitrium* spp.*, Dicranum elongatum, Pleurozium schreberi, Polytrichum* spp., and *Tortula ruralis*. Lichens may be common and can include *Cladina rangiferina, C. stellaris, Cetraria cucullata, Stereocaulon* spp., *Alectoria nigricans*, and *Thamnolia vermicularis*. Some south facing slopes also support a unique assemblage of species, including *Artemisia frigida, Artemisia alaskana, Juniperus communis, Arctostaphylos uva-ursi, Shepherdia canadensis*, *Pseudoroegneria spicata, Bromopsis pumpelliana*, *Calamagrostis purpurascens, Festuca altaica*, and *Poa* spp.
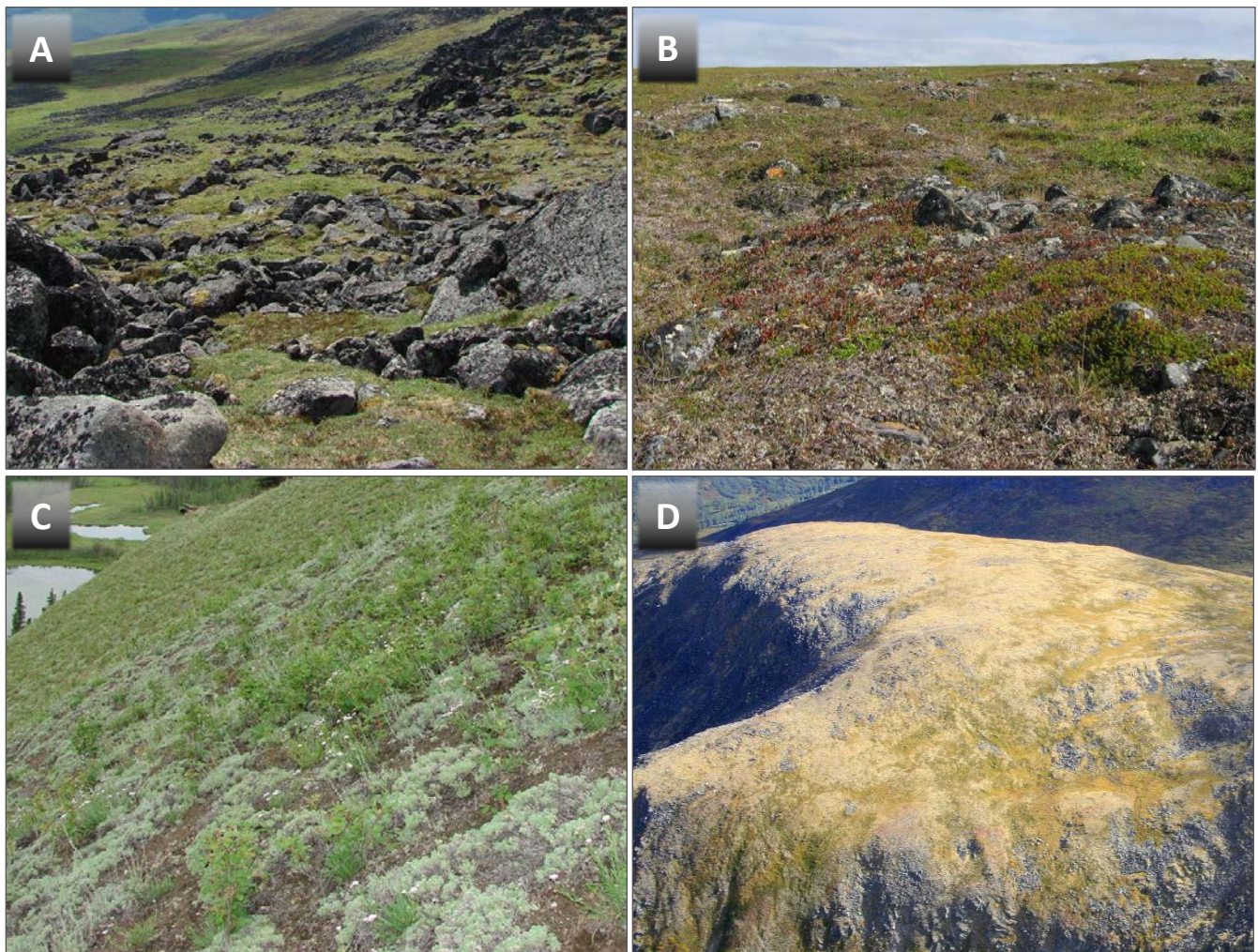


**Figure D-23.** The dwarf-shrub (mesic) CE includes sites dominated by *Dryas* spp. (A) and ericaceous shrubs (B). Unique dwarf-shrub communities dominated by sage occur on bluffs (C). Dwarf-shrub sites can have high lichen cover (D).

## Conceptual Model

The dwarf shrub CE will likely be impacted by climate change and the related direct impacts from fire regime, permafrost, and possibly insect and disease agents in the YKL study area (Figure D-24). The probability of fires occurring is predicted to increase for this CE. In addition, 8% of the total CE area will change from continuous permafrost to discontinuous permafrost by 2060. Only 2% of the dwarf shrub CE has been defoliated or impacted by insect and disease agents over the past 25 years and no non-native plants are known to be associated with this habitat.

We cannot predict the response of this CE to future changes in fire, permafrost, or insects and disease. Invasive species are unlikely to impact this CE in the near-term and long-term future. We speculate that a warming climate may increase the available habitat for dwarf shrub vegetation at higher elevations in the Kuskokwim Mountains and Lime Hills but may also increase the conversion of dwarf shrub to other vegetation classes at lower elevations.
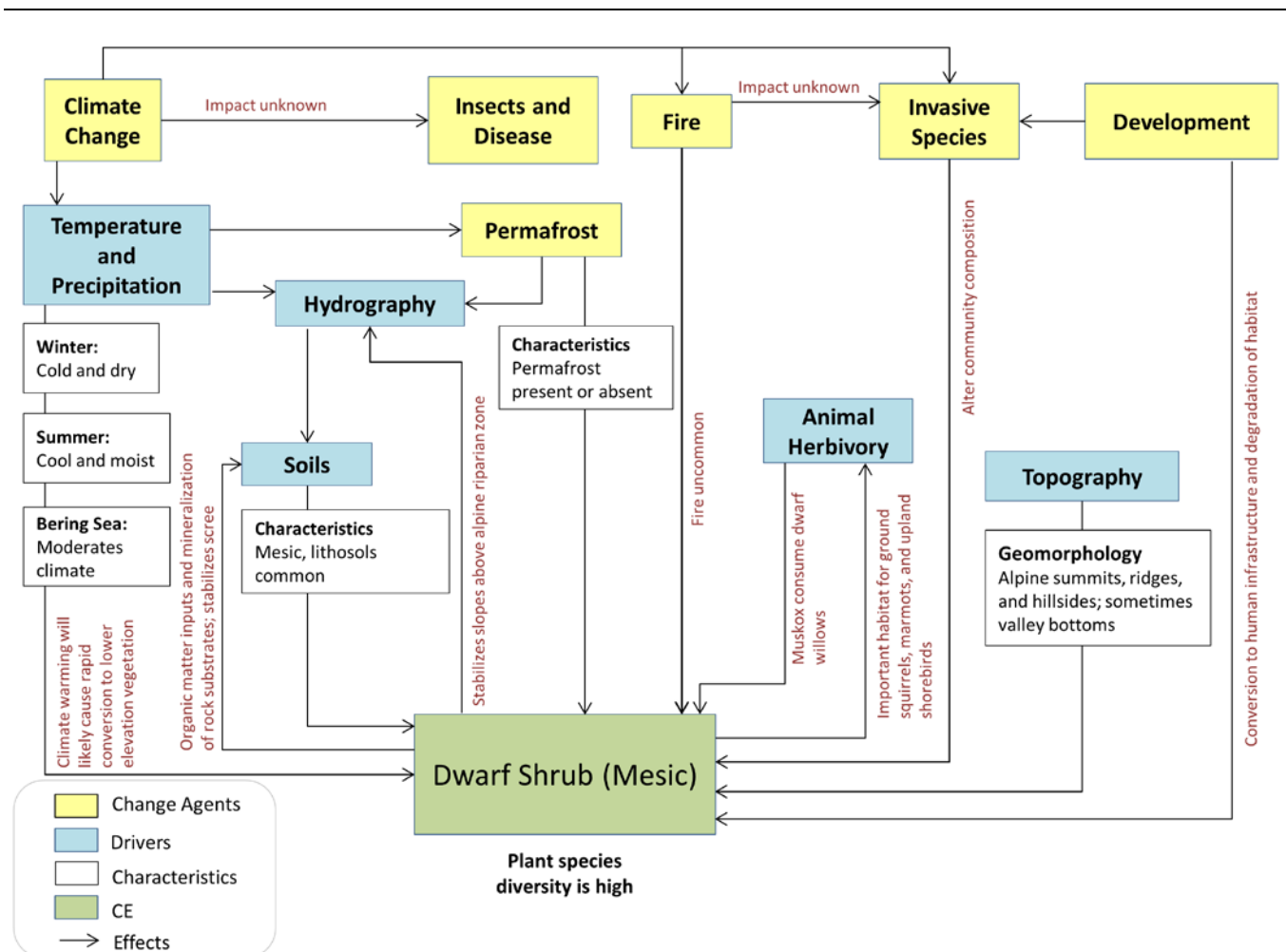


**Figure D-24.** Conceptual model for the dwarf-shrub (mesic) CE in the YKL study area.

**Current Status and Future Landscape Condition**

The intersection of the dwarf-shrub (mesic) CE distribution with the LCM indicates that over 96% of the total CE area is very high (intact) condition for current, near-term, and long-term projections (Figure D-25). The long-term (2060) landscape condition suggests almost no change in any landscape condition class, with at most 1% increase in the total CE area occupied by the low and very low condition classes.
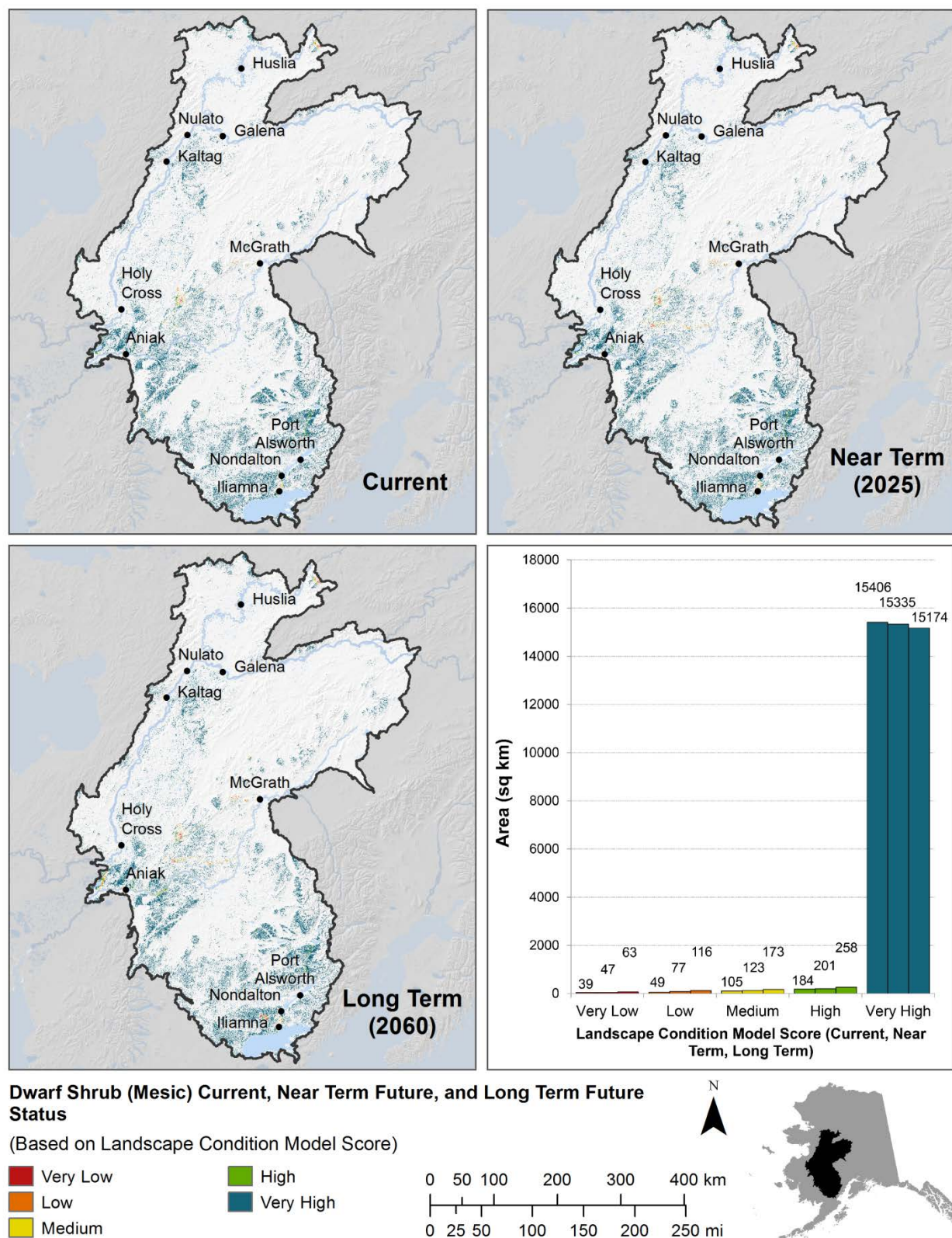
**Figure D-25.** Current, near-term (2025), and long-term (2060) status of dwarf-shrub (mesic) in the YKL study area.

## 1.9.  Herbaceous Wetlands
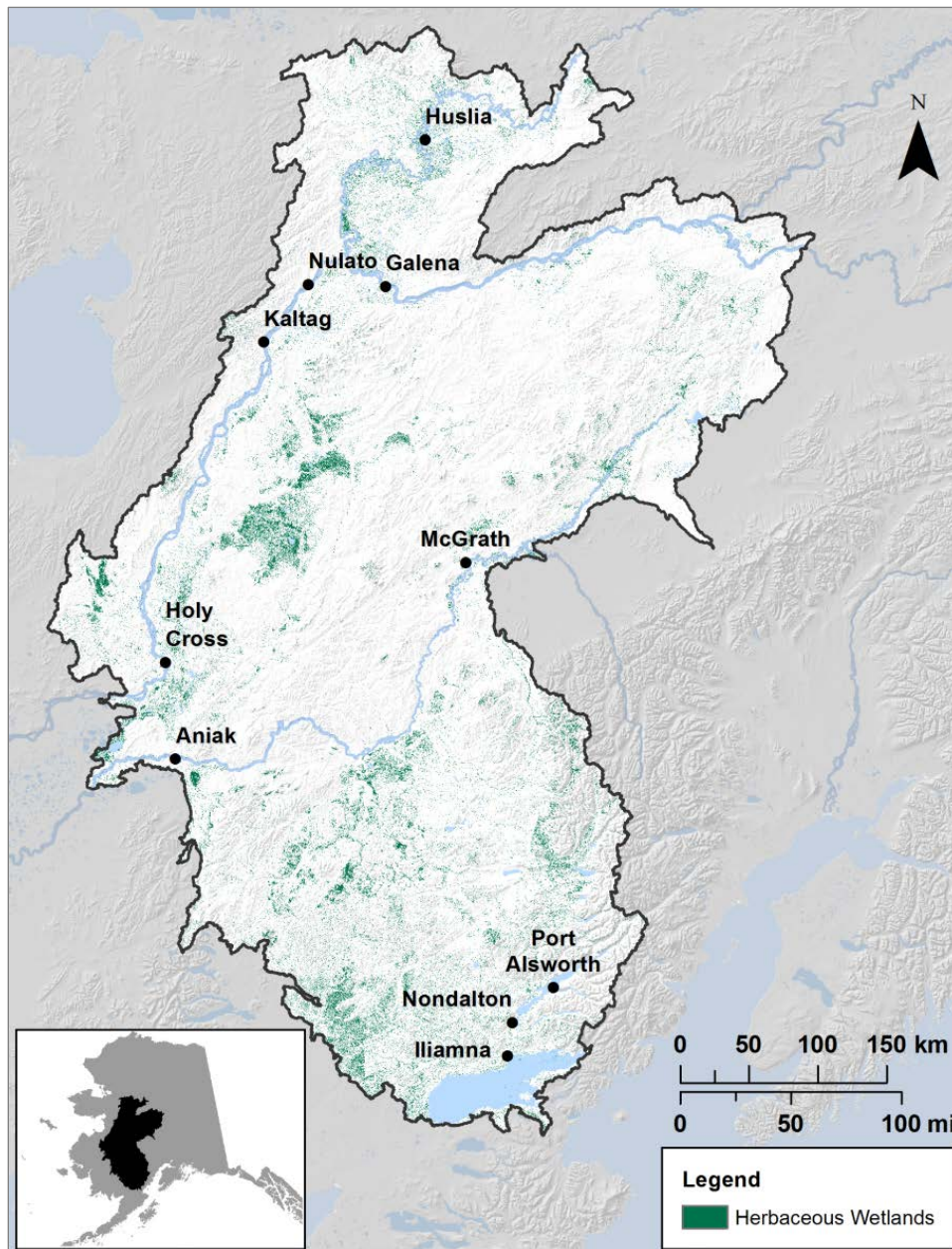


**Figure D-26.** Distribution of the herbaceous wetlands CE in the YKL study area.

Herbaceous wetlands CE covers 5% of the YKL study area and occurs throughout, with some regions having greater concentrations (Figure D-26). Shrubs contribute less than 25% of the vegetation cover, while herbaceous species contribute more than 25%. Sites range from periodically wet with no standing water, to permanently wet, to flooded with standing water, to permanently flooded and dominated by aquatic plants. Herbaceous wetlands CE do include herbaceous peatlands but not tussock tundra. Herbaceous wetlands occupy elevations ranging from 19 to 8,122 ft. in the YKL study area. Permafrost ranges from absent to common.  This class occurs in areas of thermokarst.

In periodically wet or continually flooded sites, vegetation is dominated by emergent herbaceous plants such as sedges, cattails, and rushes. Dominant vegetation include *Carex utriculata, Schoenoplectus tabernaemontani, Typha latifolia, Menyanthes trifoliata*, *Equisetum fluviatile*, *Eleocharis palustris, Comarum palustre*, *Hippuris vulgaris*, and *Arctophila fulva*. Other common species include *Carex aquatilis, C. utriculata, C. lasiocarpa, Eriophorum angustifolium, Calamagrostis canadensis, Calla palustris*, and *Equisetum palustre*. Shrubs include *Betula nana*, *Myrica gale, Alnus incana* ssp. *tenuifolia*, and *Salix* spp.

Permanently flooded sites may be dominated by a variety of rooted or floating aquatic herbaceous species, including *Nuphar polysepala, Potamogeton* spp., *Lemna minor, Sparganium* spp*.,* and *Ranunculus* spp. Other common species include *Myriophyllum* spp., *Hippuris vulgaris, Isoetes tenella*, and *Callitriche* spp.

In areas of closed bogs and poor fens, thick peat-forming sedges dominate, including *Trichophorum cespitosum, Carex pluriflora, C. chordorrhiza, C. livida*, and *Eriophorum russeolum* (Viereck et al. 1992). Dwarf and low shrubs include *Oxycoccus microcarpus, Andromeda polifolia, Vaccinium uliginosum, Rhododendron tomentosum* ssp. *decumbens*, and *Empetrum nigrum*. Aquatic mosses can be present including *Sphagnum* spp. (Viereck et al. 1992).
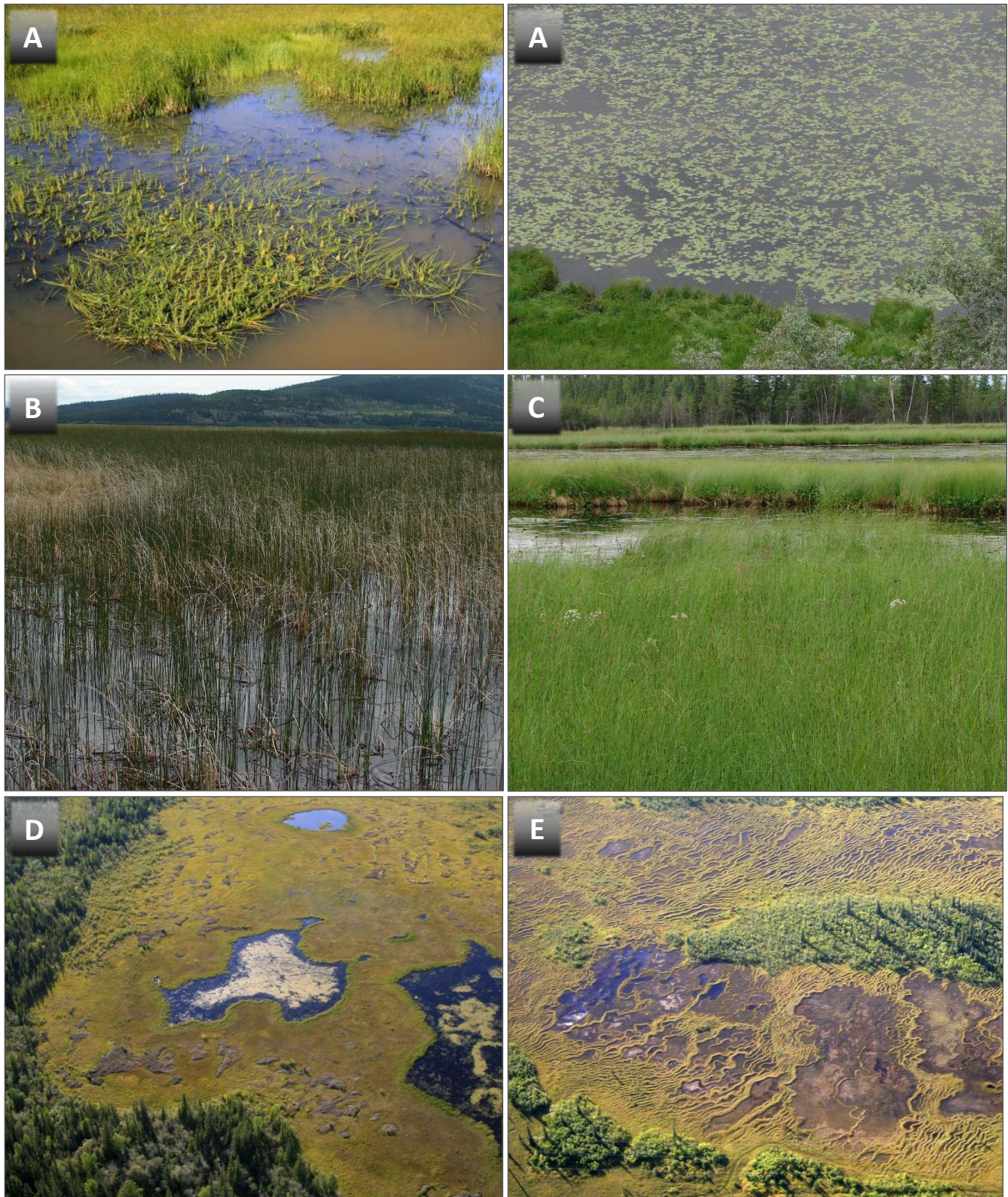
**Figure D-27.** The herbaceous wetlands CE includes a large variety of wetland types and communities: permanently flooded wetlands dominated by aquatic species (A), periodically wet or continually flooded marsh (B), seasonally saturated wetlands (C), closed bogs or poor fens with thick peat deposits (D), and nutrient rich fens (E).

## Conceptual Model

The herbaceous wetlands CE will likely be impacted by climate change and the related direct impacts from fire regime, permafrost, and possibly insect and disease agents in the YKL study area (Figure D-28).

We currently cannot predict the response of this CE to future changes in fire, permafrost, invasive species, or insects and disease. Non-native plants are not known from this habitat in the YKL, but species such as *Phalaris arundinacea* and *Elodea* spp. are two problematic wetland and aquatic species that are expanding in the interior and other regions of the state. Fire is known to be uncommon in the herbaceous wetlands CE. When it does occur, it may burn off peat or organic layers.

Thirteen percent of the total CE area will change from continuous permafrost to discontinuous permafrost by 2060. Thermokarst wetlands may increase in sites with ice-rich soils, but other permafrost supported wetlands may decrease in cover. The prevalence of insect and disease agents is largely unknown in the herbaceous wetland CE (observations indicate that 4% of the total CE area of herbaceous wetlands has been impacted by insect and disease damage).
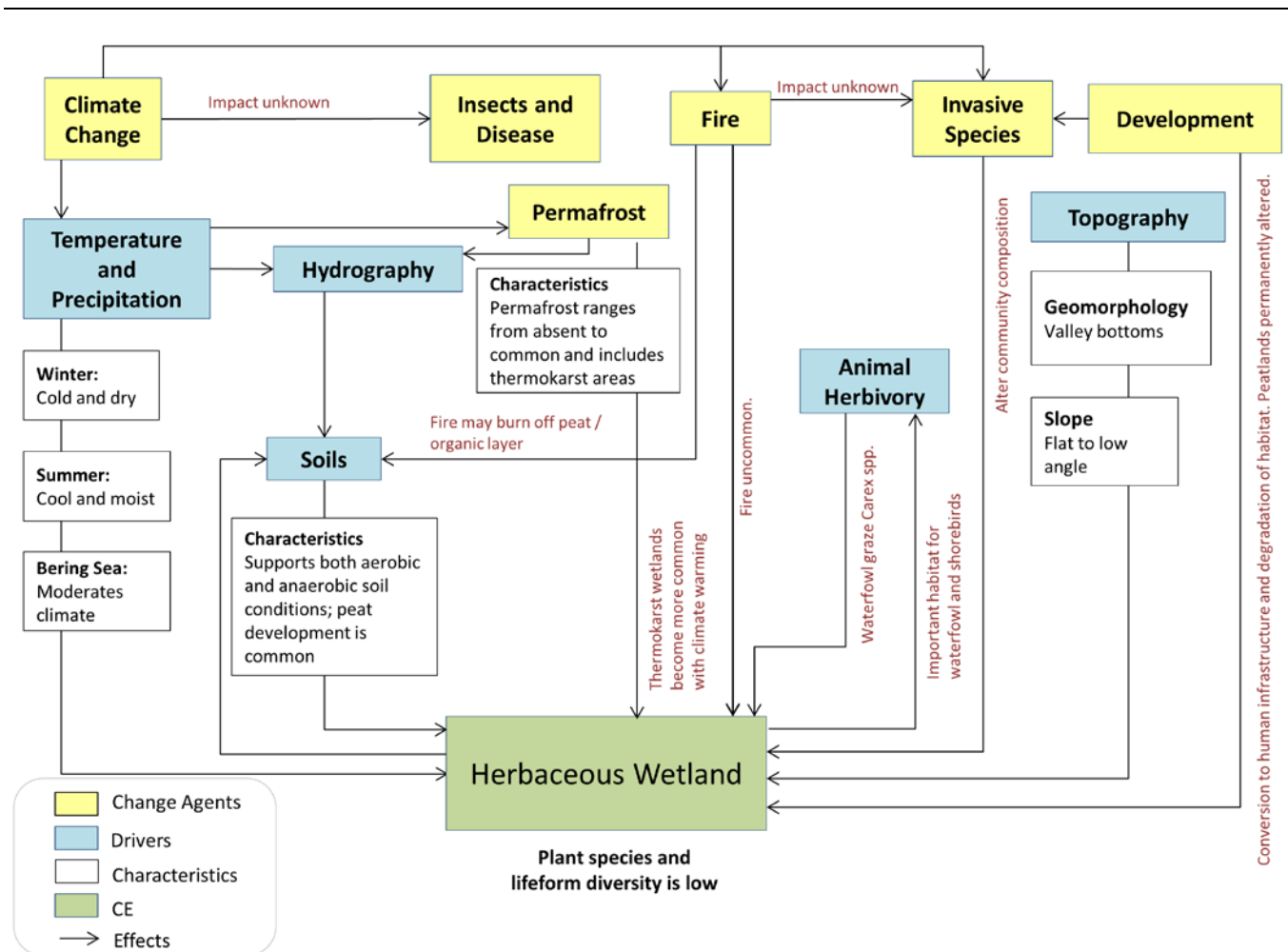


**Figure D-28.** Conceptual model for the herbaceous wetlands CE in the YKL study area.

**Current Status and Future Landscape Condition**

The intersection of the herbaceous wetlands distribution with the LCM indicates that over 96% of the total CE area is very high (intact) condition for current, near-term, and long-term projections (Figure D-29). The long-term (2060) landscape condition suggests almost no change in any landscape condition class, with at most 1% increase in the total CE area occupied by the low condition class.

**Herbaceous Wetlands Current, Near Term Future, and Long Term Future Status**

(Based on Landscape Condition Model Score)

| Very Low | High |
| Low | Very High |
| Medium | |

**Figure D-29.** Current, near-term (2025), and long-term (2060) status of herbaceous wetlands in the YKL study area.
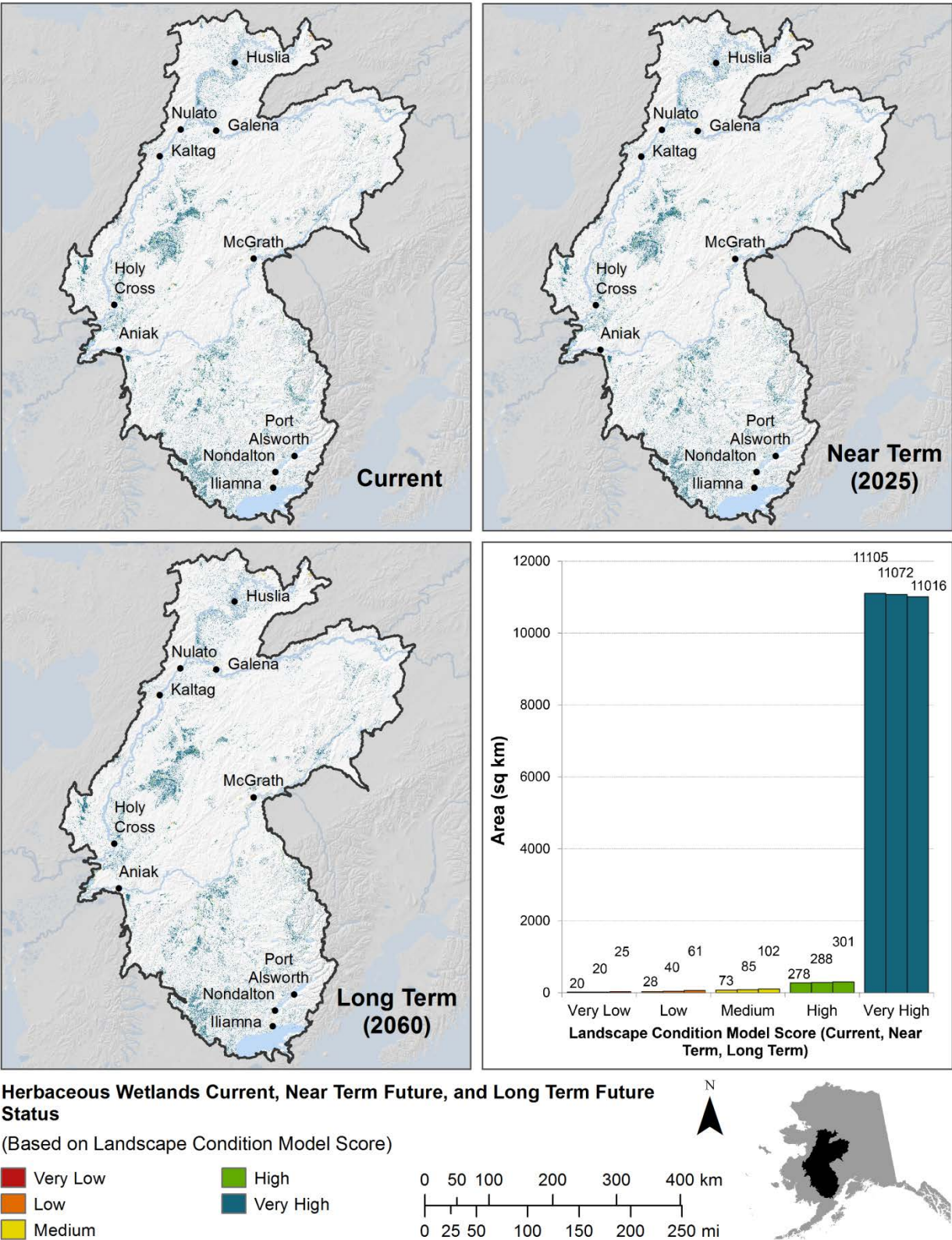
## 1.10. Large Floodplains
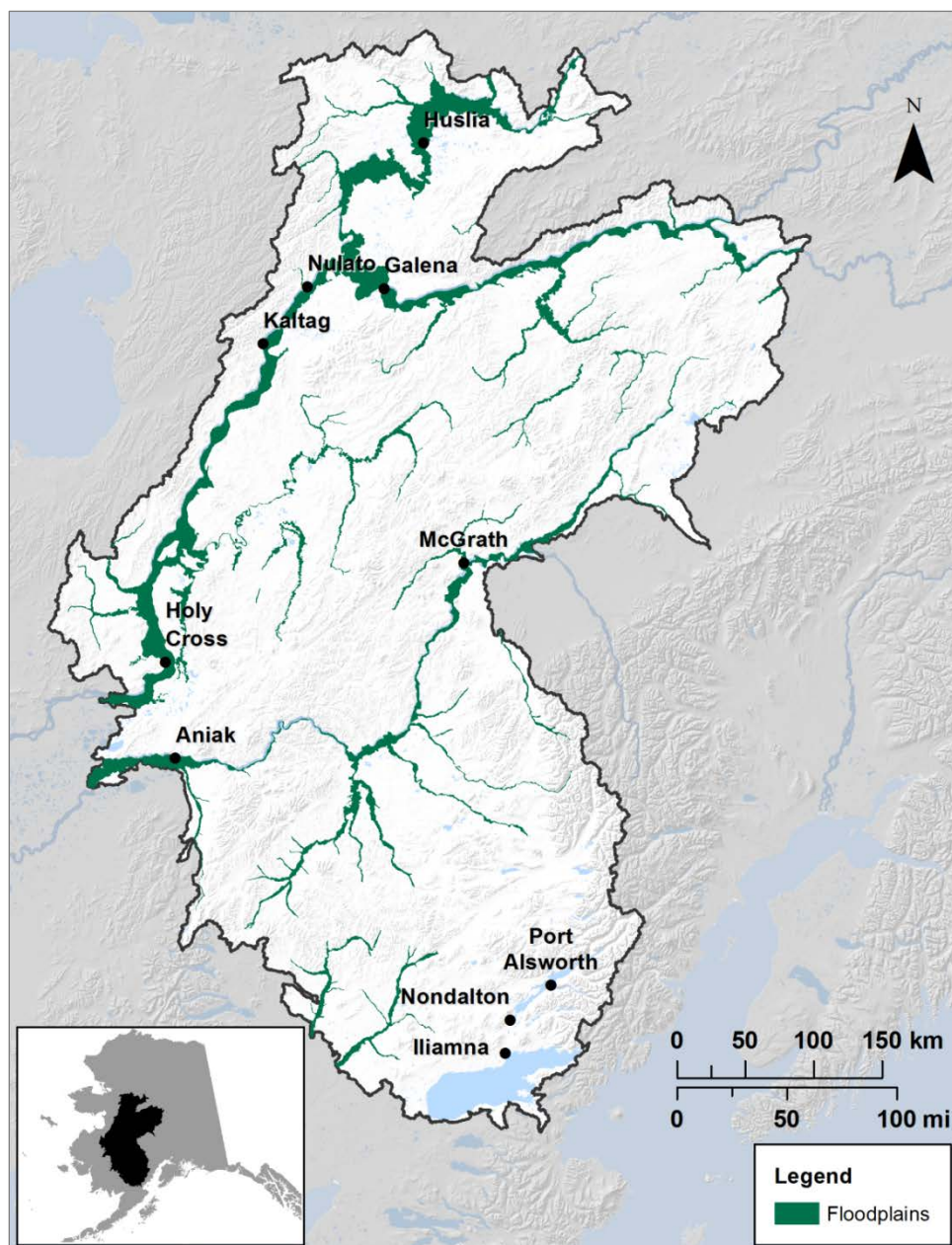


**Figure D-30.** Distribution of large floodplains CE in the YKL study area.

The floodplains CE covers 8% of the YKL study area and occurs throughout the study area (Figure D-30). Floodplains are the land adjacent to a stream or river that stretches from the banks of its channel to the base of the enclosing valley walls and experiences flooding during periods of high discharge. We also include the river, stream and exposed sandbars as part of this CE.

These fluvial plains include meandering or straight active streams, braided channels, abandoned channels, oxbows, and alluvial terraces (Figure D-31). Permafrost is typically absent. Unlike the previously described Terrestrial Coarse-Filter CEs, which were delineated using vegetation classes, the floodplain CE represents a

Biophysical Setting and occurs in large, continuously connected vegetated, unvegetated and water polygons that follow the major rivers. Two types of forested floodplain Biophysical Settings occur in the floodplains CE:

1. Colder Interior Alaska sites with permafrost underlying the ancient terraces.
2. Warmer southern Interior Alaska sites with no permafrost underlying the ancient terraces.

**Figure D-31.** Large floodplains include forested inactive alluvial terraces, abandoned channels, and active alluvial terraces (A). New active alluvial terraces are formed as sediment is deposited along convex curves in the river channel (B).

## Interior Alaska Forested Floodplains: Vegetation and Succession

Forested floodplains of colder northern Interior Alaska occur within the northern third of the YKL study area. The formation of new land in floodplain ecosystems is well documented (Friedkin 1972, Leopold et al. 1964). Along a meandering river, alluvium typically is deposited on convex curves in the river channel. The opposing concave bank is cut, providing sediment for deposition on convex curves downstream and creating a series of similar bands of alluvial deposits. The channel thus meanders laterally across the floodplain. Alluvium also is deposited on the soil surface during flooding further raising the soil surface height. However, because surface height is a

function of floodwater height, the surface height eventually stabilizes (Leopold et al. 1964). Many of the rivers and tributaries within the YKL study area are glacially fed and support high sediment loads. Flooding occurs from ice jams in the spring, rapid melting of glaciers in mid-summer, or heavy rains during spring, summer, or fall.

Permafrost typically underlies the ancient floodplains. Vegetation growing on new deposits near the river may be contrasted with vegetation on older deposits further inland or above cut banks to recognize and measure successional processes (Lindsey et al. 1961, Stevens and Walker 1970). The general pattern of succession on new alluvial bars or abandoned stream channels is *Salix* spp. initially invading, followed by either *Populus balsamifera*, or *Alnus* spp. then *Picea glauca* followed by *Picea mariana* (Drury 1956, Viereck 1970, Van Cleve et al. 1983, Viereck et al. 1993, Yarie et al. 1998).

*Salix* species tend to colonize and dominate most new deposits. Within 5 years, *Populus balsamifera* seedlings, *Equisetum* spp., *Calamagrostis canadensis,* and *Chamerion latifolium* are also common (Walker et al. 1986, Viereck et al. 1993, Boggs and Sturdy 2005). Most are deep rooted species that take advantage of the sometimes deep water table and stabilize the soils. On the Tanana River, *Picea glauca* has also been observed invading during these early seral stages, although establishment increases during the first 50 years of succession. Trees that establish during the early seral stage may not survive due to surface sedimentation (Adams 1999). Within 10 years, many early seral sites may be 1 to 2 m above mean river height because of overbank sedimentation (Yarie et al. 1998). Other early seral sites may be reclaimed by the river. Moose and hares intensively use this *Salix* stage of succession (Kielland and Bryant 1998).

On fine textured sediments on the Tanana River to the east of the study area, *Salix* is often followed by *Alnus incana* ssp. *tenuifolia* and then *Populus balsamifera* (Chapin et al. 2006), whereas *Salix* on gravel bars is often directly followed by *Populus balsamifera* saplings. Nitrogen total ecosystem stock on barren alluvial bars is approximately 10% of what eventually accumulates later by the *Populus balsamifera* stage of succession (sites approximately 50 years old and older) (Van Cleve et al. 1971, Walker 1989, Marion et al. 1993, Van Cleve et al. 1993). Nitrogen accumulation is largely caused by *Alnus* species, which have symbiotic actinorrhizal bacteria that fix nitrogen (Uliassi et al. 2000). The lack of nitrogen in the early stages of succession may strongly limit growth and productivity (Walker and Chapin 1986, Yarie 1993).

In *Alnus* dominated sites of the Tanana River, flooding frequency decreases to every 5 to 10 years (Dyrness and Van Cleve 1993). *Salix* spp. such as *Salix alaxensis* and *Salix lasiandra* are gradually eliminated as they are shaded by *Alnus* spp. and browsed by hares (McAvinchey 1991, Viereck et al. 1993). *Populus balsamifera* populations are also reduced for the same reasons. New *Picea glauca* seedlings rarely survive on the thick litter layers that develop at sites dominated by *Alnus* spp. and *Populus balsamifera*, but they thrive on sediments deposited during the occasional flooding events (Adams 1999). Snowshoe hares are a major cause of *Picea glauca* seedling mortality (Walker and Chapin 1986). The majority (60% to 70%) of the total nitrogen accumulated during the 200 year floodplain successional process is accumulated during this *Alnus* spp./*Populus balsamifera* stage of succession (Van Cleve et al. 1971, Van Cleve et al. 1983, Van Cleve et al. 1993).

Over the next 10 to 20 years, *Populus balsamifera* starts to dominate, overtopping the *Alnus* or *Salix* stands (Viereck et al. 1983, Boggs and Sturdy 2005). *Picea glauca* recruitment is greatest during this seral stage because of the occasional years when high seed production follows a year of alluvial deposition (Yarie et al. 1998, Adams 1999). *Betula neoalaskana* forests may also develop (Boggs and Sturdy 2005). Spruce mortality caused by snowshoe hares is less during this stage of succession, and *Picea glauca* grows rapidly. Litter cover is high.

Eventually, *Picea glauca* trees co-dominate with *Populus balsamifera*. *Populus balsamifera* are short-lived (100 to 150 years) (Viereck et al. 1983, Walker et al. 1986) with recruitment rare. Additionally, beavers fell *Populus balsamifera* (Oechel and Van Cleve 1986). *Picea glauca* eventually dominates the forest canopy. Initially, stands of *Picea glauca* are relatively evenly aged because many of the trees are recruited during the same years during the *Populus balsamifera* stage of succession. However, stands of *Picea glauca* become unevenly aged in older stands because of variable recruitment during the *Picea glauca* stage of succession. The oldest stands may be 300+ years old (Chapin et al. 2006). Common disturbances include flooding, browsing by snowshoe hares, and winter ice storms (Viereck et al. 1993). *Alnus* spp. dominance in the understory may still occur, and feather mosses (*Hylocomium* spp. and *Pleurozioum schreberi*) may dominate the forest floor. Permafrost less commonly underlays stands of *Picea glauca* than it does stands of *Picea mariana* (see below).

The closed *Picea glauca* canopy reduces solar radiation inputs to the forest floor, so soils thaw slowly in spring and summer. A combination of low soil temperature and other factors reduces the rate of decomposition and nutrient cycling (Flanagan and Van Cleve 1983, Van Cleve et al. 1983, Van Cleve et al. 1993), leading to the development of an organic mat on the forest floor. Thick organic mats further reduce soil temperatures.

*Picea mariana* dominated plant associations are common on ancient floodplains and are typically underlain by permafrost. Sites dominated by *Picea mariana* generally formed thousands of years ago (Mann et al. 1995) and include plant associations such as dwarf *Picea mariana* with an understory of *Betula nana - Carex bigelowii*, or *Eriophorum vaginatum* (Boggs and Sturdy 2005). Non-forest dominated plant associations that are underlain by permafrost may include *Rhododendron tomentosum* ssp. *decumbens / Eriophorum vaginatum* or *Carex aquatilis*. Thermokarst also commonly forms in forests when ice-rich permafrost thaws (Osterkamp 2000). The thawing melts the physical foundation of the forest, leading to the formation of wet sedge meadows, bogs, and ponds in the resulting depressions. Thaw subsidence is typically 1 to 2 meters.

## Southern Interior Forested Floodplains: Vegetation and Succession

Forested floodplains of warmer southern Interior Alaska occur within the southern two thirds of the YKL study area. Permafrost is typically absent from all land forms, including ancient floodplains. The following description of forested floodplains of southern Interior Alaska is derived from descriptions of succession for the Alagnak River, 20 miles south of the YKL boundary (Boucher et al. 2014, in prep). Generally, after new alluvial bars or abandoned stream channels form, *Alder* or *Salix* spp. initially invade, then *Populus balsamifera* and *Betula kenaica* establish, then *Picea glauca* and *Betula kenaica* co-dominate, and finally *Picea glauca* dominates.

Early seral floodplain sites are colonized by *Alnus incana* ssp. *tenuifolia*, *Salix alaxensis*, and/or *Salix pulchra*. Understory herbaceous species include *Calamagrostis canadensis*, *Equisetum arvense,* and *Comarum palustre*.

*Populus balsamifera* dominates the next seral stage, and *Betula kenaica* is a common associate. *Alnus incana* ssp. *tenuifolia* may be common in the shrub layer. Common species in the herbaceous layer include *Calamagrostis canadensis, Equisetum* spp*., Cornus canadensis*, *Rubus arcticus*, and *Gymnocarpium dryopteris. Picea glauca* may also invade.

Eventually, *Picea glauca* and *Betula kenaica* co-dominate and *Populus balsamifera* cover declines. The shrub layer is variable and may include *Alnus incana* ssp*. tenuifolia, Viburnum edule, Betula nana, Rhododendron tomentosum* ssp. *decumbens*, *Salix pulchra, S. glauca*, and *S. barclayi*. Dwarf shrubs such as *Vaccinium uliginosum*, *Vaccinium vitis-idaea*, and *Linnaea borealis* may be common. Herbaceous species including

*Calamagrostis canadensis, Equisetum pratense, Equisetum arvense,* and *Gymnocarpium dryopteris* may be common.

*Picea glauca* eventually dominates, and *Betula kenaica* may be a minor canopy associate. *Alnus incana* ssp. *tenuifolia*, *Salix pulchra*, and *Calamagrostis canadensis* are common in the understory.

Shrub dominated floodplain wetlands on abandoned channels also occur. The most common shrubs are *Myrica gale, Betula nana,* and *Rhododendron tomentosum* ssp. *decumbens*. Common herbaceous species include *Calamagrostis canadensis*, *Carex aquatilis*, *Carex pluriflora*, *Eriophorum vaginatum*, *Equisetum arvense*, *E. fluviatile*, *Comarum palustre*, and *Rubus chamaemorus*. Mosses such as *Sphagnum* spp. and *Tomentypnum nitens* are common in the ground layer.

Mesic herbaceous sites are typically dominated by *Calamagrostis canadensis*. Wet herbaceous sites (lacustrine deposits, sloughs, saturated river terraces, and the edges of lakes and ponds) are typically dominated by *Calamagrostis canadensis, Carex aquatilis, Carex lyngbyei, Carex pluriflora, Carex utriculata,* and *Arctophila fulva*. *Sphagnum* is the most common moss genus.

The historic floodplain of the Alagnak River does not support thermokarst pits, permafrost, tussocks, or *Picea mariana* (Boucher et al. in prep) as occurs on the "Interior Forested Floodplains".

**Conceptual Model**

We only describe vegetation changes in the Floodplains for the long-term (2060) scenario; the near-term scenario is too short term for us to evaluate meaningful vegetation responses. In the long-term, January temperatures are expected to warm the most in the more northern parts of the REA, with increases of more than 3°C (5°F). In the more southern areas, increases of about 2.5°C (4°F) are expected. Summer warming is expected to follow the same geographic patterns as winter warming, with greater changes in the northern part, and less change to the south, with an overall average increase of 1.2°C (2°F). By 2060, precipitation may increase by approximately 6%, with a slight increase in winter (December, January, and February) precipitation. This slight increase in winter precipitation may not result in increased snowfall or greater snowpack, since associated warming may mean that a greater percentage of 2060 precipitation may fall as rain.

If the region does become warmer and wetter, we expect the "southern interior forested floodplains" to expand into regions now dominated by "interior forested floodplains." Forested floodplains will also expand onto higher elevation floodplains and may retain some of the characteristics of the "interior forested floodplains". By 2060, the temperature is expected to increase by 1.2°C (2°F), resulting in a general 570 foot increase in elevation.

The vegetation response to climate change may be relatively rapid because most floodplain sites are less than 200 years old (Chapin et al. 2006) due to continual fluvial erosion and deposition (Figure D-32). Seeds also are easily transported along river corridors by wind, water, birds, mammals and local dispersal.

Relative to flooding, fire currently plays a minor role in driving succession and ecosystem processes on floodplains (Figure D-32). The current fire frequency in floodplain systems is considerably less than that of the surrounding terrain because channels can act as fuel breaks (Viereck 1973, Barney 1971, Foote 1983b). In addition, high moisture content of the vegetation, high percentage of deciduous species, and high relative humidity also contribute to making fires less frequent on floodplains than in the adjacent upland white spruce or black spruce forests. Estimated fire return intervals for white spruce forests range from 200 to 300 years in

Interior Alaska (Viereck 1973, Barney 1971, Heinselman 1981, Duchesne and Hawkes 2000). Whereas black spruce forests typically burn every 70 to 130 years (Johnstone et al. 2010). In Interior Alaska the oldest white spruce stands (350+ yrs) are commonly found on islands of floodplains where they are protected from fire (Viereck 1973).

Increased fire frequency will likely make fire a significant CA on forested floodplains. We do not know how early-seral *Alnus, Salix* and *Populus balsamifera* on floodplains will respond to fire. We speculate that the *Picea glauca–Populus balsamifera* and *Picea glauca* floodplain stands will respond to fire similar to upland stand response. For both interior and southern Interior Alaska, post-fire early seral sites are generally herbaceous or *Populus tremuloides-Betula neoalaskana* (Duchesne and Hawkes 2000). This is followed by *Picea glauca*-Deciduous tree dominated sites, and over long periods, *Picea glauca* (Viereck 1975, Foote 1983b, Payette 1992, Boucher 2003).

Non-native plant species have the potential to outcompete native vegetation. Invasive plant species are relatively common on road corridors in Interior Alaska, and where rivers and roads intersect, invasive species can rapidly travel downstream. Additionally, invasive plants that favor disturbed sites are likely to establish in disturbed areas on floodplains such as new alluvial bar deposits. A number of non-native plant infestations are currently documented from floodplains in the YKL, particularly along the Kuskokwim River between Aniak and Kalskag. Most of the non-native species associated with the floodplains (e.g., *Plantago major*, *Chenopodium album*, and *Polygonum aviculare*) are species that are not considered to be strongly invasive and they generally do not persist unless competition remains low. Rivers, however, can rapidly transport and spread invasive species and a number of known populations of more damaging floodplain invasive species are known from areas adjacent to rivers. *Melilotus albus* is known in Shageluk, Galena, Nulato, and Kuyokuk; more recent records of *M. officinalis* are known from Galena (AKEPIC 2012). *Melilotus albus* has been shown to reduce the diversity of native floodplain species and increase willow mortality in Interior Alaska (Spellman and Wurtz 2011), which may alter successional trajectories. We therefore predict that Floodplains are the most susceptible Terrestrial Coarse Filter CE likely to be impacted in the near and long term, and that areas affected are more likely to be those adjacent to and immediately downstream of the larger population centers of McGrath, Galena, and Aniak.
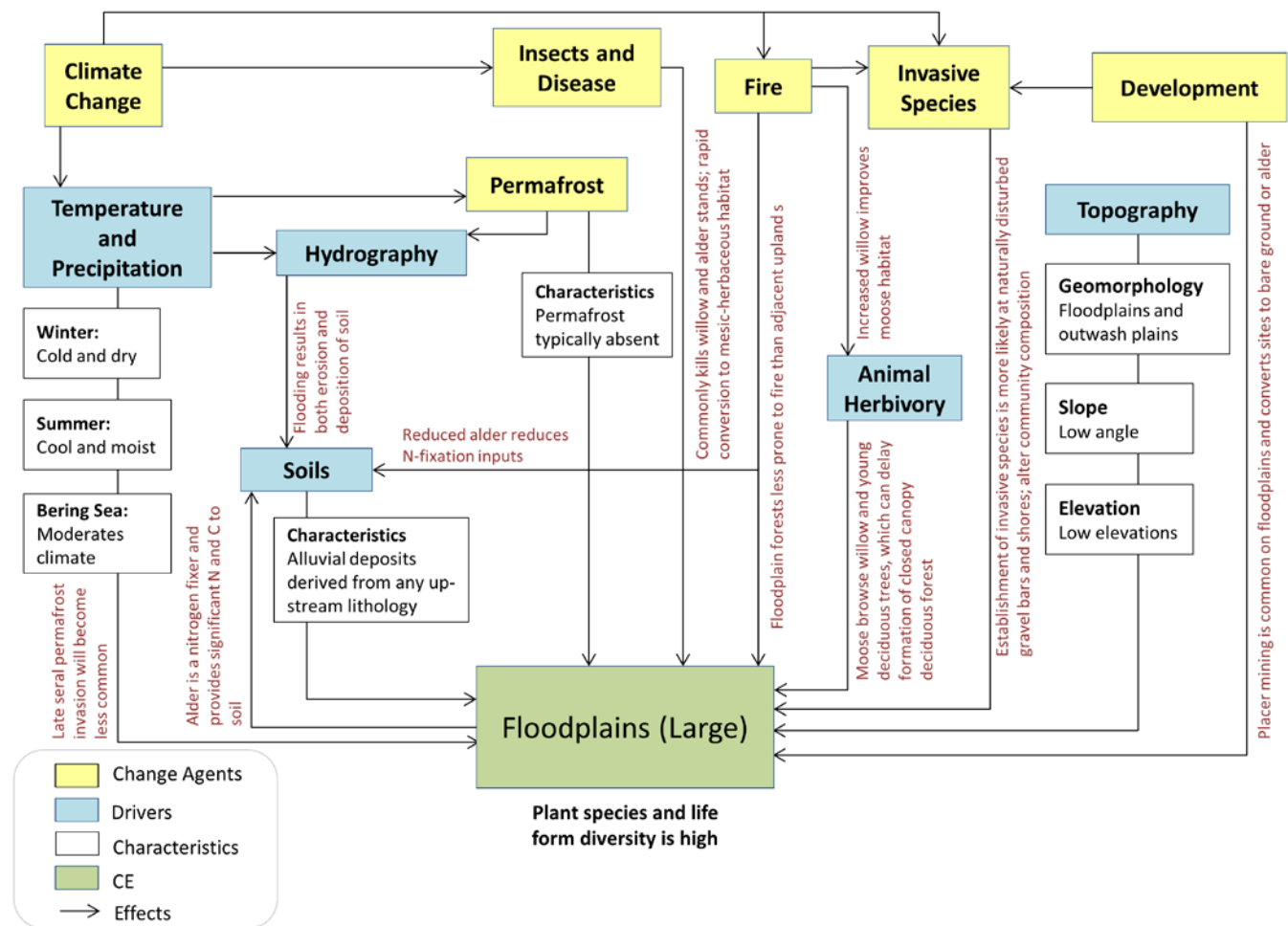
**Figure D-32.** Conceptual model for the forested floodplain CE in the YKL study area.

## Current Status and Future Landscape Condition

Human disturbance is currently minimal (0.04 %) on floodplains (Figure D-33). The percent disturbance includes the LCM scores very low, low and medium. The most obvious human disturbance is the building of villages, roads and airstrips completely or partially on floodplains. Examples include Aniak, Galena, Holy Cross, Huslia, Kaltag, McGrath and Nulato. Many of these towns are or will be subject to river erosion and flooding. Other village infrastructure includes broadband communication and cellular service towers and related infrastructure. Diesel generators are the main source of electricity in communities and require short distance transmission lines or cables.

Commercial timber harvesting is minimal in the region, although wood is harvested throughout the region for individual household fuel. Most of the villages are located adjacent to floodplains and likely obtain much of this fuel from floodplains. In addition, the largest and most productive *Picea glauca* are found on floodplains. Floodplains account for 80% of the commercial forests in other parts of Interior Alaska (Adams 1999).

Changes in moose, snowshoe hare and beaver populations all have significant effects on floodplain vegetation. For example, moose and snowshoe hares intensively use the *Salix* stage of succession on floodplains, sharply reducing the density of both *Salix* and *Populus balsamifera* (Kielland and Bryant 1998). Snowshoe hares are also a major cause of *Picea glauca* seedling mortality on floodplains (Walker and Chapin 1986, Viereck et al. 1993). Beaver also impact floodplain vegetation, felling large *Populus balsamifera* trees, consuming *Salix* spp., building dams that alter the local stream flow and flooding low lying areas.

Hunting and recreational fishing and remote lodges are common on floodplains. Rivers also function as transportation corridors for boats during the summer and fall, and for snowmachines during the winter and spring.

Predicted future 2060 human disturbance is minimal (Figure D-33) with floodplains remaining relatively intact and in good condition. The only major reduction in status is along the potential Kuskokwim Road south of McGrath, and the two proposed open-pit mines for the region: Pebble Mine and Donlin Creek Mine. Either mining project will potentially increase population size in the YKL REA. They may also alter stream channels and lake connectivity, remove or impair riparian vegetation and function, increase sedimentation to important aquatic habitats, and serve as vectors for invasive species importation. Both mines are potential sources of contamination on floodplains and in the river.
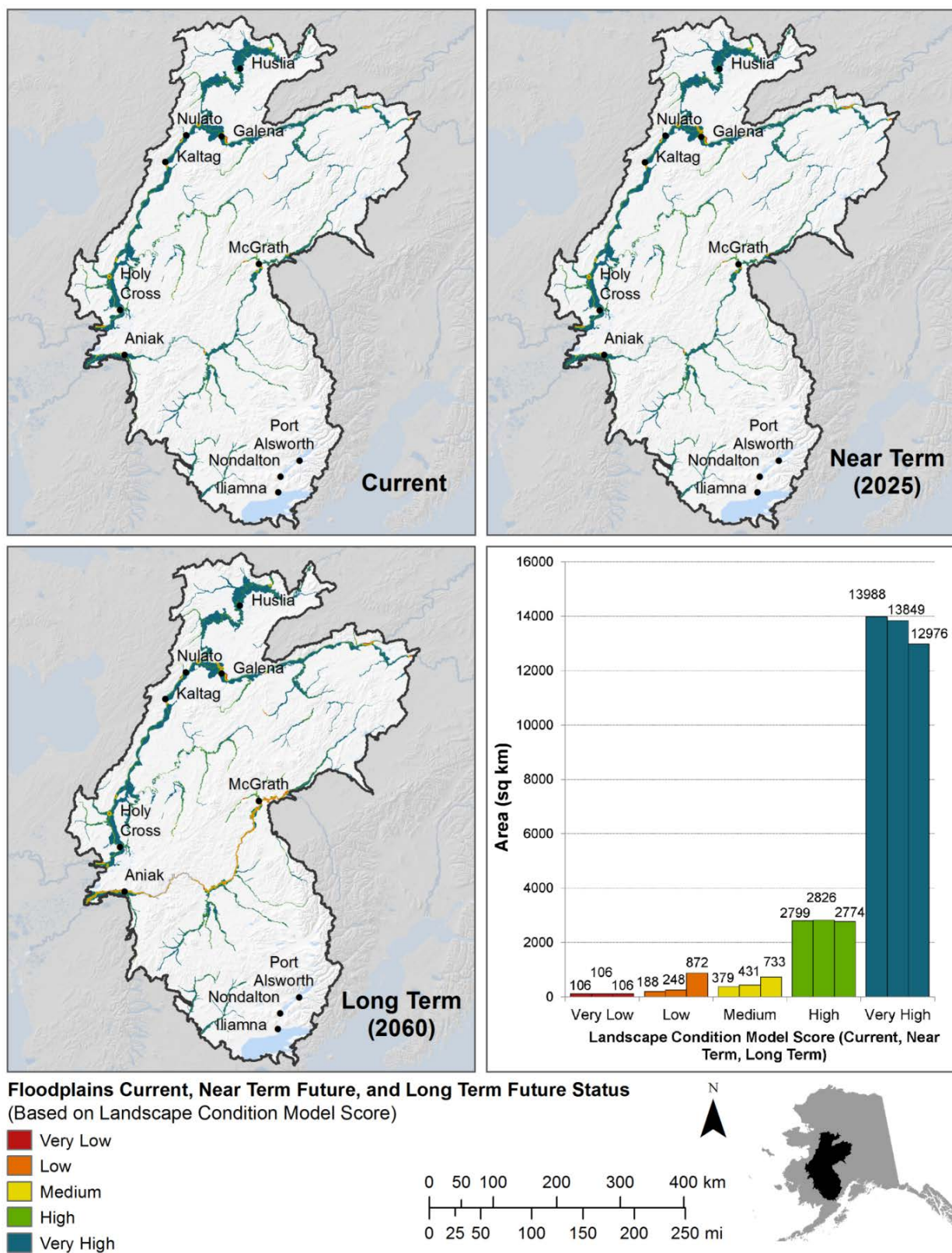
**Figure D-33.** Current, near-term (2025), and long-term (2060) status of floodplains (large) in the YKL study area.

## 1.11. Current Distribution of Vegetation Communities

The Vegetation Map and Classification – Northern, Western, and Interior Alaska (Boggs et al. 2012) used to develop the Terrestrial Coarse-Filter CEs was also used to address this MQ. Thirty-four vegetation classes cover the YKL project area. The full Users Guide (i.e. methods and results) and ArcGIS shape-files are all available at      http://aknhp.uaa.alaska.edu/ecology/vegetation-map-and-classification-northern-western-and-interior-alaska/. The percentage of each vegetation class within the YKL REA is given in Table D-11. White spruce and black spruce classes dominate (42%) the YKL REA. Next are the combined low shrub classes (12%), followed by the white spruce or black spruce-deciduous class (9%), then deciduous forest class (7%), then tall shrub (6%), and the remaining vegetated classes total 16%. Freshwater is only 4% of the YKL REA, and the bareground class is even less at 2% (Figure D-34).

| MQ 2 | What is the current distribution of vegetation communities? |
|------|------------------------------------------------------------|

**Legend**

**Vegetation Map of Northern, Western, and Interior Alaska**

Coarse Vegetation Class

- Bareground
- Deciduous Forest (Open-Closed)
- Dwarf Shrub
- Dwarf shrub-Lichen
- Fire Scar
- Freshwater or Saltwater
- Herbaceous (Aquatic)
- Herbaceous (Marsh) (Interior Alaska, Cook Inlet Basin)
- Herbaceous (Marsh) (Northern and Western Alaska)
- Herbaceous (Mesic) (Interior Alaska, Cook Inlet Basin)
- Herbaceous (Mesic) (Northern and Western Alaska)
- Herbaceous (Wet) (Interior Alaska, Cook Inlet Basin)
- Herbaceous (Wet) (Northern and Western Alaska)
- Herbaceous (Wet-Marsh) (Tidal) (Western Alaska, Cook Inlet Basin)

- Ice-Snow
- Lichen
- Low Shrub
- Low Shrub/Lichen
- Moss
- Sitka Spruce (Open-Closed)
- Sparse Vegetation (Interior Alaska, Cook Inlet Basin)
- Sparse Vegetation (Northern and Western Alaska)
- Tall Shrub (Open-Closed)
- Tussock Tundra (Low shrub or Herbaceous)
- Urban, Agriculture, Road
- White Spruce or Black Spruce (Open-Closed)
- White Spruce or Black Spruce (Woodland)
- White Spruce or Black Spruce (Woodland-Closed)
- White Spruce or Black Spruce-Deciduous (Open-Closed)
- White Spruce or Black Spruce/Lichen (Woodland-Open)

**Figure D-34.** Vegetation Map and Classification – Northern, Western, and Interior Alaska (Boggs et al. 2012) within the YKL study area.

**Table D-11.** Total area and percentage of each coarse-scale vegetation class within the YKL REA.

| Vegetation Class | Area (km$^2$) | Percent of Study Area |
|---|---|---|
| White Spruce or Black Spruce (Open-Closed) | 46528 | 20% |
| White Spruce or Black Spruce (Woodland) | 32168 | 14% |
| Low Shrub | 24986 | 11% |
| White Spruce or Black Spruce-Deciduous (Open-Closed) | 20917 | 9% |
| White Spruce or Black Spruce/Lichen (Woodland-Open) | 18106 | 8% |
| Deciduous Forest (Open-Closed) | 15736 | 7% |
| Tall Shrub (Open-Closed) | 13974 | 6% |
| Dwarf Shrub | 10133 | 4% |
| Freshwater or Saltwater | 8715 | 4% |
| Tussock Tundra (Low shrub or Herbaceous) | 6591 | 3% |
| Herbaceous (Wet) (Interior Alaska, Cook Inlet Basin) | 6474 | 3% |
| Dwarf shrub-Lichen | 5654 | 2% |
| Bareground | 5395 | 2% |
| Herbaceous (Mesic) (Interior Alaska, Cook Inlet Basin) | 3280 | 1% |
| Fire Scar | 2502 | 1% |
| Ice-Snow | 2107 | 1% |
| Low Shrub/Lichen | 1840 | 1% |
| Lichen | 1832 | 1% |
| White Spruce or Black Spruce (Woodland-Closed) | 1410 | 1% |
| Herbaceous (Mesic) (Northern and Western Alaska) | 806 | 0.3% |
| Herbaceous (Wet) (Northern and Western Alaska) | 658 | 0.3% |
| Sitka spruce (Open-Closed) | 431 | 0.2% |
| Moss | 237 | 0.1% |
| Herbaceous (Aquatic) | 128 | 0.1% |
| Herbaceous (Marsh) (Northern and Western Alaska) | 113 | 0.05% |
| Sparse Vegetation (Interior Alaska, Cook Inlet Basin) | 70 | 0.03% |
| Herbaceous (Marsh) (Interior Alaska, Cook Inlet Basin) | 44 | 0.02% |
| Sparse Vegetation (Northern and Western Alaska) | 22 | 0.01% |
| Urban, Agriculture, Road | 9 | 0.004% |
| Herbaceous (Wet-Marsh) | 3 | 0.001% |
| Herbaceous (Wet-Marsh) (Tidal) (Western Alaska, Cook Inlet Basin) | 0.03 | < .001% |

## 1.12. Applications

Prior to the start of the YKL REA, there was not a comprehensive vegetation map that provided enough detail to define Terrestrial Coarse-Filter CEs. During the project we developed the Vegetation Map and Classification – Northern, Western, and Interior Alaska (Boggs et al. 2012). In addition to the vegetation map's use in mapping the Terrestrial Coarse-Filter CES, it is a basic requirement for a variety of research and management needs such as:

- Developing insect and disease host layers (USDA State and Private Forestry).
- Developing ecosystem maps, ecosite maps, and ecological site type maps (NRCS).
- Spatially explicit landscape successional models (e.g. Biophysical Settings).
- Modeling animal and plant species distribution (USDI GAP Analysis Program).
- Predicting fire behavior (LANDFIRE Program).
- Biome climatic shift models.
- Providing reliable and consistent information for assessing the status, condition and trend of key natural resources.
- Help identify additional "Areas of Critical of Environmental Concern (ACEC)" and "Research Natural Areas (RNA)".

ACECs are special management areas designated by BLM to protect significant historic, cultural, or scenic values; fish and wildlife resources; natural process or systems; and/or natural hazards. RNAs are a network of federally administered protected public lands for the primary purposes of maintaining biological diversity, providing baseline ecological information, and encouraging research and university natural-history education. Additional BLM ACECs and RNAs should be identified based on the new information provided by the YKL REA and other data sources. New or updated information developed since ACEC's were first identified include a land cover map, list of rare ecosystems for Alaska, updated rare plant and animal information and distribution maps, and climate change threats to the ACECs.

This vegetation map also enabled us to delineate moose willow habitat, caribou lichen habitat and muskoxen habitat in the study area. This would not have been possible without the vegetation map.

The conceptual model and associated literature review also help to identify the possible relationships of the Terrestrial Coarse Filter CEs to the various CAs. Due to limited funding, we only described in detail the response of the Floodplain CE to the CAs. Specifically the potential vegetation response to climate induced changes in temperature, precipitation, fire, and permafrost. We also speculate on the rate of vegetation change, and how insects and disease and invasive species may respond. The conceptual models could also help direct future modeling efforts and aid in current and future management decision making.

## 1.13. Limitations

We could not provide accurate predictions of the CE response to climate change for all of the CEs except the Floodplain CE. Additional information needed to make accurate predictions include a soil survey map, improved vegetation map, plant association classification, and a vegetation succession map (NRCS Ecological Sites or Biophysical Settings, 2014). These are also basic ecological information needed by land management agencies such as the BLM, FWS and NPS to manage their lands.

Data recommendations for the YKL include:

- Vegetation succession map (Biophysical Setting, or Ecological Site)
- Ecological Site Descriptions or Ecotype map for region
- New map of existing vegetation using the statewide SPOT imagery
- Plant Association Classification
- Ground-based vegetation information (Inventory)

### Vegetation Succession Map (i.e. Biophysical Setting, or NRCS Ecological Site Descriptions)

For land managers, it is critical to understand vegetation succession. It allows land managers to understand how species and habitats change through time and space, to assess resource conditions, evaluate management options, address historical range of variation, productivity, habitat relationships and expected responses to management actions.

In Alaska, vegetation succession information has been developed and mapped through Ecological Site Descriptions (NRCS), a Biophysical Setting classification and, in Southeast Alaska, a habitat type classification in actively managed forests (Martin et al. 1995). NRCS Ecological Site Descriptions are comprehensive and linked to soils, but will likely take decades to develop for the entire REA. Developing a habitat type classification for the region is another option, but this classification is limited because it only provides descriptions of the late-successional vegetation (i.e. potential natural vegetation) for a region.

We, consequently, recommend improving the current Biophysical Setting classification for the YKL REA. A Biophysical Setting (BpS) represents the vegetation that dominates the landscape without human disturbance and is based on both current biophysical environment and a natural disturbance regime (LANDFIRE 2013). The "Forested Floodplain" CE described in this document is an example of an Alaskan BpS. Within a BpS, Plant Associations are typically used to describe the stages of succession and successional (i.e. state transition) models.

Another limitation to describing climate change is the rates of vegetation shift may also have a significant lag time in response to climate change. We, currently, do not understand this lag time for most of the CEs.

### Ecological Site Descriptions or Ecotype Map for Region

Ecological Site Descriptions associated with NRCS soil surveys are an important management tool for avoiding soil erosion and disturbance, developing best management practices and predicting vegetation response to disturbance. Ecological Site maps have been developed in only a few areas within the YKL. This data gap can be filled through either a NRCS Ecological Site Descriptions survey or, at a more general scale, the Ecotype approach (Jorgenson et al. 2009).

**New Map of Existing Vegetation Using the New Statewide SPOT Imagery**

A new map of existing vegetation should be developed using the new orthorectified pan-sharpened SPOT imagery (2.5 m pixel size) for the YKL REA. Most of the current Boggs et al. (2012) map is based on old imagery (2001 or older), some of the mosaicked maps have a poor accuracy assessment (Alaska BAER Earth Cover, LANDFIRE), much of the region has burned after the maps were developed, and there are also edge matching discontinuities between maps.

In addition, some important vegetation classes are not mapped. For example, *Picea glauca* and *Picea mariana* need to be mapped separately. The current maps collapse them into various "White spruce and Black spruce" vegetation classes. The separation into *Picea glauca* versus *Picea mariana* is needed because species composition is significantly different, and they respond differently to disturbances such as fire and blow-down.

**Plant Association Classification**

We recommend developing a plant association classification for the YKL REA. These classifications have only been described for a small area of the REA including Denali National Park and Preserve, and Katmai National Park and Preserve. Plant associations describes the vegetation present at a single point in time and are critical for understanding existing habitat conditions, are the basic units for describing succession and state transition models, and also for assessing resource conditions, and identifying monitoring or sampling sites. Plant Associations are the finest level of plant community classification in most "existing vegetation" classifications used in Alaska, such as The Alaska Vegetation Classification (Viereck et al. 1992), Alaska Arctic Tundra Vegetation Map (Raynolds et al. 2005), and the National Vegetation Classification System (Anderson et al. 1998).

**Ground-based Vegetation Information (Inventory)**

When making land use decisions about ground based activities it is imperative to know what plant species, habitats and soils are there. Most of the data for the YKL REA is based on remote sensed data (i.e. LandSat) and aerial plot data. Ground plots are rare and primarily collected on National Park lands or NRCS Ecological Site Surveys. Collecting ground-based vegetation information could be achieved by filling any of the following already described data gaps:

- Plant Associations
- Soil Survey or Ecotype map

## 1.14. Literature Cited

Adams, *P.* 1999. The dynamics of white spruce populations on a boreal river floodplain. Ph.D. Dissertation, Duke University, Durham, NC.

AKEPIC. 2012. Alaska Exotic Plant Information Clearinghouse Database. Alaska Natural Heritage Program, University of Alaska Anchorage.

Anderson, M., P. S. Bourgeron, M. T. Bryer, R. Crawford, L. Engelking, D. Faber-Langendoen, M. Gallyoun, K. Goodin, D. H. Grossman, S. Landaal, K. Metzler, K. D. Patterson, M. Pyne, M. Reid, L. Sneddon, and A. S. Weakley. 1998. International classification of ecological communities: Terrestrial vegetation of the United States. Volume II. The National Vegetation Classification System: List of types. The Nature Conservancy, Arlington, Virginia, USA.

Barney, R. J. 1971. Wildfires in Alaska – some historical and projected effects and aspects. *In*: Fire in the Northern Environment – a symposium. Fairbanks, Alaska. Pp. 51-59.

Berg, E. E., J. D. Henry, C. L. Fastie, A. D. De Volder, and S. M. Matsuoka. 2006. Spruce beetle outbreaks on the Kenai Peninsula, Alaska, and Kluane National Park and Reserve, Yukon Territory: Relationship to summer temperatures and regional differences in disturbance regimes. Forest Ecology and Management 227: 219-232.

Bernhardt, E. L., T.N. Hollingsworth, and F. S. Chapin III. 2011. Fire mediates climate-driven shifts in understory community composition of black spruce stands of interior Alaska. Journal of Vegetation Science 22:32-44.

Boggs, K., T. V. Boucher, T. T. Kuo, D. Fehringer, and S. Guyer. 2012. Vegetation map and classification: Northern, Western and Interior Alaska. Alaska Natural Heritage Program, University of Alaska Anchorage, Anchorage, Alaska. 88 Pp.

Boggs, K., and M. Sturdy. 2005. Plant associations and post-fire vegetation succession in Yukon-Charley Rivers National Preserve. Prepared for: National Park Service, Landcover Mapping Program, Alaska Support Office, Anchorage, Alaska. Alaska Natural Heritage Program, University of Alaska Anchorage, 707 A Street, Anchorage, AK 99501. 190 Pp.

Boggs, K., M. Sturdy, D. Rinella, and M. Rinella. 2008. White spruce regeneration following a major spruce beetle outbreak in forests on the Kenai Peninsula, Alaska. Forest Ecology and Management 255:3571-3579.

Boucher, T. V. 2003. Vegetation response to prescribed fire in the Kenai Mountains, Alaska. Research Paper PNW-RP-554. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 59 Pp.

Boucher, T., K. Boggs, B. Koltun, T. Kuo, J. McGrath, and C. Lindsay. 2012. Plant associations, vegetation succession, and earth cover classes: Aniakchak National Monument and Preserve. Natural Resource Technical Report NPS/ANIA/NRTR—2012/557. National Park Service, Fort Collins, Colorado.

Boucher, T. V., and L. A. Flagstad. *In Prep*. Alagnak Wild River: Landcover Classes and Plant Associations. Natural Resource Technical Report NPS/ALAG/NRTR—2014/XXX. National Park Service, Fort Collins, Colorado.

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

Chapin III, F.S., F., M. Oswood, K. Van Cleve, L. Viereck, and D. Verbyla. 2006. Alaska's Changing Boreal Forest. Oxford University Press. New York.

Conn, J., Z. Baer, N. Werdin-Pfisterer, and K. Mohrmann. 2007. Susceptibility of Alaska Plant Communities to Invasion by Bird Vetch (*Vicia cracca* L.). Committee for Noxious and Invasive Plant Management meeting, Alaska. http://www.uaf.edu/files/ces/cnipm/otherresources/8th_annual/Conn.pdf.

Cortés-Burns, H., and L. Flagstad. 2009. Invasive plant inventory and Bird Cherry control trials. Phase I: Non-native plants recorded along four Anchorage Municipality trail systems. Prepared for the Municipality of Anchorage and the Anchorage Parks Foundation. Alaska Natural Heritage Program, University of Alaska Anchorage, Anchorage, AK. 175 Pp.

Drury, W. 1956. Bog flats and physiographic processes in the upper Kuskokwin River region, Alaska. Contributions from the Gray Herbarium 178. 130 Pp.

Duchesne, L. C., and B. C. Hawkes. 2000. Fire in northern ecosystems. *In*: Brown, J. K. and J. K Smith (eds.) Wildland fire in ecosystems: effects of fire on flora. Gen. Tech. Rep. RMRS-GTR-42-vol 2. Ogdon, UT: USDA Forest Service, Rocky Mountain Research Station. 257 Pp.

Dyrness, C., and K. Van Cleve. 1993. Control of surface soil chemistry in early-successional floodplain soils along the Tanana River, interior Alaska. Canadian Journal of Forest Research 23: 979-994.

Flagstad, L., H. Cortés-Burns, and M. L. Carlson. *Submitted*. Demography, distribution, and reproduction of the non-native tree, *Prunus padus* in subarctic Alaska: Evidence for rapid recruitment.

Flagstad, L., H. Cortés-Burns, E. Johnson, L. Simpson, and A. Brownlee. 2010b. Viability of European bird cherry (*Prunus padus* L.) seed after two-year retention in traps along the Chester and Campbell Creek Trails, Anchorage, AK. Prepared for the Municipality of Anchorage. Alaska Natural Heritage Program, University of Alaska Anchorage, Anchorage, AK. 12 Pp.

Flagstad, L., H. Cortés-Burns, and T. Roberts. 2010a. Invasive plant inventory and Bird Cherry control trials. Phase II: Bird Cherry distribution, demography and reproduction biology along the Chester and Campbell Creek trails, Anchorage, Alaska. Prepared for the Municipality of Anchorage and the Anchorage Parks Foundation. Alaska Natural Heritage Program, University of Alaska Anchorage, Anchorage, AK. 61 Pp.

Flanagan, P., and K. Van Cleve. 1983. Nutrient cycling in relation to decomposition and organic matter quality in taiga forest ecosystems. Canadian Journal Forest Research 13: 795-817.

Foote, J. M. 1983a. Classification, description, and dynamics of plant communities after Upland White Spruce Interior PNV description, p.5 fire in the taiga of Interior Alaska. Res. Pap. PNW-307. Portland, OR. U.S. Department of Agriculture, Forest Service. Pacific Northwest Research Station. 108 Pp.

Foote, J. M. 1983b. Classification, description, and dynamics of plant communities after fire in the Taiga of Interior Alaska. Res. Pap. PNW-307. Portland, OR. U.S. Department of Agriculture, Forest Service. Pacific Northwest Research Station. 108 Pp.

Friedkin, J. 1972. A laboratory study of the meandering of alluvial rivers. *In*: Schumm, S., (ed.) River Morphology. Stroudsburg, PA: Dowden, Hutchinson, and Ross; Pp. 237-281.

Heinselman, M.L. 1981. Fire and succession in the conifer forests of northern North America. *In*: West, D. C., H. H. Shugart, and D. B. Botkin. Forest succession: concepts and application. Springer-Verlag, New York.

Holsten, E. H., 1984. Factors of susceptibility in spruce beetle attack on white spruce in Alaska. Journal of the Entomological Society of British Columbia 81: 39–45.

Johnstone, J. F., and F. Chapin. 2006. Effects of soil burn severity on post-fire tree recruitment in boreal forest. Ecosystems 9: 14-31.

Johnstone, J. F., T. N. Hollingsworth, F. S. Chapin, and M. C. Mack. 2010. Changes in fire regime break the black spruce legacy lock on successional trajectories in Alaskan Boreal forest. Global Change Biology 16: 1281-1295.

Johnstone, J. F., and E. S. Kasischke. 2005. Stand-level effects of soil burn severity on post-fire regeneration in a recently-burned black spruce forest. Canadian Journal of Forest Research 35: 2151-2163.

Jorgenson, M. T., J. E. Roth, M. D. Smith, S. Schlentner, W. Lentz and E. R. Pullman. 2001a. An ecological land survey for Fort Greely, Alaska. ERDC/CRREL TR-01-04. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH. 85 Pp.

Jorgenson, M. T., J. E. Roth, P. F. Miller, M. J. Macander, M. S. Duffy, A. F. Wells, G. V. Frost, and E. R. Pullman. 2009. An ecological land survey and landcover map of the Arctic Network. Natural Resource Technical Report NPS/ARCN/NRTR—2009/270. National Park Service, Fort Collins, Colorado.

Jorgenson, M. T., J. E. Roth, S. F. Schlentner, E. R. Pullman, and M. Macander. 2003. An ecological land survey for Fort Richardson, Alaska. ERDC/CRREL TR-03019. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, NH.

Kasischke, E. S., and J. F. Johnstone. 2005. Variation in ground-layer surface fuel consumption and its effects on site characteristics in a *Picea mariana* forest complex in Interior Alaska. Canadian Journal of Forest Research 35: 2164–2177.

Kielland, K., and J. Bryant. 1998. Moose herbivory in taiga: Effects on biogeochemistry and vegetation dynamics in primary succession. Oikos 82: 377–383.

LANDFIRE. 2013. Homepage of the LANDFIRE Project and Vegetation Produces. U.S. Department of Agriculture, Forest Service. www.landfire.gov. and www.landfire.gov/NationalProductDescriptions20.php.

Leopold, L., M. Wolman, and J. Miller. 1964. Fluvial processes in geomorphology. San Francisco, CA: Freeman and Company. 522 Pp.

Lindsey, A., R. Petty, D. Sterling, and W. VanAsdall. 1961. Vegetation and environment along the Wabash and Tippecanoe Rivers. Ecological Monographs 31: 105–156.

Mann, D., C. Fastie, E. Rowland, and N. Bigelow. 1995. Spruce succession, disturbance, and geomorphology on the Tanana River floodplain, Alaska. Ecoscience 2: 184–199.

Marion, G., K. Van Cleve, C. Dyrness, and C. Black. 1993. The soil chemical environment along a forest primary successional sequence on the Tanana River floodplain, interior Alaska. Canadian Journal of Forest Research 23: 914–922.

Martin, J. R., S. J. Trull, W. W. Brady, et al. 1995. Forest plant association management guide: Chatham Area, Tongass National Forest. Tech. Rep. R10-TP-5. Juneau, AK: U.S. Department of Agriculture, Forest Service, Alaska Region. 280 Pp.

McAvinchey, R. 1991. Winter herbivory by snowshoe hares and moose as a process affecting primary succession on an Alaskan floodplain. M.S. Thesis, University of Alaska Fairbanks.

Nawrocki, T., H. Klein, M. Carlson, L. Flagstad, J. Conn, R. DeVelice, A. Grant, G. Graziano, B. Million, and W. Rapp. 2011. Invasiveness Ranking of 50 Non-Native Plant Species for Alaska. Report prepared for the Alaska Association of Conservation Districts. Alaska Natural Heritage Program, University of Alaska Anchorage, Anchorage, AK. 253 Pp.

NRCS. 2014. Ecological Site Descriptions. U.S. Department of Agriculture. http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/ecoscience/desc/.

Oechel, W., and K. Van Cleve. 1986. The role of bryophytes in the Alaskan taiga. In: Van Cleve, K., F. Chapin III, P. Flanagan, L. Viereck, and C. Dyrness, (eds.) Forest Ecosystems in the Alaskan Taiga: A Synthesis of Structure and Function. Springer-Verlag, New York, New York, USA. Pp 121–137.

Osterkamp, T. E., L. Viereck, Y. Shur, M. T. Jorgenson, C. Racine, A. Doyle, and R. D. Boone. 2000. Observations of thermokarst and itsimpact on boreal forests in Alaska. Arctic, Antarctic, and Alpine Research 32: 303–315.

Payette, S. 1992. Fire as a controlling process in the North American boreal forest. In: Shugart, H. H.; Leemans, R; Bonan, G.B., (eds.). A systems analysis of the global boreal forest. New York: Cambridge University Press. 565 Pp.

Raynolds, M. K., D. A. Walker, and H. A. Maier. 2005. Plant community-level mapping of arctic Alaska based on the Circumpolar Arctic Vegetation Map. Phytocoenologia 35: 821–848.

Seefeldt, S.S., J.S. Conn, B. Jackson, and S. Sparrow. 2007. Control of bird vetch in Alaska. Western Society of Weed Science Meeting Proceedings. Available: http://www.ars.usda.gov/research/publications/publications.htm?SEQ_NO_115=207596.

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

Stevens, P., and T. Walker. 1970. The chronosequence concept and soil formation. Quarterly Review of Biology 45: 333–350.

Uliassi, D., K. Huss-Danell, R. Ruess, and K. Doran. 2000. Biomass allocation and nitrogenase activity in *Alnus tenuifolia*: responses to successional soil type and phosphorus availability. Ecoscience 7: 73–79.

Van Cleve, K., C. Dyrness, G. Marion, and R. Erickson. 1993. Control of soil development on the Tanana River floodplain of interior Alaska. Canadian Journal of Forest Research 23: 941–955.

Van Cleve, K., L. Oliver, R. Schlentner, L. Viereck, and C. Dyrness. 1983. Productivity and nutrient cycling in taiga forest ecosystems. Canadian Journal of Forest Research 13: 747–766.

Van Cleve, K., L. Viereck, and R. Schlentner. 1971. Accumulation of nitrogen in alder (*Alnus*) ecosystems near Fairbanks, Alaska. Arctic and Alpine Research 3: 101–114.

Viereck, L. 1970. Forest succession and soil development adjacent to the Chena River in interior Alaska. Arctic and Alpine Research 2: 1–26.

Viereck, L. A. 1973. Ecologic al effects of river flooding and forest fires on permafrost in the taiga of Alaska. *In:* Permafrost - The North American Contribution to the Second International Conference. National Academy of Sciences, Washington, DC. 60-67 Pp.

Viereck, L.A. 1975. Forest ecology of the Alaska Taiga. *In*: Proceedings of the circumpolar conference on northern ecology; 1975 September; Ottawa, ON. National Research Council of Canada: I-1 to I-22.

Viereck, L. A. 1979. Characteristics of treeline plant communities in Alaska. Holarctic Ecology 2: 228–238.

Viereck, L., Dryness, C., Batten A., and K. Wenzlick. 1992. The Alaska vegetation Classification. General Technical Report PNW-GTR-286. U.S. Forest Service, Pacific Northwest Research Station, Portland, Oregon.

Viereck, L., C. Dyrness, and M. Foote. 1993. An overview of the vegetation and soils of the floodplain ecosystems of the Tanana River, interior Alaska. Canadian Journal of Forest Research 23: 889–898.

Viereck, L., C. Dyrness, K. Van Cleve, and M. Foote. 1983. Vegetation, soils, and forest productivity in selected forest types in interior Alaska. Canadian Journal of Forest Research 13: 703–720.

Walker, L. 1989. Soil nitrogen changes during primary succession on a floodplain in Alaska, USA. Arctic and Alpine Research 21: 341–349.

Walker, L., and F. Chapin, III. 1986. Physiological controls over seedling growth in primary succession on an Alaskan flood plain. Ecology 67: 1508–1523.

Walker, L., J. Zasada, and F. Chapin, III. 1986. The role of life history processes in primary succession on an Alaskan floodplain. Ecology 67: 1243–1253.

Werner, R. A. 1996. Forest health in boreal ecosystems of Alaska. Forestry Chronicle 72: 43–46.

Yarie, J. 1993. Effects of selected forest management practices on environmental parameters related to successional development on the Tanana River floodplain, interior Alaska. Canadian Journal of Forest Research 23: 1001–1014.

Yarie, J., L. Viereck, K. Van Cleve, and P. Adams. 1998. Flooding and ecosystem dynamics along the Tanana River. BioScience 48: 690–695.

# 2. Terrestrial Fine-Filter Conservation Elements

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**Summary**

Section D-2. *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 region and potential impacts of CAs on these species.

## 2.1.   Introduction

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. Eight regionally important species were selected as Terrestrial Fine-Filter CEs for the YKL REA (Table D-12). The Terrestrial Fine-Filter CEs represent a variety of species of conservation concern and/or subsistence or ecological importance and were selected because they 1) were identified directly through management questions, 2) provided specific ecological services and/or functions identified in the ecoregional conceptual model, or 3) were suggested specifically by managers for their ecological significance.

**Table D-12.** Terrestrial Fine-Filter Conservation Elements (CEs) for the YKL REA.

| Terrestrial Fine-Filter CEs | Ecosystem Function |
|---|---|
| Moose (*Alces americanus*) | subsistence and prey resource, herbivory |
| Caribou (*Rangifer tarandus*) | subsistence and prey resource, herbivory, vegetation disturbance (trampling) |
| Muskox (*Ovibos moschatus*) | subsistence and prey resource, herbivory, vegetation disturbance (trampling) |
| North American beaver (*Castor canadensis*) | mechanical disturbance, major driver of hydrologic change on aquatic and riparian ecosystems |
| Gray wolf (*Canis lupus*) | predation (top level carnivore) |
| American peregrine falcon (*Falco peregrinus anatum*) | predation (large avian predator); also a BLM Sensitive Species |
| Trumpeter swan (*Cygnus buccinator*) | surrogate for condition and availability of freshwater resources; also a BLM Sensitive Species |
| Olive-sided flycatcher (*Contopus cooperi*) | insectivorous predator; also a boreal forest indicator species and BLM Sensitive Species |

## 2.2.   Methods

**Distribution Modeling**

The distribution of each of the eight Terrestrial Fine-Filter CEs was mapped and the potential change, caused by the individual Change Agents (CAs), was assessed. For each CE we assessed current status (2010), as well as forecasted changes in landscape status at two future time horizons: near-term (2025) and long-term (2060).

To model the distribution of the Terrestrial Fine-Filter CEs we obtained existing distribution models from the Alaska Gap Analysis Program (AKGAP; http://aknhp.uaa.alaska.edu/zoology/akgap). AKGAP models are spatial representations of a species predicted distribution, within known range limits, at 60 m pixel resolution. Models were produced through a combination of deductive and inductive modeling techniques to produce a final distribution model (Gotthardt et al. 2013). AKGAP models were assessed for accuracy and were also expert reviewed. Models were developed to depict the species distribution across its full range in Alaska. For this assessment, the AKGAP models were intersected with the REA boundary and the distribution model that fell within the boundary was extracted as the CE distribution model for this analysis. The statewide AKGAP models had an accuracy metric associated with them (AUC: area under the curve). Because the accuracy assessment of the AKGAP models utilized a pseudo-absence dataset that was stateside in scale, the assessment values for the individual models was not applicable to the extracted models from within the REA boundary. We did not run new accuracy statistics on the model extractions. Instead, we had the models for the eight Terrestrial Fine-Filter CEs reviewed by appropriate Tech Team members or outside experts familiar with each species and associated habitats in order to ascertain that the extracted models were suitable at the scale of the YKL REA. AKGAP models were considered acceptable for moose, American beaver, gray wolf, American peregrine falcon, trumpeter swan, and olive-sided flycatcher.

There were specific Management Questions (MQs) regarding the seasonal distribution of three ungulate species included in this assessment: moose, caribou, and muskox. Although the AKGAP models for these species were used to represent their "year-round" distribution, the MQs required more fine-scale modeling of seasonal use by each CE. Methods and results for distribution modeling, data inputs and geoprocessing steps of these three CEs are described within the specific MQ write-ups (MQs 6, 8, and 13). The contributing source datasets for Terrestrial Fine-Filter CEs are shown in Table D-13.

**Table D-13.** Data sources for the distribution of Terrestrial Fine-Filter CEs and related habitat.

| Conservation Element | Dataset Name | Source Agency |
|---|---|---|
| Moose | AKGAP final distribution model for moose | Alaska Gap Analysis Project |
|  | Alaska Habitat Management Guides series 1986 – moose seasonal distribution maps | Alaska Department of Fish and Game |
|  | Terrestrial coarse-filter CE distribution models | AKNHP - UAA |
|  | National Hydrography Dataset (NHD) flowlines | U.S. Geological Survey |
|  | Alaska Digital Elevation Model (DEM) | Statewide Digital Mapping Initiative (SDMI) |

| Conservation Element | Dataset Name | Source Agency |
|---|---|---|
| Caribou | AKGAP final distribution model for Caribou | Alaska Gap Analysis Project |
| | Western Arctic caribou herd seasonal range map | BLM |
| | Location data for Galena and Wolf Mountain herds | U.S. Fish and Wildlife Service, Alaska Department of Fish and Game |
| | Western Arctic caribou herd winter range (kernel analysis) | K. Joly, National Park Service |
| | Seasonal range map of all caribou herds in Alaska | Alaska Department of Fish and Game |
| | Alaska Habitat Management Guides series 1986 – caribou seasonal distribution maps | Alaska Department of Fish and Game |
| | Vegetation Map and Classification – Northern, Western, and Interior Alaska | AKNHP - UAA |
| | Alaska Fire Service's Large Fire Database | Alaska Interagency Coordination Center |
| Muskox | Gap analysis final distribution model for the Muskox | Alaska Gap Analysis Project |
| | Vegetation Map and Classification – Northern, Western, and Interior Alaska | AKNHP - UAA |
| | Large floodplain terrestrial coarse-filter CE | AKNHP - UAA |
| American beaver | AKGAP final distribution model for the American beaver | Alaska Gap Analysis Project |
| Gray Wolf | AKGAP final distribution model for the gray wolf | Alaska Gap Analysis Project |
| | Alaska Habitat Management Guides series 1986 – moose seasonal distribution maps | Alaska Department of Fish and Game |
| | Seasonal range polygons of all caribou herds in Alaska | Alaska Department of Fish and Game |
| Olive-sided flycatcher | AKGAP final distribution model for the Olive-sided Flycatcher | Alaska Gap Analysis Project |
| American peregrine falcon | Kuskokwim River Peregrine Falcon Breeding Pair Survey, 2008 | BLM |
| | Kuskokwim River Peregrine Falcon Breeding Pair Survey 2011 | BLM |
| | AKGAP final distribution model for the American Peregrine Falcon | Alaska Gap Analysis Project |
| Trumpeter swan | AKGAP final distribution model for the Trumpeter Swan | Alaska Gap Analysis Project |

**Core Analysis**

For each Terrestrial Fine-Filter CE (except muskox) the current, near- and long-term (2010, 2025, and 2060) potential for impacts by the individual CAs were evaluated. Muskoxen were not included in the core analysis, as their current range is only peripheral to the REA, and we did not feel that comparing such limited range to the CAs would produce meaningful results. These analyses are described spatially by comparing the distribution of each CE with CAs that included: temperature, precipitation, growing season length, permafrost, and fire.

The CE by 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. 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. Attributes are traits that are necessary for the survival and long-term viability of the CE, and indicators are the measureable aspects of the ecological attributes. 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 many attributes/indicators, categories were generalized based on the best available information, and include (but are not limited to):

- Poor – Fair – Good – Very Good – Unknown – None/NA
- Low/none – Moderate – High – Very High – Unknown
- Present – Absent – Unknown

In general, if we were able to establish a relationship in the literature for a particular attribute, and were then able to represent the indicator spatially, we intersected the CE specific distribution model with the indicator data layer, and attributed our outputs to quantify the level of impact on the CE (e.g., from poor to very good).

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. We did not include maps of all of the CA and CE overlays in this report, as it would be too lengthy. However, all GIS data are provided as a final product for the YKL REA and are available for future analyses. Additionally, we summarize many of the results from the CE-CA overlaps in tables throughout this section.

**Landscape Condition Model**

The overall "status" of each CE was assessed by intersecting the Landscape Condition Model (LCM) with the CE specific distribution model at current, near- (2025) and long-term (2060) time steps. In the long-term (2060) we present a hypothetical scenario of a road along the Kuskokwim River, which should be noted is a distant possibility based on the construction of a natural gas pipeline adjacent to the Kuskokwim River. The LCM is a way to measure the impact of the human footprint on a landscape. See the Landscape Integrity section (C) for a detailed description of methods.

## 2.3. Core Analysis Results

**Abiotic Change Agents**

The effects of abiotic CAs on fine-filter conservation elements are summarized below.

***Temperature and Growing Season Length***

In the next decade, little measurable change can be expected in habitats utilized by the Terrestrial Fine-Filter CEs, based solely on climate variables; however larger responses are predicted for 2060 (see Climate Change section B-1).  Between the current (2010) and the near-term (2025), some habitats are predicted to show a slight decrease (< 0°C) in July temperature, and about an equal number of sites show a slight increase (less than 1°C) (Table D-14). However, while some cooling is forecasted, it is likely a result of model insensitivity, and a direct result of the assumptions in the A2 Scenario (see Climate Change section B-1), and therefore unlikely that these changes are meaningful at the species or landscape level. However, by 2060, warming is expected to accelerate under the A2 scenario. Thus 97-100% of habitats utilized by the Fine-Filter CEs are expected to see summer temperatures greater than 1°C warmer than current averages (Table D-14). Similarly, growing season length, like July temperature, is not expected to see much change in the near term. In the longer term, however, growing season is expected to increase by at least a week for every habitat in the REA. For the Terrestrial Fine-Filter CEs, almost 70% of habitat is expected to see an increase of between one to two weeks in the growing season, with the exception of caribou calving grounds, where 58% of the area is expected to increase between one and two weeks, and 42% of the area will increase over two weeks (Table D-14).

**Table D-14.** Predicted change over the near-term (2025) 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 YKL study area.

| Terrestrial Fine-Filter CE | | Mean July Temperature Difference | | | Change in Length of Growing Season | | | |
|---|---|---|---|---|---|---|---|---|
| | | < 0°C | 0 - 0.999°C | ≥ 1°C | < 0 Days | 0 - 6 Days | 7 - 14 Days | > 14 Days |
| Trumpeter Swan | Near Term | 32% | 68% | -- | 33% | 67% | -- | -- |
| | Long Term | -- | 0% | 100% | -- | -- | 100% | 0% |
| American Beaver | Near Term | 52% | 48% | -- | 45% | 55% | -- | -- |
| | Long Term | -- | 1% | 99% | -- | -- | 80% | 20% |
| Olive-sided Flycatcher | Near Term | 46% | 54% | -- | 47% | 53% | -- | -- |
| | Long Term | -- | 1% | 99% | -- | -- | 88% | 12% |
| Peregrine Falcon | Near Term | 46% | 54% | -- | 31% | 69% | -- | -- |
| | Long Term | -- | 0% | 100% | -- | -- | 85% | 15% |
| Gray Wolf | Near Term | 46% | 54% | -- | 39% | 61% | -- | -- |
| | Long Term | -- | 0% | 100% | -- | -- | 86% | 14% |
| Caribou Calving Range | Near Term | 90% | 10% | -- | 78% | 22% | -- | -- |
| | Long Term | -- | 3% | 97% | -- | -- | 58% | 42% |
| Caribou Range (All Seasons) | Near Term | 59% | 41% | -- | 50% | 50% | -- | -- |
| | Long Term | -- | 1% | 99% | -- | -- | 78% | 22% |
| Lichen Habitat (Good and Moderate Quality) | Near Term | 74% | 26% | -- | 48% | 52% | -- | -- |
| | Long Term | -- | 3% | 97% | -- | -- | 71% | 29% |
| Moose | Near Term | 55% | 45% | -- | 48% | 52% | -- | -- |
| | Long Term | -- | 1% | 99% | -- | -- | 79% | 21% |
| Willow Habitat (Good and Moderate Quality) | Near Term | 61% | 39% | -- | 46% | 54% | -- | -- |
| | Long Term | -- | 1% | 99% | -- | -- | 73% | 27% |

*Precipitation*

In the next decade, projected changes in mean annual precipitation are slight, with most habitat areas seeing a change of less than 50 mm, and a small percentage experiencing an increase of 50-100 mm (Table D-15). As is noted in the Climate Change section of this report, annual precipitation varies regionally across the REA area, from a minimum of about 350 mm to a maximum of about 900 mm. Given that precipitation is so variable both spatially and temporally, model uncertainty is higher than it is for temperature variables, and the near-term change demonstrated here is likely to be insignificant in terms of clear impacts to the Terrestrial Fine-Filter CEs.

In the longer term, however, more marked increases in precipitation are expected, with most habitat areas experiencing an increase of 50-100 mm annually, and some areas experiencing an increase of over 100 mm – a relatively high percentage increase. Increases in precipitation of > 100 mm are expected to be the highest in lichen habitats (16%) and within the calving range of caribou (20%, all herds combined).

It should be noted that precipitation may be, overall, less important in terms of impacts to CEs than hydrologic change driven indirectly by climate, including snow-day fractions (discussed in Section B-1) and permafrost (Section B-2).

*Permafrost*

For the purposes of this analysis, "continuous permafrost" is defined as ground that has a temperature colder than -1°C at one meter depth (as projected by the SNAP/GIPL model in the Soil Thermal Dynamics section of this report). In the near term, a small but likely insignificant proportion of habitat (1-3%) is projected to shift across this threshold for the individual Fine-Filter CEs (Table D-15). However, by 2060, much more sweeping change is expected, with up to 1/3 of habitat thawing or partially thawing for some species, such as trumpeter swan and peregrine falcon (Table D-15). Note that these percentages refer to the entire habitat area, even if a portion of that area cannot thaw, since it is already permafrost-free.

**Table D-15.** Predicted change over the near-term (2025) and long-term (2060) in abiotic change agents, total annual precipitation and permafrost, within the distribution of the individual Terrestrial Fine-Filter CEs in the YKL ecoregion.

| Terrestrial Fine-Filter CE | | Total Annual Precipitation Difference | | | Continuous permafrost in 2010s that changes to discontinuous permafrost |
|---|---|---|---|---|---|
| | | ≤ 50 mm | 51 - 100 mm | > 100 mm | |
| Trumpeter Swan | Near Term | 100% | 0% | 0% | 3% |
| | Long Term | 24% | 76% | 0% | 33% |
| American Beaver | Near Term | 94% | 6% | 0% | 2% |
| | Long Term | 18% | 77% | 5% | 20% |
| Olive-sided Flycatcher | Near Term | 98% | 2% | 0% | 1% |
| | Long Term | 20% | 78% | 2% | 16% |
| Peregrine Falcon | Near Term | 100% | 0% | -- | 2% |
| | Long Term | 17% | 83% | 0% | 33% |
| Gray Wolf | Near Term | 93% | 7% | 0% | 1% |
| | Long Term | 7% | 86% | 6% | 29% |
| Caribou (Calving ) | Near Term | 79% | 21% | -- | 1% |
| | Long Term | 1% | 80% | 20% | 4% |
| Caribou (All Seasons) | Near Term | 89% | 11% | -- | 1% |
| | Long Term | 1% | 88% | 11% | 28% |
| Lichen (Good and moderate quality habitat) | Near Term | 83% | 16% | 1% | 1% |
| | Long Term | 3% | 82% | 16% | 10% |
| Moose | Near Term | 93% | 7% | 0% | 1% |
| | Long Term | 15% | 79% | 6% | 18% |
| Willow (good and moderate quality habitat) | Near Term | 93% | 7% | 0% | 1% |
| | Long Term | 10% | 83% | 7% | 19% |

*Fire*

As explained in the Fire section of this report (Section B-3), the change in fire return interval is best understood in terms of averages across broad regions (3rd-level HUCs) and refers only to forested habitats (Table D-16). The majority of total CE area for each Terrestrial Fine-Filter CE is expected to undergo a decrease in mean return interval of at least 25 years in both the near-term and long-term future. Wildfire is therefore expected to become a more frequent driver of change in wildlife habitat.

**Table D-16.** Predicted change over the near-term (2025) and long-term (2060) in fire return interval (abiotic change agent) within the distribution of the individual Terrestrial Fine-Filter CEs in the YKL ecoregion.

| Terrestrial Fine-Filter CE | | Mean Reduction in Fire Return Interval (Years) |
|---|---|---|
| Trumpeter Swan | Near Term | 36.3 (s = 4.6) |
| | Long Term | 32.1 (s = 7.2) |
| American Beaver | Near Term | 34.1 (s = 5.8) |
| | Long Term | 30.6 (s = 8.1) |
| Olive-sided Flycatcher | Near Term | 34.1 (s = 5.3) |
| | Long Term | 31.3 (s = 8.0) |
| Peregrine Falcon | Near Term | 34.5 (s = 5.8) |
| | Long Term | 30.8 (s = 7.8) |
| Gray Wolf | Near Term | 35.3 (s = 5.4) |
| | Long Term | 30.5 (s = 6.8) |
| Caribou (Calving) | Near Term | 32.0 (s = 5.9) |
| | Long Term | 29.7 (s = 7.7) |
| Caribou (All Seasons) | Near Term | 34.8 (s = 6.1) |
| | Long Term | 29.7 (s = 6.7) |
| Lichen (good and moderate quality habitat) | Near Term | 31.6 (s = 5.6) |
| | Long Term | 27.4 (s = 7.3) |
| Moose | Near Term | 33.7 (s = 5.8) |
| | Long Term | 30.2 (s = 8.1) |
| Willow (good and moderate quality habitat) | Near Term | 33.2 (s = 5.9) |
| | Long Term | 28.9 (s = 7.6) |

**Landscape Condition Model**

As was expected, most of the YKL study area is considered relatively pristine (very high condition), with intense impacts being more localized (see Landscape Integrity Section C). When the current distribution of the Terrestrial Fine-Filter CEs was compared to the LCM at current, near- (2025), and long- term (2060) time steps, over 85% of predicted habitat for all CEs was considered in very high condition, and ≥ 96% was considered high to very high at all time frames (Table D-17). When applicable, the ramifications of localized impact are discussed within the individual Terrestrial Fine-Filter CE sections, below.

**Table D-17.** Predicted change over the near-term (2025) and long-term (2060) in status based on the Landscape Condition Model, within the distribution of the individual Terrestrial Fine-Filter CEs in the YKL ecoregion.

| Terrestrial Fine-Filter CE | | Very Low | Low | Medium | High | Very High | Total Area (km²) |
|---|---|---|---|---|---|---|---|
| Trumpeter Swan | Current | 1% | 1% | 1% | 12% | 85% | |
| | Near term | 1% | 1% | 2% | 12% | 85% | 85,471 |
| | Long Term | 1% | 3% | 2% | 11% | 83% | |
| American Beaver | Current | -- | 1% | 1% | 4% | 94% | |
| | Near term | -- | 1% | 1% | 5% | 93% | 105,904 |
| | Long Term | -- | 2% | 2% | 5% | 92% | |
| Olive-sided Flycatcher | Current | 1% | 1% | 1% | 2% | 96% | |
| | Near term | 1% | 1% | 1% | 2% | 95% | 53,441 |
| | Long Term | 1% | 1% | 2% | 3% | 94% | |
| Peregrine Falcon | Current | -- | 1% | 2% | 4% | 94% | |
| | Near term | 1% | 1% | 2% | 4% | 92% | 77,999 |
| | Long Term | 1% | 3% | 4% | 5% | 88% | |
| Gray Wolf | Current | 1% | 1% | 1% | 4% | 93% | |
| | Near term | 1% | 1% | 2% | 5% | 92% | 139,467 |
| | Long Term | 1% | 2% | 2% | 5% | 90% | |
| Caribou (calving) | Current | -- | -- | -- | 2% | 97% | |
| | Near term | -- | -- | 1% | 2% | 97% | 104,884 |
| | Long Term | -- | -- | 1% | 2% | 97% | |
| Caribou (all seasons) | Current | -- | -- | 1% | 2% | 96% | |
| | Near term | -- | 1% | 1% | 2% | 96% | 17,653 |
| | Long Term | -- | 1% | 1% | 2% | 95% | |
| Moose | Current | -- | 1% | 1% | 3% | 95% | |
| | Near term | -- | 1% | 1% | 3% | 94% | 8,176 |
| | Long Term | -- | 1% | 2% | 3% | 93% | |

## 2.4.  Moose (*Alces americanus*)
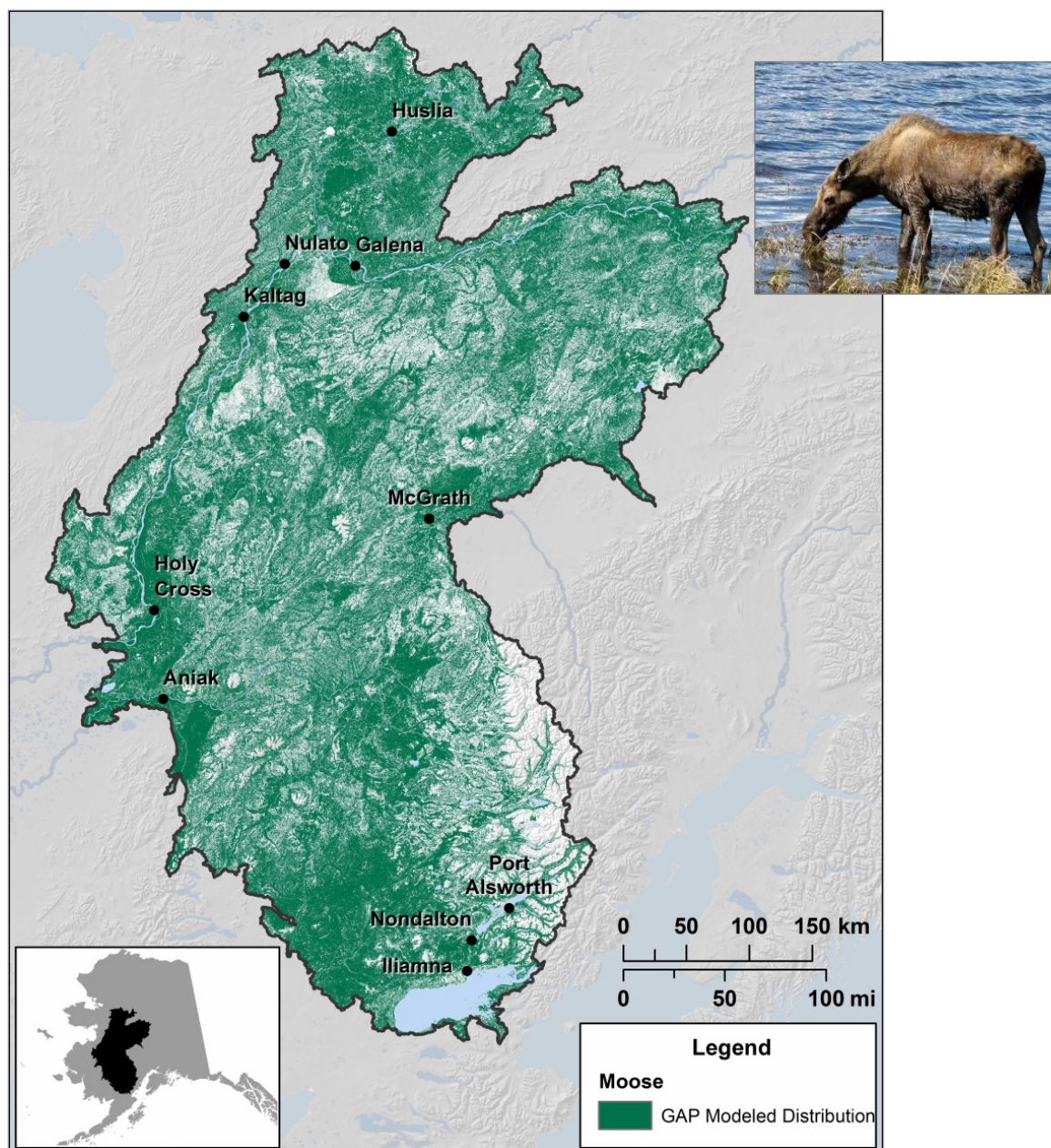


**Figure D-35.** Predicted current distribution of year-round moose habitat in the YKL study area (AKGAP 2013).

Moose occur in northern forests of North America, Europe, and Russia. In Alaska, moose are found in suitable habitats from the Stikine River in the southeastern Alaska to the Colville River on the Arctic Slope. They inhabit a variety of forest, shrub, and wetland habitats, and are most abundant in recently burned areas containing willow and birch shrubs, on timberline plateaus, and along major rivers (ADF&G 2013a; MacDonald and Cook 2009). Moose reside throughout the entire YKL study area, with the exception of the rugged peaks of the Alaska Range (Figure D-35).

Major factors that influence moose abundance in the region include: predation (wolves, black bears, and grizzly bears), severe weather, habitat availability, and hunting pressure (ADF&G 2013a; Crouse and Crouse 2008).

Predator control programs have been implemented in some locations where predation is thought to limit moose populations (Crouse and Crouse 2008).

Moose graze (feed on growing grasses and herbage) and browse (on twigs, leaves, and tree shoots), and their diet varies between seasons depending on availability of suitable forage. In some areas, moose populations are limited by the quality and quantity of food resources, particularly in the winter when snow depth limits access of browsing activity (Coady 1974; Ballard et al. 1991).

As a large-bodied herbivore, moose are able to alter the environment through their presence and resource utilization. These alterations, such as browsing and trampling, can be viewed as disturbances upon the landscape. Such disturbances can affect many elements of the landscape, including the species composition, canopy structure, rate of succession, soil parameters, fungal interactions, and biogeochemistry (Persson et al 2000).

## Current population, management and harvest status in the YKL study area

Moose are managed as a game species by the Alaska Department of Fish and Game (ADF&G 2010). Game Management Units that fall within the YKL study area include 9B, 17, 19 (all subunits), 21 (all subunits), and 24D (**Figure D-36**). Moose population sizes (and densities) are higher in the northern part of the YKL study area in GMUs 19D and 21, where they range from about 1,000 animals to 9,000 animals (Table D-18). Population trends in the southern part of the study area are stable to increasing. In the central and northern sections of the REA, population trends are more highly variable.
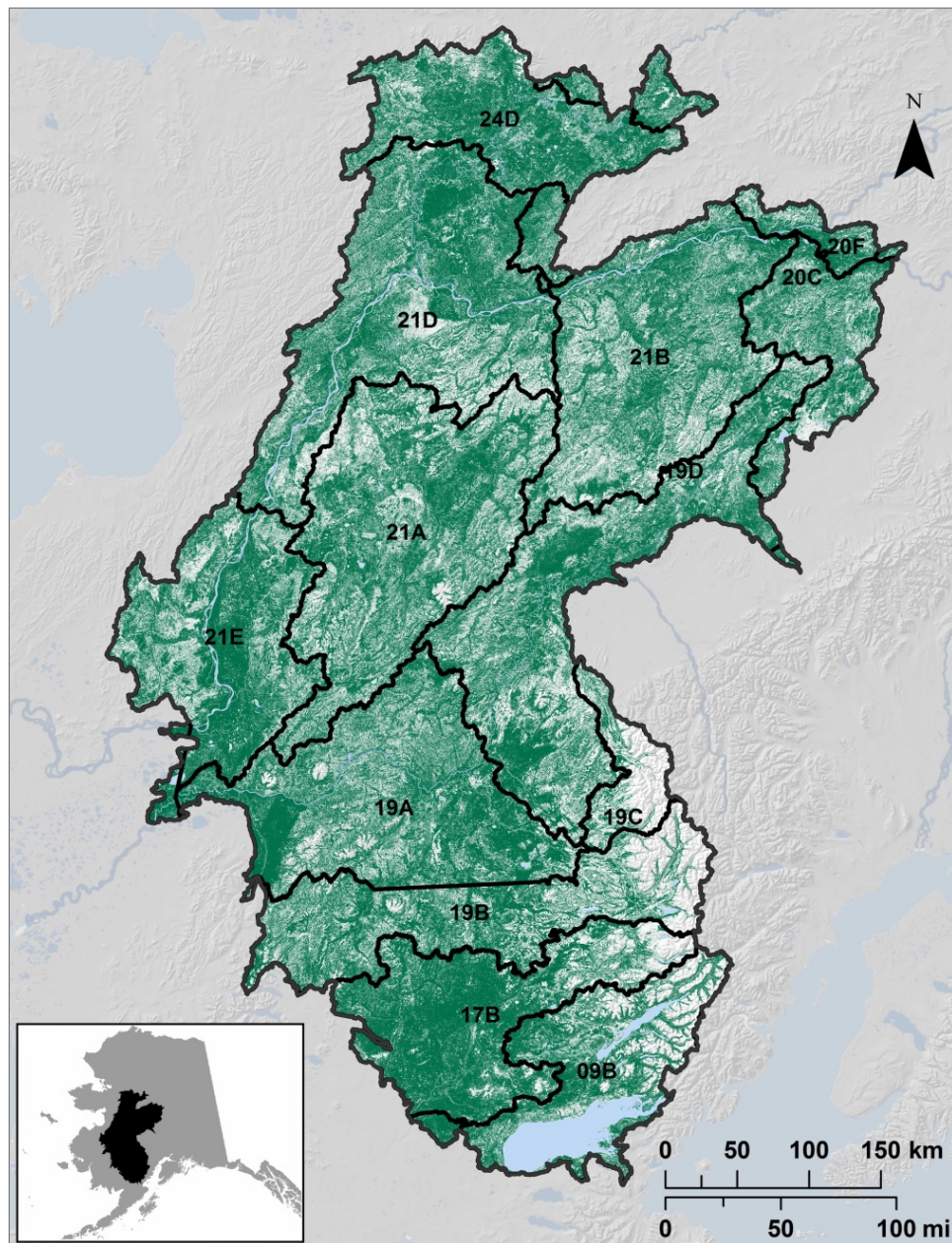
**Figure D-36.** Alaska Department of Fish and Game, Game Management Units (GMUs) within the YKL study area, overlaid on the moose habitat distribution model. The distribution model indicates predicted presence or absence of suitable habitat and is not representative of population density.

**Table D-18.** Summary of moose population trend, population size, and density (observable moose/mi$^2$) by ADF&G Game Management Units (GMU) within the YKL study area. Adapted from ADF&G 2010.

| Geographic description | GMU | Population Trend | Population Size | Density (observable moose/mi²) |
|---|---|---|---|---|
| Alaska Peninsula | 9B | stable (past 28 years) | 2,000 | Not reported |
| Northern Bristol Bay | 17B | stable to declining | 2,800-3,500 | Not reported |
| All Kuskokwim River drainages upstream from Lower Kalskag | 19A* | no trend | 1,703 | 0.44 |
| | 19B | no trend | Unknown; suspected similar to 19A | Not reported |
| All Kuskokwim River drainages upstream from Lower Kalskag | 19C | suspected stable | unknown | Not reported |
| | 19D* | increasing | 5,280 | 1.6 |
| Innoko River drainage upstream from Iditarod River | 21A | suspected declining | 4,300 – 6,480 | 0.4 – 0.6 |
| Nowitna River drainage east of Poorman Rd. | 21B | declining | 2,317 | 0.27 |
| Meloztina River above Grayling Creek | 21C | declining | 900 – 1,300 | 0.25 – 0.35 |
| Yukon River drainage from Blackburn to Ruby and Koyukuk drainage | 21D | declining | 8,103 | 1.4 |
| Yukon River drainage from Paimiut upstream | 21E | stable | 6,205, –8,747 | 1.2 |
| Koyukuk River lowlands | 24D | stable | 4,365 | 2.9 – 4.9 |
| * indicates intensive management in the unit. | | | | |

**Conceptual Model**

The conceptual model below (Figure D-37) is based on literature review and describes the relationship between the various change agents and natural drivers for moose. The boxes and arrows represent the state of knowledge about moose and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and moose. Change agents selected for this REA and considered in this analysis include: Insects and disease, Climate change, Wildland fire, Invasive species, Land use change (i.e. human development), and Harvest pressure.
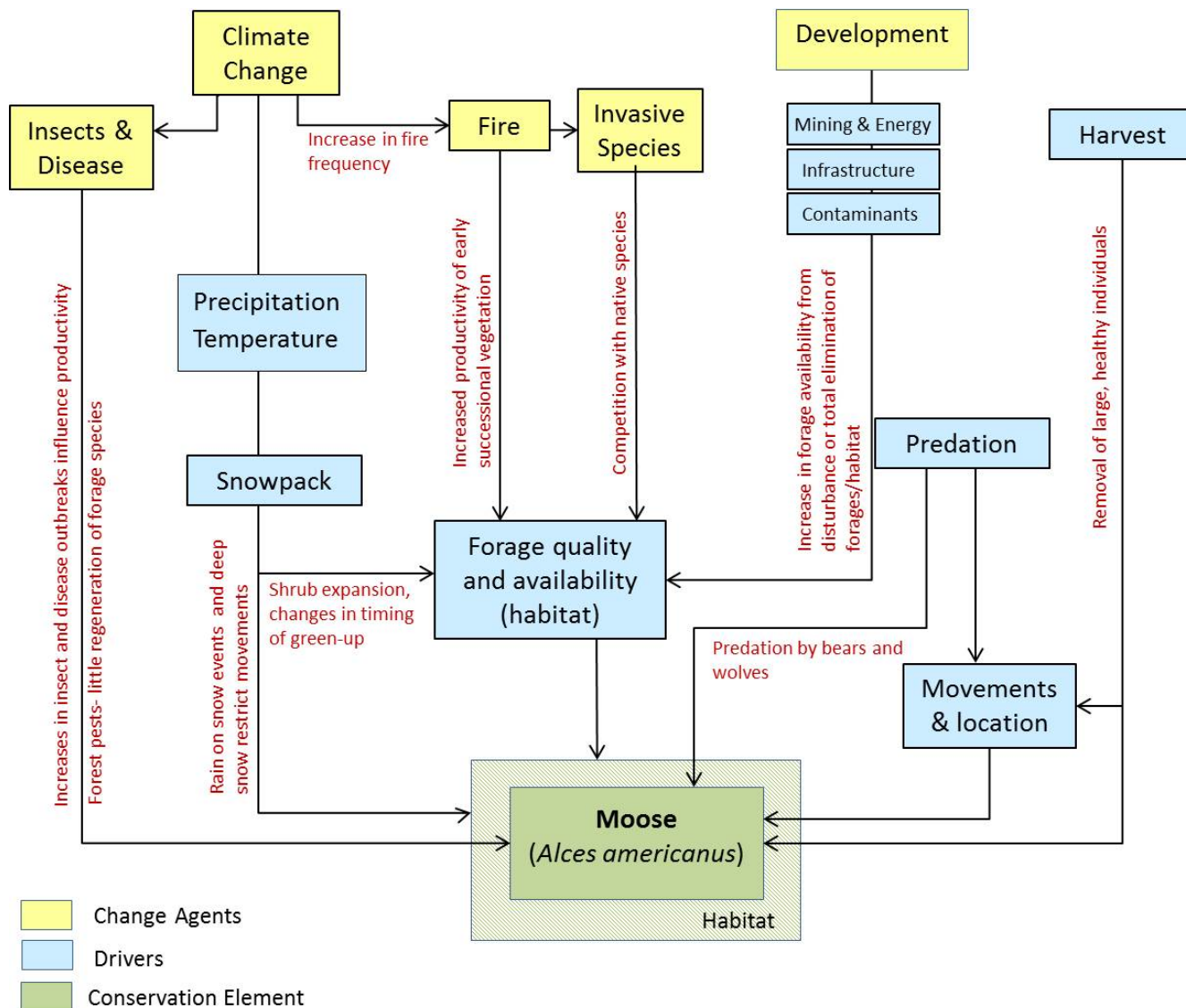
**Figure D-37.** Moose (*Alces americanus*) conceptual model.

## Current Seasonal Distribution of Moose

| MQ 6 | What is the current seasonal distribution of moose in the region? |
|---|---|

While moose are nearly ubiquitous throughout the study area, they do concentrate in specific regions seasonally. The GAP model provided (**Figure D-35**) does not include any element of seasonality or concentration. Here, we provide a synopsis of seasonal concentration areas of moose based on the Alaska Habitat Management Guides series (1986) and expert review.

*Methods*

To our knowledge, existing seasonal distribution maps for moose across the YKL study area were not available in digital format. However, paper maps of seasonal distribution by moose across the study are presented in the Alaska Habitat Management Guides series (1986). These paper maps represent a synthesis of information on select wildlife species collected from agency biologists, all of which were peer/expert reviewed. Although these maps were produced in 1986, the consensus from biologists in the region (Tom Paragi, Glenn Stout, James Woolington, ADF&G, pers. comm.) was that the atlas maps are likely still applicable under current conditions, as habitat conditions across the region have not changed significantly since the late 1980s when the atlas was produced. The Habitat Management Guides were scanned to pdf and are publically available at http://www.arlis.org/docs/vol1/C/AHMG/.

Using ArcGIS, we imported the scanned distribution maps for moose from the Habitat Management Guides and then heads-up digitized (i.e. traced) them to produce a unique spatial data layer for each distinct season. In sum, we produced three independent range maps that captured known seasonal movements and concentration areas for moose within the YKL study area. These included known calving concentration areas (spring), known rutting concentration areas (autumn), and known winter concentration areas (adapted from the Alaska Habitat Management Guides 1986) (Figure D-38 A, B, and C). These seasonal range maps are coarse-scale representations of areas where animals are known to concentrate in higher densities during calving, rutting, and winter, than during summer when forage is more widely abundant and animals are generally dispersed. These concentration areas likley represent the most suitable habitats for moose within the REA based on forage availibility and quality, and winter snow depths (when applicable); however, these covariates were not included in our mapping effort. Instead, these maps rely heavily on expert opinion and and generalized observations. Moose may also occur outside the mapped areas during any season, but likely at lower densities.

*Results*

During calving, rutting, and winter, moose are generally found concentrated around riparian areas (Figure D-38 A, B, and C). According to ADF&G management reports, the majority of radio-collared animals within Game Management Units 17, 19, 21, and 24 are generally non-migratory, which is supported by the substantial overlap in seasonal range maps (Figure D-38 A, B, and C). However, occasionally, some radio-collared animals have been observed making large-scale movements throughout the year or between seasons (ADF&G 2010).

In the Nowitna River Drainange (21B), most cows spend the summer months around open grass and shrub meadows on the floodplain, but away from the river. In October, animals move to riparian areas, where they remain until early May. In the Innoko River Drainage (21A and E), about half of radio-collared animals spent the entire year in the lowlands, while the remaining animals spent winters in the lowlands and summers in the mountains. In Northern Bristol Bay (GMU 17), much of the unit is wet or alpine tundra, and moose are located prediminantly in riparian areas thoughout the year (ADF&G 2010). Further north in GMU 24, moose appear to occupy broad riparian habitats year-round, with short seasonal migrations (ADF&G 2010).
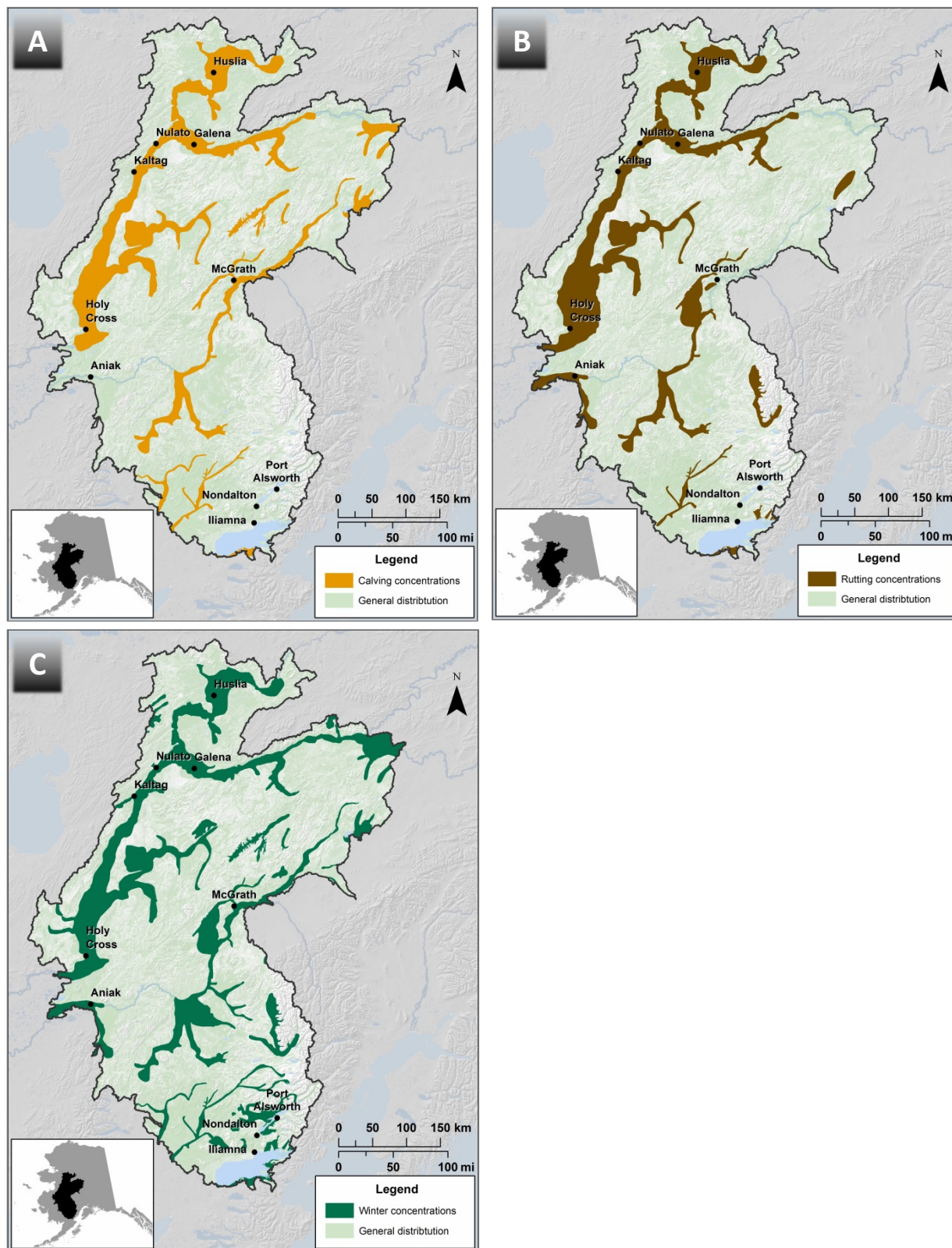
**Figure D-38.** Seasonal distribution of moose within the YKL study area during (A) calving, (B) rutting, and (C) winter.

**Distribution of Primary Winter Forage for Moose**

| MQ 7 | What is the current distribution of primary winter forage (willow) for moose in the region, and how is that expected to change? |
|------|------|

During winter, moose forage primarily on willow species (Risenhoover 1989) and are associated with areas of high willow concentration (Stephenson 2006). The distribution of primary winter forage for moose is assessed here based on the distribution of several Terrestrial Coarse-Filter CEs and the streams Aquatic Coarse-Filter CE.

*Methods*

To identify the current distribution of willow habitat in the YKL study area, we used spatial data layers from the floodplain, tall shrub (open-closed), and low shrub Terrestrial Coarse-Filter CE distribution models (see the Terrestrial Coarse-Filter CE Section D-1 for description of classes), the National Hydrography Dataset (NHD) flowlines, and the Alaska Digital Elevation Model (DEM).

Ideally we would have extracted willow classes directly from existing vegetation maps; however, existing vegetation maps for the YKL study area did not delineate willow habitat as a unique vegetation class (see the Terrestrial Coarse-Filter CE section). Instead, willow was included in more general habitat classes such as tall shrub and low shrub. Consequently, we extracted all vegetation classes that were willow dominated and described their individual forage value/quality to moose.

Because tall shrub and low shrub encompass more than just willow vegetation, we described these categories as "moderate" forage quality, while floodplains and riparian areas, which are dominated by tall and low willow (see the Terrestrial Coarse-Filter CE section), were described as "good" forage quality (Table D-19). We selected the floodplain Coarse-Filter CE to delineate large floodplains, as they are known to be willow dominated, and we used the NHD flowlines to delineate the small floodplains along streams and river banks. We removed high elevation floodplains (using treeline as the upper elevation bound) from both the large and small floodplains areas, as moose are generally not associated with high elevations during winter.

**Table D-19.** Categories used to delineate areas of willow and their forage quality.

| Categories | Forage Quality |
|------------|----------------|
| Tall Shrub | Moderate |
| Low Shrub | Moderate |
| Floodplain | Good |
| Streams and River Banks | Good |
| All other classes | Poor |

We used cliome projections (see Cliomes section B-1.3) to evaluate future willow habitat using the tall shrub and low shrub Terrestrial Coarse-Filter CE classes. We assessed how these categories might increase or decrease across the entire YKL study area. Since floodplains are restricted to areas with streams or rivers, we did not use the cliomes to predict potential movement based on changes in the climate. In order to understand the link

between river and stream systems with future climate we would need a better understanding of climate and its interaction with the hydrologic system, erosion, and sedimentation.

### Results

Figure D-39 delineates habitat classes identified as 'moderate' or 'good' willow habitat in the YKL study area. Combined, these classes cover approximately 27% of the study area (Figure D-40). As expected, 'good' willow habitat is associated with large riparian areas while the 'moderate' willow habitat is dispersed throughout the region.
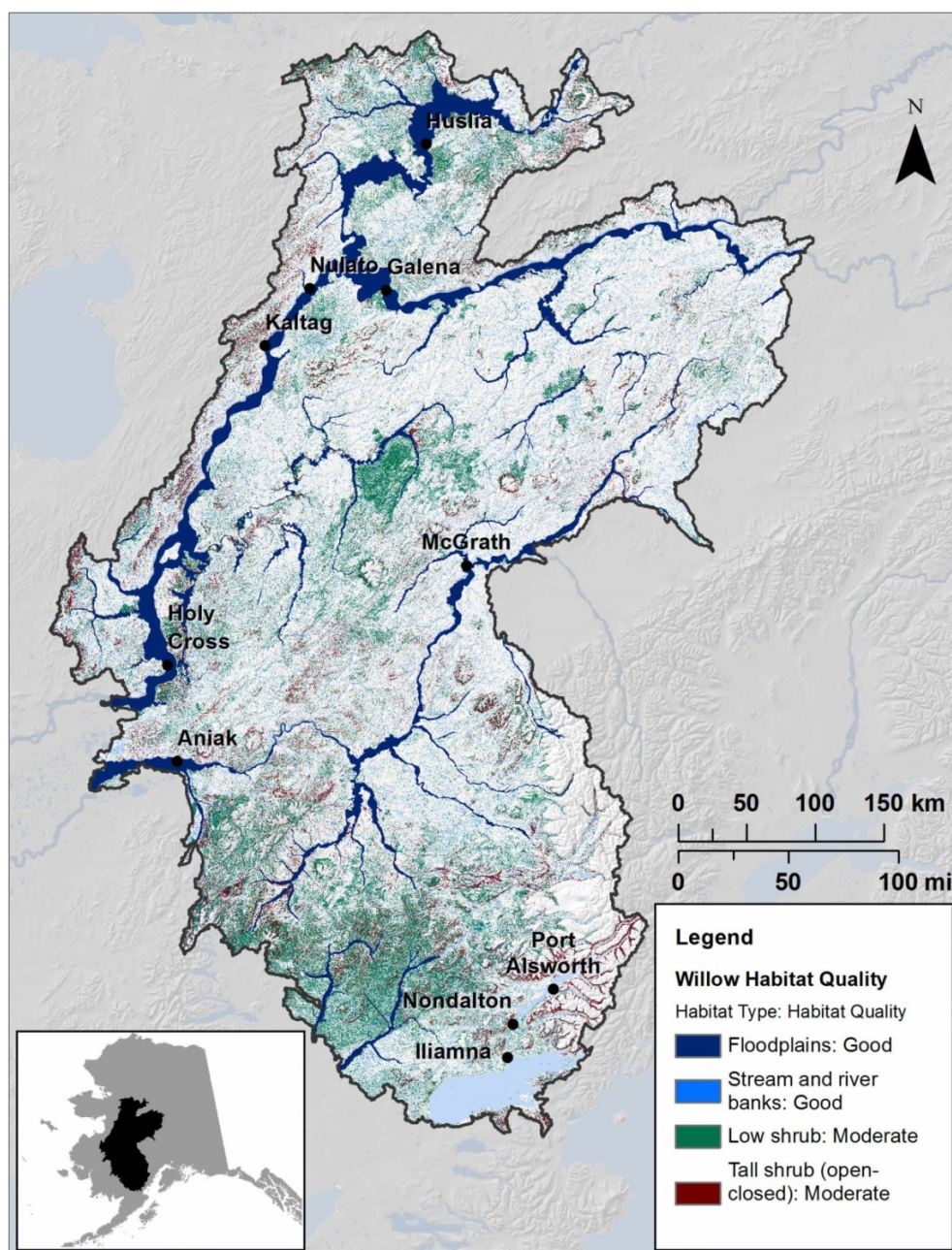


**Figure D-39.** Current distribution of vegetation classes and ecosystems that support willow.
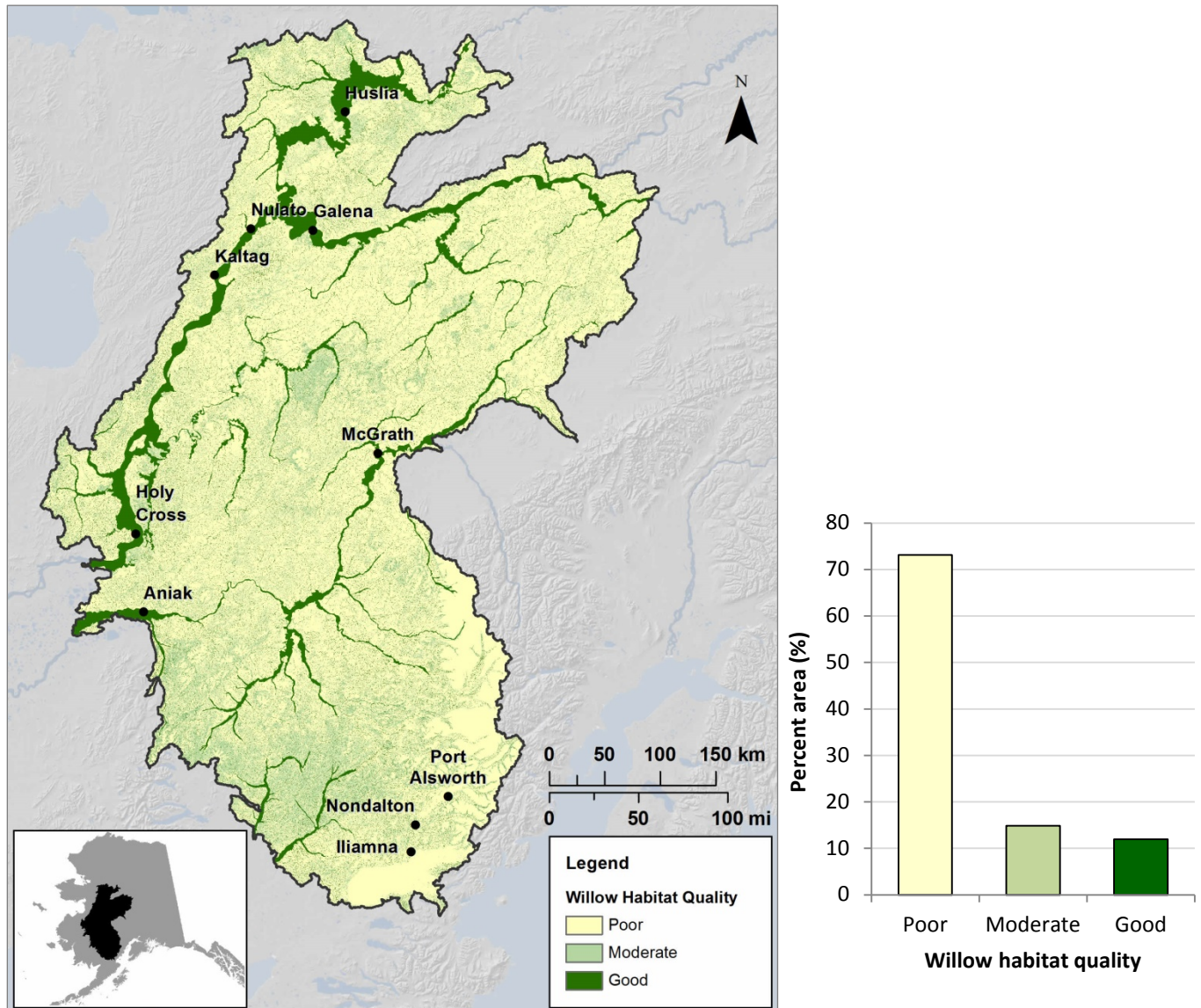
**Figure D-40.** Moose primary winter forage (willow) modeled as relative habitat quality (good, moderate, poor) in the YKL study area.

## Climate

Growing season length, rain on snow events and snow depth can affect the accessibility of moose forage and moose survivability. Climate change is expected to alter each of these factors, which will have implications for moose in the YKL study area.

Growing season length is expected to increase in the long-term (2060) as temperatures warm. For moderate to high quality moose browse (willow/alder shrubs), over 70% of this habitat is expected to see an increase of between one to two weeks in the growing season (Figure D-41). In the YKL study area, increases in growing season length will be most pronounced in the southern part of the region, around Iliamna Lake (ADF&G GMUs

17B and 9B), where growing season is projected to increase by > 20 days by 2050 (Figure D-41). Benefits to moose would include earlier access to preferred forages and potential increases in habitat as shrubs expand.
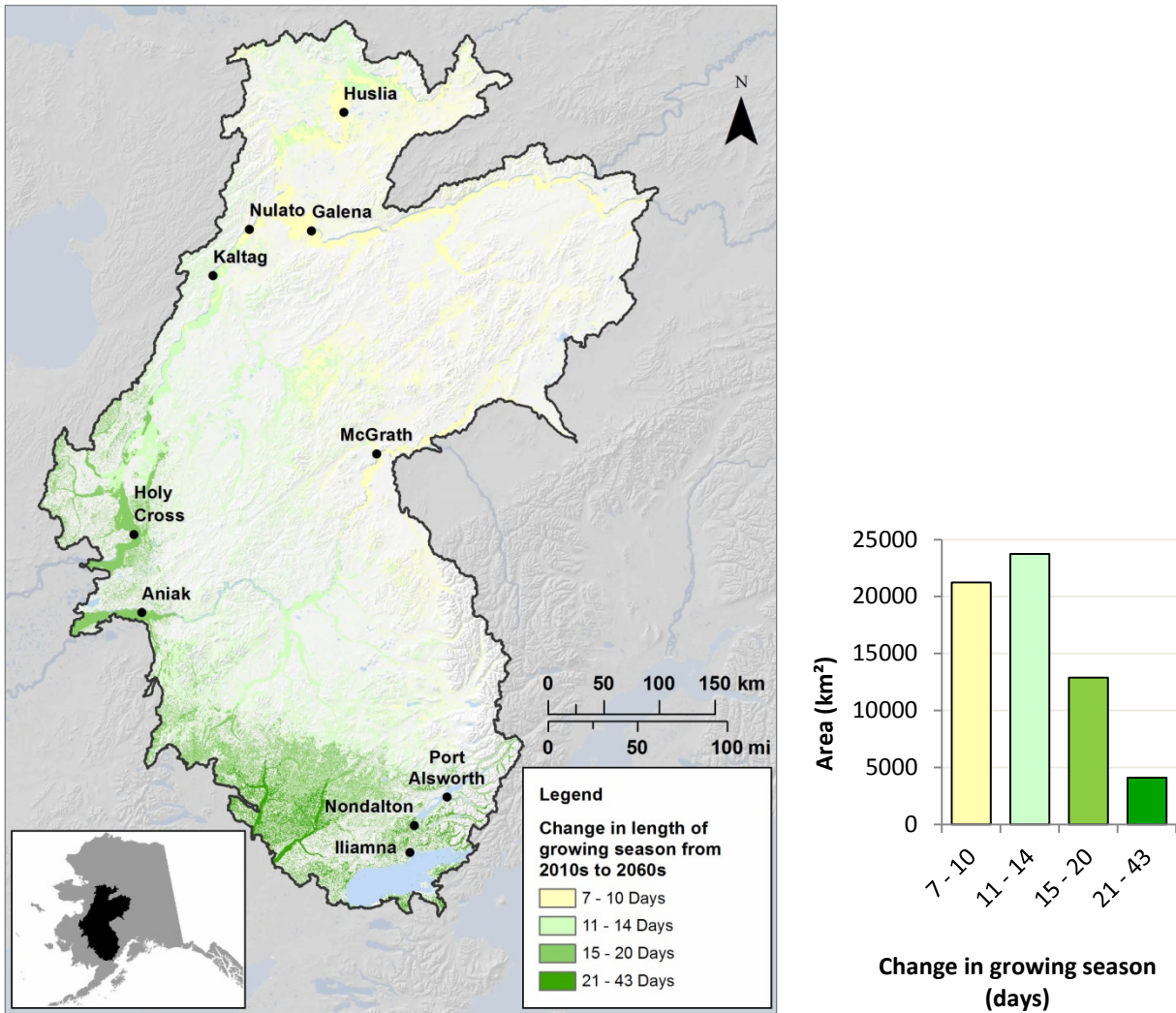


**Figure D-41.** Projected increase in growing season length for combined 'moderate' and 'good' moose forage habitat (see Figure D-40) in the YKL study area.

Rain-on-snow events, which are predicted to increase with climate change (see Climate section B-1), form a hard crust on top of the snow which may also restrict movements (Putkonen and Roe 2003). For this analysis, we used snow day fraction as a proxy for rain on snow (icing) events. Snow day fraction refers to the estimated percentage of days which precipitation would occur as snow as opposed to rain.

More than 90% of precipitation is currently likely to fall as snow for all months from November through March, throughout a majority of the study area (see Section B-1). To the south, around Iliamna however, this percentage is as low as 50% in November. Even in January, the coldest month, the snow-fraction in this region ranges from about 70-90%, meaning that as much as 30% of January precipitation falls as rain at some sites. In the near-term, some shifts are expected, such as November snow-fraction around Iliamna dropping clearly below 50%, and May precipitation around Galena dropping from 10-20% snow to less than 10%. In the more

distant future (2060), more marked changes are expected. This increase in rain-on-snow events will likely affect moose forage access and movement within the YKL study area.

Deep snow also limits moose movements and access to food resources (Coady 1974). Moose typically move to lower elevations in the winter, and in severe winters have to balance the trade-off between snow depth and browse availability (Ballard et al. 1991; Stephenson et al. 2006). Unfortunately, we did not have a suitable snow-depth layer for the REA to examine the relationship of deep snow and the distribution of moose. As such, this remains a large data gap. While winter precipitation is projected to increase (see Climate section B-1), changes in the percentage of precipitation falling as rain versus snow and changes in the density, drifting, packing, and sublimation of snowpack make predictions complex.

**Fire**

Fire frequency will likely increase for the YKL study area in both the near-term and long-term future (see Table D-16). Since fire promotes the re-sprouting and re-seeding of deciduous hardwoods, such as aspen, willow, and birch, which provide winter forage for moose, we expect to see an increase of moderate to good moose forage. In addition, some studies have found that the nutritional quality (protein, calcium, magnesium, and potassium) of the woody content of forages increases immediately after the burn (MacCraken and Viereck 1990, Oldemeyer et al. 1997). However, the rate of regeneration of forages is variable and depends on the burn severity (Nelson et al. 2008). According to some research, habitat is optimal approximately 10 to 26 years post burn when early successional vegetation is still present (Spencer and Hakala 1964, Kelsall et al. 1977, Gasaway et al. 1989, Loranger et al. 1991, Maier et al. 2005, Nelson et al. 2008).

**Insects and Disease**

Insects that harass animals and transmit disease agents may benefit from climate change. Host species that are already physiologically and energetically stressed from other changes agents (as a result of other factors of climate change) will likely be more vulnerable to disease agents (Bradley et al. 2005). See MQ #13 for a detailed discussion of specific types and potential impacts of diseases to moose populations.

In addition, forest pest infestations may affect food availability for moose as defoliating insects eat the leaves or needles of forest trees (USDA 2013). Defoliator outbreaks tend to be cyclic and closely tied to weather conditions with outbreaks of some species occurring after warmer than normal summer temperatures (Haynes et al. 2014).

**Invasive Species**

Invasive species are currently limited in distribution and abundance on the YKL landscape, yet these species have the potential to expand in several habitats and compete with native shrubs that could have negative impacts on moose. For example, white sweetclover (*Melilotus albus*), which is present in the YKL study area has been found to reduce native seed recruitment and growth on river bars in Interior Alaska and lower willow survivorship (Spellman and Wurtz 2011); the establishment of this species therefore could alter successional trajectories and forage quality. Floodplain habitats are projected to be most susceptible to impacts from this species.

Bird cherries (*Prunus padus* and *P. virginiana*) are known to have been the cause of fatal moose poisoning in Alaska (Woodford et al. 2011, UAF Extension Service 2013) and are established in the McGrath area. Further, these species are establishing rapidly in deciduous and mixed deciduous forests in southcentral Alaska and may result in significant alterations to forest composition and impacts to stream ecology (Flagstad et al. 2010a, 2010b, Roon 2011, Flagstad et al. in prep.). Areas most proximal to, and downstream of, human population centers are expected to have the highest probabilities of seeing increases in non-native plant establishment. See Invasive Species section B-4 and Terrestrial Coarse-Filter section D-1.10 for more discussion.

## Current Status and Future Landscape Condition

The intersection of the moderate to high quality winter forage with the Landscape Condition Model (LCM) indicates that the majority of floodplain and tall shrub habitat in the YKL study area is classified as being in very high (intact) condition (Figure D-42). Long-term projections (2060) of landscape condition suggest a slight decrease in very high quality condition and a slight increase in low condition, particularly around the villages of Galena and McGrath, and along the entire Kuskokwim River, which are also areas where moose are currently subject to high harvest pressure and intensive management. The anticipated lower condition in these areas is a result of increases in the human footprint, driven primarily by potential road construction and mining activity. In addition, increased hunter access via the potential Kuskokwim Road (indicated as poor landscape condition for the long term; Figure D-42) could increase hunting pressure on moose in the surrounding area.
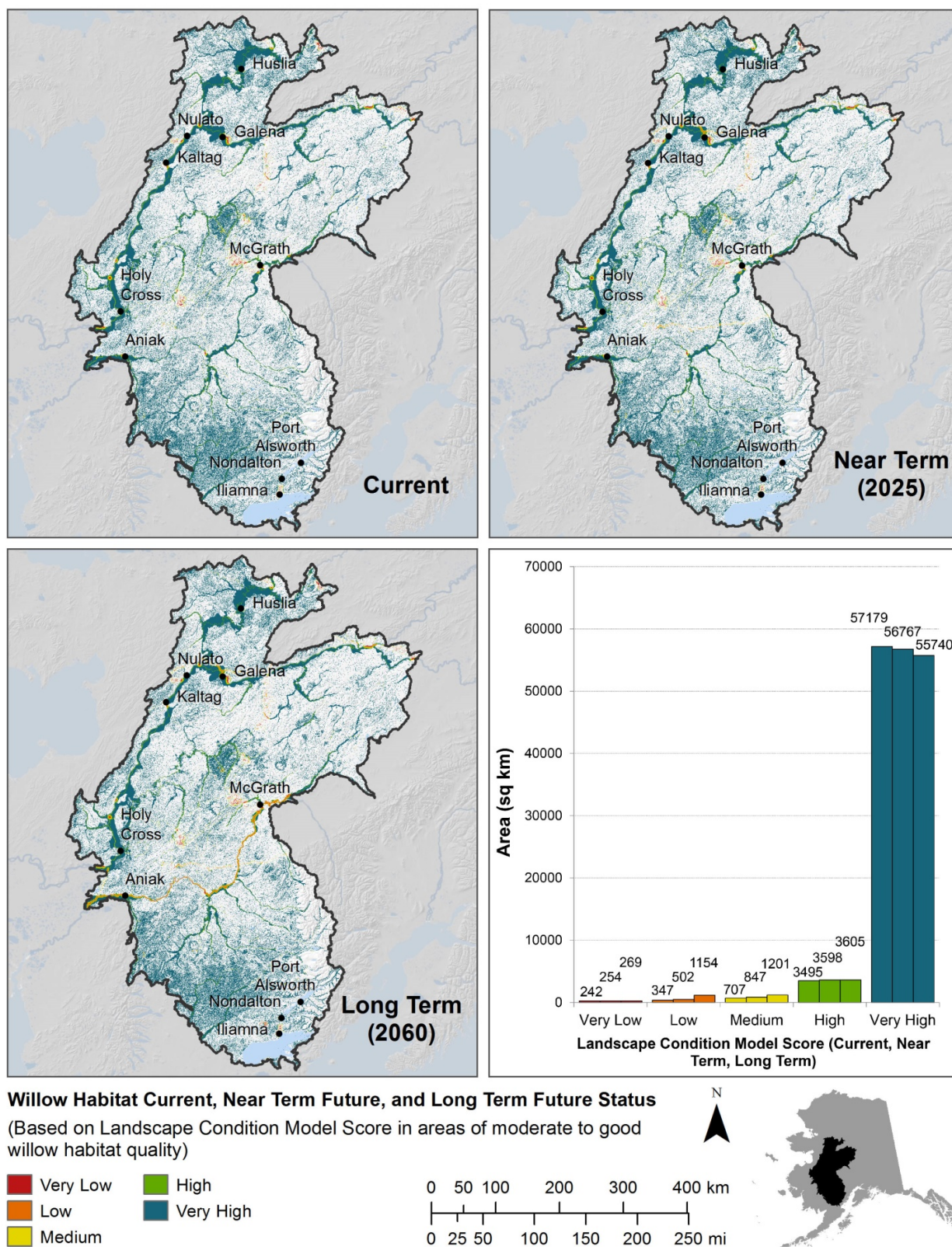
**Figure D-42.** Landscape condition modeled for current, near-term (2025), and long-term (2060) projections clipped to moderate and good winter moose forage in the YKL study area.

## Applications

This section answers specific management questions related to the seasonal distribution of moose and provides managers with a current distribution model for moose across the YKL study area. This information also provides a baseline of information about the potential availability of winter forage, which to our knowledge, has not been previously mapped across the study area.

The conceptual model and associated literature review help to identify the possible relationships of moose to the various CAs, specifically the potential effects of climate change, anthropogenic development, and other important drivers on moose habitat. The conceptual models could help direct future modeling efforts and aid in current and future management decision making.

Results of the literature review and spatial analysis indicate that climate change and increased frequency of fire will likely be favorable by increasing moose habitat in the REA. For example, moose populations increased dramatically on the Kenai Peninsula as a result of new habitat created by wildfires in 1947 and 1964 (Spencer and Hakala 1964), and researchers have reported increases in moose browse quantity and nutritive quality after prescribed burning (Asherin 1973; Arno and Harrington 1995). Hence, conservation planning should account for possible increases in moose habitat.

## Limitations and Data Gaps

Our spatial representation of moose seasonal distribution is based on the best available information, however, it should be noted that the available information was considered current only as of 1986. Expert reviewers indicated a strong need for a more up-to-date comprehensive source of information and these out-of-date data have limitations. We also note that empirical data were not used to test the accuracy of our models, therefore their accuracy is based solely on expert opinion, which was largely favorable. While empirical data are probably available for the region, moose are managed across 12 GMU subunits in the YKL study area. Collecting and then summarizing survey data from these disparate sources, which likely used varying survey techniques, was beyond the scope of the REA.

We lacked a suitable snow-depth layer for the REA that precluded examining the relationship of deep snow and the distribution of moose. This data layer is currently considered a data gap.

The development of the winter browse model could have been improved considerably if we had been able to separate the willow and alder classes from the tall shrub land cover class. However, this task proved to be impractical with current information sources and available imagery.

## 2.5. Caribou (Rangifer tarandus)



**Caribou - Seasonal ranges**
**Herd, Range**

Mulchatna, Calving Grounds
Mulchatna, Winter Range
Mulchatna, Summer Range
Galena Mountain, Calving Grounds
Galena Mountain, Summer Range
Galena Mountain, Total Range
Western Arctic, Winter Range
Western Arctic, Peripheral Range
Sunshine Mountains, Summer Range
Sunshine Mountains, Total Range
Farewell-Big River, Summer Range
Farewell-Big River, Total Range
Beaver Mountains, Summer Range
Beaver Mountains, Total Range
Wolf Mountain, Summer Range
Wolf Mountain, Total Range
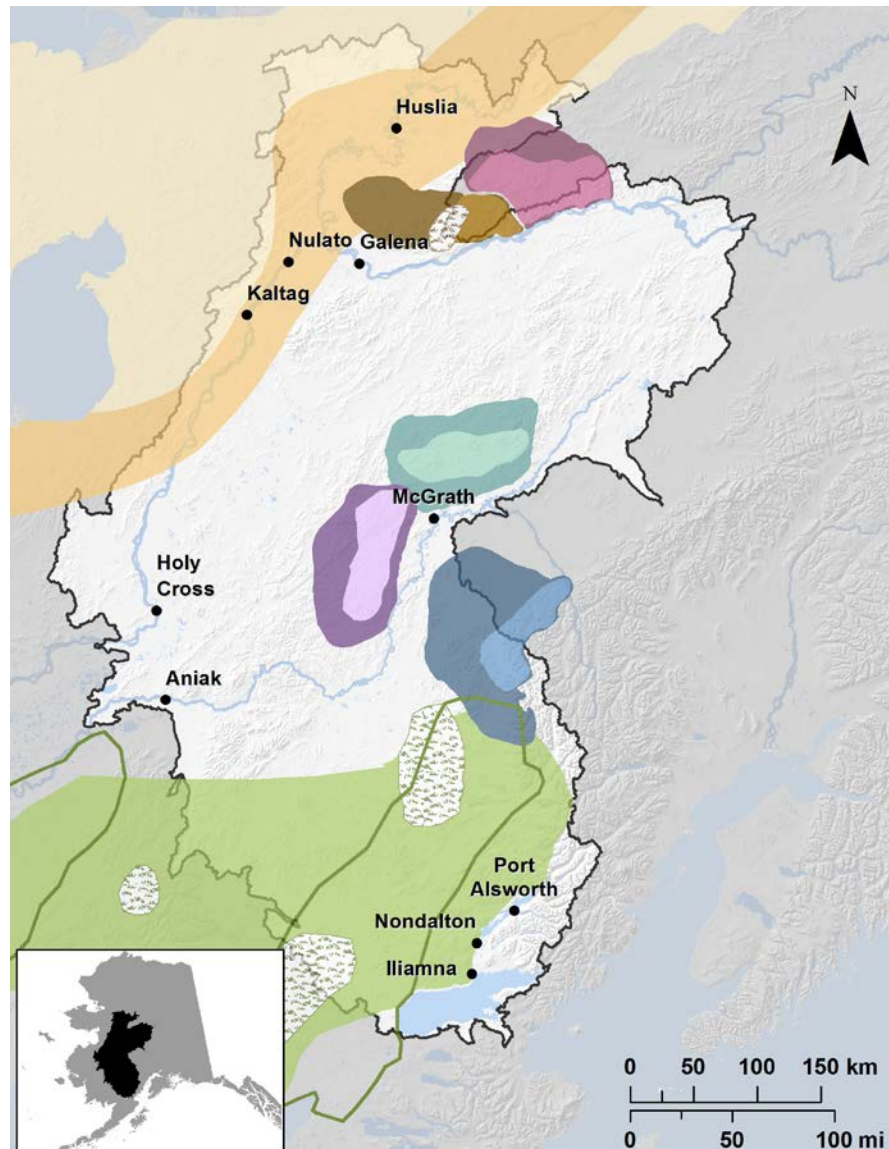
**Figure D-43.** Current seasonal range map for the seven caribou herds in the YKL study area.

Caribou are circumpolar in their distribution and occur in arctic tundra and boreal forest regions in North America and Eurasia (MacDonald and Cook 2009). In Alaska, there are 31 recognized herds of which seven regularly occur within the YKL study area, including the Mulchatna, Farewell-Big River, Beaver Mountains, Sunshine Mountains, Wolf Mountain, Galena Mountain, and Western Arctic herds (Figure D-43). Ranges of the Ray Mountain, Rainy Pass, Tonzona, and Denali herds also intersect with the REA boundary, but only peripherally, thus they were not considered in this assessment.

Population size and trends are highly variable among the different herds. Most herds in the YKL study area experienced population growth during the 1990s but have recently been declining for various reasons. Between 1981 and 1996, the Mulchatna herd increased by 17% per year (Valkenberg 1998), yet has been declining since 1999 (ADF&G 2010; Table D-20). The Western Arctic herd grew by 13% per year from 1977 to 1990, and began to stabilize due to decreased calf production (Valkenberg 1998). In 2003, the Western Arctic herd was > 490,000

animals, but by 2011 the population had declined to 325,000 animals (ADF&G 2010). Many of the smaller, interior herds declined from 1989 to 1994 due to warmer summers, severe winters, increased predation of calves, and increased vulnerability of adults to wolf predation. Many of those herds are now stable, although the Galena Mountain and Farewell-Big River herds still show declining trends (Table D-20). Overhunting caused some herds to remain low in the past. Today, varying weather patterns, population density, predation by wolves and grizzly bears, and disease outbreaks determine whether most herds increase or decrease (Valkenberg 1998; ADF&G 20I0).

**Table D-20.** Summary of caribou population size and trend by herd within the YKL study area. Adapted from ADF&G 2010.

| Herd Name | Population Estimate | Population Trend |
|---|---|---|
| Mulchatna | 30,000 | declining |
| Galena Mountain (Galena Area herds) | 89 | declining |
| Wolf Mountain  (Galena Area herds) | 434 | stable to declining |
| Beaver Mountains (McGrath Area herds) | 100-150 | stable |
| Farewell-Big River (McGrath Area herds) | 750-1,500 | declining |
| Sunshine Mountains (McGrath Area herds) | 100-125 | stable |
| Western Arctic | 348,000 | declining |

The distribution of caribou herds in Alaska has remained virtually unchanged during the last 30 or more years, with two exceptions. Despite its declining population, the Mulchatna herd in southwestern Alaska has doubled the size of its range and reoccupied winter ranges that have not been used by caribou in over 100 years (Valkenberg 1998). The Western Arctic herd has also expanded its winter range to the south and east, bringing it into the YKL study area (Joly et al. 2007). These two herds are included in this assessment.

In Alaska, caribou are managed by both state and federal entities. The Alaska Department of Fish and Game regulates the season length (some units are closed), bag limit, and number of sport hunters by issuing draw, registration, and tier II permits in areas (ADFG 2010b). The U.S. Fish and Wildlife Service also allows additional federal subsistence hunting opportunities on federally owned lands in some regions to qualified rural residents (USFWS 2010).

### Conceptual Model

The conceptual model below (Figure D-44) 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 caribou and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and caribou. Change agents selected for this REA and considered in this analysis include: Climate change, Insects and disease, Wildland fire, Invasive species, Land use change (i.e. human development) and Harvest pressure.
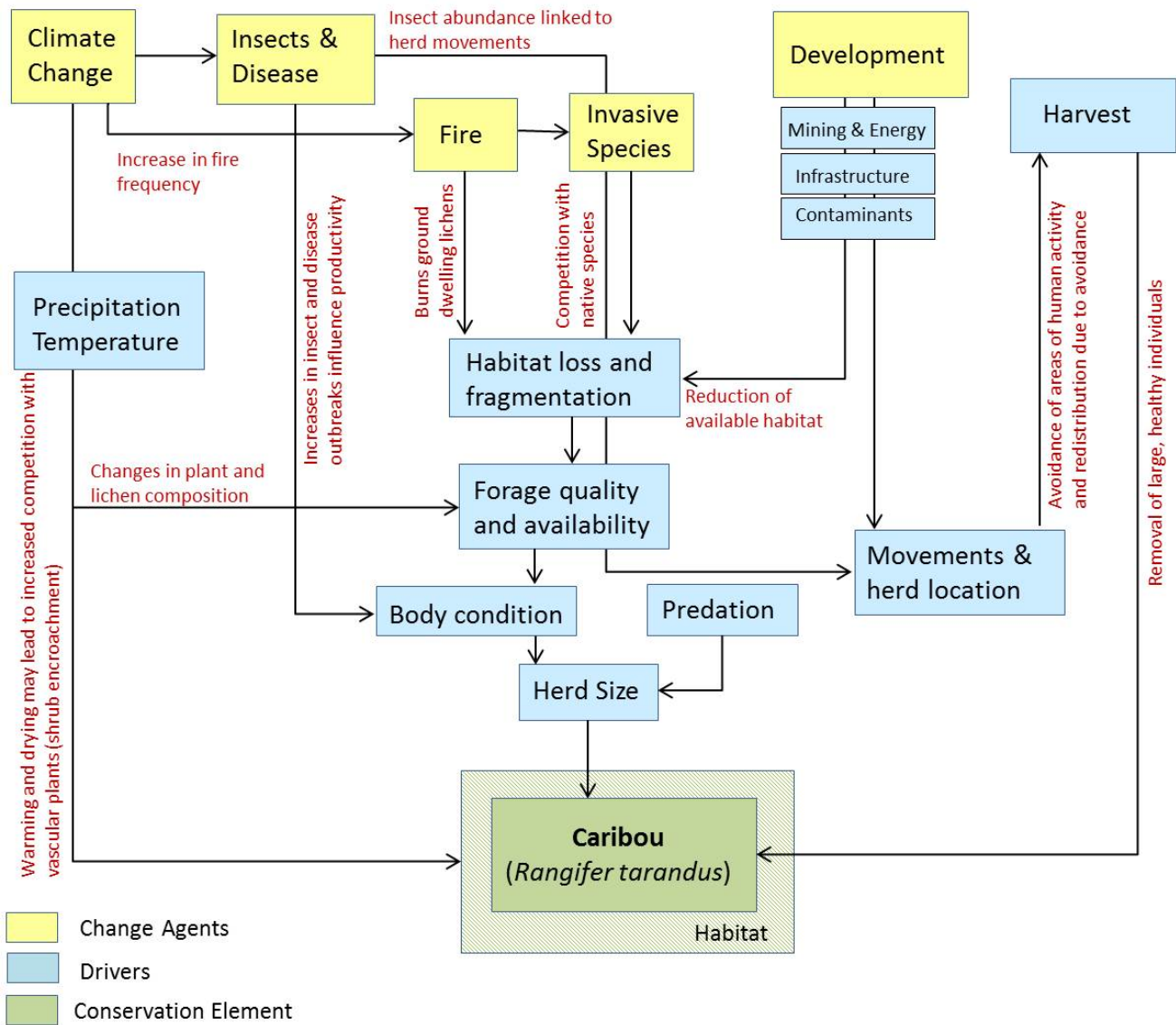
**Figure D-44.** Caribou (*Rangifer tarandus*) conceptual model.

## Distribution of Primary Winter Forage for Caribou

| MQ 4 | What is the current distribution of primary winter forage (lichen) for caribou in the region, and how is that expected to change? |
|---|---|

During winter, caribou are associated with lower elevations and areas with an adequate quantity of winter forage; primarily ground dwelling lichens (Jandt et al. 2008). A study in eastern Alaska showed that caribou strongly selected against burned areas < 35 years old throughout the winter and that lichen availability was a large factor in influencing habitat selection (Joly et al. 2003). The distribution of primary winter forage for caribou is assessed here based on a combination of coarse-scale vegetation classes that contain high lichen cover.

*Methods*

To identify the current distribution of lichen habitat in the YKL study area, we used the Vegetation Map developed by Boggs et al. (2012; see Terrestrial Coarse-Filter CE section). We identified five detailed classes as having lichen habitat suitable for caribou forage (Table D-21). From these classes, we categorized each class as having "good" or "moderate" forage quality based on the relative cover of lichen within each of these classes.

**Table D-21.** Lichen vegetation classes categorized by winter forage quality for caribou pre- and post-fire.

| Lichen vegetation classes | Forage Quality |
|---|---|
| White spruce or black spruce/lichen (Woodland-Open) | Good |
| Low shrub/lichen | Good |
| Dwarf shrub | Moderate |
| Dwarf shrub-lichen | Good |
| Lichen | Good |

Lichen regeneration, including reindeer lichens, cup lichens, felt lichens (*Peltigera* spp.), and arboreal lichens, takes 30 to 120 years or more depending on the species (Miller 1979), and caribou have been shown to avoid recently burned areas (Joly et al. 2003). We considered burn scars in our analysis of lichen habitat for this reason. Burned status was determined using the Alaska Fire Service's Large Fire Database, which maps the perimeters of fires back to 1950 (http:/fire.akblm.gov/). Thus, plots designated as burned did so within the past 58 years. We overlaid the fire scar map with the lichen vegetation class map. Any area that fell within a burn was designated as "poor" quality habitat. Areas that had not been burned received good or moderate ranks as described in Table D-21.

*Results*

The overall percent of the study area covered with good quality lichen habitats is 12%, the majority of it being white spruce or black spruce/lichen class (8%). The dwarf shrub class is the only moderate forage class and comprises 4% of the total study area (Figure D-45). These classes are widely distributed throughout the YKL study area.
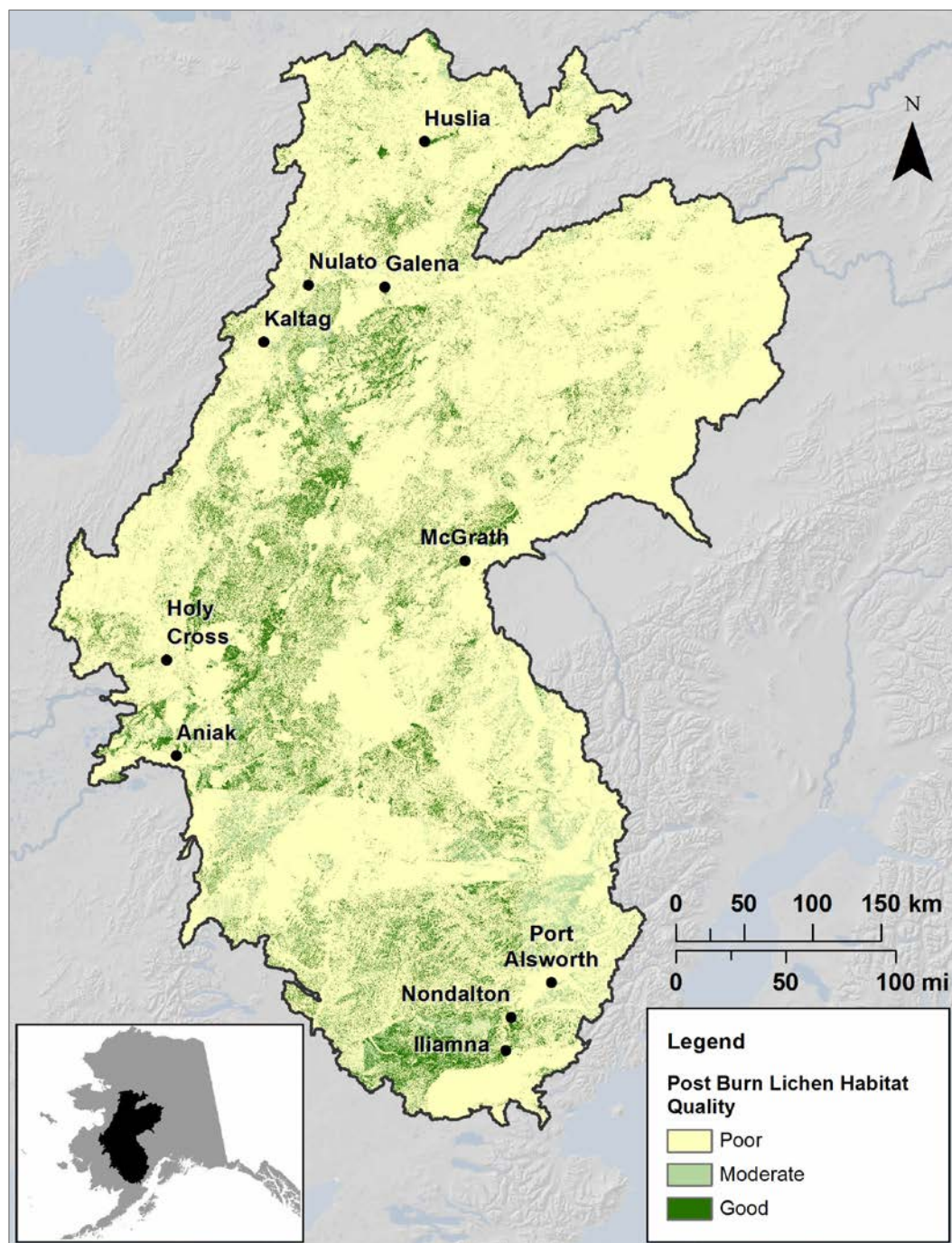
**Figure D-45.** Current distribution of lichen (primary caribou forage) throughout the YKL study area, with firescar areas omitted.

## Future Projections

To understand lichen response to fire and other disturbances we outlined the major successional pathways of each of the detailed vegetation classes with good to moderate forage and discuss lichen-related elements from the cliome model.

### White Spruce or Black Spruce/Lichen (Woodland-Open)

Lichen understory for this class is probably late-seral. The recovery of the lichens post-fire follows a general trend of initially low diversity, peaks and then declines (Holt 2007), which resembles many other successional trajectories in the boreal forest (e.g. Kershaw 1978, Coxson and March 2001). Following fire disturbance, lichens such as *Placynthiella, Lecidia*, and *Trapeliopsis* form dense crusts at the soil surface and reach maximum development within 20 years. Twenty to 70 years after fire *Cladonia* spp. and mid-successional *Cladina* spp. (e.g. *C. mitis, C. rangiferina*) generally dominate. Sixty-five years after fire, *C. stellaris* increases in importance and corresponds to the development of mature lichen-spruce woodlands (Morneau and Payette 1989) where groundcover is nearly pure *C. stellaris*, with low cover of other lichens (Kershaw and Rouse 1971, Rencz and Auclair 1977). Forage lichen species have been shown to not reach maximum productivity until after 180 years. Late successional decline in lichen abundance and diversity has been attributed to canopy closure followed by lichen displacement by mosses (Fortin et al. 1999, Morneau and Payette 1989, Boudreault et al. 2002).

### Low Shrub/Lichen

These communities may be stable over long time periods (Viereck et al. 1992). Others may develop on burned spruce forests near the tree line (Pegau 1972) and may be intermediate to spruce forest. Lichen communities of this class include many early successional species (e.g. *Cladina mitis, C. arbuscula, Flavocetraria cucullata*) and ubiquitous species (e.g. *Cetraria laevigata, Cladina amaurocraea, C. stygia*). Post-disturbance recolonization is by lichens tolerant of high vascular plant competition or those able to establish in novel sites exposed by cryoturbation, fire, or grazing.

### Dwarf Shrub

Lichens preferred by caribou in tundra uplands in Canada take 40-70 years to re-establish following fire (Thomas et al. 1996).

### Dwarf Shrub-Lichen

Successional relationships are unknown.

### Lichen

Areas with high rock cover, thin soils and low competition from vascular plants tend to have greater lichen cover and species richness. The lichen class is likely to support species that dwell strictly on rocks (e.g. *Umbilicaria* spp., *Arctoparmelia* spp.) or gravels (e.g. *Alectoria nigricans, Cetraria nigricans* and *Bryocaulon divergens*) as well as calciphiles (e.g. *Cetraria tilesii*), Alectoroid lichens and dry-associated lichens (e.g. *Asahinea chrysantha, Thamnolia subuliformis, Cetraria* spp. and *Dactylina* spp.). Because this cover class may be more resistant to fires and soil disturbance, late successional lichen species are better able to establish and become dominant.

## Caribou Calving Grounds

| MQ 5 | Where are caribou calving grounds in the region, and how are they expected to change? |
|------|---|

Calving ground ranges are a subset of the overall caribou seasonal ranges provided (**Figure D-43**). Descriptions of caribou calving ranges are provided in Table D-22 below.

*Methods*

Seasonal range maps for caribou were delineated based on descriptions from ADF&G management reports, expert opinion (i.e. personal communication with area managers), existing paper maps (from Lem Butler, Mulchatna Caribou Herd; Alaska Habitat Management Guides 1986; Hinkes et al. 2005) or digital maps (e.g., Paragi 2009; Joly 2010 and 2012). Ranges were attributed with the following seasons: calving, summer, winter, peripheral, and total (Figure D-43). When specific information on the distribution of calving grounds was lacking, the summer range was used instead.

*Results*

Caribou calving and summer ranges for the YKL study area are presented in Figure D-46 and summarized in Table D-22. During summer, caribou are generally located in alpine or subalpine areas. The Mulchatna herds calve in two distinct areas: the majority of the herd calves between Kemuk Mountain and the Nushagak River in the southeastern corner of the REA; the remainder of the herd calves near Lime Village, between Stony and the Hoholitna rivers. The Western Arctic herd does not calve or summer within the YKL study area. Each herd uses a distinct and separate calving area, but herds may mix together on winter ranges (e.g., Beaver Mountain and Sunshine Mountain herds).

We were not able to clearly delineate the calving ranges for all the herds in the YKL study area. Instead, we relied on maps of the summer range to be inclusive of the calving range for the Beaver Mountain, Farewell-Big River, Sunshine Mountains and Wolf Mountain herds. To that end, our discussion of potential changes to calving grounds will also be inclusive of the herds post-calving summer distribution.
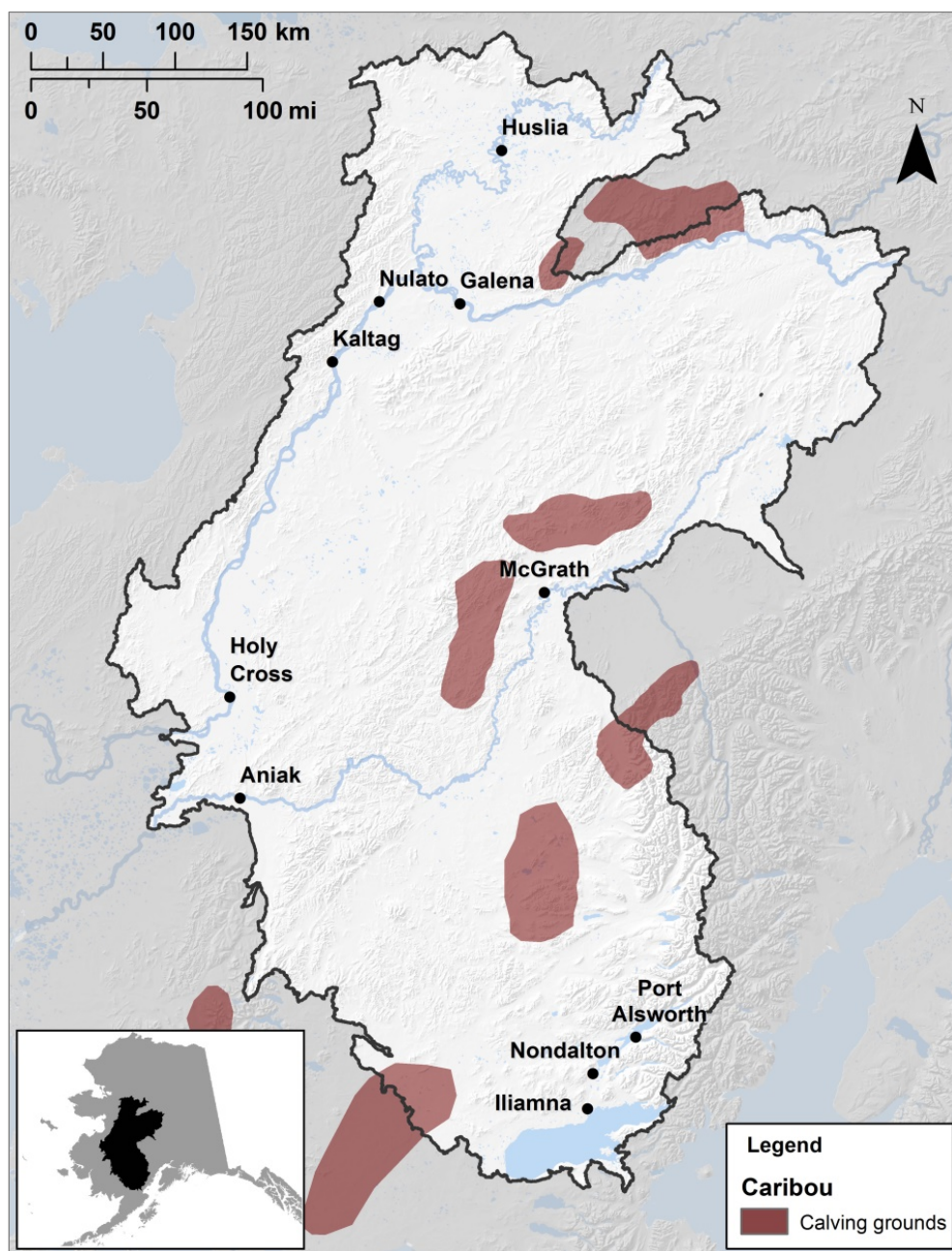
**Figure D-46.** Current distribution of calving ranges for the seven caribou herds in the YKL study area.

**Table D-22.** Descriptive summary of caribou calving (summer) ranges, by herd, for the YKL study area. Adapted from ADF&G 2010.

| Herd name | Description of calving (summer) ranges |
|---|---|
| Mulchatna | Calving areas have changed in recent years. A large part of the herd calves between Kemuk Mountain and the Nushagak River, with the remainder calving to the north between the Stoney River and Hoholitna River. |
| Galena Mountain | Calving grounds are east of Galena Mountain, on alpine slopes of the southern Kokrine Hills. It is occasionally sympatric with the Wolf Mountain herd on portions of range near Black Sand Creek during calving season. From June to September, most caribou are found in alpine areas west of the Melozitna River. |
| Wolf Mountain | Calving occurs on south facing slopes of the Kokrine Hills south of Wolf Mountain. The herd spends most of the summer in the surrounding alpine area near Wolf Mountain. |
| Ray Mountains | Calving occurs on southern slopes of the Ray Mountains, in the upper Tozitna River drainages, around Kilo Hot Springs. Summer range is in alpine areas of the Ray Mountains, frequently in the Spooky Valley area around Mount Henry Eakins; occasionally in the alpine area south of the upper Tozitna River. |
| Beaver Mountains | Calving occurs predominantly in the Beaver Mountains, but post calving groups occur throughout the herds range. |
| Farewell-Big River | Summering areas are in the foothills of the north side of the Alaska Range. |
| Sunshine Mountains | Calving occurs throughout the range, but mostly on the Nixon Flats. In midsummer, caribou are found predominantly in the Sunshine Mountains, however small groups are regularly observed on Nixon Flats. |
| Western Arctic | Summer range consists of the Brooks Range and its northern foothills west of the trans-Alaska pipeline. |

**Caribou Migration Corridors**

| **MQ 9** | What is the current distribution of migration corridors for caribou, and how are they likely to change in the future? |
|---|---|

Caribou migrate with the seasons to search for food, avoid predators, find relief from harassing insects, and give birth. Large herds often migrate long distances (up to 640 km) between summer and winter ranges. Smaller herds may not migrate at all.

***Methods***

Limited information was available on migration movement and corridors for the eight caribou herds that occur in the YKL study area. We were unable to obtain radio-collar data to inform this analysis, except for the Galena

and Wolf Mountain Herds. Instead, we relied heavily on descriptions from ADF&G management reports, expert opinion (i.e. personal communication with area managers), and existing paper maps (from Lem Butler, ADF&G, Mulchatna Caribou Herd; Alaska Habitat Management Guides 1986; Hinkes et al 2005; Jandt 1998) to provide us with the best available information on current movement patterns. We summarized this information in tabular form (Table D-23) and heads-up digitized (drew or traced) the descriptive ranges using ArcGIS to produce coarse approximations of the general direction(s) we would expect caribou to move between summer and winter ranges (Figure D-47). We then presented migration corridor maps to ADF&G caribou biologists/managers for expert review.

### *Results*

In general, the Western Arctic and Mulchatna herds make large-scale migrations between winter and summer ranges of up to 150 km, while the smaller herds make subtle movements to alpine areas in the spring and summers, and are generally considered non-migratory (Figure D-47).

**Table D-23.** Descriptive summary of caribou migration movements by heard, for the YKL study area. Adapted from ADF&G 2010.

| Herd name | Description of migration movements |
|---|---|
| Mulchatna | Does not move enmasse as a distinct herd. The herd basically splits, with part of the herd moving to the eastern side of the range during the summer and the rest of the herd traveling to the west side of the range. They then aggregate for fall rut and winter in respective areas. In late winter/early spring, the herd travels back to the middle and northern part of the range for calving. After calving, most of the herd moves to the Nushagak and Mulchatna river drainages, then either go east or west for post calving aggregations; after which the caribou become dispersed throughout the range. In the fall, they again begin forming large groups in eastern and western parts of range, where they will spend the winter. |
| Galena Mountain | Usually migrate toward alpine areas east of Galena Mountain in April. During October, the herd will migrate from alpine areas across Galena Mountain toward the Holtnakatna Hills and Hozatka Lakes, where they winter. |
| Wolf Mountain | Herd calves on south facing slopes of the Kokrine Hills south of Wolf Mountain, then spend most of the summer in the surrounding alpine area near Wolf Mountain. In October, they move north to Lost Lake on the Melozitna River. |
| Ray Mountains | Not well documented. Likely seasonal migration between area north of the Ray Mountains and the upper Tozitna River drainage. |
| Beaver Mountains | Calving in the Beaver Mountains, but post calving groups occur throughout the herds range. Wintering areas include the north side of the Kuskokwim Mountains from the Iditarod River east to the Dishna River. |
| Farewell-Big River | Summers in the foothills of the north side of the Alaska Range. Wintering areas are in the flats north of the summer range. |
| Sunshine Mountains | Predominantly in the drainages of the Nixon Fork and the Innoko River to Von Frank Mountain and in the headwaters of the Susulatna River, including Fossil Mountain and the Cripple Creek Mountains.  May mix with Beaver Mountain herd. |
| Western Arctic | During spring, mature cows travel north toward calving grounds in the Utukok Hills; bulls and nonmaternal cows lag behind and move toward summer range in the Wulik Peaks and Lisburne Hills. During summer, WAH move eastward through the Brooks Range; this is a rapid and predictable seasonal movement. During fall, caribou are more dispersed than at any other time of year as they move south toward wintering grounds; rut occurs en-route during the fall migration. |
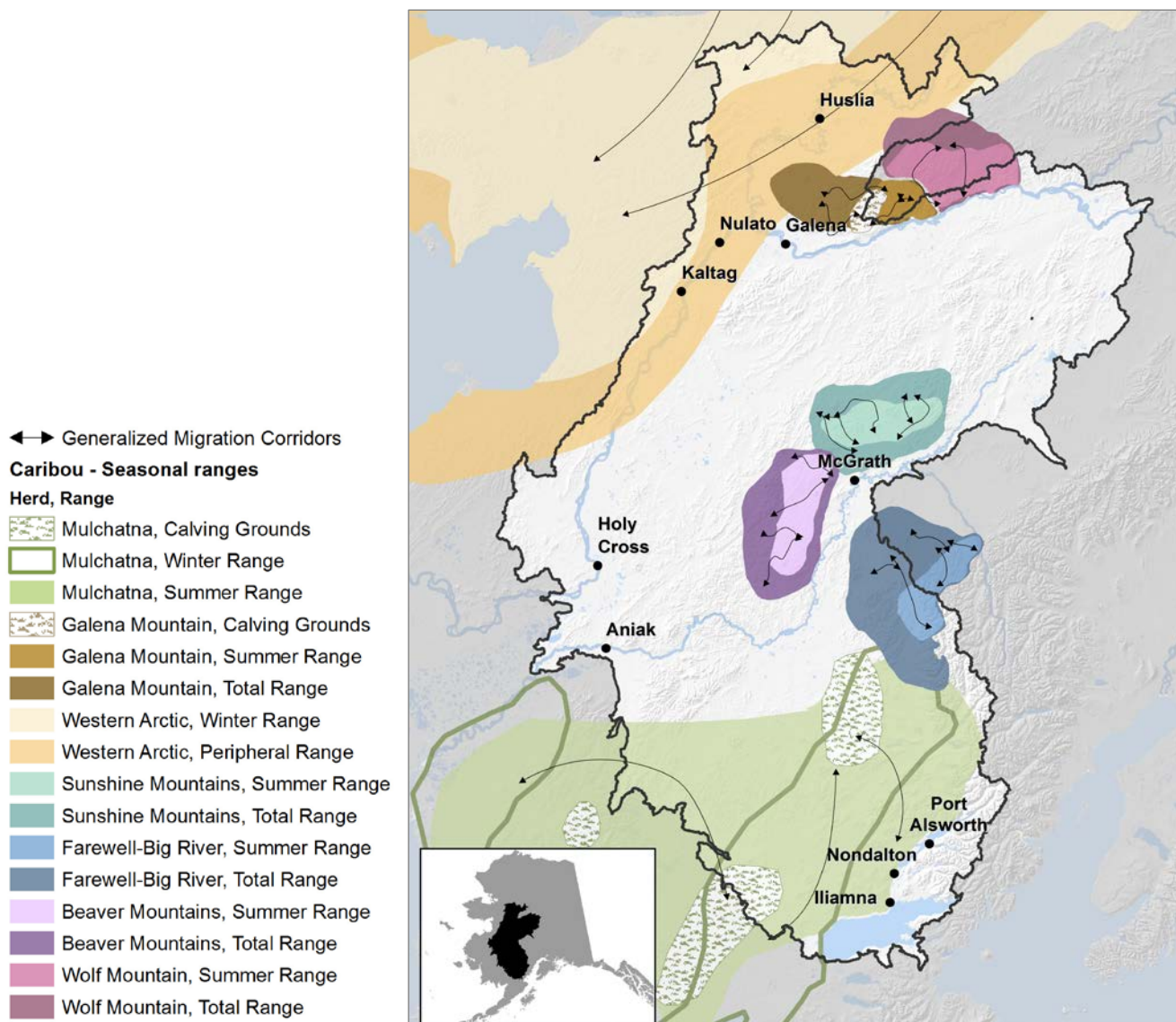
**Figure D-47.** Approximate location of migration pathways for the seven caribou herds in the YKL study area.

Expert reviewers (personal communication with ADF&G biologists J. Woolington, J. Pierce, G. Stout, T. Paragi) were generally supportive of caribou migration routes displayed here. Most biologists agreed that movements of the specific herds are not predictable enough to map accurately, therefore, we strongly emphasize that the map presented in Figure D-47 is representative of general movement patterns for the different herds between seasonal ranges and nothing more. Although we considered topography when delineating seasonal movement pathways, the arrows do not indicate actual pathways that are utilized by caribou; they merely represent the general trend in direction that caribou are expected to move.

## Climate

The growing season in the YKL study area occurs from early-June through mid to late-August. Although this is a relatively short period in the annual cycle, the growing season is key to caribou survival (Reid et al. 2013). Caribou depend on the high digestibility and nutritional value of green plants to replace body reserves used up

during the long winter to meet the demands of pregnancy and lactation during the calving season, in addition to general maintenance and preparation for the next winter season (Joly and Klein 2011).

Growing season length, like July temperature and summer temperature, is not expected to see much change in the near term.  In the longer term, however (as represented by the change between the current decade and 2060), growing season is expected to increase by at least a week for every habitat in the REA. For the mapped representation of caribou calving grounds, almost 58% of habitat (defined as habitat within the distribution of the CE) is expected to see an increase of between one to two weeks in the growing season, and an increase of 42% is expected over two weeks (Figure D-48). Climate change models indicate that growing season length will be most pronounced in the southern portion of the REA (Figure D-48). Increases in growing season could have implications for the timing of the emergence of vegetation as well as of biting and parasitic insects, both of which play a large role in driving caribou distribution during the summer.

A longer growing season may benefit caribou on their summer ranges by promoting early onset of vegetation green-up and an increase in nutrient value of summer caribou forage. If this pulse of nutrients coincides with peak lactation, we may see an increase in calf survival (Griffith et al. 2002). Increases in growing season length are projected to be the most pronounced within the summer range of the Mulchatna herd, where growing season is expected to increase by > 21 days by 2060 (Figure D-48). Conversely, advanced onset of green-up may precede calving — meaning that calves are born after most of the food has emerged, thereby reducing calf survival. 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). Low calf survival has been forwarded as one of the causes of the current decline of the Mulchatna herd, even as nutritional indices have increased (ADF&G 2011).

Because our understanding of the specific locations of migration corridors is limited, our discussion of changes in the context of climate change is a summary of generalized effects, with most of them pertaining to the timing of migration events and not specifically physical barriers on the ground. As discussed above, the growing season is expected to increase, especially in the southern part of the study area. This could result in the timing of migration becoming uncoupled from optimal foraging. As a result, caribou would have to migrate and give birth earlier to survive this pulse, but it is unknown whether they can adapt by advancing rut and changing the timing of migration (Reid et al. 2013).

The ability of caribou to get from place to place at precise times of the year is a condition of their survival and the survival of others in the food chain. With the timing of seasonal changes shifting, early and fast melts might make caribou more susceptible to encountering lakes where in years past ice provided safe migration, or rivers and streams may become impassable (Reid et al. 2013). Caribou can take longer routes around the lakes, facing exhaustion, or traverse the ice, with the risk of breaking through and dying.

Insects that harass animals and transmit disease agents may also benefit from climate change. Earlier onset of the growing season may result in earlier emergence of mosquitos and warble flies, with the possibility of harassment on the calving grounds, which are generally insect-free. Warmer summers may increase levels of harassment by warble *Hypoderma tarandi* and nose-bot flies *Cephenemyia trompe*, resulting in increased caribou agitation and decreased foraging (Vors and Boyce 2009 in Reid et al. 2013). Host species that are already physiologically and energetically stressed from other change agents (as a result of other factors of climate change) will likely be more vulnerable to disease agents (Bradley et al. 2005). Conversely, drier conditions might reduce mosquito populations (Vors and Boyce 2009 in Reid et al. 2013).

Changes in weather patterns and events due to climate change are expected to affect caribou in diverse ways. Climate is the ultimate driver influencing caribou population ecology by directly affecting growth, quantity, and nutritional quality of forage plants; through its control over snow characteristics that determine forage accessibility in winter and the vulnerability of caribou to predation; and through its influence on insects that harass and parasitize caribou in summer (Joly and Klein 2011).
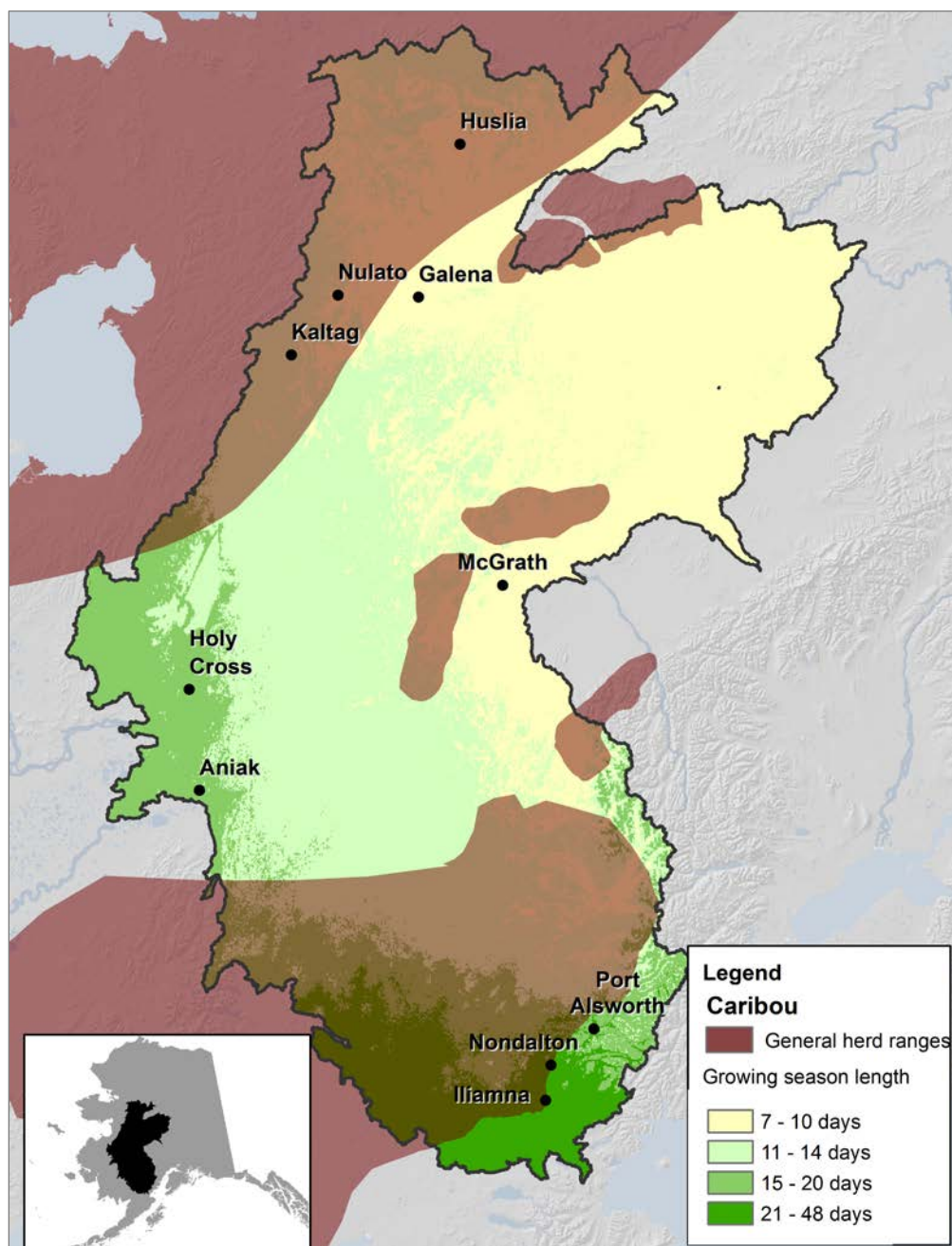


**Figure D-48.** Modeled change in frost-free season from 2010 to 2060 and current caribou ranges in the YKL study area.

Warmer winter temperatures will likely affect the amounts of precipitation, the density and hardness of snow, and will likely result in increases in icing events. By 2060, increases in precipitation of > 100 mm, which is

considered a relatively high percentage increase, are expected to occur in lichen habitats (16% of current lichen range) and within the calving range of caribou (20% of current calving range, all herds combined).

Snow is present during a major portion of the year throughout the YKL study area. Deep snow increases the energy expended for movement and to access winter forage species such as ground-dwelling lichens, which can contribute to poor body condition and greater vulnerability to predation (Putkonen and Roe 2003). Snow can also influence the timing of green-up, which may have serious nutritional and reproductive consequences. Deep snow years have been associated with poor physiological condition of cows in spring, lower calf birth weights, reduced calf survival, slower growth of surviving calves, poor body condition of calves entering winter, reduced pregnancy rates the following year, and delayed parturition the following spring (Joly and Klein 2011).

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 (Section B-1). These events will become more frequent in the southern part of the study area (Figure D-49). Denser, harder snow and the formation of a hard crust on top of the snow may also 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).
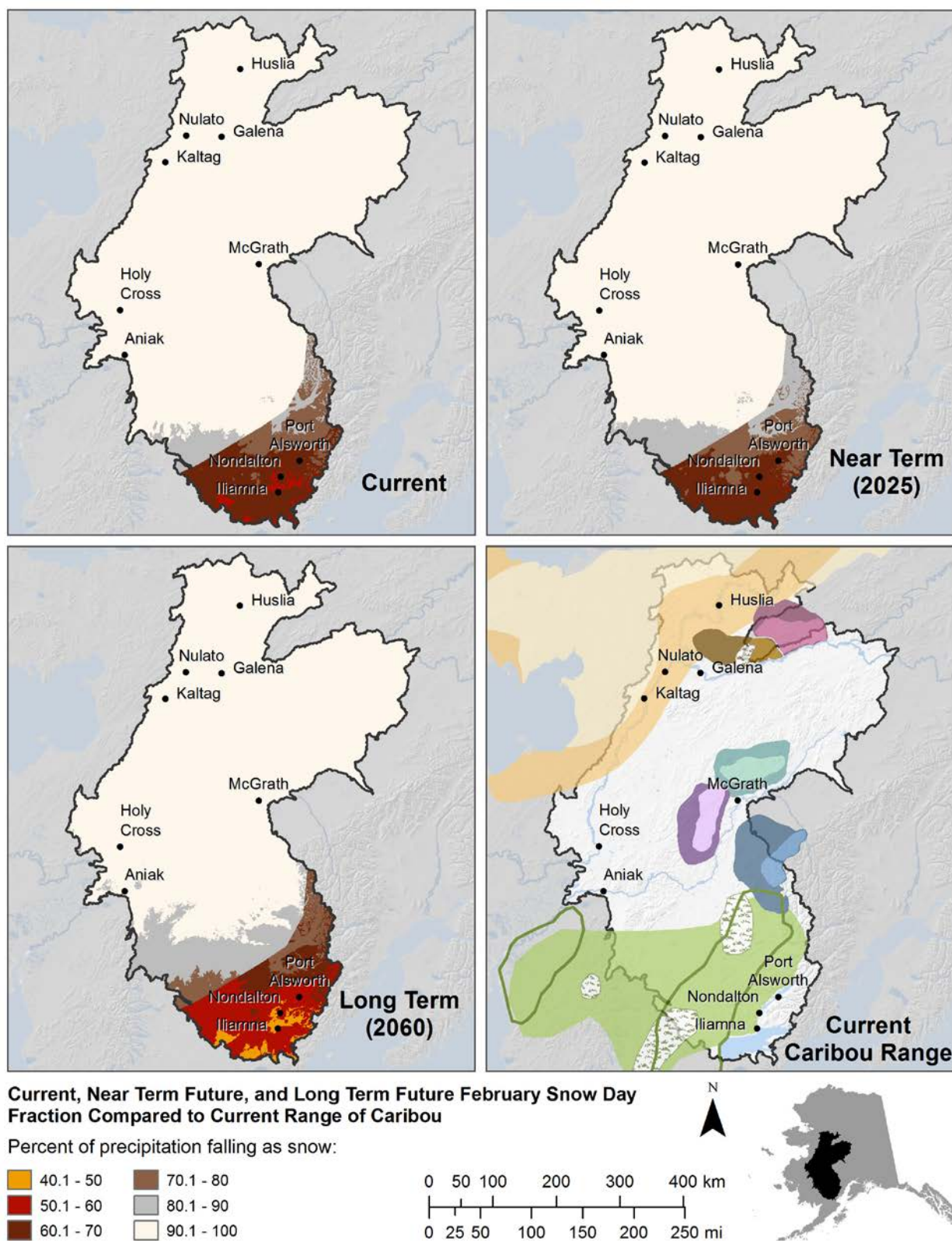
**Figure D-49.** Snow day fraction in February modeled in the YKL study area for current (2010s), near-term (2025) and long-term (2060).

**Fire**

Increased fire frequency will likely increase fire's role in driving ecosystem succession. For this assessment, the comparison of caribou habitat to area burned only includes forested areas. Since caribou also use alpine areas, inferences drawn by comparing fire and caribou habitat are limited to only those habitats utilized by caribou that are forested (e.g., white spruce or black spruce/lichen). However, forest (as defined for the purposes of the ALFRESCO model) dominates the REA area, as can be seen in the Fire section of this report (B-3).

Fire simulation models suggest that frequent and large fires reduce spruce-lichen habitats preferred by caribou (Rupp et al. 2006). In Alaska during winter, caribou were observed feeding along the edge of a burn in birch and ericaceous shrub-sedge communities near moraines (Hanson 1979). In another study, edge habitats (<1,600 feet of burned/unburned stand edge) were highly preferred over habitats >1,600 feet into either the stand or the burned area. Use of burned areas was highest in November to December, but declined during late winter and spring (Joly et al 2003). In north-central Canada, unburned remnants and unburned stands adjacent to recent burns are used for feeding (Miller 1980, 2000). Caribou rarely forage within recent burns (Miller 1980, 2000).

Caribou may use burned areas for several reasons. For instance, Miller (1980) reported that caribou used burned areas as refuges to escape predation. In another study, calving occurred in a recent burn adjacent to a traditional calving area in Alaska (Davis and Valkenburg 1983). Recent burns are also commonly used during migratory and nonmigratory movements (Miller 1980). Caribou also traverse burned areas between mature forest fragments and meadows (Hanson 1979). Fire in tundra habitats removes woody debris, which facilitates travel (Saperstein1993). However, burns in forested habitats may inhibit travel between unburned foraging sites. Surface fires can kill black spruce and burn off their roots, making standing snags susceptible to windthrow, which may hamper the movements of caribou (Klein 1982; Saperstein1993).

Lichens are typically consumed by fire, so limited food is available to caribou during early successional stages after fire (Klein 1982; Lutz 1956). Increases in fire intensity and frequency can reduce potential caribou winter range by removing the lichens that are primary winter forage (Rupp et al. 2006). Lichens can take up to a century or more to fully reestablish (Jandt et al. 2008), but regeneration time depends on many factors including burn patchiness, intensity, severity, extent of burn, seral stage, and climate (Klein 1982). Shortened fire cycles, as projected, will likely further hamper the effective reestablishment of lichen. Caribou are known to avoid burned tundra and the boreal forest habitats for decades during winter (Joly et al. 2007), likely due to the destruction of forage lichens. Thus, fire can influence the nutrition and movements of caribou and in turn affect their population dynamics (Joly and Klein 2011).

Historically, fire was considered detrimental to caribou due to the destruction of lichen forage. Now, however, fire is perceived to improve the nutrient cycling and growth of lichens, sedges, shrubs, and forbs (Saperstein 1993). Fire reduces lichen availability, but enhances short-term productivity and quality of vascular plants such as *Eriophorum vaginatum*, *Rhododendron tomentosum* ssp. *decumbens*, and *Vaccinium vitis-idaea* (Saperstein 1993). The short-term increase in vascular plants enhances forage availability on summer ranges, but the decrease in lichen availability is detrimental on winter ranges (Schaefer and Pruitt 1991). Late summer regeneration of sheathed cottonsedge following a midsummer tundra fire in Alaska provided food for a caribou herd moving through the burned area in late October (Klein 1979).

Overall, fire is necessary in the landscape to maintain lichen forage availability over the long term (Schafer and Pruitt 1991). How caribou will respond to fire is influenced by the duration of lichen recovery and availability of alternate feeding sites (Klein 1982).

**Current Status and Future Landscape Condition**

Current and future impacts based on anthropogenic activities are currently considered low in the YKL study area. Habitat within caribou calving and summer ranges is currently classified as having high landscape condition (Figure D-50). Future projections of landscape condition suggest that caribou habitat will remain relatively intact and in good condition (Figure D-50), except in the vicinity of McGrath, which is within the ranges of the Beaver and Sunshine Mountain herds, where landscape condition is currently classified as moderate to very low. In addition, increased hunter access via the proposed Kuskokwim Road (indicated as poor landscape condition for the long term; Figure D-50) may increase hunting pressure on caribou in the surrounding area.

Human and resource development has caused the fragmentation of caribou habitat and patch sizes are likely to decrease with increased development. Caribou generally avoid areas of human activity although it is dependent on the type and intensity of the activity and caribou can be displaced from preferred calving grounds by disturbance (Joly and Klein 2011; Wolfe et al. 2000). Human activities may result in increased vigilance, avoidance behaviors, and redistribution of animals (Wolfe et al. 2000). Human harvest tends to remove larger healthier animals, with sport hunters generally taking males and subsistence hunters taking both males and females.
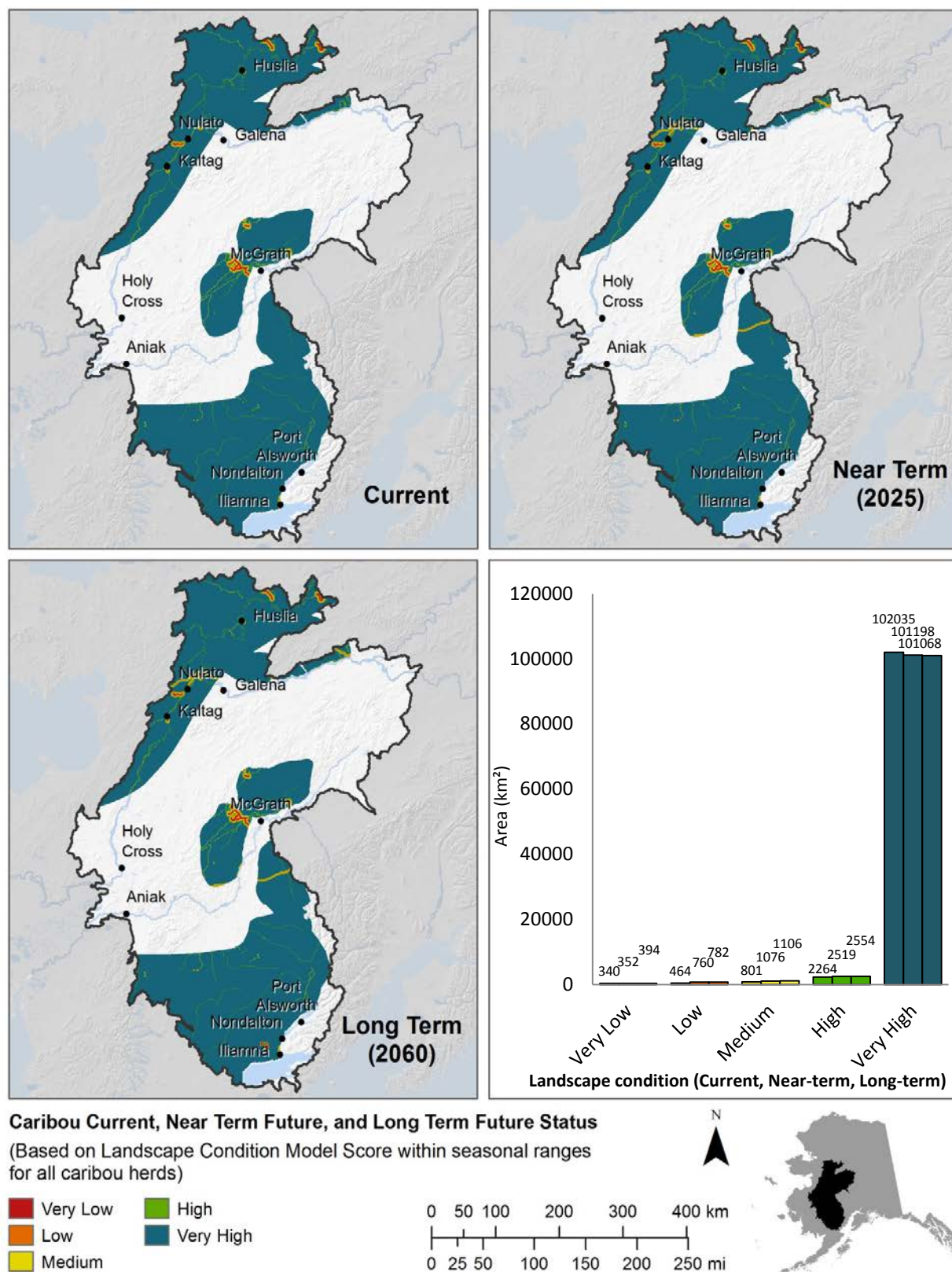
**Figure D-50.** Landscape condition modeled for current, near-term (2025), and long-term (2060) projections clipped to current caribou ranges in the YKL study area.

**Applications**

This section compiles detailed information about the eight caribou herds that use the YKL study area during some part of the year. It also answers three management questions as outlined by the BLM relating to calving distribution, migration movement and timing, and lichen availability. The seasonal range maps created for calving, summer ranges, and overall ranges, are a summary of data from numerous existing sources, which have been improved based on expert input and literature review.

The conceptual model and associated literature review help to identify the possible relationships of caribou to the various CAs, specifically the potential effects of climate change, fire, and other important drivers on caribou habitat. The conceptual models could help direct future modeling efforts and aid in current and future management decision making.

**Limitations and Data Gaps**

The spatial representation of caribou seasonal distribution is based on the best available information we could obtain, which was of very coarse scale. Empirical data were not available to develop our distribution models, with the exception of the Galena and Wolf Mountain herds. While empirical data are available for many of the other herds in the YKL study area and were requested for this analysis, we were not able to forge a data sharing agreement with the Alaska Department of Fish and Game within the timeframe of the REA. As a result, the distribution models are very coarse approximations of areas utilized by the species during different times of the year.

The same caveats apply to the assessment of migration corridors. Again, data presented are extremely coarse and should only be used to interpret the basic trends in direction of seasonal movements. Radio-collar data would greatly improve the accuracy and utility of both the seasonal distribution maps and the migration maps.

Not all lichen species are palatable or nutritious for caribou; however, the available vegetation maps do not distinguish areas with high cover of forage lichens from areas with high cover of other lichens.

Inferring climate effects on the distribution of caribou is complex, because the species often encounters a wide range of habitats during migration and dynamics are influenced by many 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). As discussed above under climate change effects, winter icing events have resulted in caribou mortality (Miller and Gunn 2003; Reid et al 2013). 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, at best.

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 (in the YKL some herds are non-migratory while others are migratory, some herds intergrade, while others are distinct), generalizations about where herds can and cannot thrive based on climate-driven modeling should be considered a hypothesis to be tested for plausible mechanisms with empirical data (Murphy et al. 2010).

Lastly, we lacked a suitable snow-depth layer for the REA that precluded examining the relationship of deep snow and the distribution of caribou and availability of lichen during winter. This data layer is also currently considered a data gap.

## 2.6.  Diseases in Ungulate Populations

| MQ 13 | What are the current types and potential impacts of diseases in ungulate populations (caribou and moose), and how are these impacts expected to change in the future? |
|---|---|



Climate change is influencing the structure and function of natural ecosystems around the world, including host-parasite interactions and disease emergence (Kutz et al. 2009). Both caribou and moose are subject to parasites and disease that have variable impacts on population health and stability. Parasites not only influence the health and sustainability of wildlife populations, they also affect the health and well-being of the people who depend on them for sustenance (Kutz et al. 2012).

Climate is an important factor determining the diversity and abundance of pathogens, as well as the patterns of disease they cause. Parasites can cause significant clinical and subclinical diseases in wildlife and consequently influence the dynamics and trajectory of wildlife populations. Therefore, understanding the influence of climate on pathogens is a key component to identifying conservation strategies (Kutz et al. 2009).

Parasites of arctic ungulates demonstrate a variety of traits that enable them to survive in an environment characterized by high seasonality, climatic and weather extremes, and generally low diversity and abundance of host species (Kutz e t al. 2012). Some of the characteristics that have ensured their success and often extensive distributions include freeze tolerance, arrested development, overwintering in/on hosts, large size and high fecundity, long life spans, and generalist life history tendencies.

A total of 19 threatening parasites have been documented in moose and caribou populations in Alaska (Table D-24). Major causes of infection include bacteria, biting flies and fly larvae, protozoa (GI, tissue and blood), nematodes, tapeworms, and viruses. Some infections are specific to either moose or caribou, while others have been shown to infect both species. Major impacts include decreased health and body condition and reduced reproductive success. Reduced fitness can directly result in increased mortality rates or indirectly as weakened animals become more susceptible to predation and hunting pressures.

**Future (Climatic) Impacts**



At high latitudes, accelerated climate change and extreme weather events can influence the ecology, impacts, and distribution of parasites, and lead to range expansions and emergence of new parasites (Kutz et al. 2012). 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). Impacts to parasites, bacteria and viruses may include increased survivability, decreased development times, and the introduction of new species (Polley et al. 2010). These changes will affect ungulate populations through increased disease exposure and infection rates, in combination with increased individual stress levels due to changing environmental conditions (Bradley et al. 2005).

Parasite species that overwinter as part of their development and life cycle are likely to benefit from warmer summers and shorter winters. In addition, longer summers may allow them to complete their development within one season and reduce the negative effects of winter mortality (Bradley et al. 2005; Hoberg et al. 2008; Kutz et al. 2009). Parasites with larvae that have temperature dependent stages of development will also benefit from warmer temperatures (Tryland 2012).

Insects, and therefore insect-borne diseases, are limited by temperature and often precipitation (Alto and Juliano 2001; Witter et al. 2012). Increases in either of these variables may increase insect-borne disease prevalence and infection (Bradley et al. 2005, Laaksonen et al. 2010, Tryland 2012). The same limitations of temperature and precipitation hold true for diseases that require snails as intermediary hosts (Martens et al. 1995).

Warming temperatures will likely allow the introduction of new parasites and disease through a northward expansion of current hosts (Bradley et al. 2005; Pickles et al. 2013). Diseases expected to expand northward or experience greater persistence with climate change include, but are not limited to: Leptospirosis (Bradley et al. 2005), winter ticks (*Dermacentor albipictus*; Rempel 2011), meningeal brain worm (*Parelaphostrongylus tenuis*; Vors and Boyce 2009) and liver fluke (*Fascioloides magna*; Murray et al. 2006).

**Table D-24.** Summary of ungulate parasites documented in Alaska. Field headers include the name and cause of the disease, symptoms, impact, intermediary host, and source(s) of transmission. Additional comments include known infestation range and climatic considerations.

| Disease | Cause | Symptoms | Impact | Intermediary host | Transmission | Additional comments | References |
|---|---|---|---|---|---|---|---|
| **Caribou** | | | | | | | |
| Besnoitiosis | Tissue and blood protozoa larvae; *Besnoitia tarandi* | Cysts, roughened bones and tendons, cutaneous lesions, lethargy | Increased susceptibility to hunting and predation; reduction in thermoregulatory abilities; decreased reproductive success. | Carnivores | Multiplies in herbivore, forms cysts containing spores. Carnivore eats meat of herbivore host and becomes infected. Parasite is excreted through carnivore feces and contaminates herbivorous forage. Transmission rates greater in the summer. | | ADF&G; Choquette et al. 1967; Ducrocq et al. 2013; Hilali et al. 1990; Kutz et al. 2012 |
| Hoof rot | Bacteria; *Spherophorous necrophorous* | Abscesses, swelling, limping | Increased susceptibility to hunting and predation. | Soil | Enters host through broken skin around hoof. Abscesses may also be found in other areas such as liver, lungs or mouth. | Observed in Mulchatna and Western Arctic caribou herds in 1990's; Can occur in any herd. Outbreaks are most severe during extended periods of rainy weather. | ADF&G; Valkenburg et al. 2003 |

| Disease | Cause | Symptoms | Impact | Intermediary host | Transmission | Additional comments | References |
|---------|-------|----------|--------|-------------------|--------------|---------------------|------------|
| Warbles | Warble fly larvae; *Hypoderma tarandi* | Weakness, swelling and fluid in tissue surrounding larvae; leg stamping, stress | Harassment and feeding interference for caribou. | Direct contact | Adult fly lays eggs on hair of caribou legs and lower body. Larvae hatch and penetrate the skin; travel under skin to animals back. Warbles grow there until early summer; break through skin and drop to ground. | Found on caribou throughout entire Alaskan range. Infections can range from 1 to 1000 warbles on each animal. | ADF&G; Ballesteros et al. 2012; Dieterich et al. 1980 |
| Nose bots | Bot fly (Oestridae) larvae; *Cephenemyia trompe* | Agitation | Reduced health, reduced reproductive success. | Direct contact | Larvae are deposited in caribou nostrils by female bot fly. Larvae attach and grow in a cluster in the caribou's throat near base of tongue. Larvae are sneezed out in the spring. | Freeze-tolerant; development is highly temperature dependent; development = 10C-30C with rate reaching max. @ 25C. Overall pupal period = 7-80 days. | ADF&G; Dieterich et al. 1980; Nilssen 2006; Hagemoen and Reimers 2002; Witter et al. 2012 |
| **Moose** | | | | | | | |
| Leg worm, foot worm | Nematode; *Onchocerca cervipedis* | Rarely any significant clinical symptoms; occasionally swelling, ulceration and hoof damage | Susceptibility to predation and hunters. | Insects: blackflies | Microfilariae produced by female parasites stay in skin and are ingested by vectors during feeding. | | Kutz et al. 2012 |
| Lymphatic worms | Nematode; *Rumenfilaria andersoni* | Blood vessel dilatation, lymphaedema, lymphangitis, granulomatous inflammation, fibrosis | Adult worms block the lymphatic vessels. | Insects | Parasites are ingested by vectors during feeding. | | Kutz et al. 2012 |

| Disease | Cause | Symptoms | Impact | Intermediary host | Transmission | Additional comments | References |
|---|---|---|---|---|---|---|---|
| Moose fly, hock sores | Biting fly; *Haematobosca alcis* | Wet open sores (up to 1" diameter) | Infection of open sores. | Direct contact | Development from egg to adult requires about 16 days at 21°C in the laboratory. Flies emerge from overwintered pupae in late spring (usually early June) and adults are active until late September. | Found wherever moose occur in Alaska. | ADF&G; Burger and Anderson 1974 |
| **Caribou and Moose** | | | | | | | |
| Brucellosis | Bacteria; *Brucella suis type 4* | Lesions, lameness, sterility, abortion | Reduced reproductive success; Increased susceptibility to predation. | | Highly contagious. Transmitted via afterbirth and fluids during calving. Predators are exposed when they feed on infected caribou. | Common in 4 caribou herds: Western Arctic; Teshekpuk, Central Arctic and Porcupine herds. | ADF&G; Dieterich et al. 1980; Neiland et al. 1968; |
| Cystic hydatid disease | Tapeworm larvae; *Echinococcus granulosus* | Lung cysts | Increased mortality and susceptibility to hunting and predation for infected moose. No significant impact on caribou pregnancy or weight. | Carnivores; rodents | Adult tapeworm grows and lays eggs in carnivores intestine. Eggs are excreted in feces, contaminates herbivore forage. Larvae hatch and travel to herbivore lungs and form cysts. Carnivores eat lungs of infected ungulates. | Eggs can persist in cool, moist conditions. | ADF&G; Craig and Craig 2005; Kutz et al. 2012; Rausch 1959; Rausch and Schiller 1951; Sweatman and Williams 1963 |
| Lumpy jaw | Bacteria (normally found in mouth of healthy animals) | Swelling, abscesses | Interferes with animal's ability to eat. | Direct contact | Bacteria enters host through wounds in the mouth. | | ADF&G |

| Disease | Cause | Symptoms | Impact | Intermediary host | Transmission | Additional comments | References |
|---------|-------|----------|--------|-------------------|--------------|---------------------|------------|
| Tapeworm cysts | Tapeworm larvae; *Taenia krabbei, Taenia arctos, Taenia hydatigena* | Cysts in muscle, heart, liver, omentum, peritoneal cavity, tongue, oesophagus | Poor body condition, tissue damage in liver. | Carnivores | Adult tapeworm grows and lays eggs in carnivore intestine. Eggs are excreted in feces, contaminates herbivore forage. Larvae hatch and travel to herbivore blood and other body parts where they form cysts in the muscle. Carnivores eat muscles of infected ungulates. | Adult tapeworm can live in carnivorous host (wolves, lynx, bears and dogs) without causing any harm. | ADF&G; Craig and Craig 2005; Haukisalmi et al. 2011; Kutz et al. 2012 |
| Rabies | Virus, type species of *Lyssavirus* genus of the *Rhabdoviridae* family | Fever, anxiety, agitation, hypersalivation, hydrophobia | Infection of central nervous system causing disease in brain and death. | Direct contact; Carnivores | Saliva of infected animals. | | Ballard et al. 1997; Dieterich et al. 1980; Dieterichet and Ritter 1982 |
| Toxoplasmo sis | Parasite; *Toxoplasma gondii* | Tissue cysts, abortion, fetal abnormalities, decreased appetite, haemorrhagic diarrhoea | Decreased life-time reproductive success. | Lynx* | | * Felids are typically the main intermediary host. Lack of free-ranging house cats in the arctic, *Lynx are expected to be a prominent intermediary host. Research into other hosts is needed. | ADF&G; Stieve et al. 2010; Zarnke et al 2000; Zarnke et al. 2001 |

| Disease | Cause | Symptoms | Impact | Intermediary host | Transmission | Additional comments | References |
|---------|-------|----------|--------|-------------------|--------------|---------------------|------------|
| GI Nematodes | Nematodes; *Marshallagia marshalli; Ostertagia gruehneri; Teladorsagia boreoarcticus; Teladorsagia circumcincta; Nematodirella longissimespicula ta; Nematodirus tarandi; Skrjabinema tarandi; Nematodirella alcidis* | Decreased food intake, weight loss, reduced pregnancy rates | Lower survival and reproduction rates. | Direct contact | Contact with oocytes in the environment. | | Kutz et al. 2012 |
| Lung worms | Nematodes; *Varestrongylus* sp.n.*; Dictyocaulus eckerti; Setaria yehi* Caribou specific: *Parelaphostrongy lus andersoni*; Moose specific: *Onchocerca cervipedis* | Coughing or difficulty breathing, general weakness, malnourishment, dull hair coat | Increased susceptibility to hunting and predation. | Snails, slugs (for some lung worm spp.). Not all lungworms need snail/slug intermediate host. Develop directly on vegetation. | Adult tapeworm lay eggs in lungs of host. Eggs hatch in host lungs. Larvae are coughed up, swallowed and excreted in host feces. Some lungworm larvae are taken up by a snail or slug where they develop into an infective stage. Infected snails/slugs are eaten on herbivore forage; larvae penetrate herbivore's intestines and travel to lungs where they develop into adults. | | ADF&G; Becklund and Walker 1969; Kutz et al. 2012; Verocai et al. 2013 |

| Disease | Cause | Symptoms | Impact | Intermediary host | Transmission | Additional comments | References |
|---|---|---|---|---|---|---|---|
| Rumen fluke | Trematode; *Paramphistomum cervi* | Diarrhea and denudation. Clinical signs generally uncommon | Increased susceptibility to hunting and predation. | Aquatic snails | Miracidia develop in eggs, hatch and develop into cercaria in aquatic snail hosts. Ungulates are infected in the summer and flukes mature by following spring, breed and die by autumn. | Growth process is temperature dependent. More prevalent in adult moose than calves or yearlings. Snail hosts limit abundance and distribution at northern latitudes. | Kutz et al. 2012 |
| Giardia | GI protozoa; *Giardia* species | Diarrhea, dehydration, weight loss* | Calf health and herd performance. | Waterborne | Animals consume giardia cysts in water. | Water-borne parasite; can also be transmitted through vegetation. Multiple freeze-thaw cycles may cause high parasite mortality. | Kutz et al. 2012 |
| GI issues | GI protozoa; *Cryptosporidium* species | Diarrhea, lethargy, decreased milk production, lower calf weights | Reduced reproductive success; Increased susceptibility to predation. | Waterborne | Animals consume giardia cysts in water. | Oocysts are freeze-intolerant; therefore, transmission may be temperature dependent. | Kutz et al. 2012; Siefker et al. 2002 |
| Neospora infection | Tissue and blood protozoa*; Neospora caninum* | Abortion, neonatal mortality, lesions on lungs, liver and kidney | Reduced reproductive success and potential population decline. | | Carnivores (canids; predator-prey); or Mother-to-fetus - transplacental. | Carried by red and arctic fox; range expansion may have implications for this disease. | Maley et al. 2006; Kutz et al. 2012; Stieve et al. 2010 |

## 2.7.  Muskox (Ovibos moschatus)
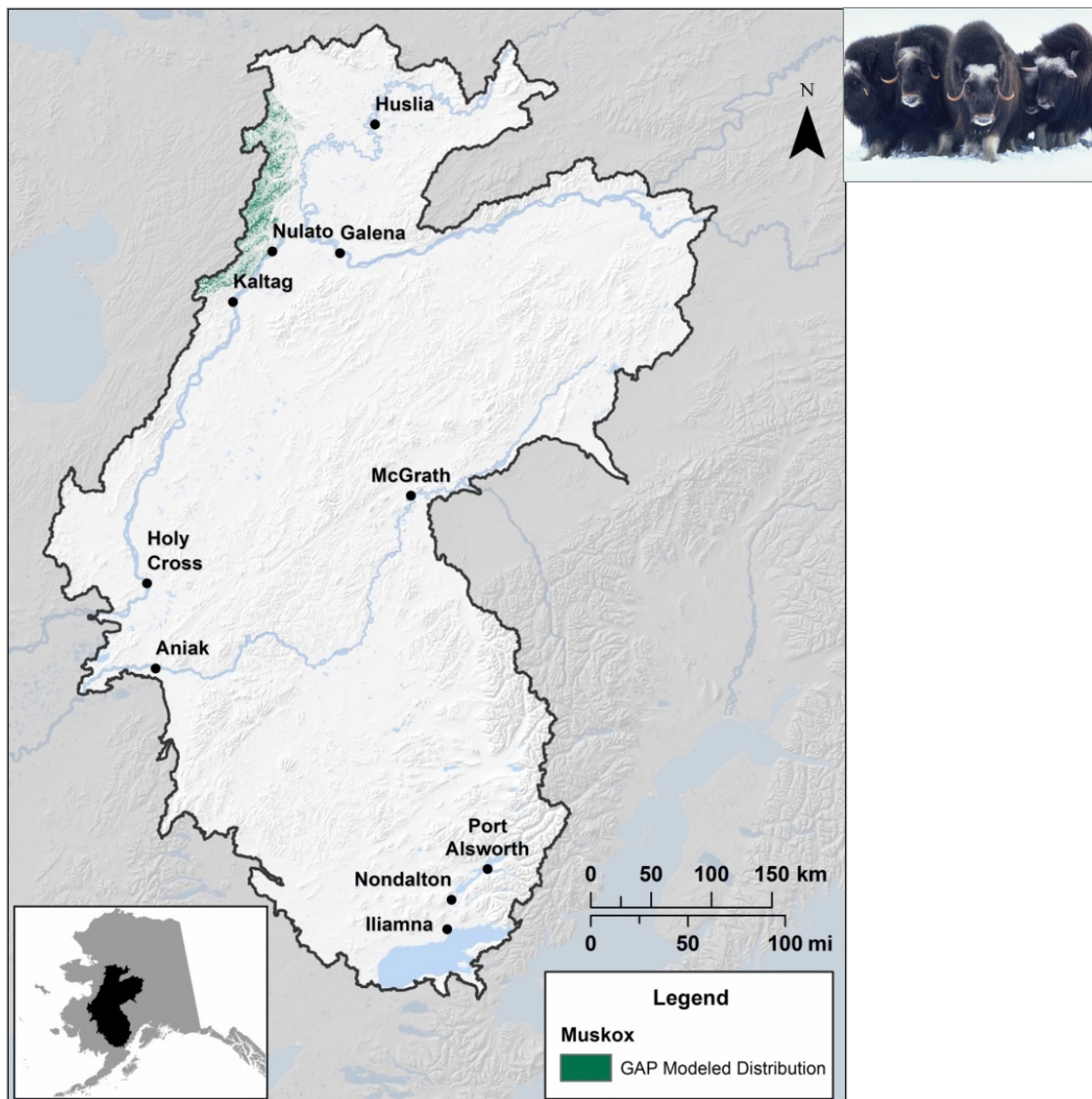


**Figure D-51.** Modeled distribution of muskox in the YKL study area.

Historically, Muskox (*Ovibos moschatus*) occupied arctic tundra habitats in Alaska, but disappeared from the state by the late 1800s and may have disappeared from the Seward Peninsula hundreds of years earlier (ADF&G 2011). In 1970, 36 muskoxen were reintroduced to the southern portion of the Seward Peninsula from Nunivak Island. An additional 35 muskoxen from the Nunivak Island herd were translocated to the existing population in 1981. Since 1970, this population has grown at about 14% per year, and in April 2010 the population was estimated at 2,903 (95% CI; 2,690 to 3,271) animals (ADF&G 2011).

Muskoxen have extended their range to occupy suitable habitat throughout the Seward Peninsula. In the northern portion of their range, herds have extended into the Nulato Hills and as far east as Ruby on the Yukon

River (ADF&G 2011). This recent expansion of their range into the YKL study area is of interest to researchers and managers. There is widespread concern across the arctic about the displacement of caribou by muskox, and these concerns cannot be dismissed. Caribou and muskox eat some of the same forage species, but widespread competition for habitat has not been documented on the Seward Peninsula or Nunivak Island (ADF&G 2011).

The breeding season begins during late summer, with mating taking place between August and October. Single calves are born between April and June to cows older than two years old. Winter herds may include as many as 75 animals. Smaller, harem groups form during the mating season containing from 5 to 15 females and sub-adults, with one dominant bull. Bulls excluded from breeding season herds wander widely in search of a harem but generally rejoin mixed sex herds during winter.

**Conceptual Model**

The conceptual model below (Figure D-52) is based on literature review and describes the relationship between the various change agents and natural drivers for musk ox. The boxes and arrows represent the state of knowledge about muskox and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and muskox. Change agents selected for this REA and considered in this analysis include: Climate change, Wildland fire, Insects and disease, Land use change (i.e. human development) and Harvest pressure.
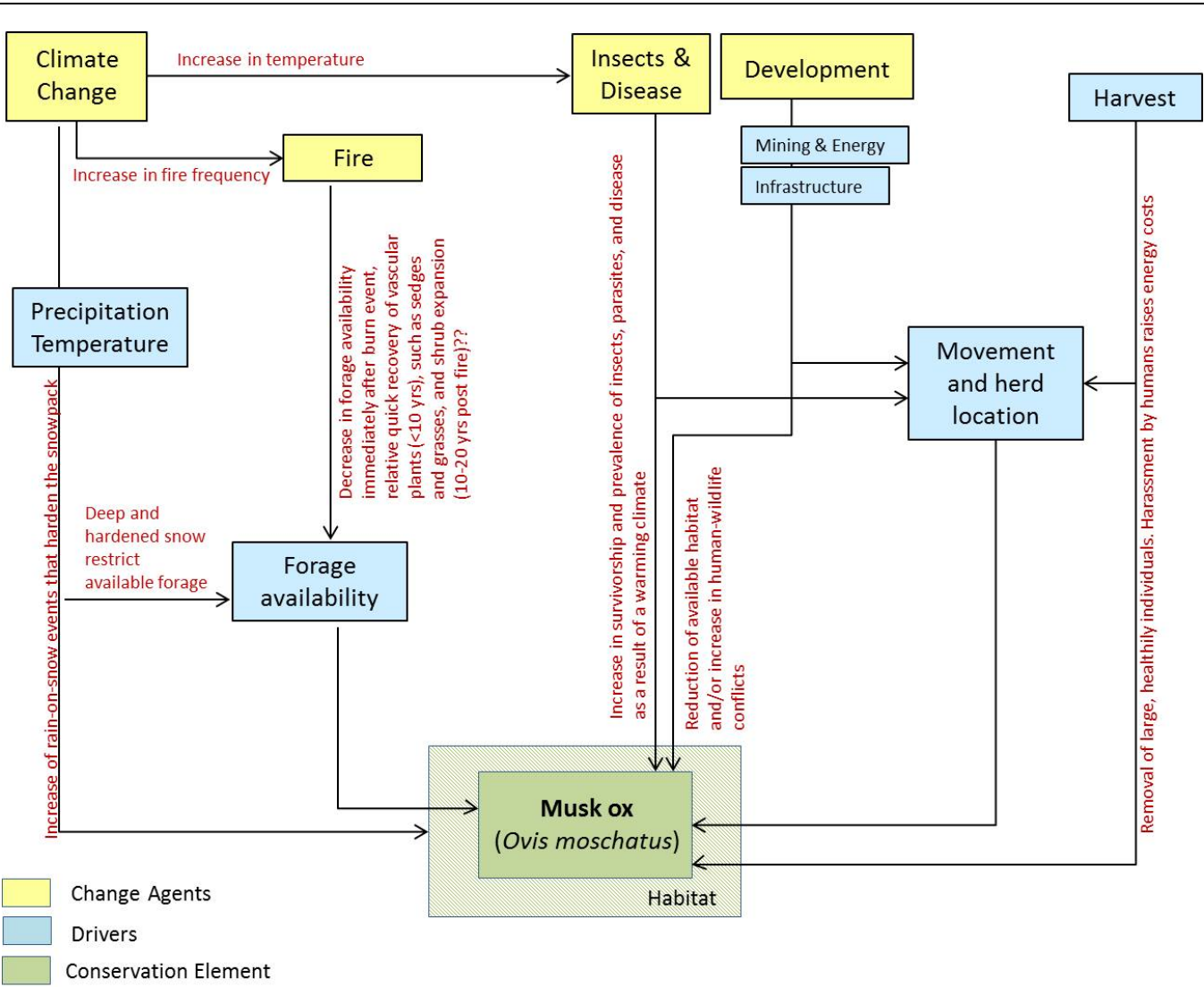
**Figure D-52.** Muskox (*Ovis moschatus*) conceptual model.

**Potential Muskox Habitat**

| MQ 8 | Is there muskox habitat in the region, and if so, how might it change in the future? |
|------|-------------------------------------------------------------------------------------|

Muskox diet is primarily comprised of sedges and grasses and to a lesser extent forbs, mosses, and willow species (Parker and Ross 1976, Wilkinson et al. 1976, Oakes et al. 1991, Smith 1994). In summer they prefer riparian/floodplain sites, and to a lesser extent upland shrublands and tussock tundra (Wilkinson 1976). In winter they also use dunes, bluffs (Bos 1967), dry ridges, and areas of low snow accumulation. Preferred vegetation types are beach-forb meadows, wet sedge tundra (Bos 1967), moist tundra and shrublands. In winter, they often use graminoid and lichen dominated habitats in areas with minimal snow accumulation, such as hilltops, slopes, and plateaus (Ihl and Klein 2001, MacDonald and Cook 2009). In upland wintering areas, muskox face a trade-off between suitable snow conditions and graminoid abundance. In some areas, muskox

will utilize lichen dominated habitats that occur in exposed areas with lower snow accumulation levels (Ihl and Klein 2001). Abundance and distribution of sedge-producing meadows may control regional abundance and distribution of muskox.

Winter movements of muskox are more limited by snow compared to other arctic ungulate species (e.g., caribou) because of their lower chest height, smaller hooves, and greater foot loading (Smith 1989, Klein 1992). Muskox select feeding sites that are in areas with shallower and softer snow than surrounding areas. These feeding sites are often located on ridges and bluffs with topographic relief and wind that redistributes the snow (Wilson and Klein 1991).

***Methods***

We used the Vegetation Map and Classification of Northern, Western, and Interior Alaska (Boggs et al. 2012) to identify muskox habitat. Forage quality was assigned as either "good", "moderate" or "poor" to each of the map classes. Forage quality was subjectively based on descriptions of habitat preferences from the literature review (Bos 1967, Parker and Ross 1976, Wilkinson et al. 1976, Oakes et al. 1991, Smith 1994, Ihl and Klein 2001). We identified three vegetation classes as good quality forage, eight classes as moderate forage, and 12 classes as being poor quality forage (Table D-25). We also provide a table outlining preferred environmental factors for muskox (Table D-26). Floodplain was the only environmental factor used in the analysis and was assigned moderate habitat quality because of the presence of willow and sedges. See the Terrestrial Coarse-Filter CE section D-1 for methods describing how the floodplains were delineated. Other environmental factors included in Table D-26 (i.e. river bluffs, dunes) were not mapped and were therefore not applied to this analysis. They are presented for descriptive purposes and to better understand muskox habitat needs.

**Table D-25.** Muskox winter and summer browse and forage quality. Diet contains similar vegetation types in summer and winter (Wilkinson et al. 1976).

| Vegetation Class | Forage Quality | Comment |
|---|---|---|
| White Spruce or Black Spruce (Open-Closed) | Poor | Typically not found in forests |
| White Spruce or Black Spruce (Woodland) | Poor | Typically not found in forests |
| White Spruce or Black Spruce-Deciduous Forest (Open-Closed) | Poor | Typically not found in forests |
| White Spruce or Black Spruce/Lichen | Poor | Typically not found in forests |
| Deciduous Forest (Open-Closed) | Poor | Typically not found in forests |
| Tall Shrub (Open-Closed) | Moderate | Willow is good browse |
| Low Shrub | Moderate | Willow is good browse |
| Low Shrub/Lichen | Poor | *Betula nana* is poor browse |
| Dwarf Shrub | Moderate | Willow and sedges good forage |
| Dwarf Shrub-Lichen | Moderate | Willow and sedges good forage |
| Tussock Tundra (Low Shrub or Herbaceous) | Moderate | Willow and sedges good forage |
| Herbaceous (Aquatic) | Poor | Use of aquatic plants unknown |
| Herbaceous (Marsh) | Poor | Water depth may be too deep |
| Herbaceous (Wet) | Good | Sedges are primary forage |
| Herbaceous (Mesic) | Good | Sedges are primary forage |
| Moss | Moderate | Willow and sedges good forage |
| Lichen | Moderate | Willow and sedges good forage |
| Sparse Vegetation | Moderate | Willow and sedges good forage |
| Bare Ground | Poor | |
| Freshwater or Saltwater | Poor | |
| Ice-Snow | Poor | |
| Fire Scar | Poor | Unknown |
| Unclassified | Poor | Unknown |
| Urban, Agriculture, Road | Poor | Unknown |

### Results and Discussion

Approximately 4% of the YKL study area has 'good' forage habitat quality (Figure D-53), primarily in lowlands. Approximately 34% of the study area has 'moderate' forage quality. The non-forested portions of floodplains occur throughout the study area with a total floodplain area of 8% for the YKL study area. Tall shrub covers 6%, low shrub covers 11%, tussock tundra covers 3%, dwarf shrub covers 7% and, moss, lichen and sparse vegetation classes combined cover less than 1% of the YKL study area. In general, moderate to good quality habitats for muskox occur in much of the YKL study area, primarily in the western and southern regions, and along the non-forested portions of floodplain corridors.

**Table D-26.** Muskox winter and summer preferred environmental factors.

| Preferred Environmental Factors |
| --- |
| **Winter** |
| Low snow accumulation |
| Shelter from wind<br><br>• Floodplains<br><br>• River bluffs<br><br>• Dry ridges<br><br>• Bluffs<br>• Dunes |
| Low angle slopes |
| **Summer** |
| Floodplain/riparian |
| Occur in all landscapes except steep mountains |
| Low angle slopes |
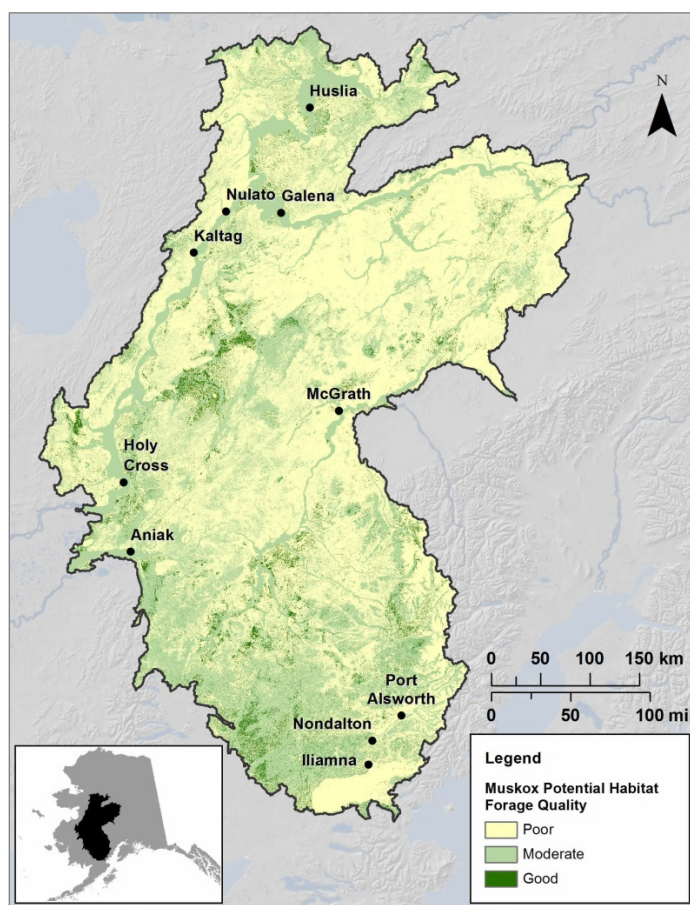


**Figure D-53.** Potential muskox habitat with associated forage quality index (good, moderate, poor) for the YKL study area.

*Future Projections*

We used the cliome projections (see Cliomes Section B-1) to evaluate the effect of climate on future muskox habitat. The final stage of the cliome analysis included grouping land cover types into those that might be considered preferred (herbaceous wetland), moderate (tall, low, and dwarf shrub or sparse vegetation), or undesirable (all other categories) as muskox habitat. We then assessed, for the entire REA, how these categories might increase or decrease. Model outputs of potential change in muskoxen forage habitat are shown in Figure D-54.
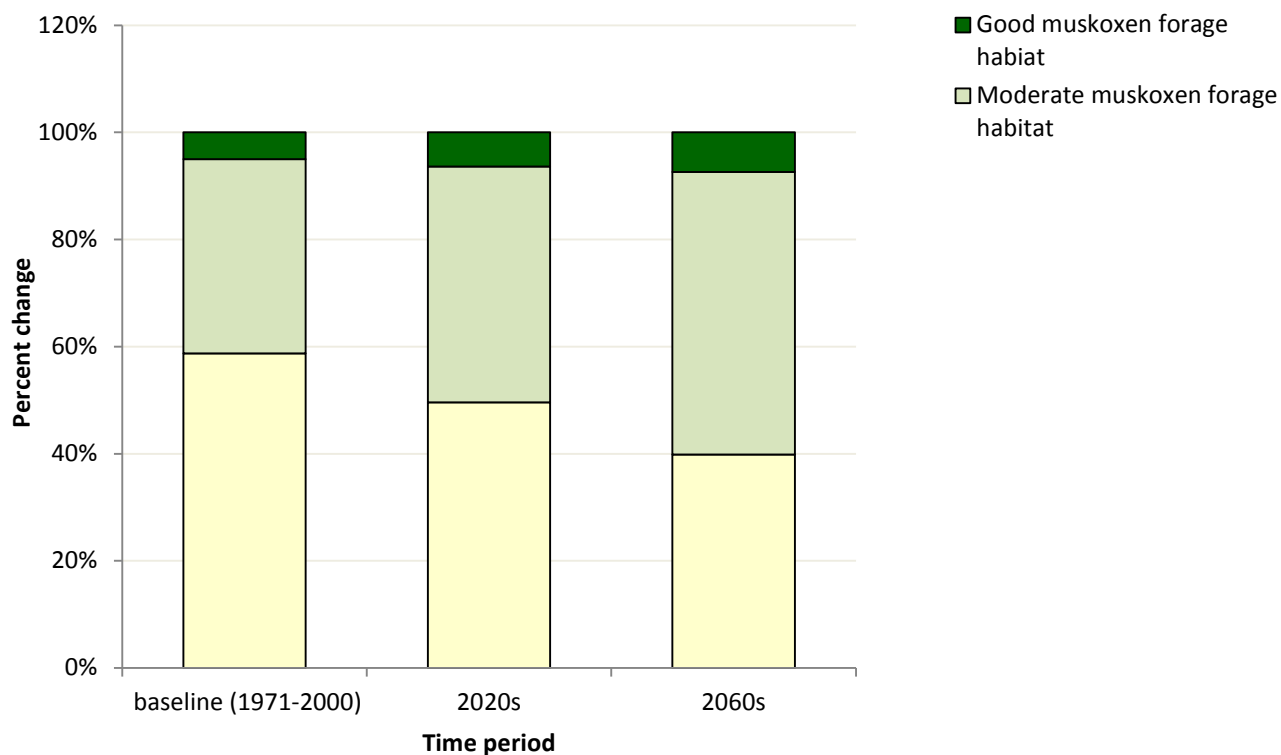


**Figure D-54.** Projected percentage change between the baseline time period and 2060 in cover types that might serve as habitat for muskox for the entire REA.

The cliome projections suggest that muskox habitat will improve at both the near-term (2025) and long-term (2060) time scales. This is primarily because these projections indicate a dramatic decrease in forested classes that is considered poor muskox habitat. Vegetation classes associated with moderate forage quality classes including tall shrub, low shrub, tussock tundra, and dwarf shrub are projected to increase. Good muskox habitat (herbaceous classes) is also predicted to increase slightly. Whether the vegetation communities will in fact respond to the projected changes in climate as suggested by the cliome analysis is debatable (see discussion in Terrestrial Coarse-Filter CEs D-1) and additional uncertainty is imbedded in the assumption of forage quality being a primary driver of muskox populations in this region.

## Climate

Warmer temperatures in winter will likely result in an increase in freeze-thaw cycles and the number of rain-on-snow (icing) events. These events harden the snowpack making travel to foraging areas more difficult and energetically costly (Forchhammer et al. 2002, Putkonen and Roe 2003). Since muskox fuel spring lactation with winter fat reserves, winter foraging and fat accumulation is essential to reproductive success (Parker and Ross 1976, White et al. 1989).

Climate change is likely to cause an amplification of parasite populations through increased rates for development, reduction in generation times, and broadened seasonal windows for transmission (Hoberg et al. 2001). In particular, warmer temperatures will likely benefit bacteria and parasites that are limited by temperature. Additionally, insects that harass animals and transmit disease agents may also benefit from climate change. Host species that are already physiologically and energetically stressed from other change agents (as a result of other factors of climate change) will likely be more vulnerable to disease agents (Bradley et al. 2005).

## Fire

On the tundra, the overall biomass of forage species is reduced immediately following a burn; however, bryophytes, grasses, and sedges recover relatively quickly (in less than 10 years). In the second and third decades following the burn, shrub coverage expands rapidly, sometime to levels greater than before the fire. There is very little recovery of sphagnum moss and fruticose lichens the first 24 years after fire (Racine et al. 2004). An increase in fire frequency will likely be less detrimental to muskox in comparison to caribou, as muskoxen are more dependent on graminoid species that recover quickly after fire.

## Applications

This section provides managers with a current predicted distribution model for muskox in the YKL study area. It also provides a map of potential habitat, should muskox continue to expand their range into the YKL REA. The recent and apparently continued range expansion of muskox into the YKL study area is of interest to managers, as there is some speculation that muskox could displace caribou by competing for similar forages. Cliome analysis indicate that the climate will be more favorable for increases in tall shrub, low shrub, tussock tundra, and dwarf shrub habitats in the YKL study area, which are all considered of moderate forage quality to muskox. The current distribution model for muskox is currently constrained by available empirical data, but the predicted habitat distribution model is not. As such, there appears to be suitable habitat available for muskox, should they expand their current range to the east of the Nulato Hills. Other topographic features, such as elevation, aspect, slope, or terrain ruggedness were not considered in this assessment, but also likely play a large role in their range expansion.

## Limitations and Data Gaps

Empirical data used to develop the current muskox distribution model were limited in scope. Muskox survey data are available for the Nulato Hills area and were requested for this analysis, but we were not able to forge a data sharing agreement with the Alaska Department of Fish and Game within the timeframe of the REA, and were not able to obtain the requested data. As a result, the muskox distribution models lack the most recent

survey data for the Nulato Hills and likely underrepresent the predicted distribution for the northern quadrant of the REA.

## 2.8.  North American beaver (*Castor canadensis*)
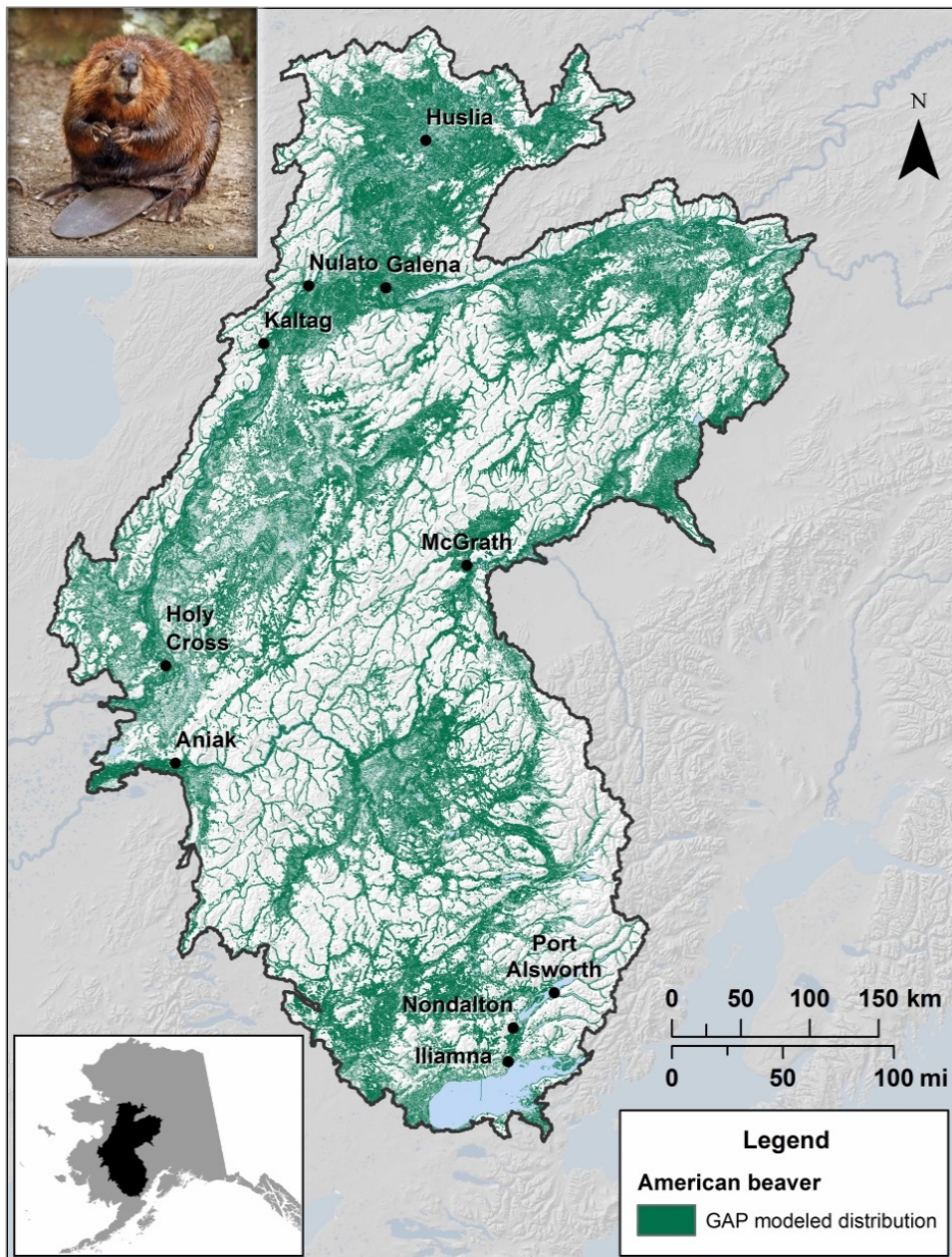


**Figure D-55.** Current habitat distribution modeled for American Beaver in the YKL study region.

The North American beaver is a semi-aquatic mammal, and a strong driver of ecosystem processes (Pollock et al. 1995, Rosell et al. 2005). Beavers are unique in their ability to create and modify their habitat by building dams. Because they exert such a strong influence on aquatic and riparian communities, the beaver is considered a keystone species. Maintaining healthy beaver populations is generally considered desirable because of the beaver's capability to restore and maintain healthy riparian ecosystems. Their removal can lead to loss of habitat for other species and reductions in ecological integrity.

Beaver are widely distributed across mainland Alaska and occur extensively throughout central Alaska (MacDonald and Cook 2009). They are found at lower elevations throughout the YKL study area (Figure D-55).

Beaver create suitable habitat by constructing dams to restrict the flow of water and construct lodges and dens for protection from predation and weather. Beaver activity results in alterations to ecosystem structure and dynamics such as modification of channel geomorphology and hydrology; increased retention of sediment and organic matter; creation and maintenance of wetlands; modification of nutrient cycling and decomposition dynamics by wetting soils, by altering hydrologic regimes and by creating anaerobic zones in soils and sediments; modification of riparian zones, and influencing the character of the water and materials transported downstream (Baker and Hill 2003, Boyle and Owens 2007, Naiman et al. 1986). Beaver activities, if unmanaged, may influence 20 to 40% of the total length in 2nd to 5th order streams (Naiman et al. 1986).

Beaver typically forage in close proximity (within 200 m) to their lodge, and increase their foraging range as nearby resources are exhausted. In summer, their diet consists of herbaceous and deciduous woody vegetation, while during the rest of the year they primarily consume trees and shrubs they have stored in their winter cache (Allen 1983). Willow, aspen, cottonwood, and alder are preferred over other tree/shrub species (Boyles and Owens 2007).

**Conceptual Model**

The conceptual model below (Figure D-56) is based on literature review and describes the relationship between the various change agents and natural drivers for American beaver. The boxes and arrows represent the state of knowledge about the American beaver and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and American beaver. Change agents selected for this REA and considered in this analysis include: Climate change, Wildland fire, Land use change (i.e. human development) and Harvest pressure.
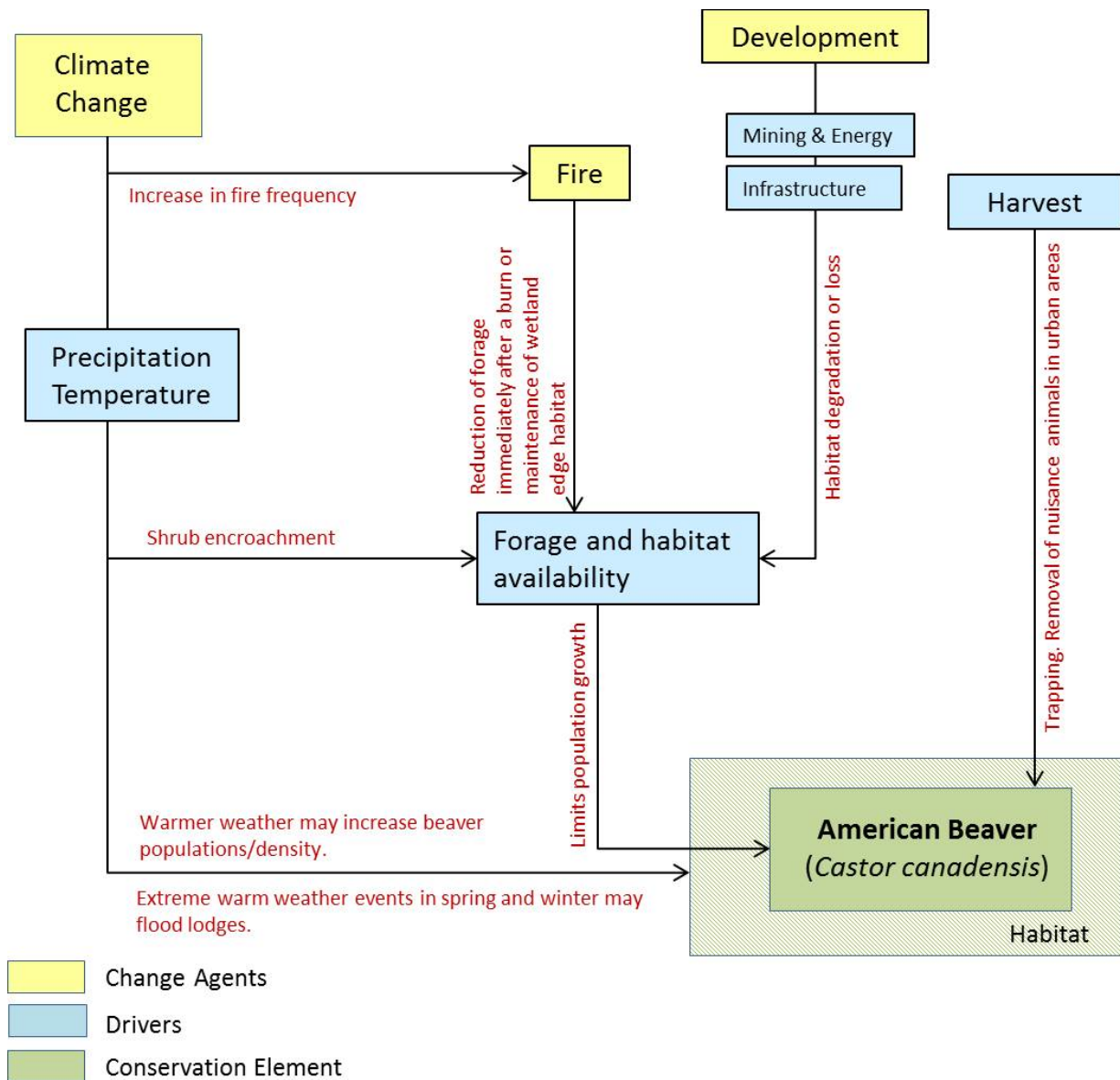
**Figure D-56.** American beaver (*Castor Canadensis*) conceptual model.

## Climate

Beaver densities are highly temperature dependent, and that dependency is non-linear. Although sparse populations are present above relatively low minimum temperature thresholds (average annual temperature above -5.1°C, maximum summer temperature above 15.2°C, and maximum spring temperature above -1.4°C), much greater densities occur in warmer locations (Jarema et al. 2009).
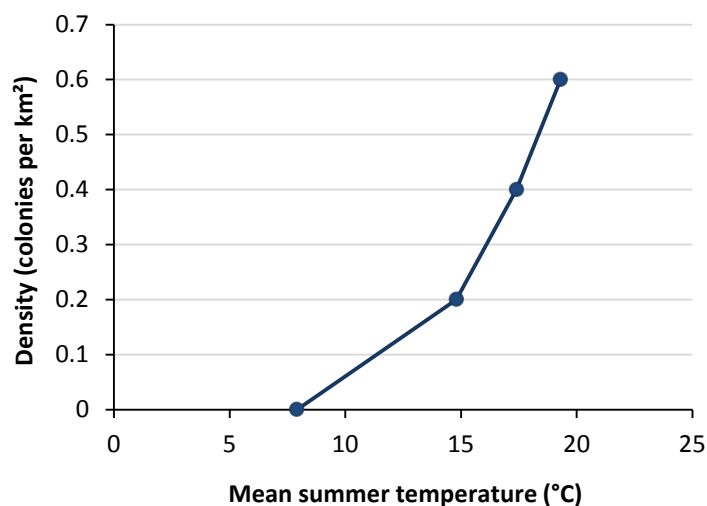
**Figure D-57.** Relationship between summer temperature and beaver density (Sampson and Murray, pers. comm., and Jarema et al. 2009).
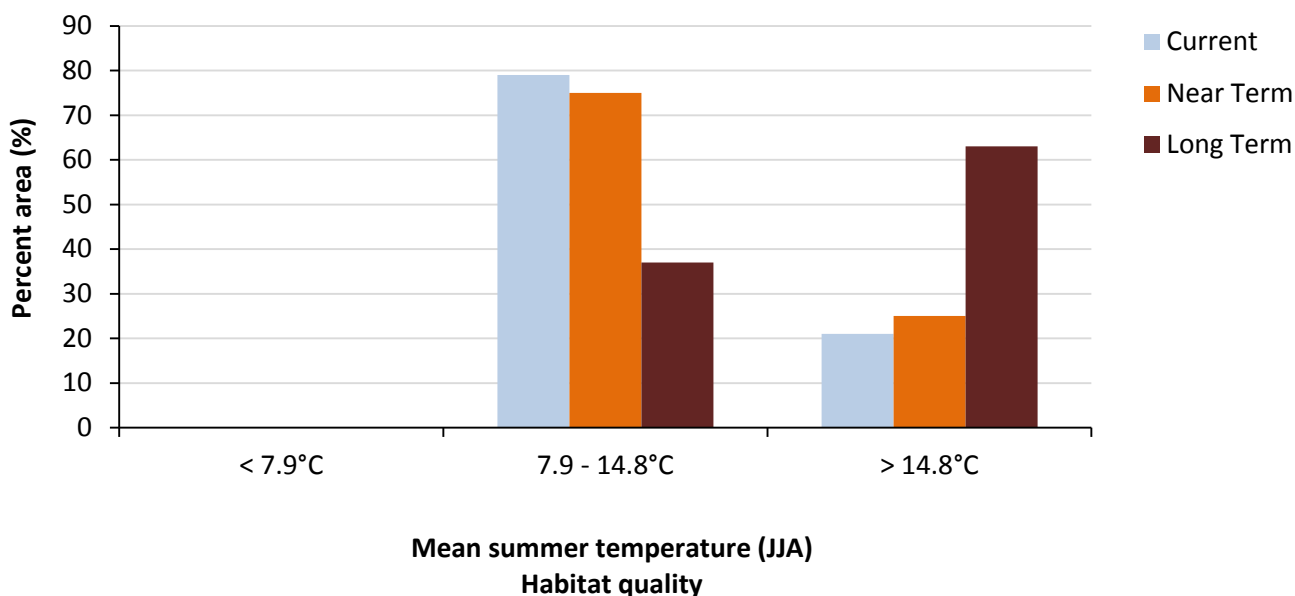


**Figure D-58.** Percent area of current beaver distribution in the YKL study region categorized by mean decadal summer (JJA) temperatures (°C) for current (2010), near-term (2025) and long-term (2060). Projections are modeled for the A2 Scenario. Temperature thresholds are indicative of poor ( <7.9°C), moderate (7.9 – 14.8°C) and good (>14.8°C) habitat as described by Jarema et al. 2009.

Increasing ambient temperatures as a result of climate change are likely to benefit beavers in the YKL study area. Data used in Jarema et al. (2009) and provided by Jason Sampson and Murray Humphries (pers. comm. 11/25/13) link beaver density to summer temperature ($r^2$=0.4926) as shown in Figure D-58.

Currently, most of the YKL study area meets the minimum summer temperature threshold (7.9°C) necessary for beaver presence. Climate models indicate that area with conditions that favor higher beaver densities (summer

temperature > 14.8°C) may more than double in parts of the YKL in the next 50 years as mean summer temperatures increase (Figure D-58). This effect will be most pronounced in the northern half of the REA, from McGrath northward (Figure D-59).

Increases in beaver population densities have implications for other wetland associated species. Beaver dams create ponds which maintain and create wetlands. This may result in increased habitat availability for waterfowl (e.g., trumpeter swan; Hansen et al. 1971). Beaver dams and ponds also contribute to the establishment of deep-rooted sedges, rushes, native hydric grasses, and woody riparian vegetation, thereby increasing habitat for numerous other mammals and birds.

Some adverse effects are associated with climate change including extreme warm weather events in winter and spring. Sudden snowmelt and violent ice breakups may raise water levels and destroy lodges and drown large numbers of beavers (Hakala 1952). In addition, increased ambient temperatures may cause the drying and warming of wetlands. However, beaver may be able to mitigate these effects with their ability to create and maintain areas of open water, which provide important habitat for many other species. Beaver are often able to regulate water levels in their ponds during cycles of drought and flooding, which result in more stable wetland systems that retain and slowly release water throughout the summer, have  cool deep water habitats, reduce erosion during high flow events, capture sediments, etc. (Hood and Bayley 2008, Bird et al. 2011).
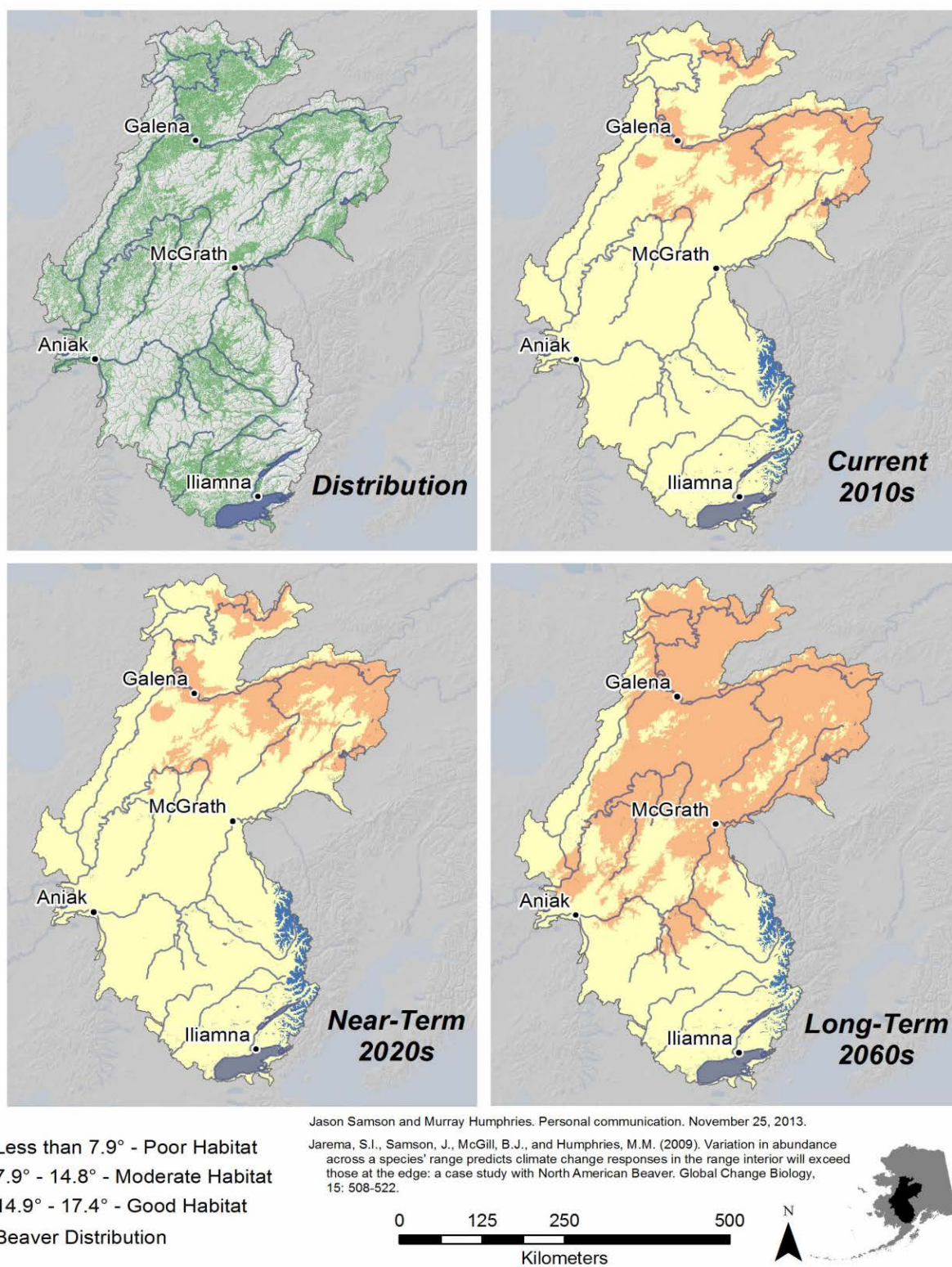
**Figure D-59.** Mean decadal summer (JJA) temperatures (°C) and beaver distribution thresholds modeled for the A2 Scenario.

**Fire**

Fire frequency and intensity are expected to increase within the YKL study area. Forest fire can have a negative effect on beaver populations and has been shown to cause reduced lodge occupancy in repeatedly burned areas (e.g., Canadian boreal forest; Hood et al. 2007). The reduction of woody vegetation in areas extensively burned reduces forage availability, increases foraging distances, and increases the risk of predation. However, fire does promote the regeneration of many woody plant species consumed by beaver and can be beneficial to beaver habitat (e.g., Slough and Sadleir 1977; Barnes and Mallik 2001). Furthermore, the anticipated northward encroachment of shrubs will likely provide additional food resources for beaver in the YKL area.  The overall benefits of this new growth likely depend on a combination of fire severity and frequency (Hood et al. 2007).

**Current Status and Future Landscape Condition**

Beavers typically occur in areas with low to moderate human activity and disturbance (Slough and Sadleir 1977). A potential landscape-scale threat to beavers is habitat fragmentation caused by development and associated water development projects. Urban development causes habitat degradation and loss, often through water storage, diversion, and channelization projects that change stream morphology and hydrology. Development in riparian areas can also result in complete loss of habitat or a reduction in food resources (Boyle and Owens 2007).

The majority of current beaver distribution in the YKL study area has very high landscape condition, although areas of "low" condition occur near McGrath and Galena (Figure D-60). Future projections of landscape condition suggest a decrease in habitat quality, with reduced landscape condition around Galena, McGrath and along both the Yukon and Kuskokwim river corridors. In general, with the predicted increase in suitable beaver habitat due to warming temperatures (see climate section above) and the relative intactness of the landscape, we suggest that future development will not have a major impact on beaver populations in the YKL study area.
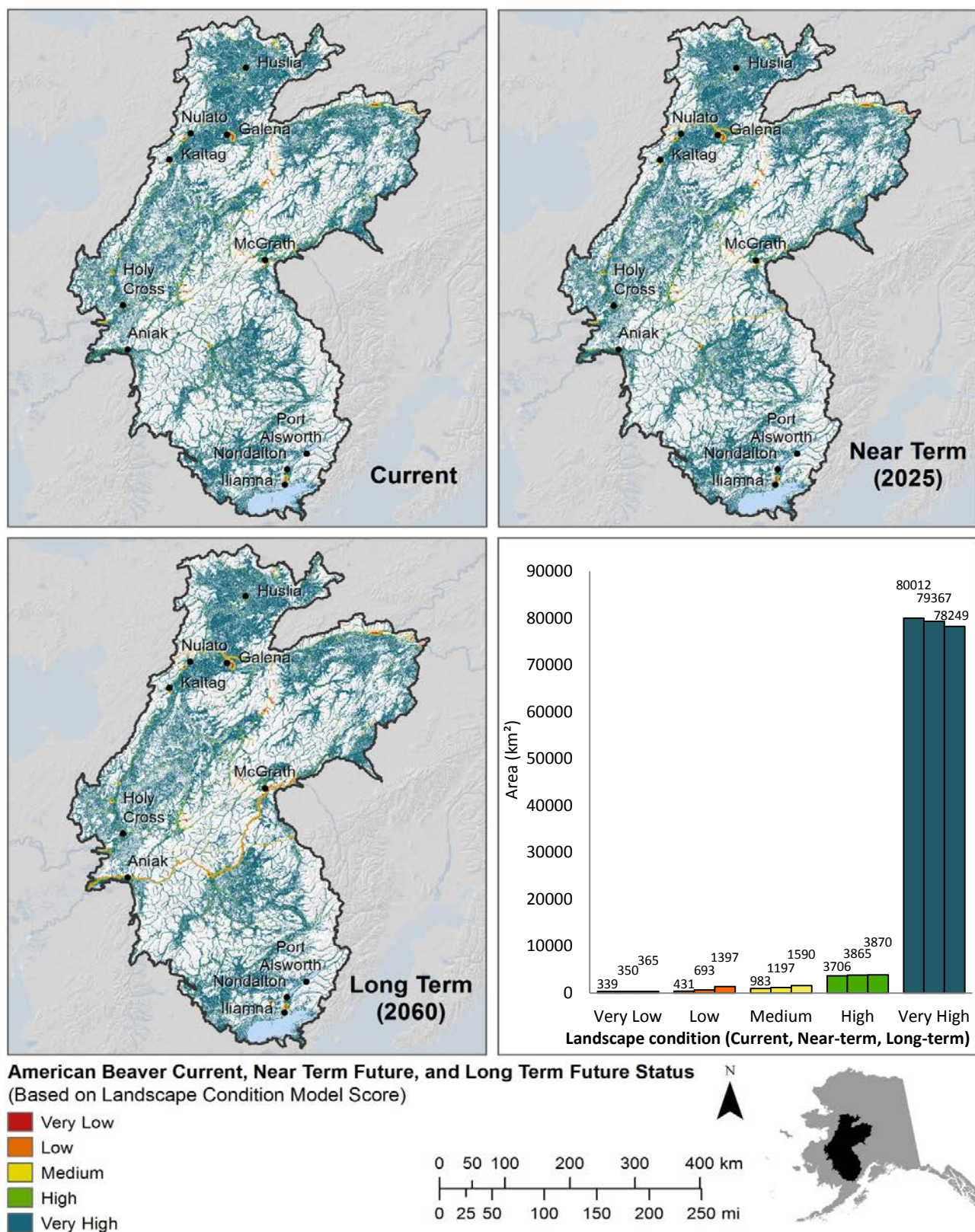
**Figure D-60.** Landscape condition modeled for current, near-term (2025), and long-term (2060) projections clipped to current American beaver habitat in the YKL study area.

**Applications**

The distribution maps created for American beaver provide managers and researchers with baseline information on their potential distribution within the REA, but do not relay specific information about beaver densities. Assessment of predicted climate change impacts on beaver indicate that densities are expected to increase with increasing summer temperatures and this effect will be most pronounced in the northern half of the YKL study area.

In drought susceptible areas, increases in beaver densities are considered beneficial and the species should be included in adaptive management strategies, as they are able to enhance the adaptive capacity of watersheds (Stein et al. 2013). However, high beaver densities can also result in the destruction of key bird habitat, and beavers can also be pests to humans. In Vermont, beaver densities increased by more than 130% from 1980 to 1990 due to a decrease in pelt values and a corresponding decrease in trapping pressure (VFWD 2004). While the creation of new dams and the expansion of dams within existing wetlands proved beneficial to a whole host of other wildlife species, it also created problems for humans, including: impoundments that threaten downstream property, upstream flooding of land, trees killed or damaged, contamination of water supplies, and impairments of drainage; impoundments that threaten downstream property; upstream flooding of land; trees killed or damaged; flooding of highways or railroads; contamination of water supplies; impairments of drainage; interference with the operation of septic systems; flooding of agricultural crops; and flooding of homes.

In Alaska, beaver are already expanding their distribution further north in response to climate induced habitat changes and increased access to woody plants. Complaints in Alaska generally relate to flooding during spring break-up, increasing giardia in the water supply and decreasing access to traditional subsistence areas by changing water flow characteristics of streams (ADF&G 2014b).

**Limitations and Data Gaps**

Unfortunately, existing baseline documentation on current density levels of beaver in the YKL study area is disparate. To our knowledge, estimates of beaver density and population status are currently assessed through trapper reports, as beaver are managed as furbearers by the Alaska Department of Fish and Game. Beaver cache surveys are also conducted in the Koyukuk/Nowitna Refuge complex, by the USFWS. Lack of long-term trend data limits our ability to assess changes over time in relation to the CAs.

## 2.9.  Gray wolf (*Canis lupus*)
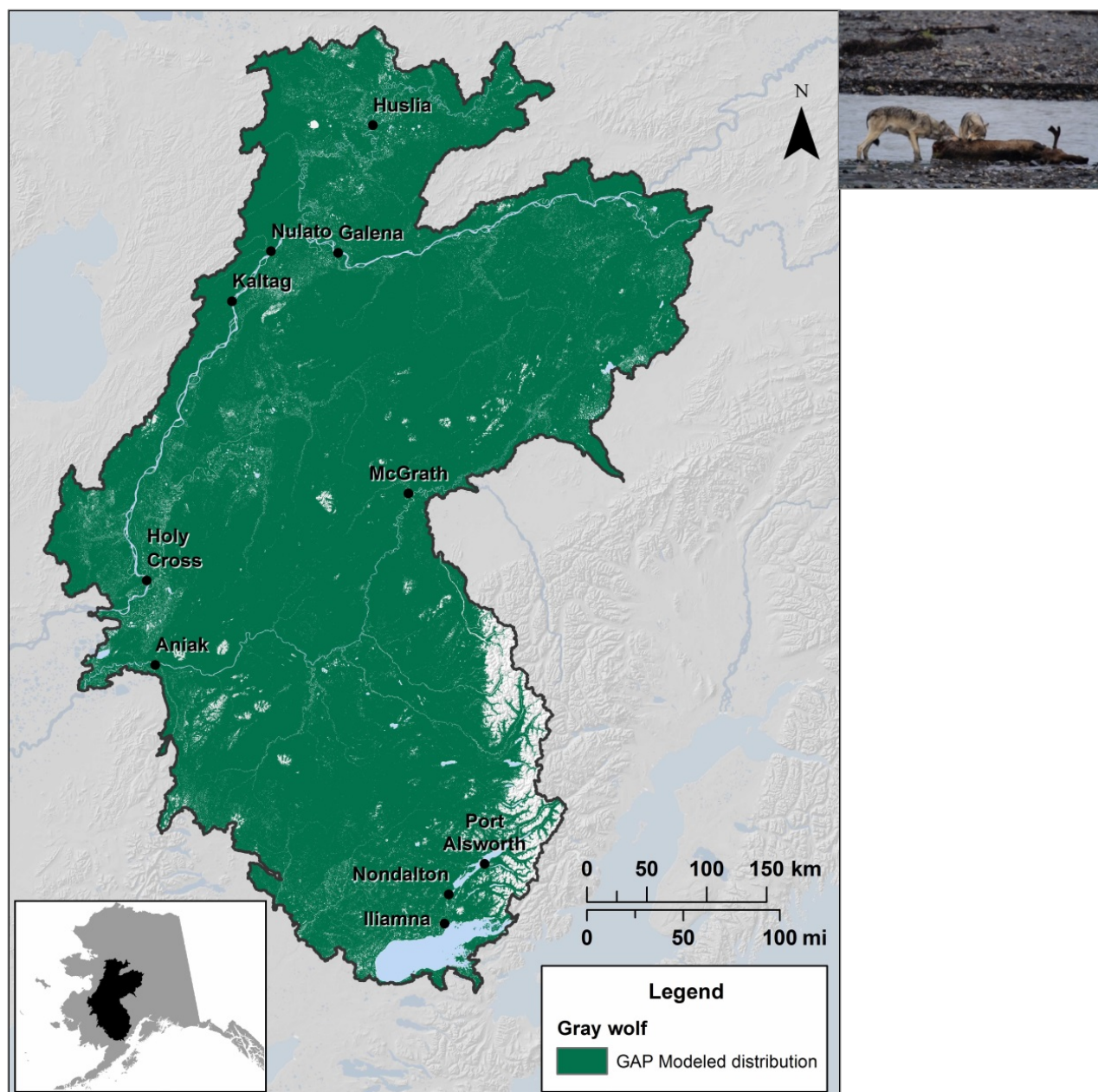


**Figure D-61.** Current habitat distribution modeled for Gray wolf in the YKL study region.

Gray wolves are distributed throughout Alaska, with a statewide population estimate of 7,000 to 11,000 individuals (ADF&G 2013c). Wolves are top level carnivores, and in most of mainland Alaska, moose and caribou are their primary source of food. Hence, habitat use by wolves is directly related to ungulate density (Ballard et al. 1987; ADF&G 2009). Although the distribution of wolves has remained relatively constant in recent times, their abundance has varied considerably as prey availability, diseases, and harvests have influenced their numbers (ADF&G 2009).

Wolves in Alaska breed from late February through early April and reproductive adult females have 6 to 7 pups per litter (Rausch 1967). Pack sizes average 6 to 7 members and can be as large as 20 to 30 individuals (ADF&G

2009). In spite of a generally high birth rate, wolves rarely become abundant because mortality is high. In much of Alaska, predation by other wolves and hunting and trapping are the major sources of mortality, although diseases, malnutrition, and accidents also act to regulate wolf numbers. Dispersing wolves are common and often find it hard to find suitable habitat that is not already occupied by other wolves (ADF&G 2009).

Wolves are hunted and trapped in Alaska with approximately 1,300 wolves harvested in the state per year and an additional 200 animals are taken by predator control programs (ADF&G 2013c). At the species level, the gray wolf has never been considered threatened or endangered in Alaska.  However, there is currently a petition to list the Alexander Archipelago wolf (*C. lupus ligoni*), native to southeastern Alaska, as threatened or endangered and to designate critical habitat under the Endangered Species Act (Federal Register Volume 79, No. 61).

**Current Population, Management, and Harvest Status for GMUs in the YKL Study Area**

Wolves are managed as both a big game species and furbearer by the Alaska Department of Fish and Game. Management Units that fall within the YKL study area include 9B, 17, 19 (all subunits), 21 (all subunits), and 24D (Figure D-62).
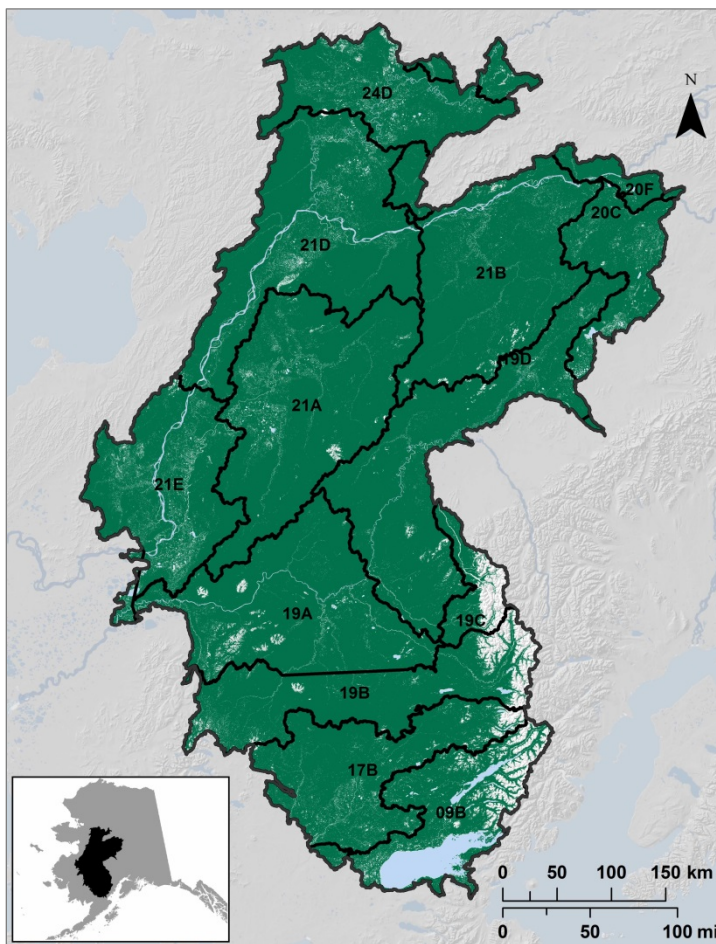


**Figure D-62.** Predicted distribution of wolf within the YKL study area overlain by Alaska Department of Fish and Game, Game Management Units (GMUs).

Population trends throughout the YKL study area are stable to increasing (Table D-27) and are highly dependent on prey densities (ADF&G 2009). Wolf control programs are active in a majority of the study area in an attempt to boost caribou and moose populations.

**Table D-27.** Summary of wolf population trend and population size by ADF&G Game Management Units (GMU) within the YKL study area. Adapted from ADF&G 2009.

| Geographic description | GMU | Population Trend | Population Size (2007-08) | Wolf control | Harvest (2003-08) |
|---|---|---|---|---|---|
| Alaska Peninsula | 9 (and 10) | Increased since 1990s | 350 – 550 wolves in **units 9 and 10.** | During 1950s; reinstated in 2008 to assist caribou calving survival (aerial). | 60 – 120 per year; Total = 498 |
| Northern Bristol Bay | 17 A, B, and C | Increasing since 1992 | *No official estimates, population numbers are based on observations.* **17A**: 20 – 30 wolves, 6 – 8 packs; **17B**: 280 – 320 wolves, 16 – 22 packs; **17C**: 150 – 200 wolves, 10 – 16 packs | No | Avg. annual harvest = 83; Total = 415 |
| Drainages of Kuskokwim River upstream from the village of Lower Kalskag | 19 A, B, C, and D | Dependent on ungulate density | 382 – 454 wolves, 65 – 80 packs (*autumn estimates for whole unit*) | Long history of aerial control. Currently supported to assist moose populations. | 50 – 140 per year; Total = 500 |
| Drainages of the Yukon River from Paimiut upstream to, but not including Blackburn Creek drainage; and the Innoko River drainage | 21 A and E | Stable | **21A**: 240 – 320 wolves, 35 – 46 packs; **21E**: 146 – 156 wolves, 19 – 25 packs; **21A and E**: 386 – 476 wolves, 54 – 71 packs | Encouragement of increased local harvest. | 5 – 25 per year; Total = 112 |
| Yukon River drainage above Paimiut to Tozitna River, including Koyukuk River up to Dulbi Slough and Nowitna River drainage | 21 B, C, and D | Stable | 442 – 771 wolves, 52 – 80 packs | During 1940s and 1950s; not currently. | 48 – 116 per year (estimated); Total = 321 (estimated); Total = 206 (reported) |
| Koyukuk River drainage above Dulbi River | 24 | Stable; dependent on ungulate density | 374 – 541 wolves, 57 – 68 packs | No | 53 – 87 per year (estimated); Total = 387 (estimated); Total = 197 (reported) |

## Conceptual Model

The conceptual model below (Figure D-63) is based on literature review and describes the relationship between the various change agents and natural drivers for gray wolf. The boxes and arrows represent the state of knowledge about gray wolf and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and gray wolf. Change agents selected for this REA and considered in this analysis include: climate change, wildland fire, land use change (i.e. human development) and harvest pressure.
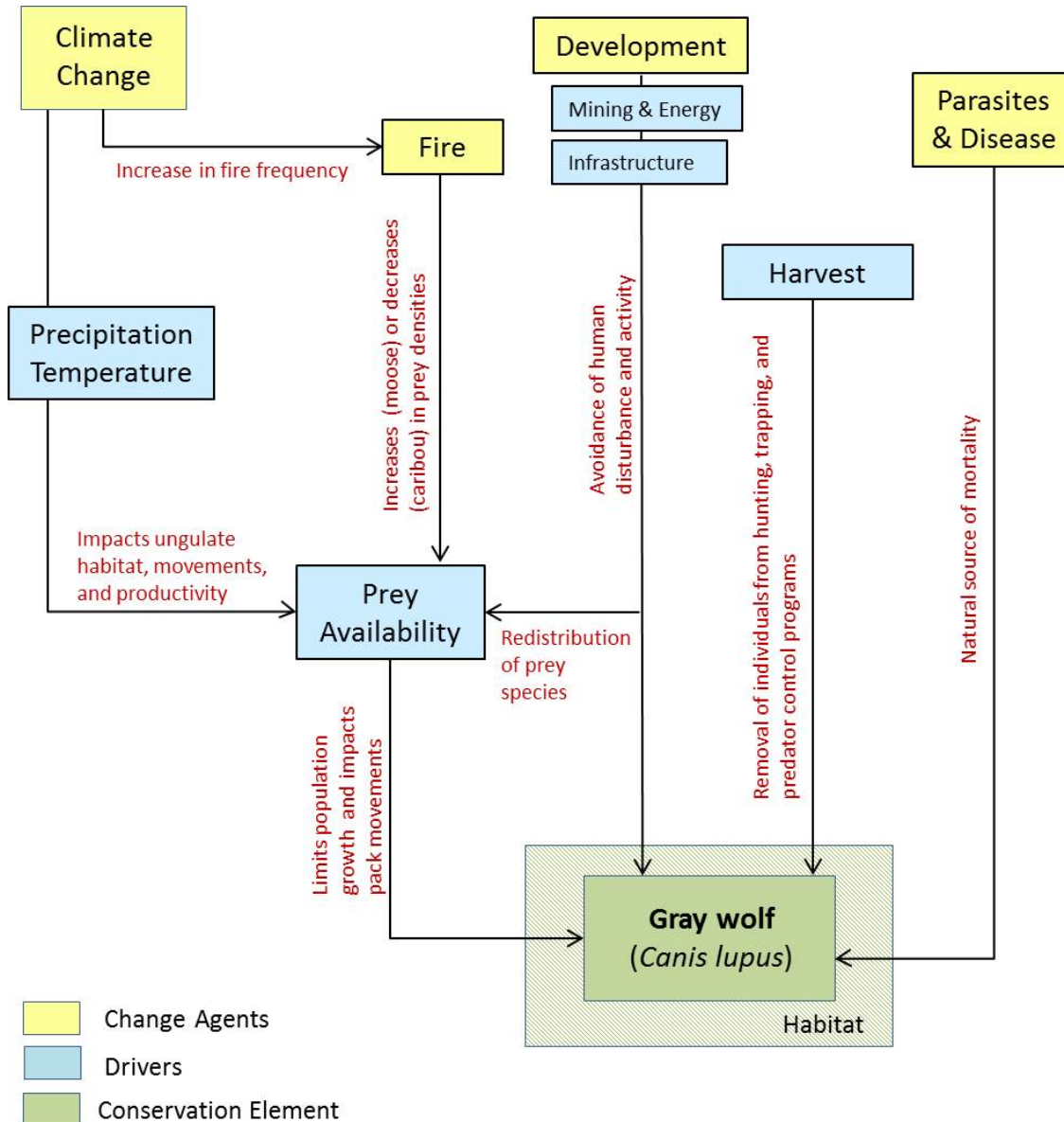


**Figure D-63.** Gray wolf (*Canis lupus*) conceptual model.

## Habitat use

Wolves occur throughout the entire YKL study area in virtually every habitat type (Figure D-61). However, habitat use by wolves is directly related to density of ungulate prey (Ballard et al. 1987). Primary prey items throughout interior Alaska include moose and caribou (ADF&G 2009; Ballard et al. 1987; Rausch 1967; Seavoy 2009). Additional prey items include sheep, beaver, and snowshoe hare (Rausch 1967). Wolf packs will migrate to follow the seasonal movements of caribou within their denning range (Schoen and Senner 2002) and will follow the elevational movements of moose within their ranges (Ballard et al. 1987).

To assess the impacts of climate change and human development on wolf distribution, we refined the wolf distribution map so it reflected the close association of wolves with the seasonal availability of ungulate prey (Figure D-64). To do this, we overlaid moose winter, rutting, and calving ranges, and caribou winter and calving ranges (Figure D-38 and Figure D-47) with predicted wolf distribution (Figure D-61). We classified areas of overlap from low (1) to high (6): low indicating no overlap with either moose or caribou, and high indicating overlap with both moose and caribou across all seasons considered. We then used this classification system for further analysis with climate and landscape condition.
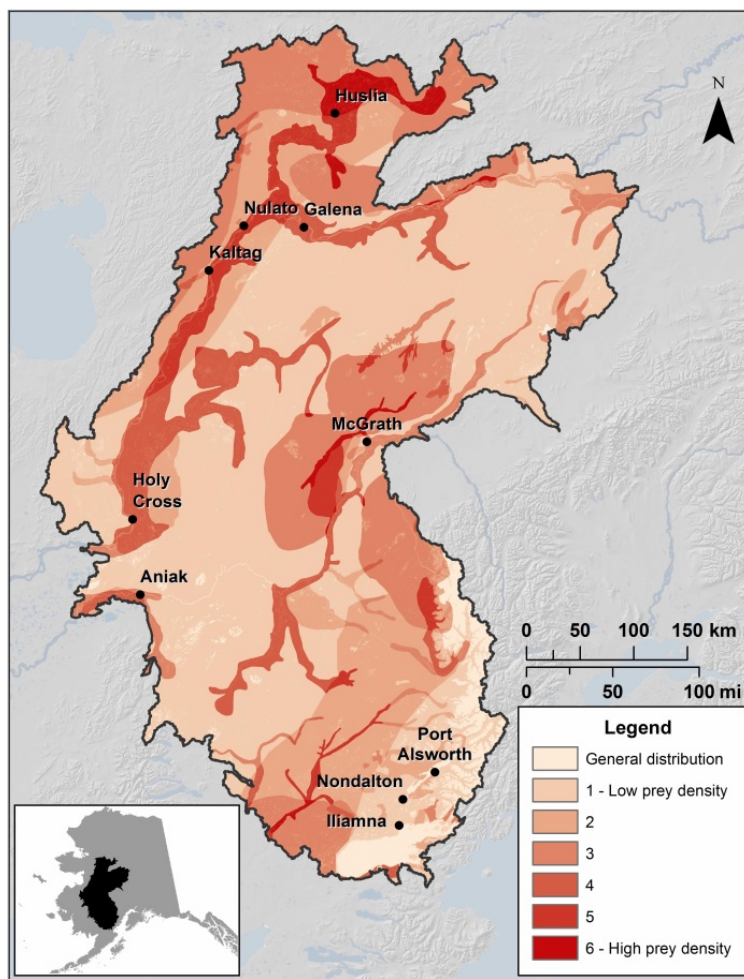


**Figure D-64.** Potential distribution for gray wolf in the YKL study area, overlaid with caribou and moose winter and calving ranges, indicating potential areas of low to high prey encounter.

**Climate**

Climate change will likely alter the abundance and distribution of ungulate species, thus impacting wolf population dynamics. See the individual moose and caribou descriptions for details on how climate change is expected to impact their ecology through winter weather severity, forage availability, and insect and disease outbreaks.

**Parasites and Disease**

Disease outbreaks (e.g., rabies, canine distemper, parvovirus, etc.) might infrequently limit local populations of wolves (National Research Council Committee on Management of Wolf and Bear Populations in Alaska 1997). Rabies epizootics have occurred in Northwestern Alaska and have the potential to eliminate wolf packs (Chapman 1978), alter den site usage (Weiler et al. 1995), and limit populations (Ballard and Krausman 1997). In addition, lice outbreaks can impact pack health yet experimental treatment of packs in the Tanana Flats area has yielded successful eradication results (Gardner et al. 2013).

**Fire**

Fire frequency is expected to increase within the YKL study area. Fire is likely to indirectly affect wolves by impacting the quality and quantity of ungulate habitat (Nelson et al. 2008). Scarification from fire promotes the regeneration of willow thus benefitting moose populations. Fire decreases the value of winter habitat for caribou by removing ground-dwelling lichens that take decades to regenerate. For a more detailed description on the impacts of fire on the habitat of these prey species, see individual moose and caribou summaries.

**Current status and future landscape condition**

The intersection of the gray wolf prey density distribution map with the Landscape Condition Model indicates that the majority of wolf habitat in the YKL study area is classified as being in very high (intact) condition (Figure D-65). Long-term projections (2060) of landscape condition suggest a slight decrease in very high quality condition and a slight increase in low condition, particularly around the villages of Galena and McGrath, as well as along both the Yukon and Kuskokwim river corridors, which are also areas of high density prey habitat.

Wolves tend to avoid areas of human development and hunting pressure can cause reductions in wolf populations near villages (Schoen and Senner 2002). In winter, snowmachine activity and trails can displace animals and disrupt their activities; however, trails can also provide a well packed travel corridor. Hunting and trapping pressures along trails can be high, especially later in the winter when animals are more stressed, and the benefit to wolves using the trail system is likely outweighed by the potential costs associated with human access (Rinaldi 2010). In the Kenai National Wildlife Refuge, winter movements indicated that wolves avoided year-round public use roads that had substantial traffic, but utilized seasonally closed roads and roads with little human use (Thurber et al. 1994). In some areas of the state, predation by wolves keep ungulate populations significantly below the habitat's carrying capacity, thus limiting ungulate hunting and trapping opportunities for humans. As a result, intensive management programs (i.e., predator control) have been enacted in some areas to reduce wolf population numbers and increase ungulate harvest opportunities.
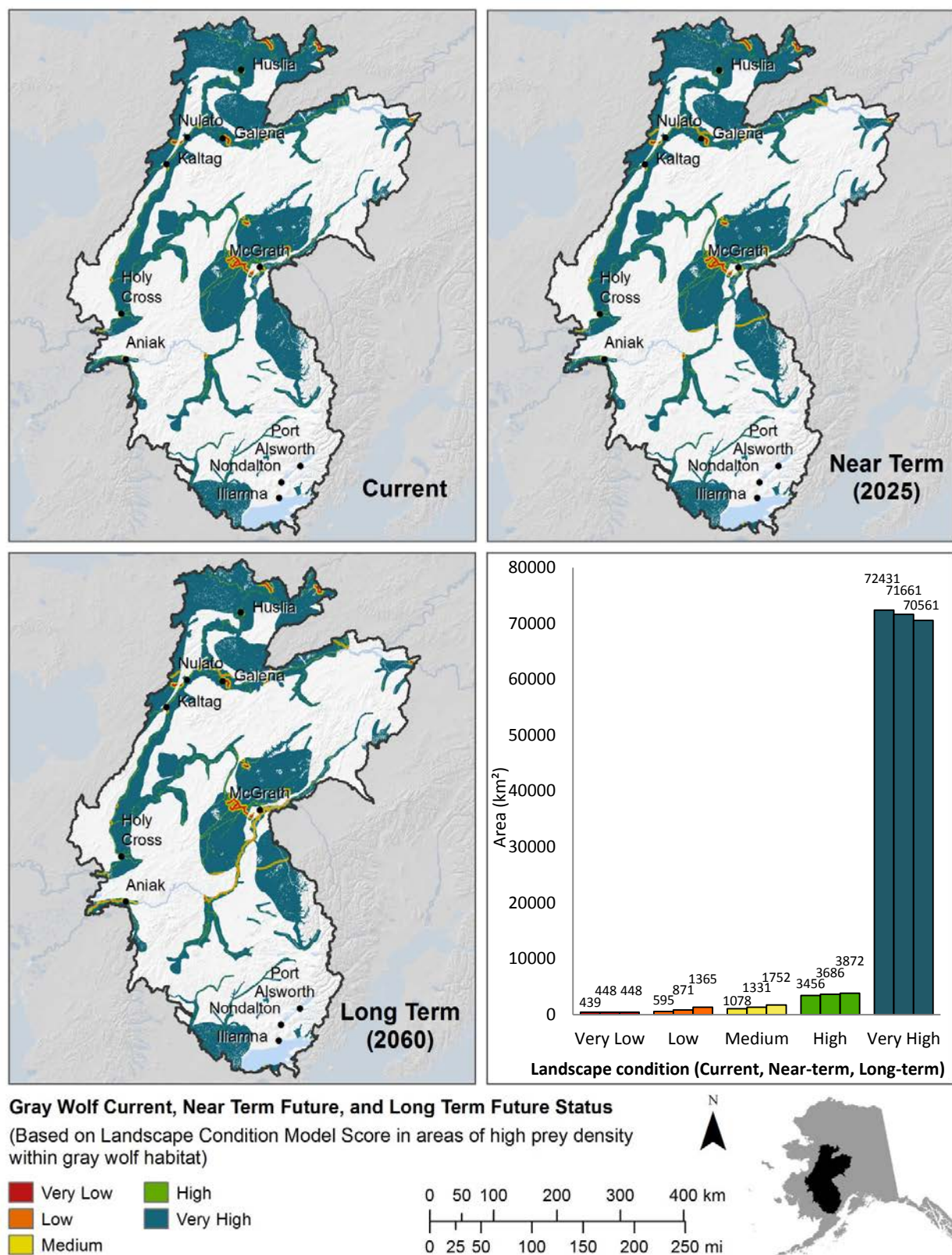
**Figure D-65.** Landscape condition modeled for current, near-term (2025), and long-term (2060) projections clipped to current high gray wolf prey density in the YKL study area.

**Applications**

This section provides managers with a summary of wolf population numbers, harvest effort, and ADF&G management objectives by game management units within the YKL study area. We also provide a habitat distribution model based on ungulate prey concentration areas. Additionally, we provide conceptual models with information on the potential effects of climate change, anthropogenic development, and other important drivers on gray wolf that could help direct future modeling efforts and aid in current and future management decision making.

Wolves play an essential role in maintaining the health and ecological integrity of the landscape. The gray wolf is considered a keystone species, one that has a disproportionate impact on its environment relative to its abundance. Recent findings by Wilmers and Getz (2005) indicate that wolves may help buffer the impacts of climate change for scavengers by providing them with a food source in winter. In Yellowstone National Park, wolves have been shown to mitigate late-winter reduction in carrion due to earlier snow thaws. By buffering the effects of climate change on carrion availability, wolves allow scavengers (e.g., bears, coyotes, eagles and ravens) to adapt to a changing environment over a longer time scale more commensurate with natural processes. The Yellowstone study indicated that ecosystems that have lost a keystone predator may exhibit less resilience to the impacts of climate change (Wilmers and Getz 2005); therefore an emphasis should be placed on maintaining intact food chains.

Understanding the mechanisms by which climate and predation patterns by top level predators co-vary to affect community structure accrues added importance as humans exert growing influence over both climate and regional predator assemblages (Wilmers and Getz 2005), and should be considered in any adaptive management strategy. The wolf has a complex relationship with humans, and it is easy to focus on the perceived negative impacts of wolves, especially the heavy predatory pressures they exert on ungulate populations. However, it is also important to recognize the benefits they provide to the ecosystem. Wolves help to regulate the overall fitness of ungulate populations by removing sick animals, thereby reducing the transmission and prevalence of wildlife diseases. As shown in the Yellowstone study, wolves also play an important role in providing food for scavengers, especially during winter. Wolves may also help regulate beaver populations. For example, a study in southeastern Alaska found that 31% of wolf feces contained the remains of beaver (Kohira and Rexstad 1997). They may also play a role in regulating fox numbers, by killing the animals or scaring them away from areas frequented by wolves (Palomares and Caro 1999; Elmhagen and Rushton 2007).

**Limitations and Data Gaps**

Since limited data were available on climate change or anthropogenic impacts to wolves, most changes were qualitatively described based on literature review and incorporated into the conceptual models. Our assessment of wolf distribution in relation to known prey concentration areas is an attempt to highlight areas where wolves would be more likely to occur based on proximity to their prey, but the resulting maps are generalizations at best and were not tested with empirical data.

## 2.10. Olive-sided flycatcher (*Contopus cooperi*)
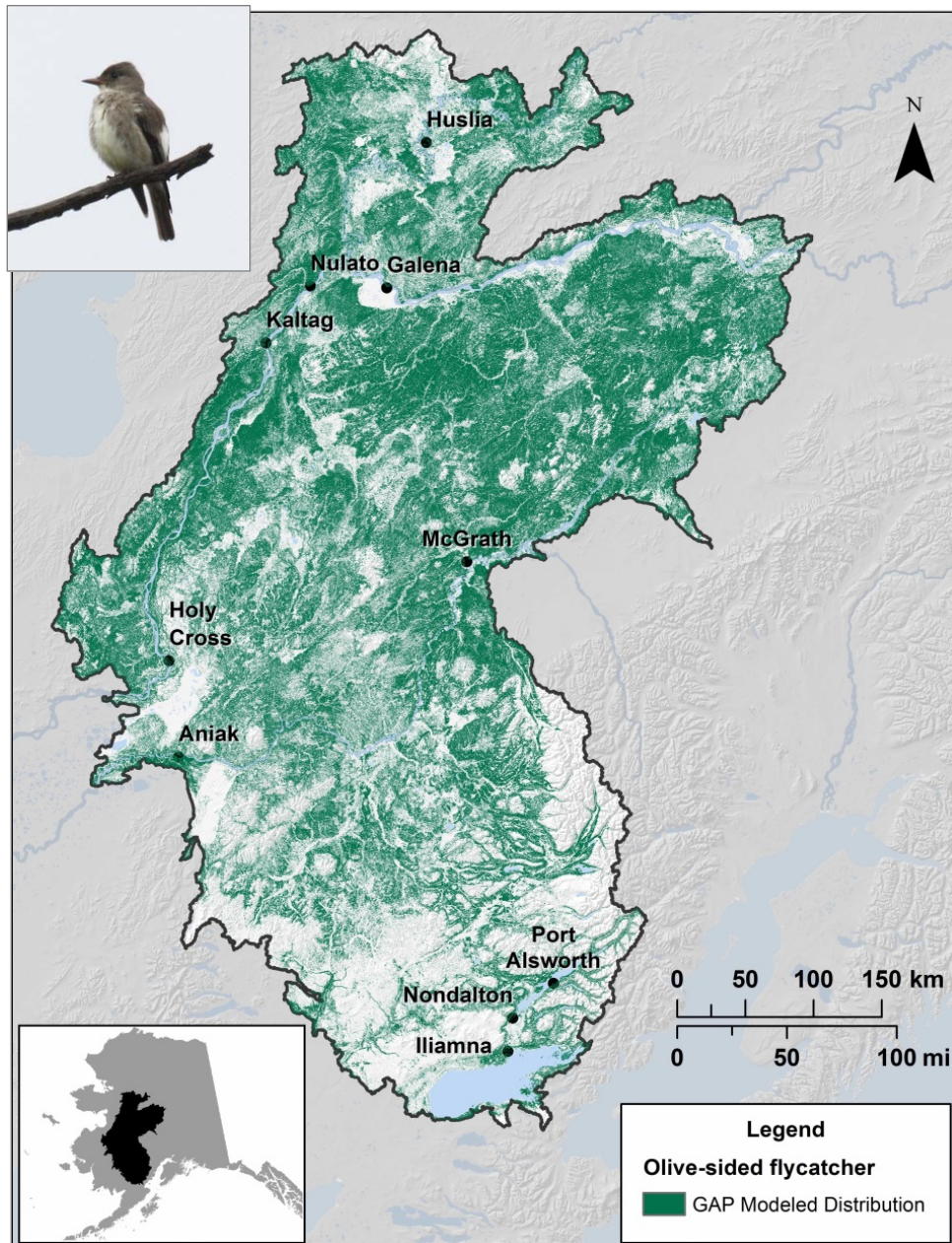


**Figure D-66.** GAP modeled current habitat distribution for Olive-sided fly catcher in the YKL study area.

A medium-sized songbird, the olive-sided flycatcher is considered an indicator species of the coniferous forest biome throughout North America, and at more northerly latitudes, is closely associated with large expanses of boreal forest (Bent 1942; Godfrey 1979). The olive-sided flycatcher prefers open forest habitats such as along wooded shorelines of streams, lakes, and wetland complexes that provide natural openings and an abundance of insect prey (Altman and Sallabanks 2012). They are often associated with open areas that form following natural and anthropogenic disturbances, such as tree fall gaps, fire, and logging.

Olive-sided flycatchers breed primarily in coniferous forests where temperatures tend to be cooler (Bent 1942). In central Alaska, they are primarily found in white and black spruce (Picea glauca, P. mariana) forest with

adequate edge habitat (e.g. muskegs, meadows, burns, logged areas) and in close proximity to water (Altman and Sallabanks 2012). Females produce one brood per season (two to five eggs) and in central Alaska; clutch initiation begins May 31st to June 16th. Eggs are incubated for approximately two to three weeks and hatching occurs around June 28th. Chicks fledge in mid-July (Wright 1997). Autumn departure from Alaska to wintering grounds (Central and South America) begins in early August (Altman and Sallabanks 2012). The olive-sided flycatcher has a relatively low reproductive rate, and as a result, habitat loss can have a large effect on population stability.

The olive-sided flycatcher is considered a Sensitive Species by the Bureau of Land Management (BLM 2010).

## Conceptual Model

The conceptual model below (Figure D-67) is based on extensive literature review and describes the relationship between the various change agents and natural drivers for the olive-sided flycatcher. The boxes and arrows represent the state of knowledge about the olive-sided flycatcher and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and the olive-sided flycatcher. Change agents selected for this REA and considered in this analysis include: Insects and disease, Climate change, Wildland fire, Invasive species, and Land use change (i.e. human development).
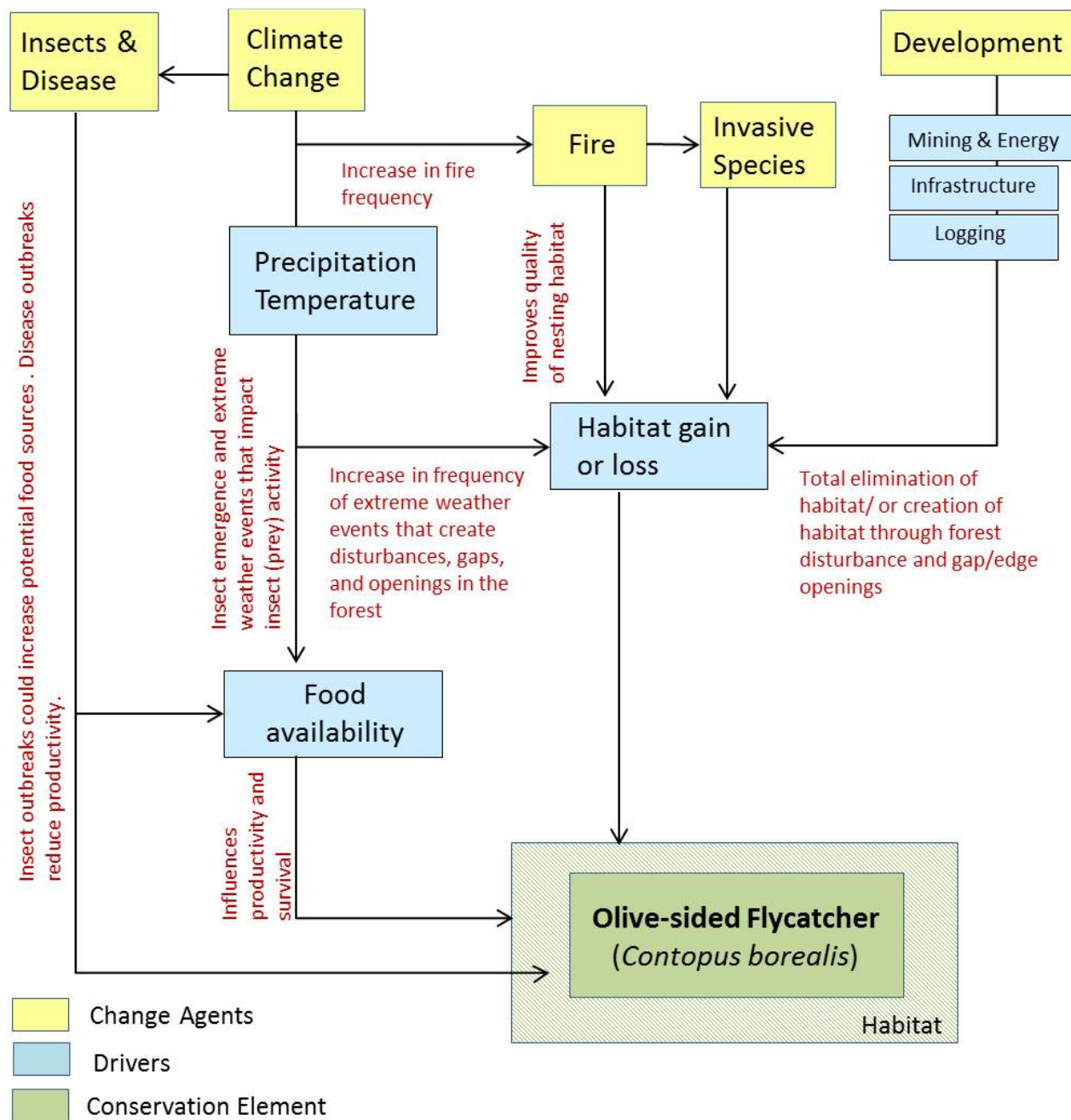
**Figure D-67.** Olive-sided flycatcher (*Contopus borealis*) conceptual model.

## Climate

Climate change may indirectly affect olive-sided flycatchers by creating more suitable conditions for their prey, which include flying insects such as bees, wasps, moths, grasshoppers, and dragonflies (Altman et al. 2012). Studies have shown that insect abundance is directly influenced by mean ambient temperature and the number of frost-free days (Bolduc et al. 2013). Warmer spring temperatures and earlier thaw could result in increases in prey abundance and/or shift the emergence date of insects forward.

Between the current (2010) and the near-term (2025), some areas within the range of the olive-sided flycatcher show a slight decrease (< 0°C) in July temperature, and about an equal number of sites show a slight increase (less than 1°C) (Table D-14).  The effect of temperature is more pronounced when averaged across the entire summer (June, July, and August) for the same time period. Model results indicate about 11% of habitat will undergo a slight decrease (< 0°C) in summer temperature while 88% will show a slight increase (less than 1°C). By 2060, warming is expected to accelerate, and >99% of habitat within the current distribution of the olive-sided flycatcher is expected to see summer temperatures greater than 1°C warmer than current averages (Table D-14).

Climate models (see Climate section B-1 for methods) suggest that a majority of the YKL study area will experience a 7 to 14 day increase in growing season length, with the southern region around Lake Iliamna experiencing increases of up to 29 days (Figure D-68). For the olive-sided flycatcher, almost 88% of their current distribution is expected to see an increase of between one and two weeks in the growing season, and 12% will see an increase of greater than two weeks (Table D-14).
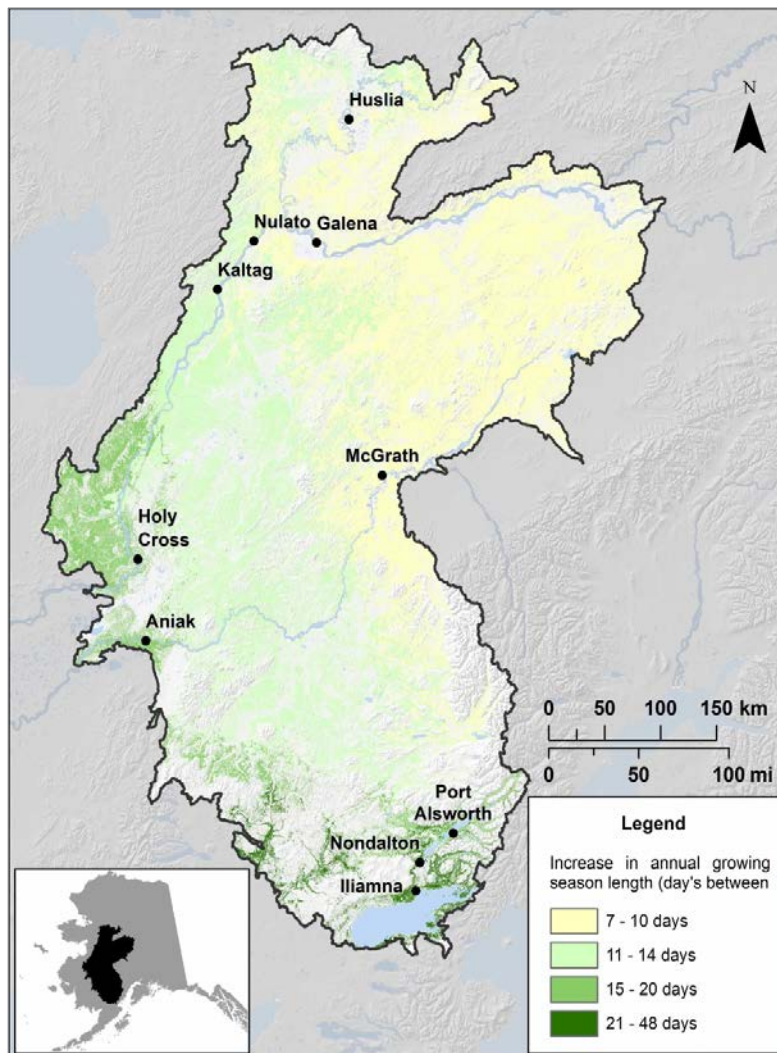


**Figure D-68.** Modeled increase in annual growing season (# days between DOT and DOF; 2010 - 2060) clipped to current Olive-sided flycatcher distribution.

A longer growing season combined with warmer ambient temperatures could potentially result in increased insect outbreaks, which, in turn, could provide additional food sources for the olive-sided flycatcher. Conversely, increases in summer temperatures could result in potential loss of breeding habitat suitability and the availability of flying insect prey if favored habitats (i.e. muskeg, bogs and streams) undergo drying (Schmidt et al. 2011).

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. Shifts in the timing of insect emergence brought on by an earlier growing season could be potentially deleterious to olive-sided flycatcher survival if the insect outbreaks are not synchronous with migration and breeding events. In Europe, some populations of pie-billed flycatchers have declined by 90% over the past two decades, which has been attributed to the species failure to keep pace with climate change (Both et al. 2006). With their insect prey numbers peaking earlier due to warming, but migration timing unchanged, they no longer arrive in their breeding grounds in time to match peak food supply with peak nestling demands. At present, we lack information on changes in the timing of arrival of olive-sided flycatchers to make determinations as to whether earlier insect emergence would result in a trophic mismatch.

Lastly, under climate change scenarios, extreme weather events are expected to increase. Increases in severe storms may alter the activity patterns and availability of insects (Altman and Sallabanks 2012), potentially reducing access to prey.

**Fire**

Fire has been used as a management tool to benefit the olive-sided flycatcher in some areas (e.g., California; Raphael et al. 1987). In many parts of their range, a natural, unaltered fire regime and windfall gaps create a mosaic of disturbance and forests openings. However, in the past 50 to 100 years, wildfires have been suppressed in many areas, thus eliminating and decreasing the suitability of habitat for the species. Fire suppression results in monospecific stands rather than uneven-aged stands preferred by the olive-sided flycatcher.

Fire frequency is expected to increase within the YKL study area. Moderate to severe fires could create suitable habitat for approximately 20 years, depending on the rate of regeneration, after the burn (Kotliar 2007). Because fire occurrence varies with climate and can vary regionally, the availability of olive-sided flycatcher habitat may vary temporally and spatially across large landscapes (Kotliar 2007).

**Current status and future landscape condition**

The olive-sided flycatcher is widely distributed throughout the YKL study area. The majority of their distribution occurs in areas with very high landscape condition (Figure D-69), however, areas of low condition occur near McGrath and east of Galena. Future projections of landscape condition suggest that olive-sided flycatcher habitat will remain relatively intact and in good condition throughout the study area (Figure D-69). Given their wide range, abundance of suitable habitat and known adaptability, small areas of reduced landscape condition are unlikely to affect olive-sided flycatcher population status in the YKL study area.

Anthropogenic activities to consider in future land-use planning may include logging and fire management. Logging has the potential to create habitat. Small clear-cuts adjacent to mature forests are ideal for the olive-sided flycatcher, as well as retention of snags, stream buffers and small clumps of residual trees. Singing males

have been detected in logged areas where snags remain, but some speculate that logging is not equivalent to fire, and that logged areas may not provide adequate prey or may expose olive-sided flycatchers to increased predation (Robertson and Hutto 2007). Infrequent, high intensity burns seem to be strongly attractive to olive-sided flycatchers, therefore, allowing fires to burn and refraining from salvage logging is suggested (CalPIF 2002).
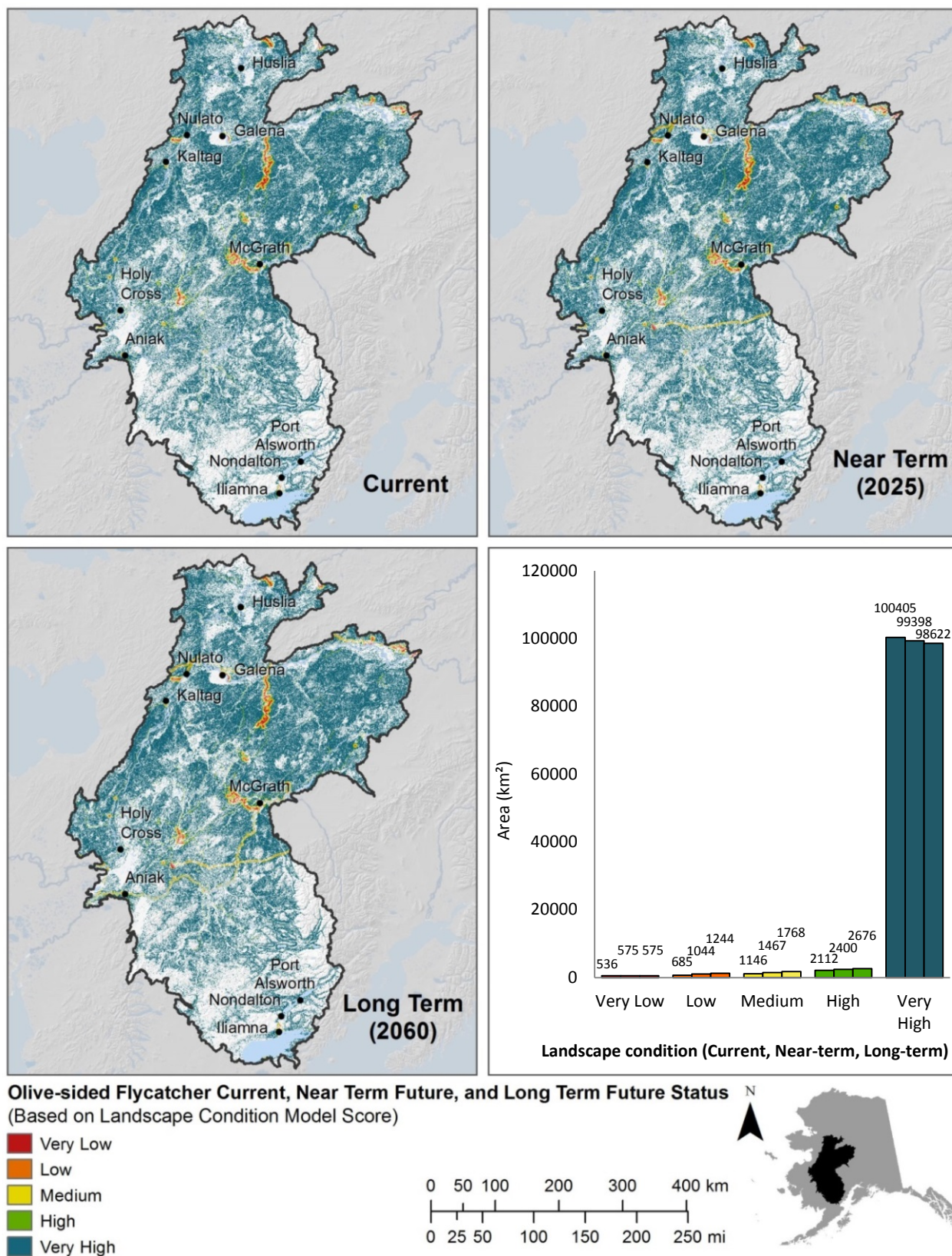
**Figure D-69.** Landscape condition modeled for current, near-term (2025) and long-term (2060) projections clipped to current olive-sided flycatcher habitat in the YKL study area.

**Applications**

This section provides managers with a general habitat distribution model and an explanation of potential effects of climate change and forest fires in the region. Finer scale climate data may provide more insight into severe storm events which affect both habitat and prey abundance and/or availability for the olive-sided flycatcher (e.g., May storm events can change activity patters and availability if insects; Altman and Sallabanks 2012). We provide conceptual models with information on the potential effects of climate change, anthropogenic development, and other important drivers on the olive-sided flycatcher that could help direct future modeling efforts and aid in current and future management decision making, such as information on logging and fire suppression.

The olive-sided flycatcher can be used as a proxy species for coniferous forest birds such as woodpeckers, brown creeper, dark-eyed junco, wood warblers, fox sparrow, and red-breasted nuthatch.

**Limitations and Data Gaps**

Since limited spatial data were available on anthropogenic impacts to the olive-sided flycatcher, most changes were qualitatively described based on literature reviews and incorporated into the conceptual models. Climate-linked species-specific models that focused specifically on changes in the arrival and nesting dates of the olive-sided flycatcher in relation to timing of emergence of key insectivorous prey would benefit future management efforts. Although the literature suggests allowing fires to burn and refraining from salvage logging to maintain habitat for this species, the effects of disturbance from fires, insect outbreaks, and disturbances associated with salvage logging still need to be evaluated (CWCS 2006).

## 2.11. American peregrine falcon (*Falco peregrinus anatum*)
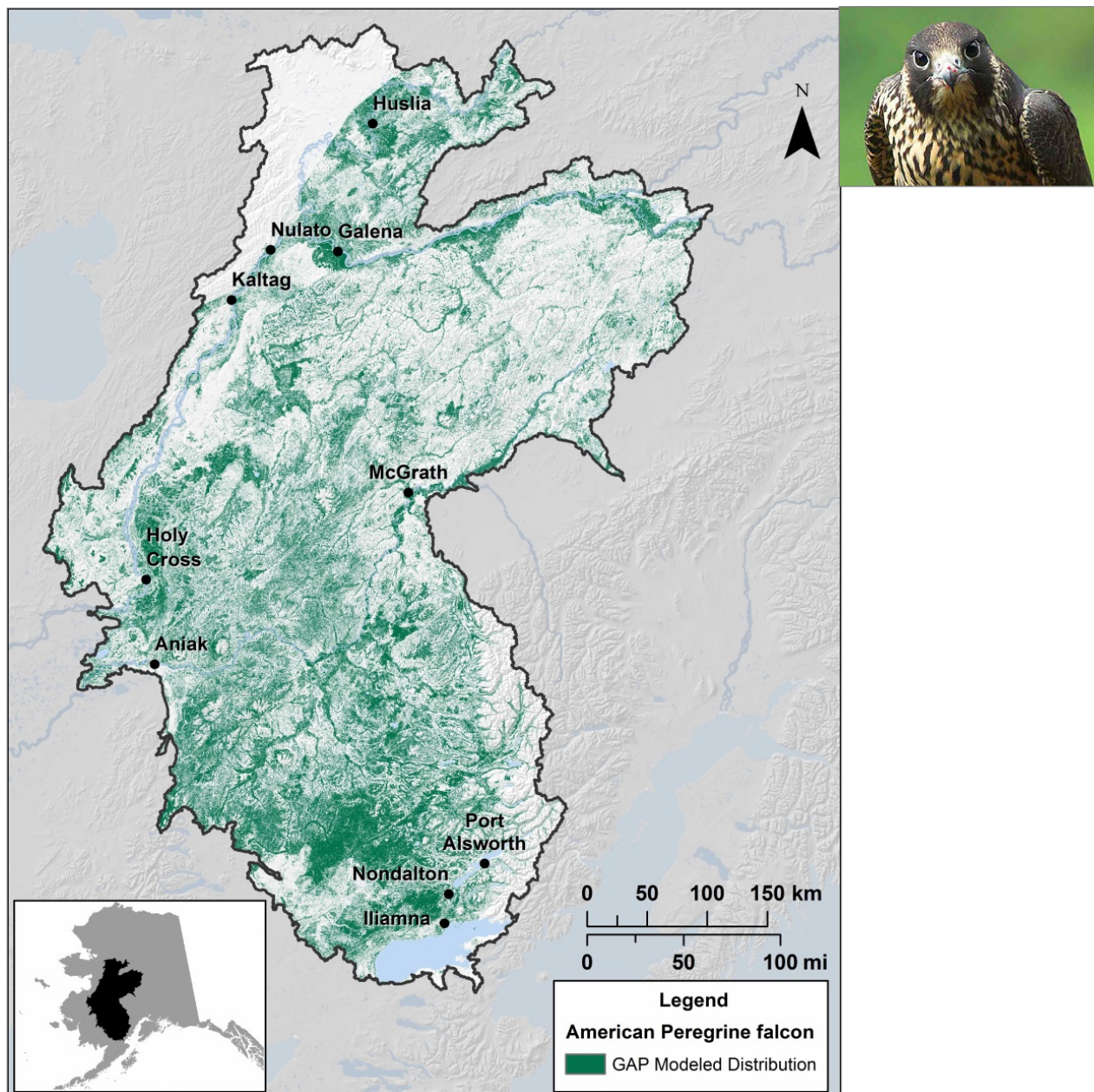


**FigureD-70.** GAP modeled habitat distribution for American peregrine falcon in the YKL study area.

The American peregrine falcon is the most common of three peregrine falcon subspecies in the United States. It nests from central Alaska to north-central Canada, south to central Arizona and Baja, California. Individuals that breed in Alaska are migratory and spend winters in Central and South America (White et al. 2002).

In central Alaska, it occurs in the forested interior, nesting primarily on cliffs along major rivers. Principle nesting areas in the YKL study area include the Kuskokwim and Yukon River drainages (Mindell and Craighead 1982, Seppi 2007).

Individuals are typically present on their breeding grounds from mid-April/mid-May to mid/late August, and generally depart for wintering grounds in late September (Cade 1960). They lay one clutch (avg. 3 eggs) per year (Cade et al. 1968; Wright and Bente 2001), which is incubated for 33 to 35 days (White et al. 2002).

Nest sites are often located in close proximity to a water source and adequate prey base of small to medium sized birds (Hayes and Buchanan 2002). In Alaska, nesting pairs are separated, on average, by 5.4 to 5.6 km, with the closest pairs being 0.3 to1.0 km apart (White et al. 2002). Density estimates on the Kuskokwim River were 1 pair/9-47 km (Mindell et al. 1982) In general, passerines, shorebirds, and waterfowl are the most frequently hunted prey (Mindell and Craighead 1981; review in White et al.2002).

Peregrine falcon productivity along the Kuskokwim River has been studied since the late 1970s (Seppi 2007 and sources therein) and the suitability and importance of the cliff nesting habitats along the river were recognized earlier (Cade 1960). Peregrine falcon populations in Alaska (and globally) declined in the 1960s, due to the national use of pesticides (Cade et al. 1968), yet stabilized in the mid-1970s, and began to increase in the late 1970s on the upper Yukon and Tanana rivers, where the *F. p. anatum* subspecies is known to breed (Ambrose et al. 1988). The most current population estimate for American peregrine falcon is 250 pairs in the state (Ambrose et al. 1988). As a top trophic-level predator, changes in their status could be indicative of large scale ecosystem changes.

## Conceptual Model

The conceptual model below (Figure D-71) is based on literature review and describes the relationship between the various change agents and natural drivers for the American peregrine falcon. The boxes and arrows represent the state of knowledge about the American peregrine falcon and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and the American peregrine falcon. Change agents selected for this REA and considered in this analysis include: Climate change, Wildland fire and Land use change (i.e. human development).
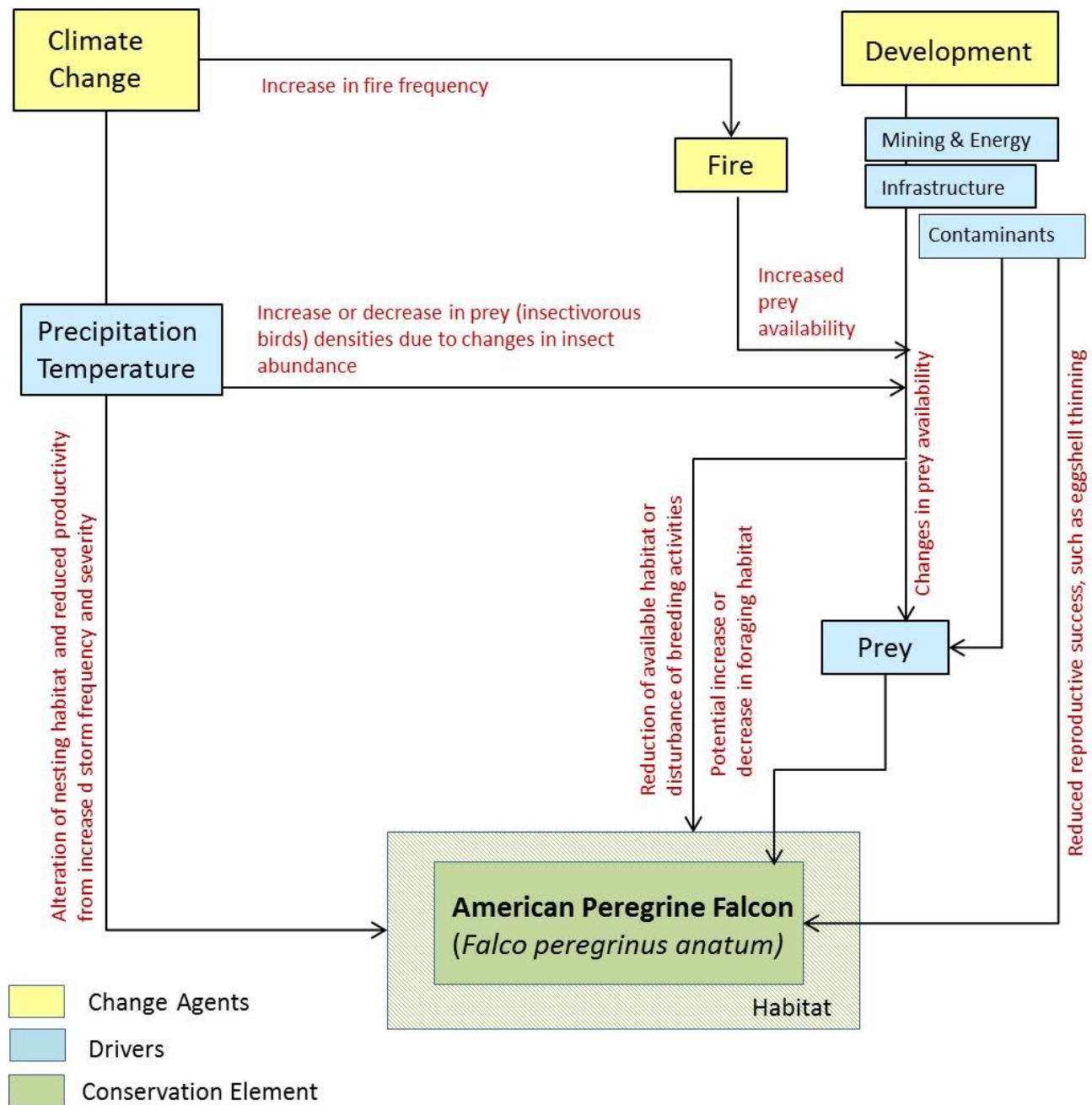
**Figure D-71.** American peregrine falcon (*Falco peregrinus anatum*) conceptual model.

**Current and Future Distribution of Peregrine Falcon**

| | |
|---|---|
| **MQ 11** | What is the current distribution of the American Peregrine Falcon in the region, and how is that expected to change? |

**Methods**

Peregrine falcon distribution maps were generated by the Alaska Gap Analysis Project (AKGAP). These maps were produced through a combination of inductive and deductive modeling techniques (Gotthardt et al. 2013). AKGAP models are spatial representations of a species predicted distribution, within known range limits, at 60 m pixel resolution. Maps were produced to represent the distribution of the species across its range in Alaska. For this assessment, we overlaid the statewide distribution map with the YKL boundary to produce a distribution model for the study area only.

During the breeding season, peregrine falcons are closely associated with cliffs and riparian areas that provide suitable nest sites and good foraging opportunities (Cade 1982; Hunter et al. 1988). In the YKL study area, peregrine falcons have been found in high concentrations along the Kuskokwim and Yukon Rivers (Seppi 2007; Mindell and Craighead 1981; Seppi, pers comms.), due to the abundance of cliff nesting habitat. The AKGAP models are representative of predicted habitats in general, and do not differentiate between high and low quality habitats. However, due to the species' apparent affinity to riparian corridors, we felt it important to emphasize them in this assessment. Therefore, we used the AKGAP predicted distribution map and buffered major rivers at a distance of 20 km. The buffer distance of 20 km was selected based on occurrence delineation guidelines developed for NatureServe (Canning 2002). Habitats within this buffer were classified as "high quality", while distribution outside the buffer were considered "general habitat".

**Current Distribution**

Predicted suitable habitat for the American peregrine falcon is widely distributed throughout the YKL study area (Figure D-72). Large cliffs with views of the surrounding area are often favored over smaller cliffs. However, in Alaska, peregrine falcons are often observed nesting on lower, more exposed cliff sites (Seppi 2007). Mixed spruce-quaking aspen (*Picea* spp. — *Populus tremuloides*) forests with prickly rose (*Rosa acicularis*) characterize cliff brinks on the Yukon River (Cade 1961).
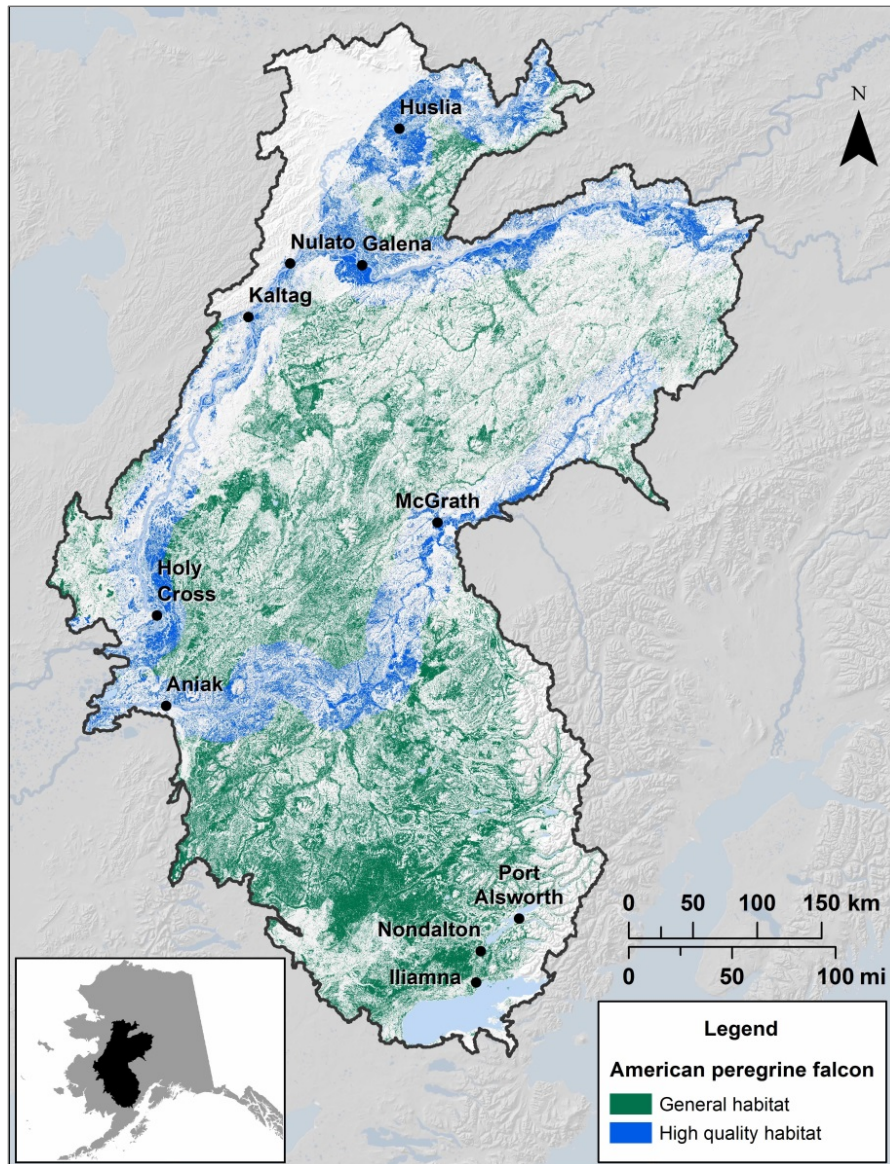
**Figure D-72.** Predicted current distribution for American peregrine falcon in the YKL study area, with a 20 km buffer around riparian areas (major rivers only) representing higher quality breeding habitat.

## Future Distribution Changes

We did not predict future changes in peregrine falcon distribution. Instead, we compared current distribution to changes in climatic conditions, fire frequency, and landscape condition in both the near- and long-term, and then describe how these future changes in the CAs could potentially affect current habitat used by peregrines.

## Climate

Peregrine falcons feed primarily on medium-size passerines up to small waterfowl. Climate change has the potential to alter populations of important prey species like insectivorous birds (e.g., passerines, shorebirds and ducks). Higher daily temperatures, a longer growing season, and increased precipitation may act to increase

insect abundance (Bale et al. 2002; Bolduc et al. 2013), and consequently, the health and abundance of insectivorous prey species. In addition, a longer growing season may allow for earlier spring arrival of prey species (Murphy-Klassen et al. 2005) providing the peregrine falcon with more abundant prey resources in the spring. The results of our analysis indicate that growing season length and average annual precipitation are projected to increase in the long-term, with the greatest increases in the southern portion of the YKL study area (Figure D-73).
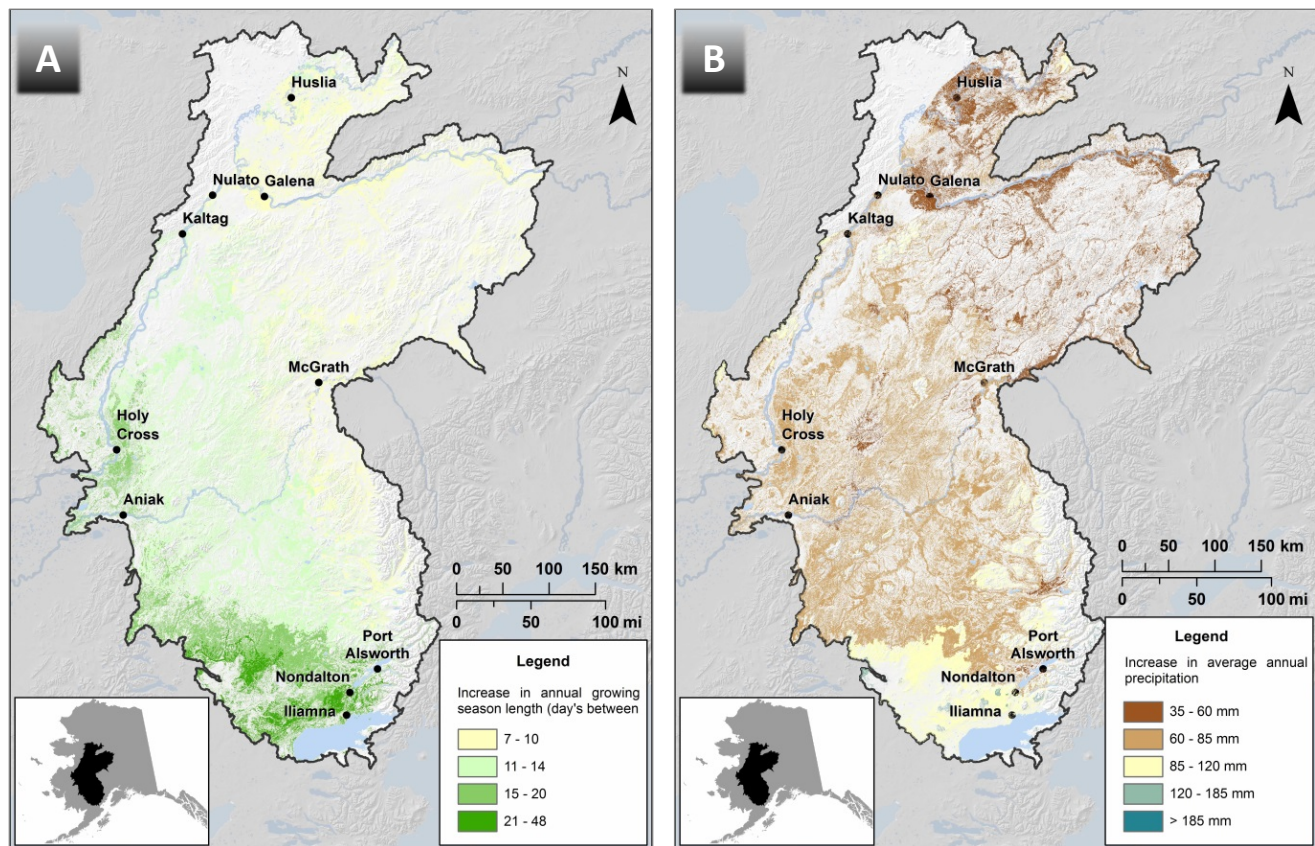


**Figure D-73.** Increase in (A) annual growing season (# days between DOT and DOF) and (B) average annual precipitation (mm) modeled from 2010 – 2060, overlaid with American peregrine falcon distribution.

Warming temperatures may reduce cold related stress during early season, however, an increase in frequency and severity of erratic weather events has the potential to cause heavy rains that may influence productivity during incubation and brood rearing (Cade et al. 1971, Liebezeit et al. 2012, Ontario Peregrine Falcon Recovery Team 2010).

## Fire

Peregrine falcons in Alaska favor cliff habitats near large river systems and coastal areas (Cade 1960; Reed 1956). The landscape along the Yukon River, Alaska, has abundant cliffs and diverse lowlands comprised of low, rounded benches and ridges spanning southwest to northeast. These areas experience frequent wildfires and other disturbances (Ambrose and Ulvi 1990). Fire frequency is expected to increase within the YKL study area as

a result of climate change. In the long-term future, fire return interval is expected to decrease by at least 25 (Table D-6).

The impact of fire and its potential increase in frequency and severity with a warming climate is unknown. Due to their high mobility, fire-related mortality of adult raptors is likely low. Nestling mortality is potentially higher (Luensmann 2010). However, since peregrine falcons nest on cliff faces, rock outcrops, and similar sites, the potential for damage to the nesting site or nestling mortality is low, but possible if vegetation on the nest ledge catches fire. Fire can also have an indirect effect on prey populations by promoting an increase in vegetation and bird diversity. The American peregrine falcon feeds primarily on birds and locally abundant small mammals; therefore, increases in avian prey species after fire may benefit the species (Luensmann 2010). When small mammals are attracted to abundant new growth in the months following fire, predators and scavengers are attracted too. Abundant prey attracted golden eagles (*Aquila chrysaetos*) and peregrine falcons to recently burned areas in New Mexico and southern California (Lehman and Allendorf 1987).

**Current Status and Future Landscape Condition**

The majority of current peregrine falcon distribution is in areas with very high (intact) landscape condition (Figure D-74). Future projections of landscape condition suggest a very slight decrease in habitat quality, with reduced landscape condition around Galena, McGrath and along both the Yukon and Kuskokwim river corridors.

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). Peregrines show 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 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). Frequent interruptions during nesting can lengthen the incubation period and delay hatching (White et al. 2002). The encroachment of human development and land use activities can decrease prey abundance and availability of foraging habitat.

Human activities often introduce contaminants into the environment. Peregrine falcons are predators at the top of the food chain, making them particularly susceptible to bioaccumulation and bio-magnification of contaminants in their tissues. Historically, the use of DDT caused eggshell thinning, which was largely responsible for population declines in the past. New and emerging chemicals may pose potential exposure and bioaccumulation problems and threats such as embryo mortality, reduced fertility, suppression of egg formation and impaired incubation and chick rearing behaviors (Fry 1995; Ontario Peregrine Falcon Recovery Team 2010). Thus, limiting disturbance near active nest sites may promote peregrine falcon populations (Luensmann 2010).
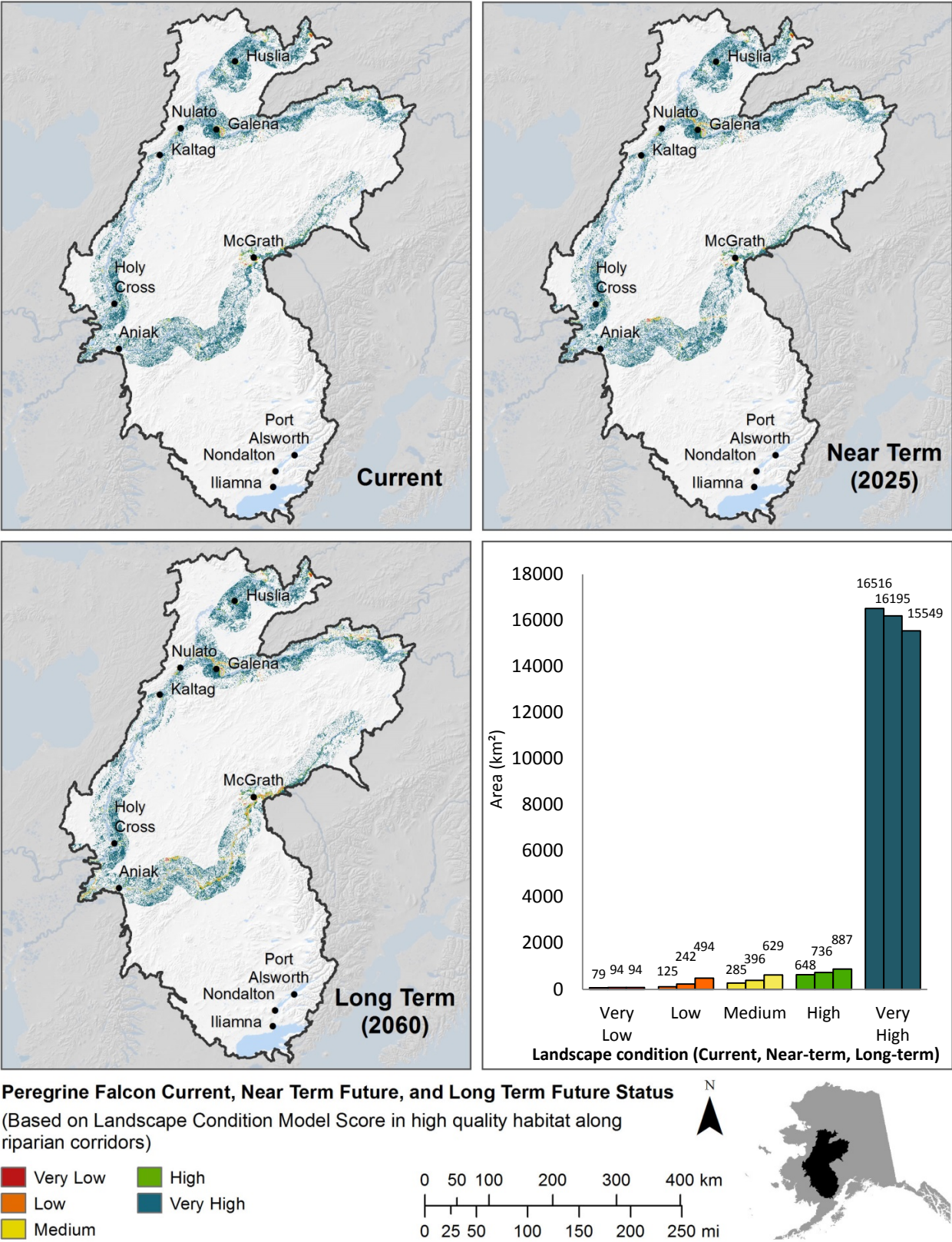
**Figure D-74**. Landscape condition modeled for current, near-term (2025) and long-term (2060) projections clipped to current American peregrine falcon habitat in the YKL study area.

## Applications

The distribution map created for the American peregrine falcon can provide managers and researchers with baseline information for the YKL study area. We also provide conceptual models with information on additional potential effects of climate change, anthropogenic development, and other important drivers on American peregrine falcon that could help direct future modeling efforts and aid in current and future management decision making.

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 (Kifff 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.

Human disturbance may disrupt the reproductive behavior of peregrine falcons (Ellis 1982). Specific types of disturbance are addressed above under Current Status.  The timing of disturbance at nest sites also seems to be critical (Ratcliffe 1993). Nesting peregrine falcons are intolerant of excessive human disturbance; they may abandon a nesting site during courtship and move to another ledge or cliff if possible. 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 human 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). This is especially important to consider when if planning occurs for the potential Kuskokwim Road, as it is slated to follow along high quality riparian habitat.

## Limitations and Data Gaps

Since limited spatial data were available on fire, anthropogenic impacts, and other drivers to American peregrine falcon, most potential changes were qualitatively described based on literature reviews and incorporated into the conceptual models.

Although peregrine falcons are currently monitored along the Kuskokwim River (Seppi 2007, 2011) as part of the peregrine falcon recovery plan, populations elsewhere in the YKL study area remain inadequately assessed or monitored. As such, long term data are not available within the study area to assess population changes over time in relation to the CAs.

The distribution model of peregrine falcon habitat is a coarse approximation at best. The model was generated by selecting habitat types known to be used by peregrines in Interior Alaska from the LandFire map (http://www.landfire.gov/). While forested habitats were mapped quite well, cliff habitats along riparian corridors were not. As such, the original GAP models received low expert approval, and the resulting model provided here should be approached as a generalization of habitat, at best, and should not be used for finer scale analyses.

## 2.12. Trumpeter swan (Cygnus buccinator)
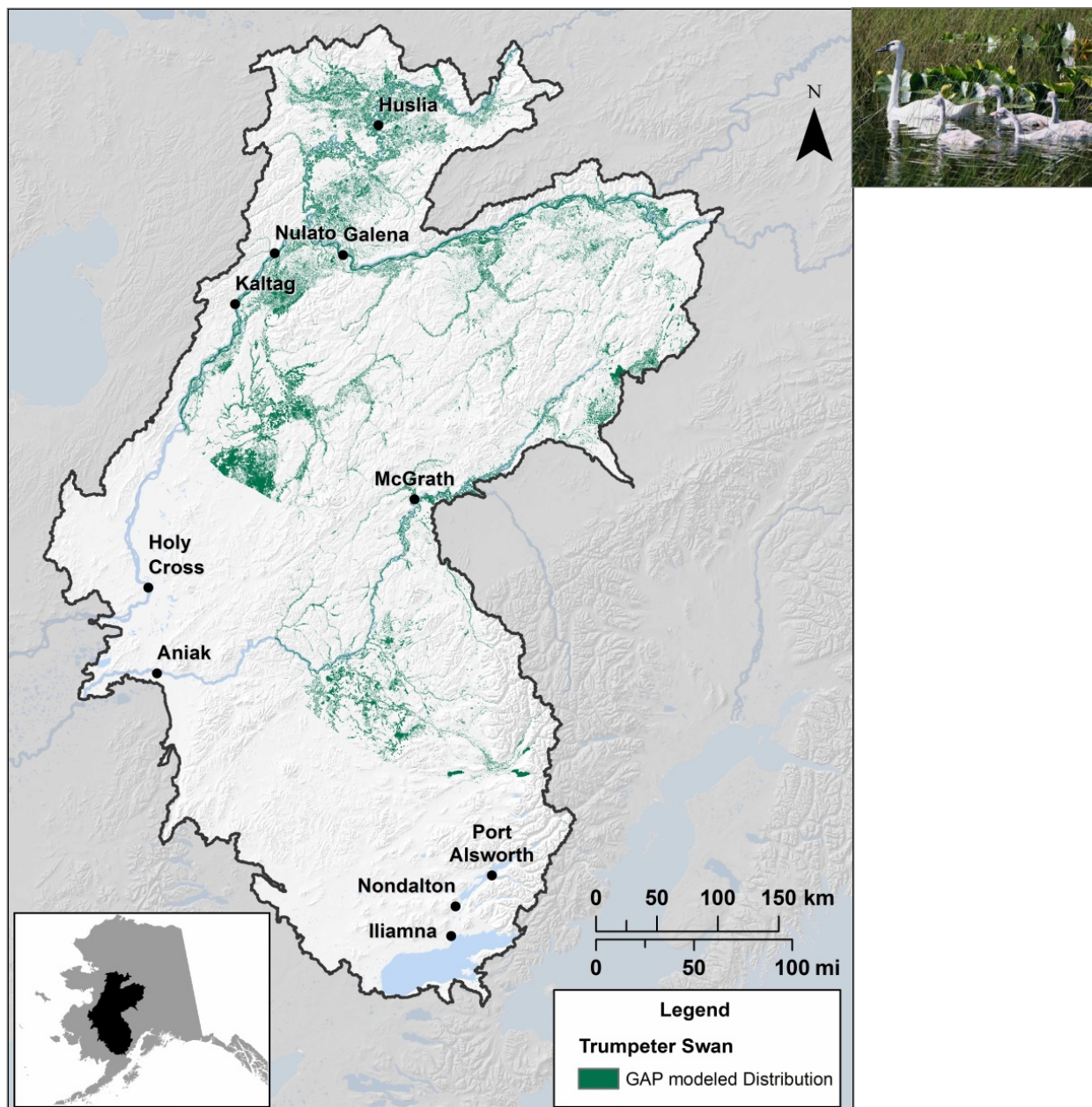


**Figure D-75.** Current habitat distribution for Trumpeter swan in the YKL study area.

Historically, the trumpeter swan was widespread and abundant in North America, however, the early fur trade and European settlement of North America (1600s-1800s) nearly extirpated the entire population. Recent conservation efforts have resulted in a steady increase in population size and breeding distribution in Alaska. The trumpeter swan was formerly harvested for subsistence; however harvest is no longer permitted in Alaska (PFC 2006). The trumpeter swan is currently considered a Sensitive Species by the Bureau of Land Management in Alaska.

During the summer, trumpeter swans utilize a variety of freshwater wetland habitats for breeding, such as marshes, ponds, lakes and occasionally rivers (Banko 1960; Hansen et al. 1971; Gale et al. 1987). In Alaska, they

breed primarily in the interior and coastal regions of the south central region including the Copper River Delta, Cook Inlet Lowlands, Gulkana Basin and the Tanana River valley (PFC 2006). Trumpeter swans occur in the northern and eastern part of the YKL study area, but are absent from the southern and southwestern portion of the REA.

Spring migration to Alaska occurs in late March with pairs occupying nesting areas by mid to late May, depending on ice-retreat from water bodies. Mean clutch size varies from 4.4 to 5.7 with incubation lasting from 33 to 37 days throughout Alaska. Chicks fledge between 90 to 105 days after hatching. In autumn, trumpeter swan departure is timed with freeze-up and usually occurs in early October (Hansen et al. 1971). This species typically migrates to wetland habitats in coastal British Columbia and western Washington where it spends the winter months (PFC 2006).

**Conceptual Model**

The conceptual model below (Figure D-76) is based on literature review and describes the relationship between the various change agents and natural drivers for the trumpeter swan. The boxes and arrows represent the state of knowledge about the trumpeter swan and its relationships to each attribute. The arrows and red text represent/describe relationships between the change agents, natural drivers and the trumpeter swan. Change agents selected for this REA and considered in this analysis include: Insects and disease, Climate change, Wildland fire, Invasive species, Land use change (i.e. human development) and Human Activity.
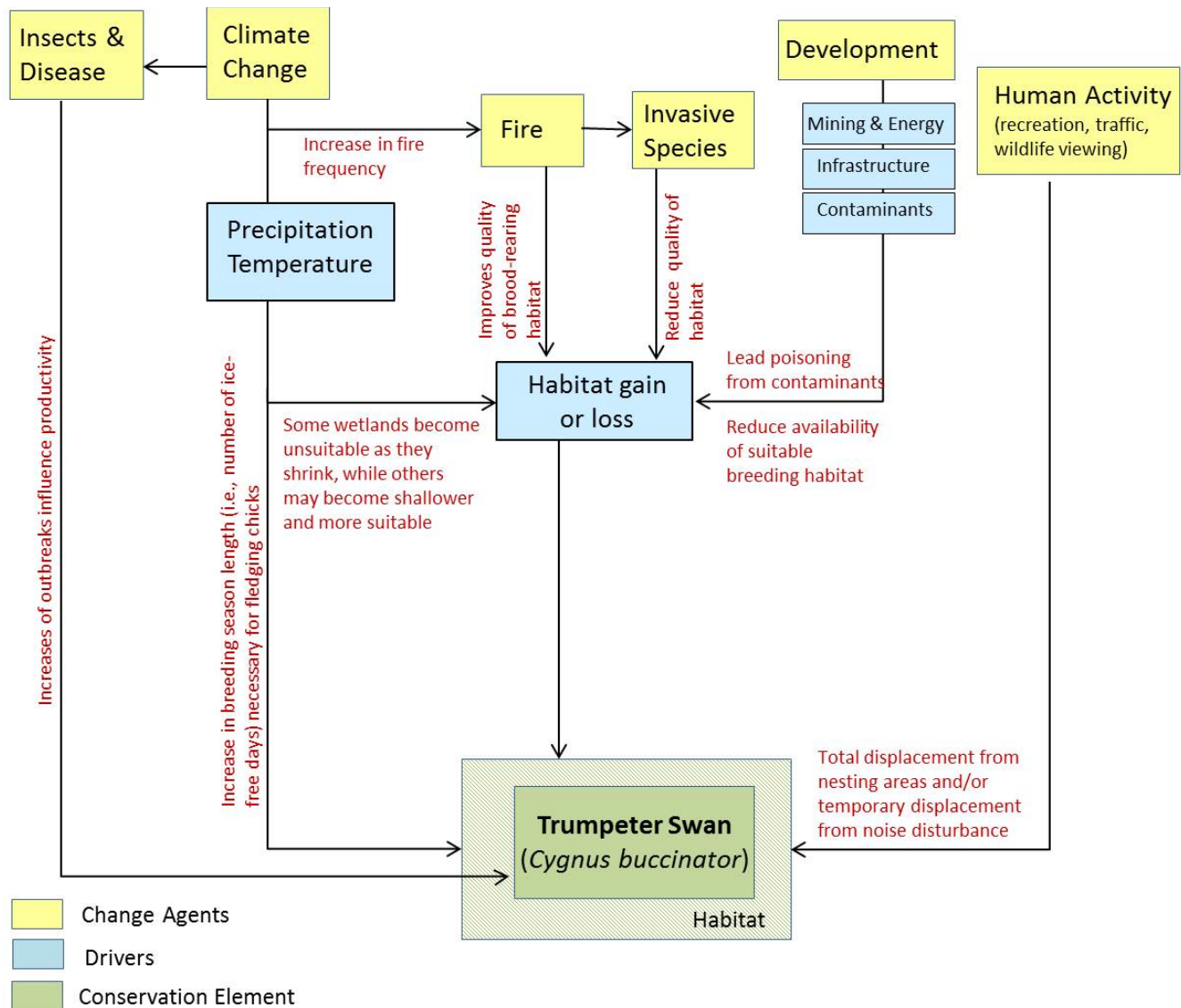
**Figure D-76.** Trumpeter swan (*Cygnus buccinators*) conceptual model.

## Climate

As a result of climate change, length of growing season and spring temperatures, are expected to increase in the YKL study area (see Climate section B-1). Changes in growing season length could benefit trumpeter swans by promoting fledging success, while warmer springs may trigger earlier migrations necessary to capitalize on this extended season. In addition, climate change is expected to result in warming soils and associated permafrost thaw, which is likely to increase trumpeter swan habitat.

Studies have shown that trumpeter swans typically require a minimum of 140 ice-free days to breed and successfully fledge young (Hansen et al. 1971). The majority of the YKL study area meets this 140 day minimum (Figure D-77 a). However, deeper examination of the literature (Hansen et al. 1971) reveals that most swans are slower than the fastest nesting pairs at every stage of the process (arrival, nesting, egg laying, hatching, and rearing). Thus, only the most efficient pair of swans can fledge cygnets in 140 days.
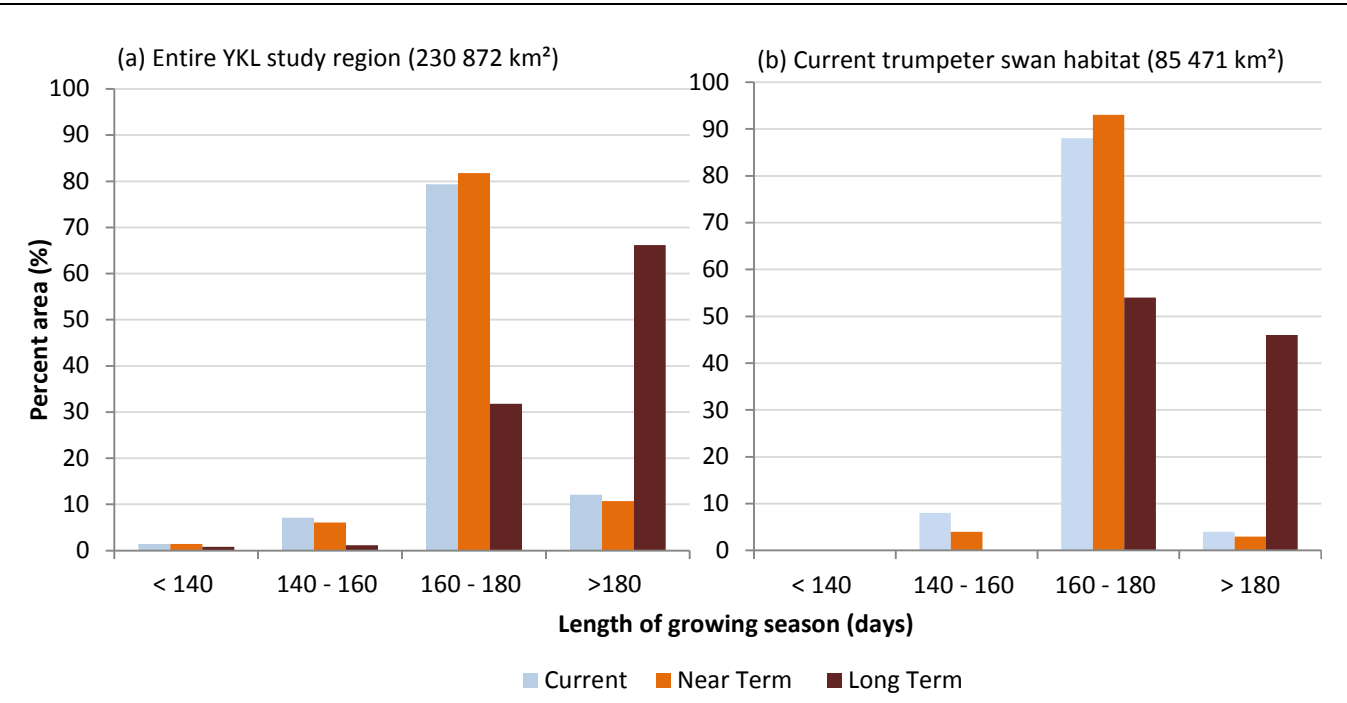
**Figure D-77.** Percent area of the (a) YKL study area, and (b) current trumpeter swan habitat in the YKL study region categorized by length of growing season modeled for current (2010), near-term (2025) and long-term (2060).

Swans that arrive earlier in the spring can accelerate nesting and hatching and give cygnets more time for development before heading south (Hansen et al. 1971). This may allow for increased cygnet survival and reproductive success, boosting trumpeter swan populations in the YKL study region. A recent study suggests that northern expansion of the trumpeter swan is already occurring as a result of earlier spring breakup dates and warmer ambient temperatures (Schmidt et al. 2011).

Using the ranges for each variable shown in the literature, we found that the added benefit of increased open-water season length continues up to more than 180 days. Climate models indicate that under current conditions, only approximately 12% of the YKL study region and less than 5% of the current trumpeter swan habitat in the region offer 180 ice-free days (Figure D-77 and Figure D-78). However, by 2060, an ice-free period of 180 days or more can be expected for more than 65% of the YKL study region and more than 45% of current trumpeter swan habitat (Figure D-77 and Figure D-78; see Climate section B-1 for model details). Thus, swan density (or breeding success) is likely to increase with a warming climate, and new habitat may potentially become available to trumpeter swans as growing season length increases across the YKL study region.
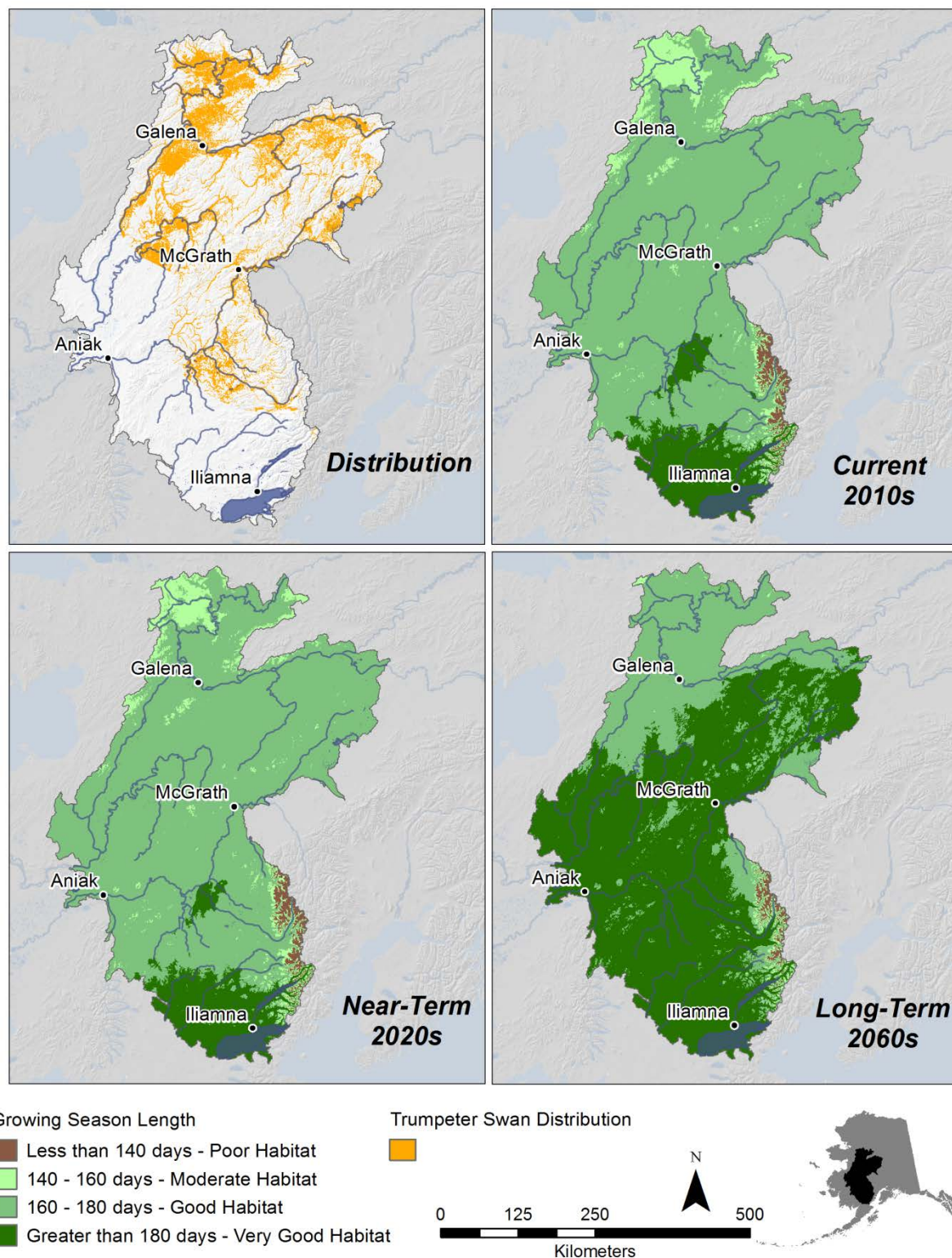
**Figure D-78.** Current trumpeter swan distribution and projected change in growing season length in the YKL study area.

There is loose evidence that increased monthly temperature in spring may affect arrival dates of migratory waterfowl (Murphy-Klassen et al. 2005). If this theory holds true for the trumpeter swan in Alaska, we could

expect to see earlier spring arrival of swans, which would allow them to capitalize on the increased growing season length (Figure D-78).
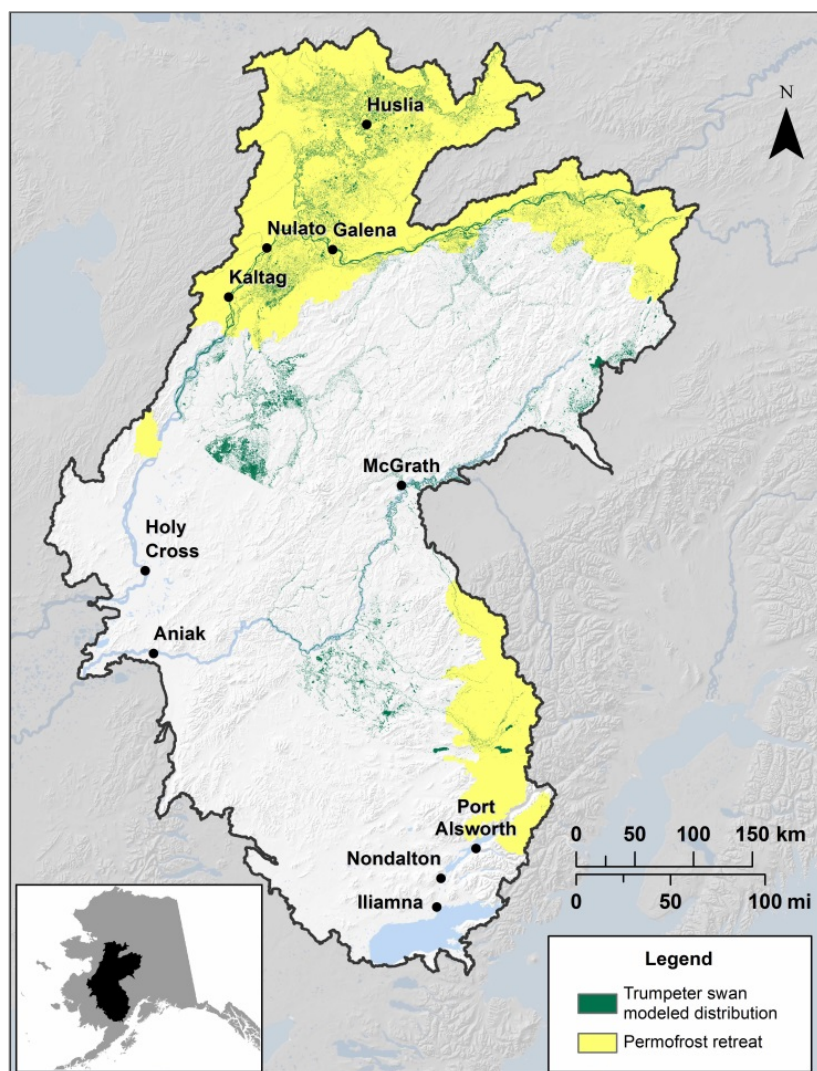


**Figure D-79.** Areas of permafrost retreat modeled from 2010-2060.

In addition to affecting cygnet fledging success, climate change has the potential to impact trumpeter swans via habitat changes linked to permafrost thaw and associated wetland drying and shrinkage. Some wetlands are likely to become less suitable as they shrink and become more shallow, while other deeper waters may become shallower and thus more suitable (Schmidt et al. 2011). Climate models indicate permafrost retreat in the northern portion of the YKL study area by 2060 (Figure D-79). By 2060, approximately 33% of trumpeter swan habitat currently underlain by continuous permafrost will become discontinuous (Figure D-79). It should be noted that permafrost varies at a finer resolution than can be captured in these maps. Areas that are shown as "thawed" may have frozen pockets, and areas shown as below freezing at one meter depth may have permafrost-free zones. This is particularly true near lakes and streams, which are also prime swan habitat. Despite these caveats, the broader picture informs the question of whether landscape-level drainage patterns are likely to change.

Permafrost thaw may open up new wetland areas and increase the amount of suitable habitat in this area. Studies have shown that the age of first reproduction for trumpeter swans is negatively associated with nest density (Hansen et al. 1971; Banko 1960; Monnie 1966). New territories and increased habitat created by permafrost melt may result in swans reproducing at an earlier age, thereby boosting the population.

Permafrost retreat in the southeastern portion of the YKL study area would likely not be as beneficial to trumpeter swans as growing season length in this area is not projected to reach minimum thresholds for swan reproductive success in the next 50 years (< 140 days).

**Fire**

Fire frequency and intensity are expected to increase within the YKL study area. No specific information was found in the literature regarding fire-related effects on trumpeter swan habitat. Fire occurring in wetland habitats, however, often removes excessive accumulations of fast growing hydrophytes, permitting better waterfowl access and growth of more desirable forage such as pondweed and duckweed (Vogl 1967; Schmidt et al. 2009).

**Invasive Species**

Climate change is also likely to cause an increase of the number of disease outbreaks and increase the abundance of invasive plant species. Invasive plant species have the potential to change the habitat structure, biodiversity, productivity, nutrient cycling, and trophic ecology of wetlands ecosystems, which may result in habitat loss (Zedler and Kercher 2004); however, the implications for trumpeter swan habitat and their forage remains unclear.

**Current Status and Future Landscape Condition**

The majority of current trumpeter swan habitat is in areas with very high (intact) landscape condition (Figure D-80). Future projections of landscape condition suggest an increase in low and medium quality habitat, with reduced landscape condition around Galena and McGrath.

Changes in land use including infrastructure, transportation, and natural resource development can often result in partial or complete loss of wetland habitat. Trumpeter swans are sensitive to human activities on their breeding grounds. Human activity and disturbance such as recreation, vehicle traffic, and wildlife viewing, cause noise disturbance that often results in either total or temporary displacement of female swans from nesting sites (Henson and Grant 1991; Schmidt et al. 2009), as well as movements from breeding and staging areas (Henson and Grant 1991). Trumpeter swans will not nest on lakes intensively developed for recreation. The swans are most sensitive to disturbance from mid-April to mid-June (Henson and Grant 1991).

In addition, trumpeter swans are susceptible to lead poisoning. While non-toxic ammunition are required for waterfowl hunting in Alaska, contaminated vegetation or sediments associated with mining and smelting wastes may pose a risk (Blus et al. 1989). Both trumpeter and tundra swans (*C. columbianus*) were historically harvested for subsistence, but current harvest of trumpeters is not permitted (PFC 2006).
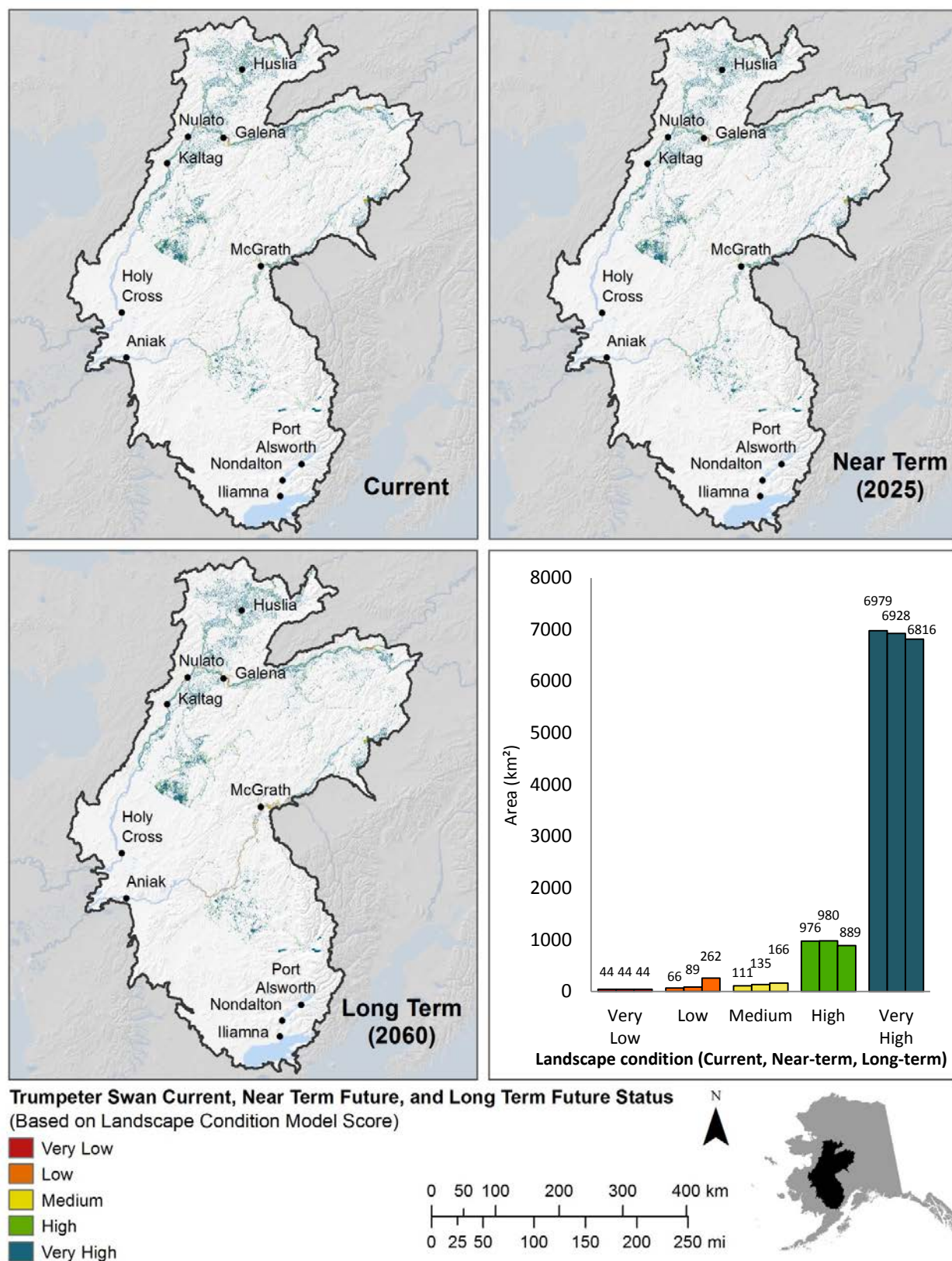
**Figure D-80.** Landscape condition modeled for current, near-term (2025) and long-term (2060) projections clipped to current trumpeter swan habitat in the YKL study area.

## Applications

This section provides managers with a general habitat distribution model for the Trumpeter swan in the YKL study area. The Trumpeter swan can be used as a proxy for other wetland associated species, representing the condition and availability of freshwater resources. Here we provide interpretation of predicted climate change effects, which appear to be favorable for trumpeter swans. In particular, changes in growing season length could benefit trumpeter swans by promoting fledging success, while warmer springs may trigger the earlier migrations necessary to capitalize on this extended season. In addition, climate change is expected to result in warming soils and associated permafrost thaw, which may increase trumpeter swan habitat.

## Limitations and Data Gaps

Since limited spatial data were available on fire, anthropogenic activities, and invasive species to trumpeter swan, most potential changes were qualitatively described based on literature review and incorporated into the conceptual models. It should also be noted that although model estimates for season length do not include the lag time between the date at which running mean temperatures cross the freezing point and the date at which freeze or thaw occurs, these lag times will tend to cancel one another out. Nonetheless, data used for "summer season length" is only an estimate for ice-free days, and true values will vary between water bodies.

## 2.1. Sensitive Species Habitat

| MQ 12 | Where is habitat for sensitive species that are also conservation elements? |
|-------|------------------------------------------------------------------------------|

Three Terrestrial Fine-Filter CEs included in the YKL assessment are also included in the Bureau of Land Managements' "Sensitive Species" list (BLM 2010). These include: American peregrine falcon (*Falco peregrinus anatum*), olive-sided flycatcher (*Contopus cooperi*), and trumpeter swan (*Cygnus buccinator*).

**Methods**

Methods used to map the habitats (predicted distribution) of each of the "Sensitive Species" CEs are described in section 2.2. We also conducted a literature review to provide descriptive habitat associations for each species.

To assess habitat for sensitive species collectively, we intersected the distribution models for the three species of concern to develop a composite model of sensitive species habitat use. Pixels that contained only one species received a value of "1" and two species received a "2". No pixels contained all three sensitive species. We then overlaid the sensitive species distribution with the Vegetation Map of Northern, Western, and Interior Alaska (Boggs et al. 2012) and extracted those landcover classes that overlapped areas with presence of two sensitive species.

**Habitat Descriptions**

*American peregrine falcon*

Breeding habitat includes various open situations from tundra, steppe, and seacoasts, especially where there are suitable nesting cliffs, to mountains, open forested regions, and human population centers (AOU 1983). When not breeding, peregrines occur in areas where prey concentrate, including farmlands, marshes, lakeshores, river mouths, tidal flats, dunes and beaches, and broad river valleys. In central Alaska, they occur in the forested interior, nesting primarily on cliffs along major rivers.

Peregrine falcons often nest on ledges or holes on faces of rocky cliffs or crags. River banks, tundra mounds, open bogs, large stick nests of other species, tree hollows, and man-made structures (e.g. ledges of city buildings) are used locally (Cade 1982). Nests typically are situated on ledges of vertical rocky cliffs, commonly with a sheltering overhang (Palmer 1988, Campbell et al 1990). Ideal locations include undisturbed areas with a wide view, near water, and close to plentiful prey.

*Olive-sided flycatcher*

Prefers forest and woodland habitats, especially in burned-over areas with standing dead trees, in taiga, subalpine coniferous forest, and mixed coniferous-deciduous forest. The species has a strong preference for forest edges, including forested habitats in central Alaska, where forests are naturally open or semi-open. Considered an indicator species for the coniferous forest biome, olive-sided flycatchers are also found in mixed deciduous/coniferous forests. The species is closely associated with openings, water, and dead standing trees, as well as recently burned areas (Campbell et al. 1997).

### *Trumpeter swan*

Found in ponds, lakes, and marshes, they breed in areas of reeds, sedges, or similar emergent vegetation. They are primarily found in freshwater, and only occasionally in brackish situations. Prefer water bodies with ample room for takeoff and structures, such as islands, for nesting (Mitchell 1994).
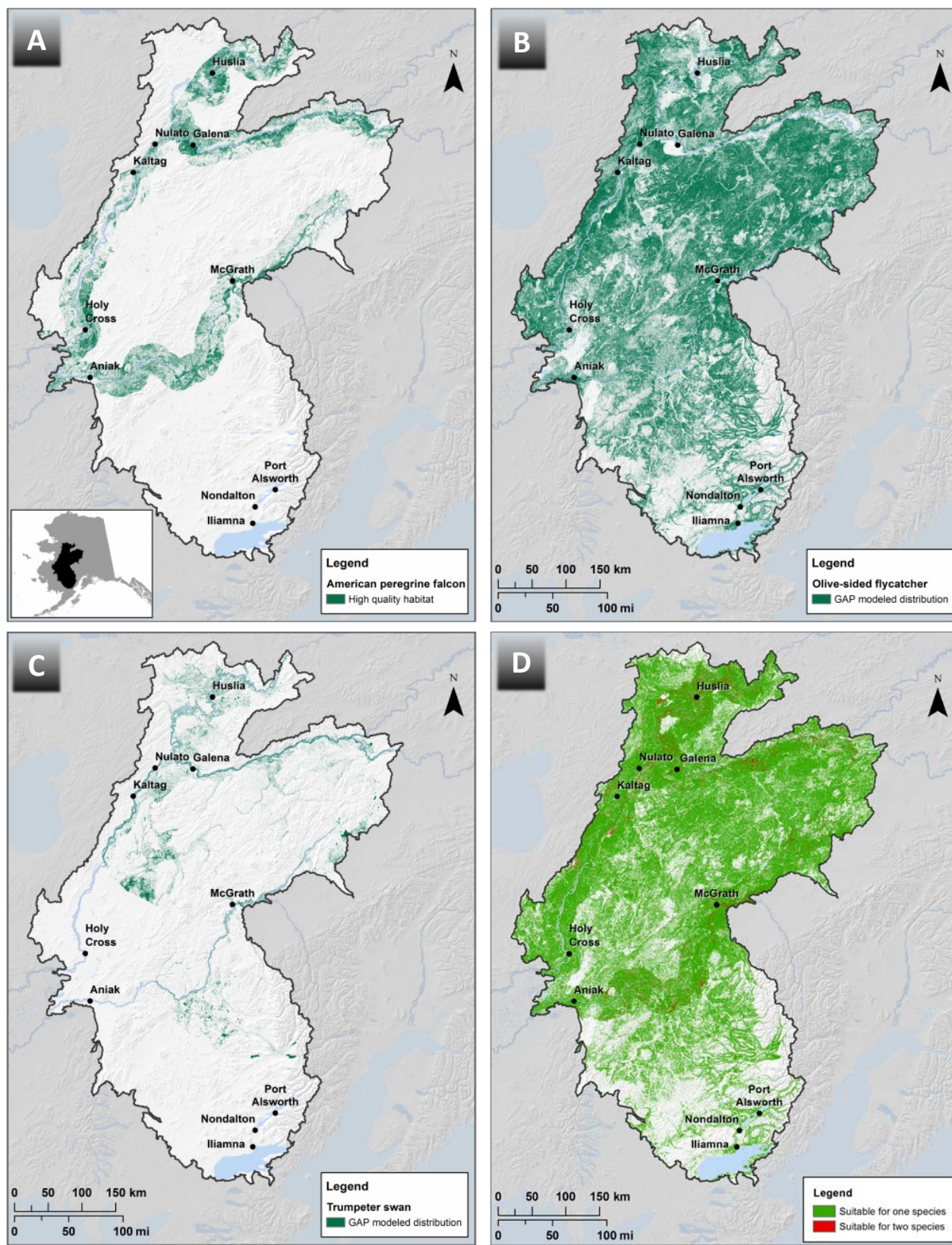
**Figure D-81.** Current distribution of (a) Peregrine falcon, (b) olive-sided flycatcher, (c) trumpeter swan and (d) overlap of species habitat in the YKL study area.

**Sensitive Species Habitat**

The composite map of the distribution of the three sensitive species is presented in Figure D-81d. Although 56% of the YKL study area is suitable habitat for at least one sensitive species, only slightly over 1% of the YKL study area is suitable habitat for two sensitive species. No habitat is suitable for three all three species at the scale of a 60 x 60 m grid. Areas identified as suitable habitat for two species are associated with riparian areas in the central and northeastern sections of the study area where the habitats for American peregrine falcon and trumpeter swan sometimes overlap. These areas are mainly associated with white and black spruce woodland-closed forest (Figure D-82 and Figure D-83).
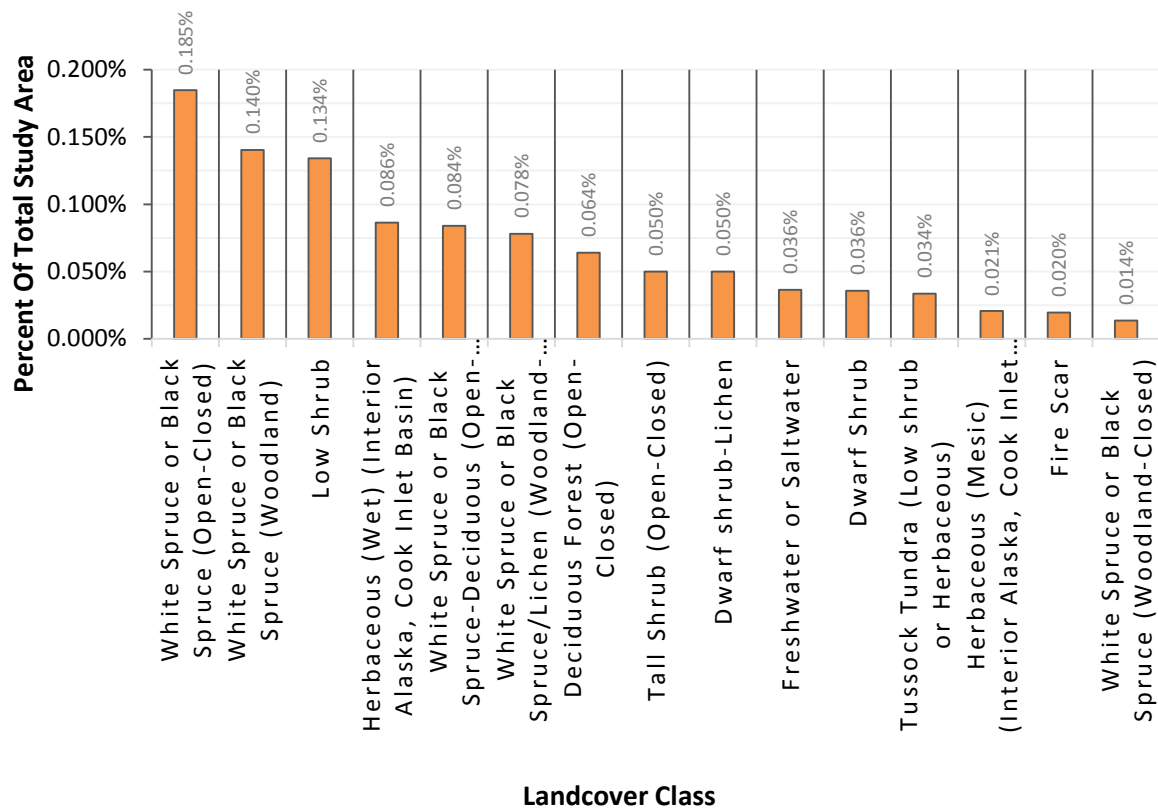


**Figure D-82.** Vegetation type by percent of total study area currently classified as suitable habitat for two sensitive species. Land cover classes with an area < 0.01% were omitted from the table.

**Figure D-83.** Land cover classes from the YKL Vegetation Map (Boggs et al. 2012) in areas of habitat overlap between two or more sensitive species (Peregrine falcon, trumpeter swan and olive-sided flycatcher) in the YKL study region.

## 2.2.  Distribution of Key Prey Species

| MQ 10 | Where are key prey species located in the region? |

"Prey species" considered for this question include small and medium-bodied herbivores, as they provide food for a wide-range of avian and mammalian predators. The small-bodied voles and lemmings are relatively inconspicuous, but they are often the most numerous mammals in tundra ecosystems, providing food for most carnivores and playing a key role in energy flow through the ecosystem (Krebs et al. 2003). Medium-bodied herbivores include the hares and larger rodents (ground squirrel, muskrat, marmot, and beaver). These are generally found at lower densities than small mammals, but can be locally more abundant depending on habitat patchiness. By diversifying the food supply for carnivores, they have a stabilizing role in food webs (Reid et al. 1997). The northern red-backed vole (*Myodes rutilus*), Nearctic brown lemming (*Lemmus trimucronatus*), and snowshoe hare (*Lepus americanus*) were selected as representative prey species for the YKL region, as they inhabit a wide-variety of habitats, are prey for a large number of birds and mammals, and their ranges extend throughout the entire study area.


Northern red-back voles are one of the most ubiquitous and common species in Alaska. They live in a variety of habitats from upland forests to grassy meadows, but are most abundant in forest, woodland and shrub habitats (Douglass 1984; West 1982; Sullivan et al. 1999), and prefer environments with dense ground cover for protection from weather and predation (Wein 1975; Bangs 1984). Red-backed voles are mostly solitary or live in small family groups. They do not build runways, but will use those built by *Microtus* voles if they live in the same area. An omnivorous species, they eat mostly grasses, seeds, fruits, lichens, fungi, insects and meat (Bangs 1984).


Nearctic brown lemmings play a keystone role in supporting biodiversity due to their widespread but cyclic abundance, and their consequent role as prey for many raptors and mammalian predators (Angerbjörn et al. 1999; McLennan et al. 2012). They are also a major consumer of plant production (Krebs 2011). They inhabit a variety of arctic, alpine tundra, and taiga habitats including sedge-grass tundra above tree line and spruce bogs or wet meadows below tree line (Batzli et al. 1983). During winter, they remain under the snowpack, and eat moss shoots and leaf bases of perennial grasses and sedges (Peterson et al. 1976). During summer, their diet consists of mosses, grasses, and sedges (Batzli and Pitelka 1983).


Snowshoe hares are widely distributed throughout the taiga of Alaska, except for the lower Kuskokwim Delta and the Alaska Peninsula (MacDonald and Cook 2009), and are considered an important herbivore in the food web of the boreal forest. Snowshoe hares prefer the dense cover of coniferous and mixed forests with abundant understory cover and riparian shrub thickets. Coniferous swamps and second-growth areas adjacent to mature forests, and alder fens and conifer bogs are also utilized.

## Current distribution and habitat preferences
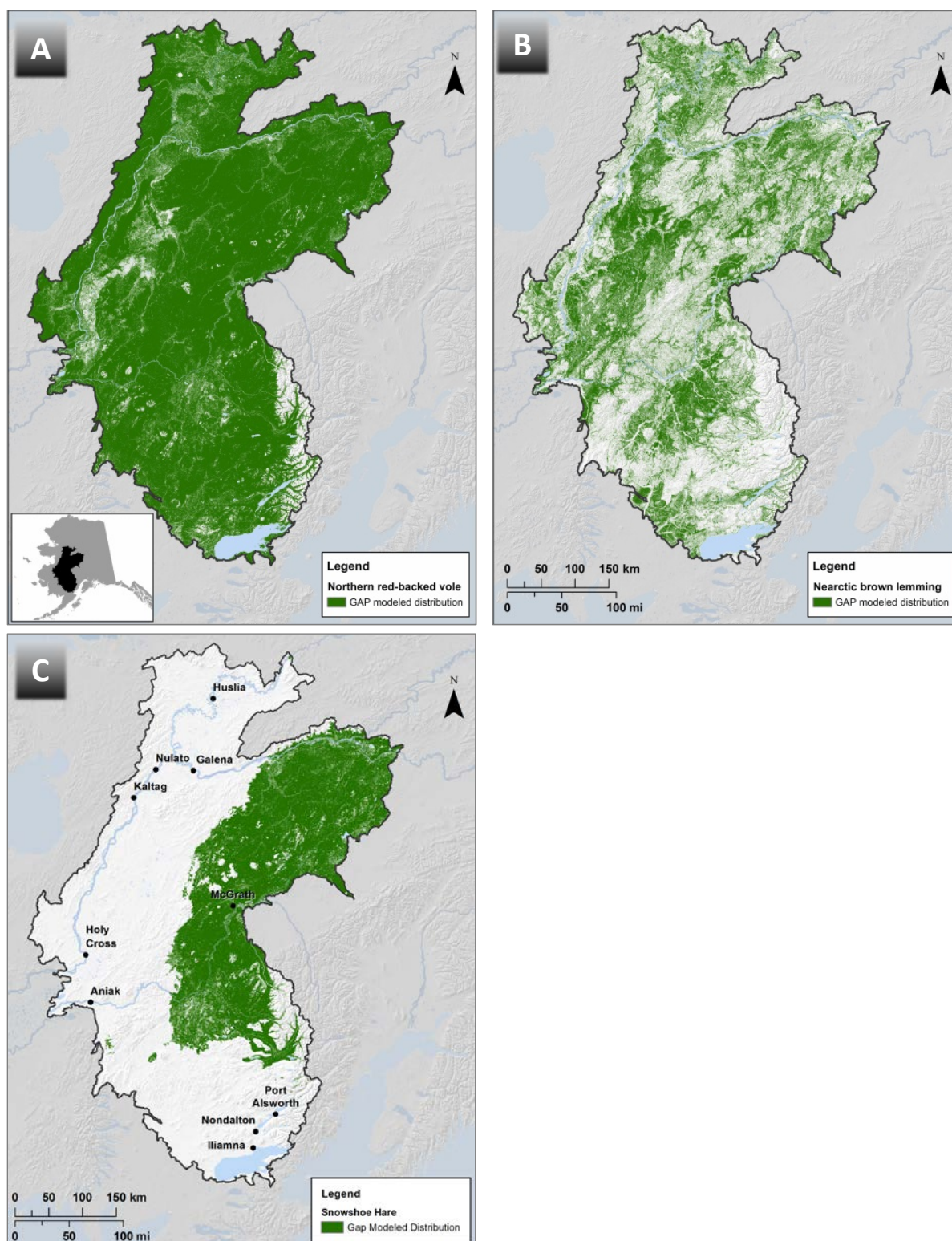


**Figure D-84.** Predicted distribution of northern red-backed vole (a), Nearctic brown lemming (b), and snowshoe hare (c) in the YKL REA.

In the boreal forest, habitat preferences, and hence, distribution of the northern red-backed vole and snowshoe hare are very similar. Both species are closely associated with forested, woodland, and shrub habitats, and their distributions in the YKL region are closely aligned (Figure D-84). Although often largely associated with arctic tundra habitats, within the YKL area the Nearctic brown lemming is generally found in moist habitats below tree-line, with a preference for spruce bogs and wet meadows (Figure D-84b).

## Major Predators

Predation is well documented as a significant mortality factor limiting numbers in lemming and hare populations (Krebs 2011). The Nearctic brown lemming is a primary food source for many specialist predators including weasels, owls and seasonally, the Arctic fox (where ranges overlap). Snowshoe hares are important prey for numerous mammalian species, including ground squirrels and red squirrels, foxes, coyotes, wolves, lynx, and mink. Most snowshoe hares typically die of predation (Hodges 2000). Although wild hares can reach five to six years of age, typically over 70% of the spring breeding population is composed of yearlings (Hodges 2000). Red-backed voles are the staple foods of weasels, marten, foxes, coyotes, all owls, most hawks, inland breeding gulls, jaegers, and occasionally other voles (Lensink et al. 1955; Luttich et al. 1970; Buskirk and MacDonald 1984; Thurber et al. 1992).

## Population Cycling

Herbivore populations often exhibit dramatic population fluctuations through time, independent of human actions (Reid et al. 2013). These fluctuations appear cyclic with amplitude of one or two orders of magnitude, which are influenced by both extrinsic factors (e.g., predation) and intrinsic factors (e.g., pup survival) (Gunn 2003). Lemming population patterns typically occur in three to four year cycles (Gruyer et al. 2008), with large population increases occurring during favorable winter snow conditions (McLennan et al. 2012). Northern red-backed vole population patterns also typically occur in three to four year cycles that are dependent on food and social behaviors (Krebs et al. 2014); however, limited berry crops can cause irregular population fluctuations (Boonstra and Krebs 2012; Krebs et al. 2010). Snowshoe hare populations are also subject to cycles of high abundance and scarcity. Snowshoe hare abundance in boreal forest cycles at 8 to 13 years with a mean of 9 to 10 years (Gunn 2003). During periods of peak abundance, there are as many as 600 animals per square mile (230/km²) of range. Many snowshoe hare predators also display cyclic dynamics, often with a lag of one to three years behind the hare cycle (Hodges 2000). Perturbations to these cycles could result in cascading effects throughout the food chain.

## Responses to Climate Induced Change

Among the environmental conditions that are predicted to change in the future due to climatic warming, changes in snow depth and duration, as well as increased ice-crusting in winter and spring are considered to have the greatest impact on the dynamics of terrestrial vertebrates at northern latitudes (Gilg et al. 2009). Winter conditions are critical for the demography of many high-latitude rodents. When available, the subnivian space provides thermal insulation, access to food plants and protection from generalist predators like foxes, owls, corvids and raptors (Kausrud et al. 2008). Snow quality and quantity likely play a prominent role in population dynamics and are changing as the climate becomes warmer.

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 subnivean reproduction of brown lemmings and

tundra voles (Reid et al. 2013). 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). Summer breeding for Northern red-backed voles is related to the timing of snowmelt (Martell and Fuller 1979). Late snow melt delays maturation of young-of-the-year females and reduces reproductive success (Martell and Fuller 1979). Under warming climatic conditions, snow is tending to accumulate later and melt earlier and winter rains and thaws make it less insulative. Changes in the condition and/or the duration of the subnivian habitat are thus likely to affect the performance of rodent communities through temperature stress, flooding risk, food limitation, and even predator access (Kausrud et al. 2008).

For the snowshoe hare, the potential direct and indirect effects of a warming climate could be beneficial, through improved food quantity with increasing primary production and proliferation of willows; or detrimental, by reducing access to winter foods with deeper and harder snow packs, and increasing predation pressure coupled with expanding diversity and abundance of other herbivores, including other hare species and ungulates (Klein 1995; Murray 2003).

Climate change may turn regular population cycles into noncyclic dynamics (Gilg et al. 2009) or dampen population cycles substantially (Kausrud et al. 2008). Rodent cycles in the Arctic seem to have become more variable in period and amplitude in recent decades. However, long-term data are currently lacking to be able to determine whether changes are part of the general variability of these populations or a definite response to a changing climate (Reid et al. 2013). Reduced maximum densities of key prey species could be detrimental to predator populations that are adapted to make use of the years of high prey abundance (Gilg et al. 2009). Gilg et al. (2009) found that the reduced amplitude of collared lemming population fluctuations in Greenland resulted from decreases in the duration of annual snow cover and increases the frequency of thaw-refreeze events during winter. Between 2000 and 2008, collared lemmings ceased to cycle, resulting in low population densities and a complete absence of snowy owl predators (Gilg et al. 2009). On the Scandinavian Peninsula, the recent absence of regularly occurring large-scale rodent peak years is responsible for the declines in arctic foxes and snowy owls in that region (Kausrud et al. 2008).

## 2.3.  Literature Cited

Alaska Department of Fish and Game (ADF&G). 2009. *In:* P. Harper (ed.) Wolf management report of survey-inventory activities 1 July 2005 - 30 June 2008. Juneau, Alaska.

Alaska Department of Fish and Game (ADF&G). 2011. *In:* P. Harper (ed.) Muskox management report of survey inventory activities 1 July 2008 – 30 June 2010.  Juneau, Alaska.

Alaska Department of Fish and Game (ADF&G). 2013a. Species profile: Moose (*Alces alces*) Available: http://www.adfg.alaska.gov/index.cfm?adfg=moose.main.

Alaska Department of Fish and Game (ADF&G). 2013b. Species profile: Caribou (*Rangifer tarandus granti*). Available: http://www.adfg.alaska.gov/index.cfm?adfg=caribou.main.

Alaska Department of Fish and Game (ADF&G). 2013c. Species profile: Wolf (*Canis lupus*). Available: http://www.adfg.alaska.gov/index.cfm?adfg=wolf.main.

Alaska Department of Fish and Game (ADF&G). 2014. Parasites and Disease. Available: http://www.adfg.alaska.gov/index.cfm?adfg=disease.specieslist.

Alaska Department of Fish and Game (ADF&G). 2014b. Living with Beavers. Available: http://www.adfg.alaska.gov/index.cfm?adfg=livewith.beavers.

Allen, A. W. 1983. Habitat suitability index models: beaver. U.S. Fish and Wildlife Service. FWS/OBS-82/10.30.

Altman, B., and R. Sallabanks. 2012. Olive-sided Flycatcher (*Contopus cooperi*). *In:* A. Poole (ed.) The Birds of North America Online. Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/.

Alto, B. W. and S. A. Juliano. 2001. Precipitation and temperature effects on populations of *Aedes albopictus* (Diptera: Culicidae): implications for range expansion. Journal of medical entomology 38: 646-656.

Ambrose, R. E., R. J. Ritchie, C. M. White, P. F. Schempf, T. Swem, and R. Dittrick. 1988. Changes in the status of peregrine falcon populations in Alaska. In Peregrine falcon populations: their management and recovery. The Peregrine Fund, Boise, Idaho. Pp. 73–82.

Ambrose, S., and S. Ulvi. 1990. Peregrine falcon research in the Yukon-Charley Rivers National Preserve, Alaska. Park Science 10: 18–20.

American Ornithologists' Union (AOU). 1983. Check-list of North American birds. 6th ed. American Ornithologists' Union, Washington D. C.

Angerbjörn, A., M. Tannerfeldt, and S. Erlinge. 1999. Predator-prey relationships: arctic foxes and lemmings. Journal of Animal Ecology 68: 34–39.

Arno, S. F. and M. G.Harrington. 1995. Use thinning and fire to improve forest health and wildlife habitat. Tree Farmer. May/June: 6-8, 23.

Asherin, D. A. 1973. Prescribed burning effects on nutrition, production and big game use of key northern Idaho browse species. Dissertation. Moscow, ID: University of Idaho. 96 pp.

Baker, B. W., and E. P. Hill. 2003. Beaver (*Castor canadensis*). *In*: G. A. Feldhamer, B. C. Thompson, and J. A. Chapman (eds.) Wild Mammals of North America: Biology, Management, and Conservation. The Johns Hopkins University Press, Baltimore, Maryland. Pp. 288-310.

Bale, J. S., G. J. Masters, I. D. Hodkinson, C. Awmack, T. M. Bezemer, V. K. Brown, J. Butterfield , A. Buse, J. C. Coulson, J. Farrar, J. E. G. Good, R. Harrington, S. Hartley, T. H. Jones, R. L. Lindroth, M. C. Press, I. Symrnioudis, A. D. Watt, and J. B. Whittaker. 2002. Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. Global Change Biology 8: 1–16.

Ball, M. C., M. W. Lankester, and S. P. Mahoney. 2001. Factors affecting the distribution and transmission of *Elaphostrongylus rangiferi* (Protostrongylidae) in caribou (*Rangifer tarandus caribou*) of Newfoundland, Canada. Canadian Journal of Zoology 79: 1265–1277.

Ballard, W. B., E. H. Follmann, D. G. Ritter, M. D. Robards, and M. A. Cronin. 2001. Rabies and canine distemper in an arctic fox population in Alaska. Journal of Wildlife Diseases 37: 133–137.

Ballard, W. B., and P. R. Krausman. 1997. Occurrence of rabies in wolves in of Alaska. Journal of Wildlife Diseases 33: 242–245.

Ballard, W. B., J. S.Whitman, and C. L. Gardner. 1987. Ecology of an exploited wolf population in south-central Alaska. Wildlife Monographs Pp. 3–54.

Ballard, W. B., J. S. Whitman, and D. J. Reed. 1991. Dynamics of moose in south-central Alaska. Wildlife Monographs 114: 3–49.

Ballesteros, M., B. J. Bårdsen, K. Langeland, P. Fauchald, A. Stien, and T. Tveraa. 2012. The effect of warble flies on reindeer fitness: a parasite removal experiment. Journal of Zoology 287: 34–40.

Bangs, E. E. 1984. Summer food habits of voles, *Clethrionomys rutilus* and *Microtus pennsylvanicus*, on the Kenai Peninsula, Alaska. Canadian Field-Naturalist 98: 489–492.

Banko, W. E. 1960.The Trumpeter Swan: Its history, habits, and population in the United States. North American Fauna 63: 1-214.

Barnes, D. M., and A. U. Mallik. 2001. Effects of Beaver, *Castor canadensis*, herbivory on streamside vegetation in a northern Ontario watershed. Canadian Field-Naturalist 115: 9–21.

Batzli, G., and F. Pitelka. 1983. Nutritional ecology of microtine rodents: food habits of lemmings near Barrow, Alaska. Journal of Mammalogy 64: 648-655.

Batzli, G., F. Pitelka, and G. Cameron. 1983. Habitat use by lemmings near Barrow, Alaska. Holarctic Ecology 6: 255-262.

Becklund, W. W. and M. L. Walker. 1969. Taxonomy, hosts, and geographic distribution of the *Setaria* (Nematoda: Filarioidea) in the United States and Canada. The Journal of Parasitology 55: 359-368.

Bent, A. C. 1942. Life histories of North American flycatchers, larks, swallow, and their allies. U.S. National Museum, Washington, D.C. 555 pp.

Bird, B., M. O'Brien, and M. Petersen. 2011. Beaver and climate change adaptation in North American. A simple, cost-effective strategy. Wild Earth Guardians.

Blus, L. J., R. K. Stroud, B. Reiswig, and T. McEneaney. 1989. Lead poisoning and other mortality factors in trumpeter swans. Environmental Toxicology and Chemistry 8: 263–227.

Bolduc, E., N. Casajus, P. Legagneux, L. McKinnon, H. G. Gilchrist, M. Leung, R. I. G. Morrison, D. Reid, P. A. Smith, C. M. Buddle, and J. Bêty. 2013. Terrestrial arthropod abundance and phenology in the Canadian Arctic: modelling resource availability for Arctic-nesting insectivorous birds. The Canadian Entomologist 145: 1–16.

Boonstra, R., and C. J. Krebs. 2012. Population dynamics of red-backed voles (Myodes) in North America. Oecologia 168: 601–620.

Bos, G. N. 1967. Range types and their utilization by muskox on Nunivak Island, Alaska: A reconnaissance study. Master of Science. University of Alaska.

Both C., S. Bouwhuis, C. M. Lessells, and M. W. Visser. 2006. Climate change and population declines in a long-distance migratory bird. Nature 441: 81.

Boudreault, C., Y. Bergeron, S. Gauthier, and P. Drapeau. 2002. Bryophyte and lichen communities in mature to old-growth stands in eastern boreal forests of Canada. Canadian Journal of Forest Research 32: 1080-1093.

Boyle, S., and S. Owens. 2007. North American Beaver (*Castor canadensis*): a technical conservation assessment. USDA Forest Service, Rocky Mountain Region.
Available: http://www.fs.fed.us/r2/projects/scp/assessments/northamericanbeaver.pdf

Bradley, M. J., S. J. Kutz, E. Jenkins, and T. O. O'Hara. 2005. The potential impact of climate change on infectious diseases of arctic fauna. International Journal of Circumpolar Health 64: 468–477.

Bureau of Land Management (BLM). 2010. BLM – Alaska Sensitive Animal and Plant Lists.

Burger, J. F., and J. R. Anderson. 1974. Taxonomy and life history of the Moose Fly, *Haematobosca alcis* and its association with the Moose, *Alces alces shirasi* in Yellowstone National Park. Annals of the Entomological Society of America 67: 204–214.

Buskirk, S. W., and S. O. MacDonald. 1984. Seasonal food habits of marten in south-central Alaska. Canadian Journal of Zoology 62: 944–950.

Cade, T. J. 1960. Ecology of the Peregrine and Gyrfalcon populations in Alaska. University of California Press, Berkeley, California. Pp. 151–290.

Cade, T. J. 1982. Peregrine (great-footed falcon, duck hawk): *Falco peregrinus*. *In:* T. J. Cade (ed.) The falcons of the world. Cornell University Press, Ithaca, New York. Pp. 58–68.

Cade, T. J., J. L. Lincer, C. M. White, D. G. Roseneau, and L. G. Swartz. 1971. DDE residues and eggshell changes in Alaskan falcons and hawks. Science 172: 955–957.

Cade, T. J., C. M. White, and J. R. Haugh. 1968. Peregrines and pesticides in Alaska. The Condor 70: 170–178.

CalPIF (California Partners in Flight). 2002. Version 1.1. The coniferous forest bird conservation plan: a strategy for protecting and managing coniferous forest habitats and associated birds in California (J. Robinson and J. Alexander, lead authors). PRBO Conservation Science, Petaluma, California. http://www.prbo.org/calpif/plans.html.

Campbell, R. W., N. K. Dawe, I. McTaggart-Cowan, J. M. Cooper, G. W. Kaiser, M. C. E. McNall, and G. E. J. Smith. 1997. The Birds of British Columbia. Volume 3. Passerines: flycatchers through vireos. University of British Columbia Press, Vancouver. 693 pp.

Chapman, R. C. 1978. Decimation of a wolf pack in arctic Alaska. Science 201: 365–367.

Coady, J. W. 1974. Influence of snow on behavior of moose. Nat. Can. 101: 417–436.

Coxson, D. S., and J. Marsh. 2001. Lichen chronosequence (postfire and postharvest) in lodgepole pine (*Pinus contorta*) forests of northern interior British Columbia. Canadian Journal of Forest Research 79: 1449-1464.

Craig, H. L., and P. S. Craig. 2005. Helminth parasites of wolves (*Canis lupus*): a species list and an analysis of published prevalence studies in Nearctic and Palaearctic populations. Journal of Helminthology 79: 95-103.

Crouse, J., and S. Crouse. 2008. Moose. Alaska Wildlife Notebook Series. Original text by: R. A. Raush, B. Gasaway, and C. Schwartz. Alaska Department of Fish and Game, Juneau, Alaska.

Davis, J. L. and P. Valkenburg. 1983. Calving in recently burned habitat by caribou displaced from their traditional calving area. In: Alaska/Canada north, neighbors in science: proceedings of the 34th Alaska science conference; 1983 September; Whitehorse, YT. [Fairbanks, AK]: American Association for the Advancement of Science, Arctic Division; Ottawa, ON: Department of Indian and Northern Affairs, Northern Program: 19.

Dieterich, R. A., and D. G. Ritter. 1982. Rabies in Alaskan reindeer. Journal of the American Veterinary Medical Association 181: 1416.

Dieterich, R. A., E. Reimers, E. Gaare, and S. Skjenneberg. 1980. Current status of reindeer/caribou diseases in Alaska. In Proceedings of the Second International Reindeer/Caribou Symposium, 1979 September, Roro, Norway, Part B [Abstract]. Direktorat for Vilt og Ferskvannsfisk.

Douglass, R. J. 1984. Ecological distribution of small mammals in the De Long Mountains of Northwestern Alaska. Arctic 37: 148–154.

Ellis, David H. 1982. The peregrine falcon in Arizona: habitat utilization and management recommendations. Institute for Raptor Studies: Research Reports. No. 1. 24 p.

Elmhagen, B., and S. P. Rushton. 2007. Trophic control of mesopredators in terrestrial ecosystems: top-down or bottom-up? Ecology Letters 10: 197–206.

Federal Register. 2014. Endangered and Threatened Wildlife and Plants; 90-Day Finding on a Petition to List the Alexander Archipelago Wolf as Threatened or Endangered. Federal Register Volume 79, No. 61. Monday, March 31, 2014.

Flagstad, L., H. Cortés-Burns, and T. Roberts. 2010a. Invasive plant inventory and Bird Cherry control trials. Phase II: Bird Cherry distribution, demography and reproduction biology along the Chester and Campbell Creek trails, Anchorage, Alaska. Prepared for: Municipality of Anchorage and the Anchorage Parks Foundation. Alaska Natural Heritage Program, University of Alaska Anchorage, Anchorage, Alaska. 61 pp.

Flagstad, L., H. Cortés-Burns, E. Johnson, L. Simpson, and A. Brownlee. 2010b. Viability of European bird cherry (*Prunus padus* L.) seed after two-year retention in traps along the Chester and Campbell Creek Trails, Anchorage, AK. Prepared for the Municipality of Anchorage. Alaska Natural Heritage Program, University of Alaska Anchorage, Anchorage, Alaska. 12 pp.

Flagstad, L., H. Cortés-Burns, and M. L. Carlson. *In Prep.* Demography, distribution, and reproduction of the non-native tree, *Prunus padus* in subarctic Alaska: Evidence for rapid recruitment.

Forrester, S. G., and M. W. Lankester. 1998. Over-winter survival of first-stage larvae of *Parelaphostrongylus tenuis* (Nematoda: Protostrongylidae). Canadian Journal of Zoology 76: 704–710.

Fortin, M., S. Payette, and K. Marineau. 1999. Spatial vegetation diversity index along a postfire successional gradient in the northern boreal forest. Ecoscience 6: 204-213.

Fry, D. M. 1995. Reproductive effects in birds exposed to pesticides and industrial chemicals. Environmental Health Perspectives 103: 165–171.

Gale, R. S., E. O. Garton, and I. J. Ball. 1987. The history, ecology, and management of the Rocky Mountain Population of Trumpeter Swans. U.S. Fish & Wildl. Service, Montana Cooperative Wildl. Research Unit, Missoula, Montana.

Gardner, C. L., K. B. Beckmen, N. J. Pamperin, and P. Del Vecchio. 2013. Experimental treatment of dog lice infestation in interior Alaska wolf packs. Journal of Wildlife Management 77: 626–632.

Gasaway, W. C., S. D. Dubois, R. D. Boertje, D. J. Reed, and D. T. Simpson. 1989. Response of radio-collared moose to a large burn in central Alaska. Canadian Journal of Zoology 67: 325–9.

Gilg, O., B. Sittler, and I. Hanski. 2009. Climate change and cyclic predator-prey population dynamics in the High Arctic. Global Change Biology 15: 2634–2652.

Godfrey, W. E. 1979. Birds of Canada. National Museums of Canada, Bryant Press Ltd., Toronto, ON. 428 pp.

Griffith, B., D. C. Douglas, N. E. Walsh, D. D. Young, T. R. McCabe, D. E. Russell, R. G. White, R. D. Cameron, and K. R. Whitten. 2002. Section 3: The porcupine caribou herd. *US Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR-2002-0001.* Pp. 8-37.

Gruyer, N., G. Gauthier, and D. Bertreaux. 2008. Cyclic dynamics of sympatric lemming populations on Bylot Island, Nunavut, Canada. Canadian Journal of Zoology 86: 910–917.

Gunn, A. 2003. Voles, lemmings and caribou – population cycles revisited. Rangifer 14: 105–111.

Hagemoen, R. I. M., and E. Reimers. 2002. Reindeer summer activity pattern in relation to weather and insect harassment. Journal of Animal Ecology 71: 883–892.

Hakala, J. B. 1952. The life history and general ecology of the beaver (*Castor canadensis* Kuhl) in interior Alaska. M. S. Thesis, University of Alaska Fairbanks.

Hansen, H. A., P. K. Shepard, J. G. King, and W. A. Troyer. 1971. The Trumpeter Swan in Alaska. Wildlife Monographs 26: 1-83.

Hanson, W. A. 1979. Preliminary results of the Bear Creek fire effects studies. Proposed open file report. Anchorage, AK: U.S. Department of the Interior, Bureau of Land Management, Anchorage District Office. 83 pp.

Haukisalmi, V., A. Lavikainen, S. Laaksonen, and S. Meri. 2011. *Taenia arctos* n. sp.(Cestoda: Cyclophyllidea: Taeniidae) from its definitive (brown bear *Ursus arctos* Linnaeus) and intermediate (moose/elk Alces spp.) hosts. Systematic Parasitology 80: 217–230.

Hayes, G. E., and J. B. Buchanan. 2002. Washington State status report for the Peregrine Falcon. Washington Dept. Fish and Wildlife, Olympia. 77 pp.

Henson, P., and T. A. Grant. 1991. The effects of human disturbance on Trumpeter Swan breeding behavior. Wildlife Society Bulletin 19: 248–257.

Hoberg, E. P., A. A. Kocan, and L. G. Rickard. 2001. Gastrointestinal strongyles in wild ruminants. *In:* W. M. Samuel, M. J. Pybus, and A. A. Kocan (ed.) Parasitic diseases of wild mammals. Iowa State University Press, Iowa. Pp. 193–227.

Hoberg, E. P., L. Polley, E. J. Jenkins, S. J. Kutz, A. M. Veitch, and B. T. Elkin. 2008. Integrated approaches and empirical models for investigation of parasitic diseases in northern wildlife. Emerging Infectious Diseases 14: 10–17.

Hodges, K. E. 2000. The ecology of snowshoe hares in northern boreal forests. *In:* Ruggiero, L. F., K. B. Aubry, S. W. Buskirk, G. M. Koehler, C. J. Krebs, K. S. McKelvey, and J. R. Squires (eds.) The ecology and conservation of lynx in the United States. University Press of Colorado, Boulder, Colorado.

Holt, E. A., B. McCune, and P. Neitlich. 2007. Successional and community gradients of arctic macrolichens and their relation to substrate, topography and rockiness. Pacific Northwest Fungi 2: 1-21.

Hood, G. A., S. E. Bayley, and W. Olson. 2007. Effects of prescribed fire on habitat of beaver (*Castor canadensis*) in Elk Island National Park, Canada. Forest Ecology and Management 239: 200–209.

Hood, G. A., and S. E. Bayley. 2008. Beaver (*Castor canadensis*) mitigate the effects of climate on the area of open water in boreal wetlands in western Canada. Biological Conservation 114: 556–567.

Hunter, R. E., J. A. Crawford, and R. E. Ambrose. 1988. Prey selection by peregrine falcons during the nesting stage. Journal of Wildlife Management 52: 730–736.

Jandt, R. R., K. Joly, C. R. Meyers, and C. Racine. 2008. Slow recovery of lichen on burned caribou winter range in Alaska tundra: potential influences of climate warming and other disturbances. Arctic, Antarctic and Alpine Research 40: 89–95.

Jandt, R. R. 1998. Ray Mountains caribou: distribution, movements, and seasonal use areas, 1994-1997. U.S. Department of the Interior, Bureau of Land Management, Alaska State Office, Anchorage, Alaska. Open File Report 69. BLM/AK/ST-98/007+6500+020.

Jarema, S. I., J. Samson, B. J. Mcgill, and M. M. Humphries. 2009. Variation in abundance across a species' range predicts climate change responses in the range interior will exceed those at the edge: a case study with North American beaver. Global Change Biology 15: 508–522.

Joly, K., F. S. Chapin III, and D. R. Klein. 2010. Winter habitat selection by caribou in relation to lichen abundance, wildfires, grazing, and landscape characteristics in northwest Alaska. Ecoscience 17: 321–333.

Joly, K., B. Dale, W. B. Collins, and L. G. Adams. 2003. Winter habitat use by female caribou in relation to wildland fires in interior Alaska. Canadian Journal of Zoology 81: 1192–1201.

Joly, K., R. R. Jandt, and D. R. Klein. 2009. Decrease of lichens in Arctic ecosystems: the role of wildfire, caribou, reindeer, competition and climate in northwest Alaska. Polar Research 28: 433–442.

Joly, K., R. R. Jandt, C. R. Meyers, and M. J. Cole. 2007. Changes in vegetative cover on Western Arctic Herd winter range from 1981-2005: potential effects of grazing and climate change. Rangifer 17: 199-207.

Joly, K., and D. R. Klein. 2011. Complexity of caribou population dynamics in a changing climate. Alaska Park Science 10: 27-31.

Kausrud, K. L., A. Mysterud, H. Steen, J. O. Vik, E. Østbye, B. Cazelles, and N. C. Stenseth. 2008. Linking climate change to lemming cycles. Nature 456: 93–97.

Kelsall, J. P., E. S. Telfer, and T. D. Wright. 1977. The effects of fire on the ecology of the Boreal Forest, with particular reference to the Canadian north: a review and selected bibliography. Canadian Wildlife Service Occasional Paper Number 32, Ottawa: Canadian Wildlife Service.

Kershaw, K. A. 1978. The role of lichens in boreal tundra transition areas. The Bryologist 81: 294-306.

Kershaw, K. A., and W. R. Rouse. 1971. Studies on lichen-dominated ecosystems. Canadian Journal of Botany 49: 1389–1410.

Kiff, L. F. 1988. Changes in the status of the peregrine in North America: an overview. *In:* T. J. Cade, J. H. Enderson, C. G. Thelander, and C. M. White, (eds.) Peregrine falcon populations: Their management and recovery. The Peregrine Fund, Inc., Boise, Idaho. Pp. 123-139.

Kingston, N., A. Franzmann, and L. Maki. 1985. Redescription of *Trypanosoma cervi* (Protozoa) in moose, *Alces alces*, from Alaska and Wyoming. Proceedings of the Helminthological Society of Washington 52: 54-59.

Klein, D. 1979. Wildfire, lichens and caribou. *In:* M. Hoefs and D. Russell (eds.) Wildlife and wildfire: Proceedings of workshop; 1979 November, Whitehorse, YT. Whitehorse, YT: Government of Yukon, Yukon Wildlife Branch. Pp. 37–65.

Klein, D. R. 1982. Fire, lichens, and caribou. Journal of Range Management. 35: 390–395.

Klein, D. R. 1995. Tundra or Arctic hares. *In:* E.T. LaRoe, G.S. Farris, C.E. Puckett, P.D. Doran, and M.J. Mae (eds.) Our living resources: a report to the nation on the distribution, abundance, and health of U.S. plants, animals, and ecosystems. National Biological Services, U.S. Department of Interior, Washington, D.C. p.359.

Kohira, M., and E. A. Rexstad. 1997. Diets of wolves, *Canis lupus*, in logged and unlogged forests of southeastern Alaska. Canadian Field-Naturalist 111: 429–435.

Kotliar, N. B. 2007. Olive-sided Flycatcher (*Contopus cooperi*): a technical conservation assessment. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/olivesidedflycatcher.pdf.

Krebs, C. J., R. Boonstra, S. Boutin, A. R. E Sinclair, J. N. M. Smith, B. S. Gilbert, K. Martin, M. O'Donoghue, and R. Turkington. 2014. Trophic Dynamics of the Boreal Forests of the Kluane Region. Arctic 67: 11.

Krebs, C. J., K. Cowcill, R. Boonstra, and A. J. Kenney. 2010. Do changes in berry crops drive population fluctuations in small rodents in the southwestern Yukon? Journal of Mammalogy 91: 500–509.

Krebs, C. J., K. Danell, A. Angerbjörn, J. Agrell, D. Berteaux, K. Bråthen, Ö. Danell, S. Erlinge, V. Fedorov, K. Fredga, J. Hjältén, G. Högstedt, I. S. Jónsdóttir, A. J. Kenney, N. Kjellén, T. Nordin, H. Roininen, M. Svensson, M. Tannerfeldt, and C. Wiklund. 2003. Terrestrial trophic dynamics in the Canadian Arctic. Canadian Journal of Zoology 81: 827–843.

Kutz, S. J., J. Ducrocq, G. G. Verocai, B. M. Hoar, D. D. Colwell, K. B. Beckmen, L. Polley, B. T. Elkin, and E. P. Hoberg. 2012. Parasites in Ungulates of Arctic North America and Greenland: A View of Contemporary Diversity, Ecology and Impact in a World Under Change. Advances in parasitology 79: 99–252.

Kutz, S. J., E. J. Jenkins, A. M. Veitch, J. Ducrocq, L. Polley, B. Elkin, and S. E. Lair. 2009. The Arctic as a model for anticipating, preventing, and mitigating climate change impacts on host–parasite interactions. Veterinary Parasitology 163: 217–228.

Laaksonen, S., J. Pusenius, J. Kumpula, A. Venäläinen, R. Kortet, A. Oksanen, and E. Hoberg. 2010. Climate change promotes the emergence of serious disease outbreaks of filarioid nematodes. EcoHealth 7: 7–13.

LandFire 1.1.0. Existing Vegetation Type layer. U.S. Department of the Interior, Geological Survey. Available at: http://www.landfire.gov/NationalProductDescriptions21.php.

Lehman, R. N., and J. W. Allendorf. 1987. The effects of fire, fire exclusion and fire management on raptor habitats in the western United States, in Pendleton, B. G., Proceedings of the Western Raptor Management Symposium and Workshop. Boise, Idaho. National Wildlife Federation Scientific and Technical Series 12: 236-244.

Lensink, C. J., R. O. Skoog, and J. L. Buckley. 1955. Food habits of marten in interior Alaska and their significance. The Journal of Wildlife Management 19: 364–368.

Liebezeit, J., E. Rowland, M. Cross, and S. Zack. 2012. Assessing Climate Change Vulnerability of Breeding Birds in Arctic Alaska. A report prepared for the Arctic Landscape Conservation Cooperative. Wildlife Conservation Society, North America Program, Bozeman, Montana. 167 pp.

Loranger, A. J., T. N. Bailey, and W. W. Larned. 1991. Effects of forest succession after fire in moose wintering habitats on the Kenai Peninsula, Alaska. Alces 27: 100-9.

Luensmann, P. 2010. Falco peregrinus. *In:* Fire Effects Information System. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis/.

Luttich, S., D. H. Rusch, E. C. Meslow, and L. B. Keith. 1970. Ecology of red-tailed hawk predation in Alberta. Ecology 51: 190–203.

Lutz, H. J. 1956. Ecological effects of forest fires in the interior of Alaska. Tech. Bull. No. 1133. Washington, DC: U.S. Department of Agriculture, Forest Service. 121 pp

MacCracken, J. G., and L. A. Viereck. 1990. Browse regrowth and use by moose after fire in interior Alaska. Northwest Science. 64: 11–18.

MacDonald, S. O., and J. A. Cook. 2009. Recent mammals of Alaska. University of Alaska Press, Fairbanks, Alaska.

Maier, J. A. K, J. M. Ver Hoef, A. D. McGuire, R. T. Bowyer, L. Saperstein, and H. A. Maier. 2005. Distribution and density of moose in relation to landscape characteristics: effects of scale. Canadian Journal of Forest Research 35: 2233-43.

Maley, S. W., D. Buxton, C. N. Macaldowie, I. E. Anderson, S. E. Wright, P. M. Bartley, I. Esteban-Redondo, C. M. Hamilton, A. K. Storset, and E. A. Innes. 2006. Characterization of the immune response in the placenta of cattle experimentally infected with *Neospora caninum* in early gestation. Journal of Comparative Pathology 135: 130–141.

Martell, A. M., and W. A. Fuller. 1979. Comparative demography of *Clethrionomys rutilus* in taiga and tundra in the low Arctic. Canadian Journal of Zoology 57: 2106–2120.

Martens, W. J. M., T. H. Jetten, J. Rotmans, and L. W. Niessen. 1995. Climate change and vector-borne diseases: a global modelling perspective. Global Environmental Change 5: 195–209.

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

Miller, D. R. 1980. Wildfire effects on barren-ground caribou wintering on the taiga of northcentral Canada: a reassessment. *In:* E. Reimers, E. Gaare, and S. Skjenneberg (eds.) Proceedings of the 2nd international reindeer/caribou symposium; 1979 September; Roros, Norway. Trondheim, Norway: Direktoratet for vilt og ferskvannsfisk Pp. 84–98.

Miller, D. 2000. Lichens, wildfire, and caribou on the taiga ecosystem of northcentral Canada. *In:* R. Farnell, D. Russell, and D. van de Wetering (eds.) Proceedings of the 8th North American caribou worksop, 1998 April, Whitehorse, YT. Rangifer. Special Issue. No. 12: 197–207.

Miller, F.L., and A. Gunn. 2003. Catastrophic die-off of Peary caribou on the western Queen Elizabeth Islands, Canadian high arctic. Arctic 56: 381–390.

Mindell, D. P., and F. L. Craighead. 1981. Peregrine Falcon Status and Prey and Observations of Other Raptors on the Middle and Lower Yukon River, Alaska. Office of Endangered Species.

Mindell, D. P. and R. A. Dotson. 1982. Distribution and abundance of nesting raptors in southwestern Alaska. *In:* W. N. Ladd, and P. F. Schempf (eds.) Raptor management and biology in Alaska and western Canada: Proceedings of a symposium and workshop; 1981 February; Anchorage, AK. FWS/AK/PROC-82. Anchorage, AK: U.S. Department of the Interior, Fish and Wildlife Service, Alaska Regional Office: 112-137

Mitchell, C. D., and M. W. Eichholz. 2010. Trumpeter Swan (*Cygnus buccinator*). *In:* A. Poole (ed.) The Birds of North America Online. Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu/bna/species/.

Monnie, J. B. 1966. Reintroduction of the trumpeter swan to its former prairie breeding range. Journal of Wildlife Management 30: 691–696.

Morneau, C., and S. Payette. 1989. Postfire lichen-spruce woodland recovery at the limit of the boreal forest in northern Quebec. Canadian Journal of Botany 67: 2770–2782.

Murphy, K., F. Huettmann, N. Fresco, and J. Morton. 2010. Connecting Alaska landscapes into the future. Results from an interagency climate modeling, land management and conservation project. Final Report. 96 pp.

Murphy-Klassen, H. M., T. J. Underwood, S. G. Sealy, and A. A. Czyrnyj. 2005. Long-term trends in spring arrival dates of migrant birds at Delta Marsh, Manitoba, in relation to climate change. The Auk 122: 1130–1148.

Murray, D. L., E. W. Cox, W. B. Ballard, H. A. Whitlaw, M. S. Lenarz, T. W. Custer, T. Barnett, and T. K. Fuller. 2006. Pathogens, nutritional deficiency, and climate influences on a declining moose population. Wildlife Monographs 166: 1–30.

Murray, D. L. 2003. Snowshoe hares and other hares. *In:* G. A. Feldhamer, B. C. Thompson, and J. A. Chapman (eds.) Wild mammals of North America: biology, management and conservation. The Johns Hopkins University Press, Baltimore. Pp. 147-175.

Myers-Smith, I. H., B. C. Forbes, M. Wilmking, M. Hallinger, T. Lantz, D. Blok, K.D. Tape, M. Macias-Fauria, U. Sass-Klaassen, E. Lévesque, S. Boudreau, P. Ropars, L. Hermanutz, A. Trant, L. S. Collier, S. Weijers, J. Rozema, S. A. Rayback, N. M. Schmidt, G. Schaepman-Strub, S. Wipf, C. Rixen, C. B. Ménard, S. Venn, S. Goetz, L. Andreu-Hayles, S. Elmendorf, V. Ravolainen, J. Welker, P. Grogan, H. E. Epstein, and D. S. Hik. 2011. Shrub expansion in tundra ecosystems: Dynamics, impacts and research priorities. Environmental Research Letters 6: 045509.

Naiman, R. J., J. M. Melillo, and J. E. Hobbie. 1986. Ecosystem alteration of boreal forest streams by beaver (*Castor canadensis*). Ecology 67: 1254–1269.

National Research Council (U.S.) Committee on Management of Wolf and Bear Populations in Alaska. 1997. Wolves, bear, and their prey in Alaska: biological and social challenges in wildlife management. National Academy Press, Washington, DC.

Neiland, K. A., J. A. King, B. E. Huntley, and R. O. Skoog. 1968. The diseases and parasites of Alaskan wildlife populations, Part I. Some observations on brucellosis in caribou. Journal of Wildlife Diseases 4: 27-36.

Nelson, J. L., E. S. Zavaleta, and F. S. Chapin III. 2008. Boreal fire effects on subsistence resources in Alaska and adjacent Canada. Ecosystems 11: 156–171.

Nordmeyer, D. L. 1999. Effects of jet aircraft overflights and other potential disturbances on behavioral responses and productivity of nesting peregrine falcons. M.S. Thesis, Oregon State University, Oregon.

Oakes, E. J., R. Harmsen, and C. Eberl. 1992. Sex, age, and seasonal differences in the diets and activity budgets of muskoxen (*Ovibos moschatus*). Canadian Journal of Zoology 70: 605–616.

Oldemeyer, J. L., A. W. Franzmann, A. L. Brundage, P. D. Arneson, and A. Flynn. 1977. Browse quality and the Kenai moose population. Journal of Wildlife Management 41: 533–542.

Ontario Peregrine Falcon Recovery Team. 2010. Recovery strategy for the Peregrine Falcon (*Falco peregrinus*) in Ontario. Ontario Recovery Strategy Series. Prepared for the Ontario Ministry of Natural Resources, Peterborough, Ontario. 36 pp.

Oregon Department of Transportation. 2007. Peregrine Falcon management plan 2002–2007. Oregon Department of Transportation Environmental Services, Salem, Oregon.

Pacific Flyway Council (PFC). 2006. Pacific Flyway management plan for the Pacific coast population of Trumpeter Swans. Pacific Flyway Study Comm. [c/o USFWS, DMBM], Portland, Oregon.

Palmer, A. G., D. L. Nordmeyer, and D. D. Roby. 2003. Effects of jet aircraft overflights on parental care of peregrine falcons. Wildlife Society Bulletin 31: 499–509.

Palomares, F., and T. M. Caro. 1999. Interspecific killing among mammalian carnivores. American Naturalist 153: 492–508.

Parker, G. R., and R. K. Ross. 1976. Summer habitat use by muskoxen (*Ovibos moschatus*) and Peary caribou (*Rangifer tarandus pearyi*) in the Canadian High Arctic. Polarforschung 46: 12-25.

Pegau, R. E. 1972. Caribou investigations-analysis of range. *In:* R. E. Pegau and J. E. Hemming (eds) Caribou report. Volume 12. Progress report. Federal Aid in Wildlife Restoration, Projects W-17-2 and W-17-3, Job 3.3R. Alaska Department of Fish and Game, Juneau, Alaska. Pp. 1-216.

Persson, I., K. Danell, and R. Bergström. 2000. Disturbance by large herbivores in boreal forests with special reference to moose. Annales Zoologici Fennici 37: 251–263.

Peterson, R., G. Batzli, and E. Banks. 1976. Activity and energetics of the brown lemming in its natural habitat. Arctic and Alpine Research 8: 131–138.

Pickles, R. S., D. Thornton, R. Feldman, A. Marques, and D. L. Murray. 2013. Predicting shifts in parasite distribution with climate change: a multitrophic level approach. Global Change Biology 19: 2645–2654.

Polley, L., E. Hoberg, and S. Kutz. 2010. Climate change, parasites and shifting boundaries. Acta Veterinaria Scandinavica 52: S1.

Pollock, M. M., R. J. Naiman, H. E. Erickson, C. A. Johnston, J. Pastor, and G. Pinay. 1995. Beaver as engineers: influences on biotic and abiotic characteristics of drainage basins. Linking Species & Ecosystems. Pp. 117 – 126.

Putkonen, J., and G. Roe. 2003. Rain-on-snow events impact soil temperature and affect ungulate survival. Geophysical Research Letters 30: 37-1.

Racine, C., R. Jandt, C. Meyers, and J. Dennis. 2004. Tundra fire and vegetation change along a hillslope on the Seward Peninsula, Alaska, U.S.A. 2004. Arctic, Antarctic, and Alpine Research 36: 1-10.

Raphael, M. G., M. L. Morrison, and M. P. Yoder-Williams. 1987. Breeding bird populations during twenty-five years of postfire succession in the Sierra Nevada. Condor 89: 614-626.

Ratcliffe, D. 1993. The peregrine falcon. T. and A. D. Poyser, London, U.K. 454 pp.

Rausch, R. A. 1967. Some aspects of the population ecology of wolves, Alaska. American Zoologist 7: 253-265.

Rausch, R. L., and E. L. Schiller. 1951. Hydatid disease (echinococcosis) in Alaska and the importance of rodent intermediate hosts. Science 113: 57–58.

Reed, E. B. 1956. Notes on some birds and mammals of the Colville River, Alaska. The Canadian Field-Naturalist 70: 130-136.

Reid, D. G., C. J. Krebs, and A. J. Kenney 1997. Patterns of predation on non-cyclic lemmings. Ecological Monographs 67: 89–108.

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

Rempel, R. S. 2011. Effects of climate change on moose populations: Exploring the response horizon through biometric and systems models. Ecological Modelling 222: 3355-3365.

Rencz. A. N., and A. N. D. Auclair. 1978. Biomass distribution in a sub-arctic *Picea mariana-Cladonia alpestris* woodland. Canadian Journal of Forest Research 8: 168–172.

Reynolds, P. E., K. J. Wilson, and D. R. Klein. 2002. Section 7: Muskoxen in Arctic Refuge Coastal Plain Terrestrial Wildlife Research Summaries. Biological Science Report USGS/BRD 2002-0001: 54-64.

Rinaldi, T. A. 2010. Influence of linear features and snowmachine activity on resource selection by wolves. Master's Thesis, University of Northern British Columbia.

Risenhoover, K. L. 1989. Composition and quality of moose winter diets in interior Alaska. Journal of Wildlife Management 53: 568–577.

Robertson, B. A., and R. L. Hutto. 2007. Is selectively harvested forest an ecological trap for Olive-sided flycatchers? The Condor 109: 109–121.

Roon, D. A. 2011. Ecological effects of invasive European bird cherry (*Prunus padus*) on salmonid food webs in Anchorage, Alaska streams. Master's Thesis, University of Alaska Fairbanks. http://aknhp.uaa.alaska.edu/botany/akepic/publications/.

Rossel, F., O. Bozsér, P. Collen, and H. Parker. 2005. Ecological impact of beavers *Castor fiber* and *Castor Canadensis* and their ability to modify ecosystems. Mammal Review 35: 248–276.

Rupp, T .S., M. Olson, L. G. Adams, B. W. Dale, K. Joly, J. Henkelman, W. B. Collins, and A. M. Starfield. 2006. Simulating the influences of various fire regimes on caribou winter habitat. Ecological Applications 16: 1730–1743.

Saperstein, L. 1993. Winter forage selection by barren-ground caribou: effects of fire and snow. Thesis. University of Alaska Fairbanks, Fairbanks, Alaska. 79 pp.

Schmidt, J. H., M. S. Lindberg, D. S. Johnson, and J. A. Schmutz. 2009. Environmental and human influences on Trumpeter Swan habitat occupancy in Alaska. The Condor 11: 266–275.

Schmidt, J. H., M. S. Lindberg, D. S. Johnson, and D. L. Verbyla. 2011. Season length influences breeding range dynamics of Trumpeter Swans *Cygnus buccinators*. Wildlife Biology 17: 364–372.

Schoen, J. W., and S. E. Senner. 2002. Alaska western arctic, a summary and synthesis of resources- draft. Audubon Alaska, Anchorage, Alaska.

Seppi, B. E. 2007. Peregrine Falcons: *Falco peregrinus* in the Central Kuskokwim River Area, Alaska. BLM Alaska Open File Report 117. BLM/AK/ST-07/019+6700+040. Available: http://www.blm.gov/pgdata/etc/medialib/blm/ak/aktest/ofr.Par.92182.File.dat/Peregrine_OFR_May07.pdf.

Sharma, S., S. Couturier, and S. Cote. 2009. Impact of climate change on the seasonal distribution of migratory caribou. Global Change Biology 15: 2549–2562.

Slough, B. G., and R. M. F. S. Sadleir. 1977. A land capability classification system for beaver (*Castor canadensis* Kuhl). Canadian Journal of Zoology 55: 1324–1335.

Spellman, B. 2008. The impact of invasive sweetclover (*Melilotus alba*) in early successional floodplain habitats in Alaska. Masters of Science, University of Alaska Fairbanks, Fairbanks, Alaska.

Spencer D. L., and J. Hakala. 1964. Moose and fire on the Kenai. Proceedings of the 3rd tall timbers fire ecology conference. Pp. 10–33.

Stephenson, G. M. Calcarone, (eds.) Southern California mountains and foothills assessment: Habitat and species conservation issues. Gen. Tech. Rep. PSW-GTR-172. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station: 111–222.

Stephenson, J. R., and G. M. Calcarone. 1999. Potentially vulnerable species: animals. *In:* J. R. Stephenson, T. R., V. Van Ballenberghe, J. M. Peek, and J. G. MacCracken. 2006. Spatio-temporal constraints on moose habitat and carrying capacity in coastal Alaska: vegetation succession and climate. Rangeland Ecology & Management 59: 359–372.

Stieve, E., K. Beckmen, S. A. Kania, A. Widner, and S. Patton. 2010. *Neospora caninum* and *Toxoplasma gondii* antibody prevalence in Alaska wildlife. Journal of Wildlife Diseases 46: 348–355.

Sullivan, T. P., R. A. Lautenschlager, and R. G. Wagner. 1999. Clearcutting and burning of northern spruce-fir forests: implications for small mammal communities. Journal of Applied Ecology 36: 327–344.

Sweatman, G. K., and R. J. Williams. 1963. Comparative studies on the biology and morphology of *Echinococcus granulosus* from domestic livestock, moose and reindeer. Parasitology 53: 339–390.

Terry, C. J. 1981. Habitat differentiation among three species of *Sorex* and *Neurotrichus gibbsi* in Washington. American Midland Naturalist 106: 119–125.

Thomas, D., S. Barry, and G. Alaie. 1996. Fire-caribou relationships in northern Canada. Rangifer 16: 57–67.

Thompson, I. D., M. D. Flannigan, B. M. Wotton, and R. Suffling. 1998. The effects of climate change on landscape diversity: an example in Ontario forests. Environmental Monitoring and Assessment 49: 213–233.

Thurber, J. M., R. O. Peterson, J. D. Woolington, J. A. Vucetich. 1992. Coyote coexistence with wolves on the Kenai Peninsula, Alaska. Canadian Journal of Zoology 70: 2494–2498.

Thurber, J. M., R. O. Peterson, T. D. Drummer, and S. A. Thomasma. 1994. Gray wolf responses to refuge boundaries and roads in Alaska. Wildlife Society Bulletin 22: 61–68.

Tryland, M. 2012. Are we facing new health challenges and diseases in reindeer in Fennoscandia? Rangifer 32: 35-47.

UAF Extension Service. 2013. Moose and Cherry Trees: Is moose browse behavior affected by wild cherry trees? University of Alaska Fairbanks. Available: http://www.uaf.edu/ces/pests/cnipm/k12/moose-and-cherry-trees/.

U.S. Department of Agriculture (USDA). 2013. Forest health conditions in Alaska – 2012. Available: http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprd3797075.pdf.

U.S. Fish and Wildlife Service (USFWS). 2010. Regulations for the 2010 Alaska subsistence spring/summer Migratory Bird Harvest. Alaska Migratory Bird Co-Mgt Council, U. S. Fish and Wildlife Service, Anchorage, Alaska.

Valkenburg, P., T. H. Spraker, M. T. Hinkes, L. H. Van Daele, R. W. Tobey, and R. A. Sellers. 2000. Increases in body weight and nutritional status of transplanted Alaskan caribou. Rangifer 12:133–138.

Vermont Fish and Wildlife Department (FFWD). 2004. Best management practices for resolving human-beaver conflicts in Vermont. Prepared by the Vermont Fish and Wildlife Department and the Vermont Department of Environmental Conservation. 28 pp. Available: http://www.vtfishandwildlife.com/library/reports_and_documents/Furbearer/Best_Management_Practices_for_Human-Beaver_Conflicts.pdf

Verocai, G. G., M. Lejeune, G. L. Finstad, and S. J. Kutz. 2013. A Nearctic parasite in a Palearctic host: *Parelaphostrongylus andersoni* (Nematoda; Protostrongylidae) infecting semi-domesticated reindeer in Alaska. International Journal for Parasitology: Parasites and Wildlife 2: 119–123.

Vogl, R. J. 1967. Controlled burning for wildlife in Wisconsin. *In:* Proceedings, 6th annual Tall Timbers Fire
    Ecology Conference, 1967 March, Tallahassee, FL. No. 6. Tallahassee, FL: Tall Timbers Research Station: 47-
    96.

Vors, L. S., and M. S. Boyce. 2009. Global declines of caribou and reindeer. Global Change Biology 15: 2626-2633.

Weiler, G. J., G. W. Garner, and D. G. Ritter. 1995. Occurrence of rabies in a wolf population in northeastern
    Alaska. Journal of Wildlife Diseases 31: 79-82.

Wein, R. W. 1975. Vegetation recovery in arctic tundra and forest-tundra after fire. ALUR Report 74. Ottawa, ON.
    Department of Indian Affairs and Northern Development, Arctic Land Use Research Program. Pp. 75-62.

West, S. D. 1982. Dynamics of colonization and abundance in central Alaskan populations of the Northern red-
    backed vole, *Clethrionomys rutilus*. Journal of Mammalogy 63: 128-143.

White, C. M. 1969. Breeding Alaskan and arctic migrant populations of the peregrine. *In:* J. Hickey (ed.) Peregrine
    falcon populations: Their biology and decline. University of Wisconsin Press, Madison, Wisconsin. Pp. 45-
    51.

White, C. M., N. J. Clum, T. J. Cade, and W. G. Hunt. 2002. Peregrine Falcon (*Falco peregrinus*). *In:* A. Poole (ed.)
    The Birds of North America Online. Ithaca: Cornell Lab of Ornithology; Retrieved from the Birds of North
    America Online: http://bna.birds.cornell.edu/bna/.

White, R. G., D. F. Holleman, and B. A. Tiplady. 1989. Seasonal body weight, body condition and lactational
    trends in muskoxen. Canadian Journal of Zoology 67: 1125–1133.

Wilkinson, P. F., C. C. Shank, and D. F. Penner. 1976. Muskox-caribou summer range relations on Banks Island,
    NWT. The Journal of Wildlife Management Pp.151-162.

Wilmers, C. C., and W. M. Getz. 2005. Gray wolves as climate change buffers in Yellowstone. PLoS Biology 3(4):
    e92.

Windoor, J. 1977. The response of peregrine falcons (*Falco peregrinus*) to aircraft and human disturbance.
    Canadian Wildlife Service, Ottawa, Ontario, Canada.

Witter, L. A., C. J. Johnson, B. Croft, A. Gunn, and L. M. Poirier. 2012. Gauging climate change effects at local
    scales: weather-based indices to monitor insect harassment in caribou. Ecological Applications 22: 1838–
    1851.

Wolfe, S. A., B. Griffith, and C. A. G. Wolfe. 2000. Response of reindeer and caribou to human activities. Polar
    Research 19: 63–73.

Woodford, R., and C. Harms. 2011. Cyanide-poisoned Moose Ornamental Chokecherry Tree a Devil in Disguise.
    Alaska Fish and Wildlife News. March 2011.
    Available: http://www.adfg.alaska.gov/index.cfm?adfg=wildlifenews.view_article&articles_id=501&issue_id
    =96.

Wright, J. M. 1997. Olive-sided Flycatchers in central Alaska, 1994-1996.Final Rep. Proj. SE-3-4. Alaska Dept. Fish
    and Game. Fed. Aid in Wildl. Restoration, Juneau, Alaska.

Zarnke, R. L., J. P. Dubey, J. M. Ver Hoef, M. E. McNay, and O. C. H. Kwok. 2001. Serologic survey for *Toxoplasma
    gondii* in lynx from interior Alaska. Journal of Wildlife Diseases 37: 36–38.

Zarnke, R. L., J. P. Dubey, O. C. H. Kwok, and J. M. Ver Hoef. 2000. Serologic survey for *Toxoplasma gondii* in
    selected wildlife species from Alaska. Journal of Wildlife Diseases 36: 219–224.

Zedler, J. B., and S. Kercher. 2004. Causes and consequences of invasive plants in wetlands: opportunities,
    opportunists, and outcomes. Critical Reviews in Plant Sciences 23: 431–452.

# 3. Aquatic Coarse-Filter Conservation Elements

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**Summary**

Section D-3. *Aquatic Coarse-Filter Conservation Elements* provides the detailed descriptions, methods, datasets, results, and limitations for the assessments of three habitats considered to be of high ecological importance in the region and potential impacts of CAs on these habitats.

## 3.1.  Introduction

Aquatic Coarse-Filter CEs are regionally important and characterize habitats that encompass many of the dominant ecological processes and patterns of the YKL study area. Together the Coarse-Filter CEs address the habitat requirements of most native species. Three habitats were selected as Coarse-Filter CEs: streams, connected lakes, and disconnected lakes. Due to the lack of an aquatic habitat map for the study area, the Aquatic Coarse-Filter CEs were identified as a data gap. The distribution of all three habitats were mapped based on data obtained from the National Hydrography Datasets (see Methods below).

**Table D-28.** Aquatic Coarse-Filter Conservation Elements selected for the YKL REA.

| Aquatic Coarse-Filter CEs | Ecological Importance |
|---|---|
| Streams | High stream connectivity in the summer, important spawning, rearing, and overwintering habitat for fish. |
| Connected lakes | Important breeding habitat for aquatic insects, fish, waterbirds and shorebirds and provide subsistence and recreational use. |
| Disconnected lakes | Important breeding habitat for aquatic insects, fish, waterbirds and shorebirds, flood storage, groundwater regeneration, invertebrate and waterfowl habitat. |

The Coarse-Filter CEs section is organized by first describing the methods used to develop the distribution models for all the CEs. We then describe the characteristics, spatial distribution, and relationship of Aquatic Coarse-Filter CEs to the current, near-term (2025), and long-term (2060) landscape condition, as well as selected climate and CA variables understood to be critical.

## 3.2. Methods

For each Aquatic Coarse-Filter CE we developed distribution maps based on data obtained from the National Hydrography Dataset (NHD) (Table D-29). The NHD is a digital representation of the stream network and lakes shown on USGS topographic maps, which were created from historic aerial photos and is the best available spatial data of aquatic resources for the YKL REA study area. However, the NHD has several limitations:

- The NHD underrepresents small streams because they are often masked by vegetation cover and not visible on aerial photography
- The NHD is outdated (most topographic maps were created in the 50's and 60's) and stream locations and lake areas have likely changed due to natural hydrologic disturbances and climate change
- Both stream order and stream gradient are needed to map aquatic habitats; the NHD is not attributed with stream order and does not align with valley bottoms in the Digital Elevation Model (DEM) so stream gradient cannot be calculated accurately

Additionally, the best available DEM for the study area is the National Elevation Dataset (60 m pixels). Due to the limitations of the NHD, aquatic habitats must be mapped by creating a stream network from the DEM, which has its own set of drawbacks:

- Utilizing a coarse DEM to map streams results in a gross oversimplification of the stream network length and complexity
- The DEM does not match the NHD, which is the best available representation of what exists on the ground
- When creating a stream network from a DEM, a decision must be made regarding the size of the watershed required to initiate a first order stream; there is no available data relating area to perennial flow initiation for the study area and due to the diversity of topographic, geologic, and permafrost characteristics across the REA study areas, this relationship is expected to vary

In addition to the limitations of the data available for mapping aquatic habitats, it was beyond the scope of this project to create an aquatic habitat classification relating aquatic habitat types to physical, chemical, and biological conditions for the YKL study area. Thus, for each Aquatic Coarse-Filter CEs, we developed distribution maps that were drawn directly from the National Hydrography Dataset (NHD) without additional processing or attribution.

**Table D-29.** Source datasets for the distribution of Aquatic Coarse-Filter CEs.

| Dataset Name | Data source |
|---|---|
| National Hydrography Dataset Waterbodies | USGS |
| National Hydrography Dataset Flowlines | USGS |

### Conceptual Models

These analyses are further aided by the development of CE-specific conceptual models. The CE-specific conceptual models represent a general review of the relationship between the CE, CAs and natural drivers in graphical formats.

**Core Analysis**

For each Aquatic Coarse-Filter CE, we extracted the current (2010), near-term (2025), and long-term (2060) status of CAs to the current CE distribution. See Table D-30 for a list of data sources. These analyses were described spatially by comparing the distribution of each CE with thresholds for all CAs. These analyses are further aided by the development of CE specific conceptual models. The CE specific conceptual models represent the state of knowledge between the CE, CAs and other resources. Conceptual models are based on literature review and describe the relationship between the various change agents and natural drivers in graphical formats. Distribution maps and conceptual models are presented within the following specific Aquatic Coarse-Filter CE sections.

**Table D-30.** Source datasets for Core Analysis.

| Dataset Name | Data source |
|---|---|
| Mean July Temperature Difference from 2010s-2020s and 2010s-2060s | SNAP, UAF |
| Total Annual Precipitation Difference from 2010s-2020s and 2010s-2060s | SNAP, UAF |
| Areas of Permafrost Change from 2010s-2020s and 2010s-2060s | SNAP, UAF |

## 3.3.  Streams
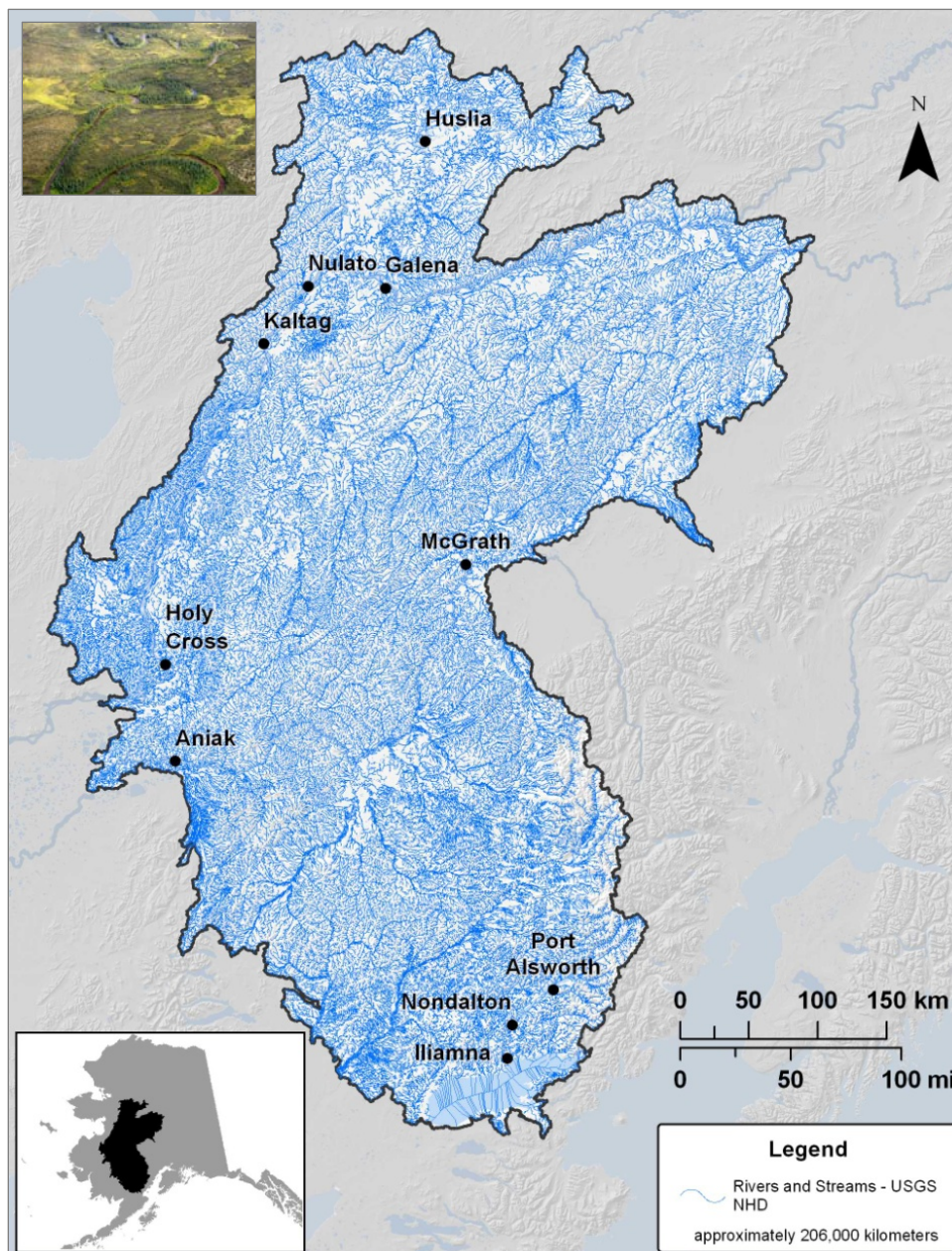


**Figure D-85.** Current known distribution of streams within the YKL study area.

Streams are ubiquitous throughout the YKL study area and range from smaller first and second order headwater streams, to third order and higher order streams, including the Yukon and Kuskokwim rivers. The majority of streams within the YKL study area are considered clear-water streams, although the Yukon, Kuskokwim and numerous streams originating in the Alaska Range are glacially influenced and thus have higher sediment loads.

Stream ecosystems provide an important ecological link between terrestrial and aquatic habitats. Additionally streams are important habitat for aquatic insects, fish, and waterbirds. Stream ecosystems support spawning and rearing habitat for salmon (e.g., chum salmon and Chinook salmon) that support important commercial and subsistence fisheries. Streams also provide important recreational and personal uses for local residents.

**Conceptual Model**

The conceptual model below (Figure D-86) is based on a review of the literature and describes the relationship between the various change agents and natural drivers for streams. The boxes and arrows represent the state of knowledge about streams and the relationship to each attribute.
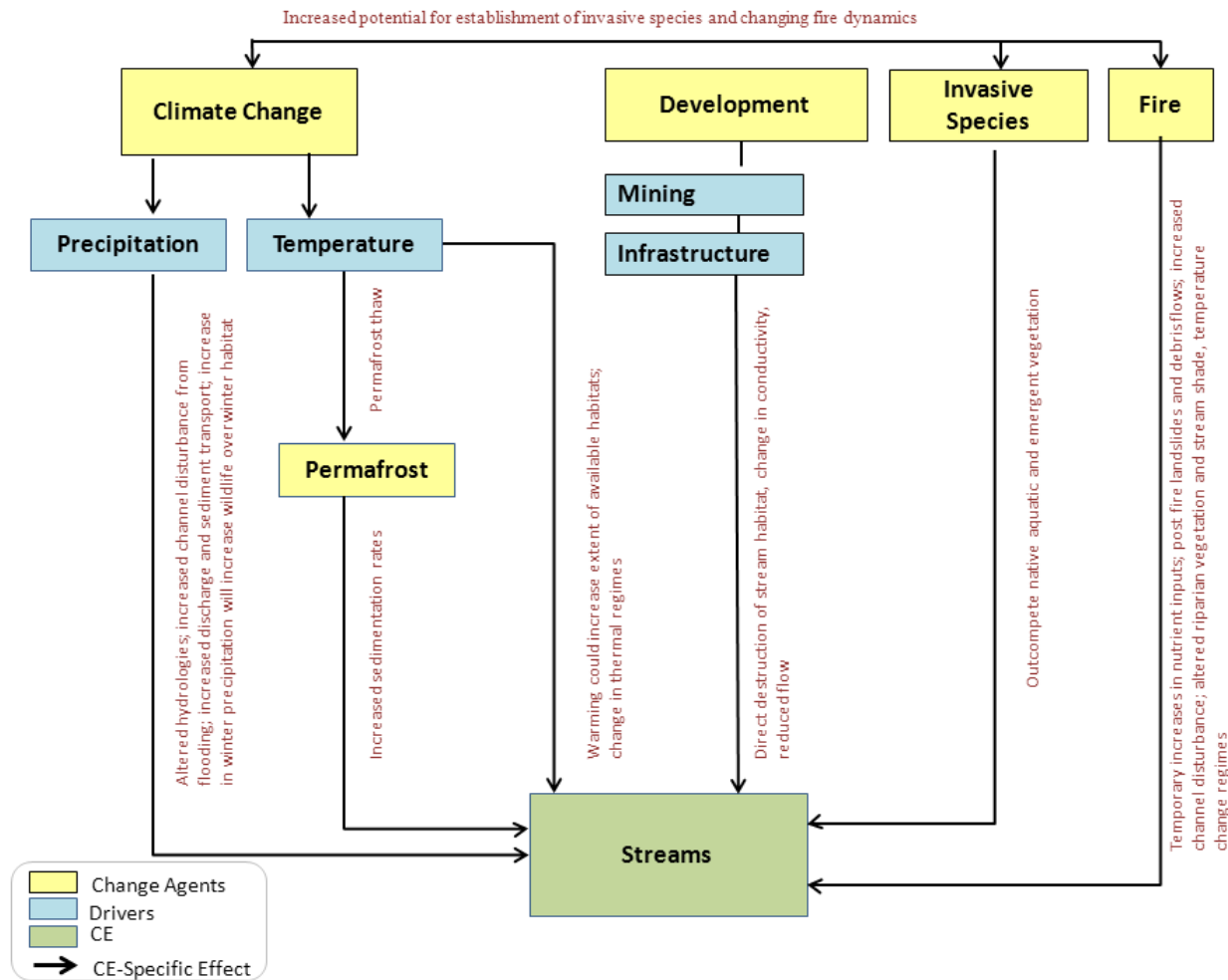


**Figure D-86.** Principal interactions among population drivers and change agents for streams within the YKL study area.

### *Climate Change*

Warmer air temperatures, increased precipitation variability, decreased snowpack, permafrost thaw, and increased wildfire activity are predicted for the region and stream ecosystems could respond to these changes in a variety of ways. Future precipitation scenarios for the YKL study area are uncertain, but there is a projected trend for increased winter precipitation. Higher levels of precipitation are expected to increase channel disturbance, increased flooding, sedimentation, and erosion, which could have negative impacts for stream ecosystems of this region. However, increased winter precipitation may increase overwinter habitat areas for fish and wildlife species. Moreover, the effects of warming temperatures on the timing of streamflow and flooding may have greater effects than seasonal changes in precipitation. Warmer weather is expected in

summer which may lead to higher evapotranspiration and a resulting decrease in runoff which could, in turn, result in channel stability. With summer temperatures, warmer water temperatures could modify the distribution of aquatic organisms by limiting movements through stream networks. Movement could be reduced due to thermal barriers, low water levels, lower dissolved oxygen, and higher mortality rates. In addition, some habitats, such as upstream areas, where cold temperatures previously limited habitat suitability may become more suitable with increasing summer temperatures.

Permafrost thaw has been shown to enhance groundwater discharge to streamflow within the lower Yukon River drainage basin (Brabets and Walvoord 2009). Changes in groundwater flow, especially during spring/winter could alter the timing and extent of ice cover and alter stream habitats by directly impacting aquatic organisms (e.g., fish migrations) and by changing stream velocities, water temperatures, concentrations of suspended sediments, and cause channel disturbance from flooding and scouring (Dingham 1973, Prowse 2001). Fish spawning areas might be especially susceptible to the effects of permafrost thaw as scouring of eggs and destruction of salmon spawning habitat are likely. Additionally, recent studies within the Yukon River Basin have found increased mercury contamination related to permafrost thaw (Schuster et al. 2011), which could have negative impacts on macroinvertebrate and fish populations. However, in other parts of Alaska, permafrost thaw has been linked to short-term increases in nutrients such as nitrogen and phosphorous which could have positive impacts for aquatic organisms (Bowden et al. 2008).

### *Fire*

Changes in wildfire extent and severity could have important compounding effects on stream ecosystems. Increased wildfire activity could result in warmer stream temperatures, altered stream hydrology, increased landslides, and altered channel disturbances. Additionally, fires that burn across small streams may cause fish mortalities from excessive temperatures, although these effects are often short term (Hitt 2003). Fires also alter riparian vegetation and stream shade (Pettitt and Naiman 2007), resulting in more chronic thermal effects within streams.

### *Invasive species*

Invasive plant species have the potential to outcompete native aquatic and emergent vegetation. However, few invasive plant species have been documented within the YKL study area and no aquatic invasive species have yet been documented. *Phalaris arundinacea* and *Elodea* (including *E. canadensis* and *E. nuttallii*) are invasive plants that are known from Interior Alaska that could adversely affect streams in the YKL region if they become established. *Phalaris arundinacea* populations derived from cultivars (mixed native and non-native genotypes) can aggressively colonize riparian habitats associated with headwater streams to larger rivers, such as the Kenai, in Alaska. While native genotypes of this species are present in small warm springs in Interior Alaska (Jakubowski et al. 2012), these populations do not demonstrate the aggressive behaviors of the cultivar. The most severe ecological impacts of *P. arundinacea* stem from its ability to clog waterways (Lavergne and Molofsky 2004), due to the species' growth-form and aggressive sod-forming underground stems (Coops et al. 1996). Colonization of stream channels by *P. arundinacea* can lead to reductions in flow velocities and increased sedimentation (Hodgson 1968, Lefor 1987), with potential impacts to salmon spawning and rearing habitats. Dense growths can also impede fish movement, as in the case of an infested tributary in Washington where 158 pre-spawn coho salmon died after stranding in a flooded *P. arundinacea* meadow (Carrasco 2000).

*Elodea* is an aquatic plant that has recently been documented in southcentral Alaska and Chena slough, near Fairbanks. *Elodea* can outcompete other aquatic plant species in slow moving streams or small, shallow lakes and ponds with silty or organic substrates and form extremely dense populations (Larsen and Lisuzzo 2012). *Elodea* infestations can cause decreased stream velocity, increased sedimentation, decreased turbidity, and alter dissolved oxygen content and invertebrate communities (Buscemi, 1958, Pokorny et. al., 1984, Rorslett et. al., 1986). *Elodea* negatively impacts Chinook salmon breeding habitat in its native range (Merz et. al., 2008). The quality of grayling habitat in Chena Slough has been documented to have declined dramatically with increasing *Elodea* cover and other hydrological changes (Larsen and Lisuzzo 2012). Thus, small streams with slow moving waters would be most susceptible to invasion of *Elodea*, but many other variables such as proximity to roads and transportation hubs are important indicators to the likelihood of *Elodea* colonizing stream habitats within the YKL study area.

### *Development*

Construction or development, especially large scale mining operations, along stream and river margins will alter stream channels and lake connectivity, remove or impair riparian vegetation and function, and increase sedimentation to important aquatic habitats (Section D-4; MQ #14). Similarly, removal of vegetation along streams banks for construction or infrastructure development (e.g., placer mining, road and trail construction) can alter stream thermal regimes (Moore et al. 2005). These activities could have cascading negative effects on stream resources and aquatic organisms within the YKL study area.

### Applications

The streams distribution map provides managers and researchers with baseline distribution information within the YKL study area. Streams are ubiquitous and abundant throughout the YKL REA study area, thus it is hard to discern specific stream systems using the map scale provided in Figure D-85. However, the original GIS data layers for all Aquatic Coarse-Filter CEs will be made available as a final product and thus land managers will be able to view specific areas of interest at a finer scale to better evaluate the distribution of these streams and to better assess specific areas of management concern.

### Limitations and Data Gaps

The lack of an aquatic habitat classification for the YKL study area (and for Alaska statewide) represents a huge data gap that could be preventing more effective management of aquatic habitat resources. This is especially important given the spatial inaccuracies and limited attribute information in the NHD that can be used to map aquatic habitats. Even an updated NHD (e.g., NHD Plus) and an updated DEM with finer resolution (i.e., <60m) would significantly increase our ability to more accurately and reliably map stream locations, calculate stream gradient, and estimate stream flow and velocity. Limited information exists for specific threshold effects of CA attributes and indicators for all Aquatic Coarse-Filter CEs. For example, there currently are no climate change predictions specific to aquatic habitats, such as changes to water temperature or hydrologic regime. The stream conceptual model can serve as a reference point for future research and management efforts with respect to climate change and other CAs. In particular, climate-linked aquatic models would benefit future efforts that focused specifically on water temperature changes and better understanding the likely impacts of permafrost thaw on stream hydrology.

## 3.4.  Connected Lakes
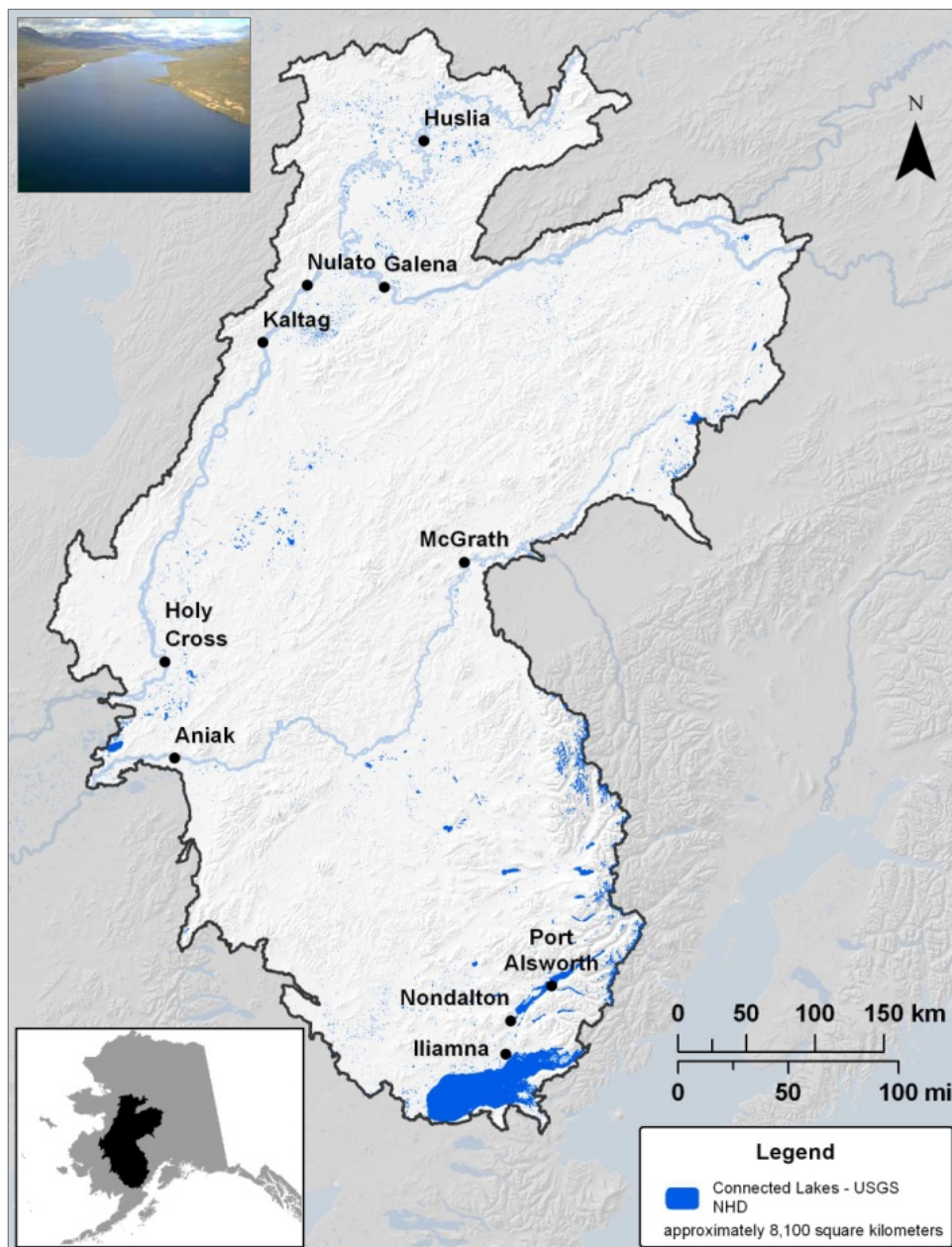


**Figure D-87.** Current known distribution of connected lakes within the YKL study area.

Connected lakes are classified based on their connection to the stream network and cover approximately 8,100 km$^2$ within the YKL study area. Connected lake systems throughout the YKL study area support a rich biodiversity of aquatic organisms and represent important breeding habitat for aquatic insects, fish, waterbirds and shorebirds. Additionally, connected lakes provide important overwintering habitat for fish and provide recreational and personal uses for local residents (e.g., subsistence harvest of fish and wildlife).

**Conceptual Model**

We anticipate that the physical and ecological relationships among change agents will be similar among both connected and disconnected lakes. The conceptual model below (Figure D-88) is based on literature review and

describes the relationship between the various change agents and natural drivers for connected and disconnected lakes. The boxes and arrows represent the state of knowledge about connected lakes and the relationship to each attribute.
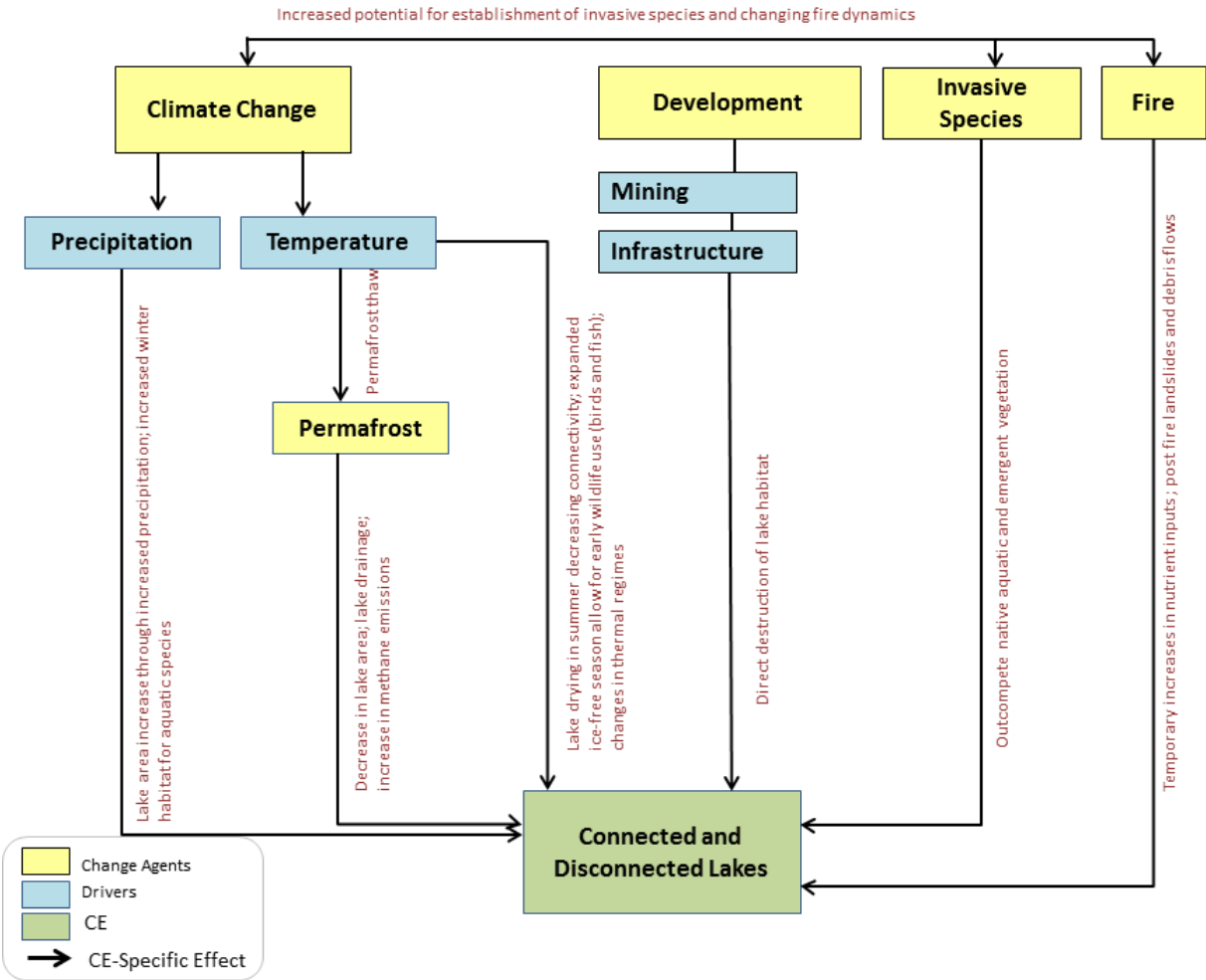


**Figure D-88.** Principal interactions among population drivers and change agents for connected lakes within the YKL study area.

## 3.5.  Disconnected Lakes
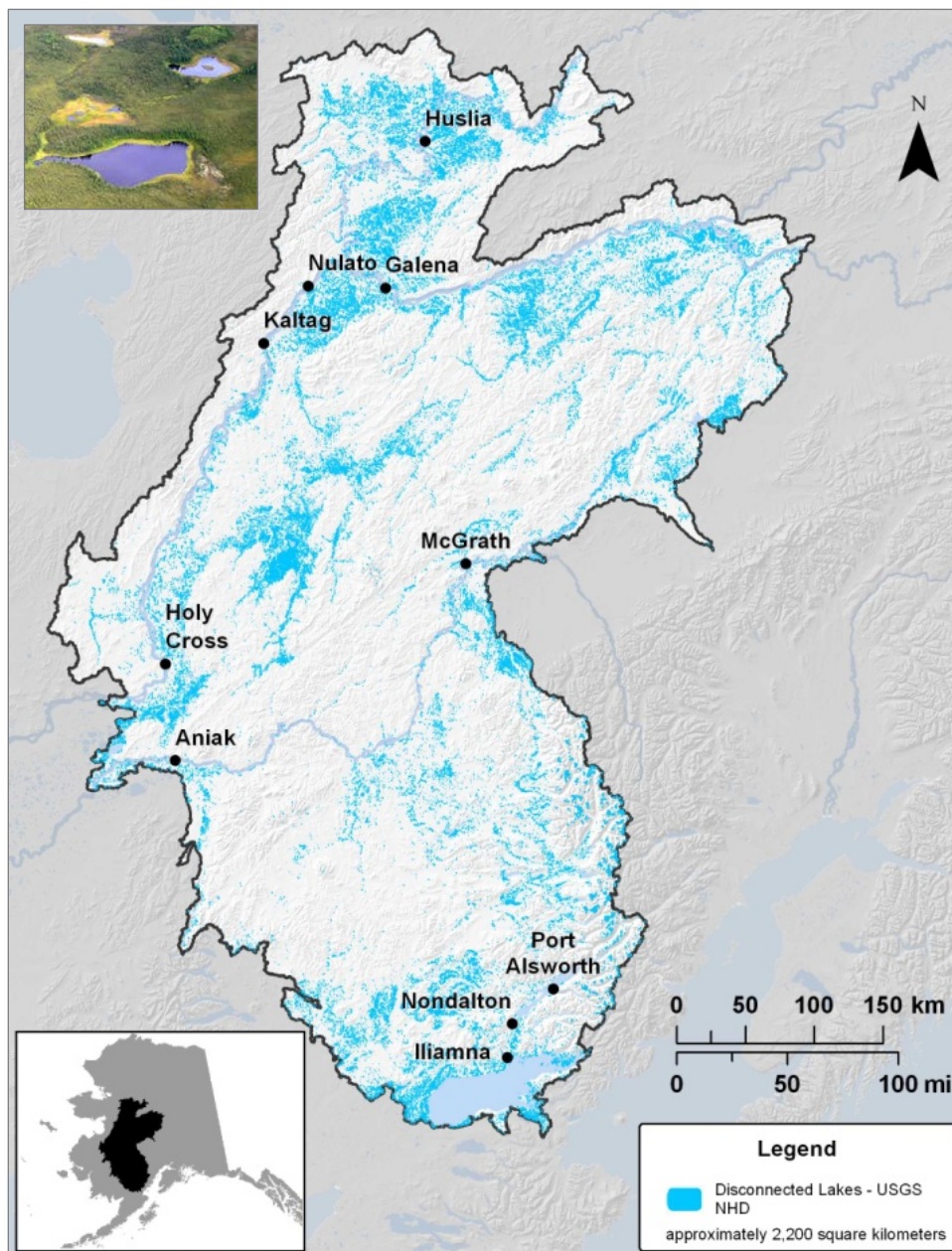


**Figure D-89.** Current distribution of disconnected lakes within the YKL study area.

Disconnected lakes cover approximately 2,200 km$^2$ within the YKL study area and lack connectivity to the stream network. Disconnected lakes throughout the YKL study area support a rich biodiversity of aquatic organisms and represent important breeding habitat for aquatic insects, fish, waterfowl, and shorebirds. Additionally, disconnected lakes provide a source for groundwater regeneration and flood storage and provide important recreational and personal uses for local residents.

**Conceptual Model**

The conceptual model for disconnected lakes is the same as that for connected lakes included in Section D-3.2.

### *Climate Change*

Increased precipitation and thawing permafrost could temporarily increase the nutrient loading to lakes, which in turn could increase primary productivity (Hobbie et al. 1995), and benefit numerous wildlife species that forage in these lakes. Increased air temperature and a longer ice-free season may promote thermal stratification in lakes, increase the length of the stratified season, and could increase the depth of mixing. The longer stratified season should lead to lower oxygen concentrations and increase stress on cold water organisms (Rouse et al. 1997). However, a longer ice-free season could result in a longer growing season by increasing the length of underwater light conditions for primary producers (Rouse et al. 1997).

On the other hand, thawing permafrost and increased evaporation have been linked to declines in lake area, especially for disconnected lakes within the Yukon River Basin (Roach et al. 2013). Disconnected lakes were more likely to decline in lake area than lakes that had stream inputs and outputs (Roach et al. 2013). Furthermore, thawing of permafrost was linked to increases in substrate permeability and drainage to either deep or shallow groundwater systems, particularly on coarse, well-drained soils, and within disconnected lakes (Roach et al. 2013). In addition to direct effects on lake habitats, thawing permafrost along lake margins could increase the amount of methane released to the atmosphere (Walter et al. 2007) and mercury input to lakes (Schulster et al. 2011).

Lake ice melt plays an important role in the break-up of spring ice. Warmer temperatures combined with increased snow cover are expected to have a significant impact on the annual heat budget of high latitude lakes (Schindler and Smol 2006). Increased snow cover is expected to insulate lakes and result in thinner ice. Thinner lake ice would melt faster in spring, leading to earlier break-up of spring ice and earlier seasonal rise in water temperature. Earlier ice-outs could result in channel blockage for lakes with connected streams, and both connected and disconnected lakes could be affected by shoreline scouring. However, in warmer parts of the YKL study area, snowpack is unlikely to be deeper, as a higher percentage of precipitation will fall as rain.

Fish access, as well as nutrient status, is related to the degree of connectivity of lakes with stream and river systems. Increased temperatures could result in lake drying which in turn could decrease connectivity between lakes and inlet and outlet streams. Warmer temperatures coupled with increased evapotranspiration, especially later in the summer and early fall, could cause a drying effect that would lead to a lack of connectivity between streams and lakes. A lack of connectivity between inlet and outlet streams would limit access to important spawning areas, affect the amount of available overwintering habitat, and potentially disrupt the timing of annual migrations for fish species.

### *Fire*

Increased wildfire activity could result in increased landslides and debris flows along lake edges/shorelines. Temporary increases in nutrient inputs could temporarily benefit aquatic organisms (e.g., juvenile fish and aquatic insects). However, an increase in nutrient loading could cause eutrophication of lakes (Wright 1976), although this effect would be short-lived.

### *Invasive species*

Invasive species are not known from connected or disconnected lakes in the YKL study area. If established, *Elodea* has the potential to cause disruptions in lake ecology and is discussed at greater length in the Stream

Invasive Species section above. Small, shallow lakes and ponds with silty or organic bottoms are most vulnerable to *Elodea* establishment (Larsen and Lisuzzo 2012). Similarly, if invasive quagga and zebra mussels (*Dreissena*) become established, they have the capacity to severely impact lake ecology of the region. When these invasive mussels reach high densities they can cause cascading trophic impacts through aquatic foodwebs that negatively impact salmon and other native species populations (see Bunnell et al. 2009, Cuhel and Aguilar 2013). These mussels have not been found in Alaska despite targeted surveys (Bogan 2011); however they have recently been found in British Columbia and have expanded rapidly in North America. Lakes within and adjacent to population centers and those most heavily used by floatplanes are those deemed most likely to see introductions of these invasive species.

### *Development*

Construction or development, especially large-scale mining operations near connected or disconnected lakes could increase sedimentation to lakes. Mining operations near streams that are connected to lake systems could also have negative impacts on the water quality of connected lakes. Run-off from unpaved roads can result in sedimentation to lakes increasing the turbidity of lake waters and impacting the quality of water for aquatic organisms and human use. Increased development, especially the construction of new roads can facilitate the dispersal of aquatic invasive species to both connected and disconnected lakes. Furthermore, with increased road access communities may increase fishing pressure and possibly negatively impact water quality of lake habitats within the YKL study area.

### Applications

The distribution maps created for connected and disconnected lakes provide managers with baseline distribution information on the location of waterbodies within the YKL study area. Most of the lakes are relatively small, thus it is hard to discern individual lakes using the map scale provided. However, the original GIS data layers for all Aquatic Coarse-Filter CEs will be made available as a final product and managers will be able to view specific areas of interest at a finer scale to better evaluate the distribution of these waterbodies and to better assess specific areas of management concern.

### Limitations and Data Gaps

The lack of a statewide aquatic habitat classification represents a huge data gap that could be preventing more effective management of aquatic habitat resources within this region. This is especially important given the spatial inaccuracies and limited attribute information in the NHD and the coarse resolution of the DEM available for the YKL study area. Limited information exists for specific threshold effects of CA attributes and indicators for the Aquatic Coarse-Filter CEs. For example, there currently are no climate change predictions specific to aquatic habitats, such as changes to water temperature or hydrologic regime. Since no direct data were available on climate change impacts to aquatic systems, changes were qualitatively described based on literature reviews and incorporated into the conceptual models. Climate-linked aquatic models would benefit future efforts that focused specifically on water temperature changes and better understanding the likely impacts of permafrost thaw on lake hydrology (especially for disconnected lakes).

## 3.6. Aquatic Coarse-Filter Core Analysis Results

**Abiotic Change Agents – Temperature, Precipitation, and Permafrost**

In the next decade, little meaningful change can be expected within Aquatic Coarse-Filter habitats, based solely on climate variables. Changes in climate over this short timeframe are expected to be small (see Section B-1).

Because we lack water temperature data for the YKL study area, air temperature was used as a proxy for water temperature changes for Aquatic Coarse-Filter CE analyses. Between the current (2010) and the near-term (2025), there is a projected slight decrease in July air temperature throughout much of the YKL study area, although about an equal portion of the study area shows a slight increase (less than 1°C; Table D-31). It is unlikely that these changes are meaningful at the landscape level. However, by the 2060, warming is expected to accelerate under the A2 scenario (see Section B-1). Thus 100% of Aquatic Coarse-Filter CEs are expected to experience summer air temperatures more than 1°C warmer (Table D-31) than current averages, and 89% to 98% of habitat is expected to be at least 1°C warmer for the month of July alone.

In the next decade, projected changes in precipitation are slight, with most of the YKL study area seeing a change of less than 50 mm, and a small percentage experiencing an increase of 50-100 mm (Table D-31). As is noted in the Climate Change section of this report, annual precipitation varies regionally across the REA area, from a minimum of about 350 mm to a maximum of about 900 mm. Given that precipitation is so variable both spatially and temporally, model uncertainty is higher than it is for temperature variables, and the near-term change demonstrated here is likely to be insignificant in relation to clear impacts on Aquatic Coarse-Filter CEs.

In the longer term, a marked increase in precipitation is expected, with most habitat areas experiencing an increase of 50-100 mm annually and some areas experiencing an increase of over 100 mm – a relatively high increase when compared to the modest totals for this area (Table D-31). It should be noted that precipitation may be less important in terms of impacts to CEs than hydrologic change driven indirectly by climate, including snow-day fractions and permafrost (discussed under Soil Thermal Dynamics).

**Table D-31.** Aquatic Coarse-Filter CEs and predicted change in climate variables from current to near-term (2025) and current to long term (2060) as percent of total CE area.

| Aquatic Coarse-Filter CEs | | Mean July Temperature Difference | | | Total Annual Precipitation Difference | | |
|---|---|---|---|---|---|---|---|
| | | < 0°C | 0 - 0.999°C | ≥ 1°C | ≤ 50 mm | 51 - 100 mm | > 100 mm |
| Streams | Near Term | 61% | 39% | -- | 92% | 8% | 0% |
| | Long Term | -- | 2% | 98% | 14% | 79% | 8% |
| Disconnected Lakes | Near Term | 54% | 46% | -- | 74% | 23% | 2% |
| | Long Term | -- | 4% | 96% | 15% | 62% | 22% |
| Connected Lakes | Near Term | 83% | 17% | -- | 43% | 54% | 3% |
| | Long Term | -- | 11% | 89% | 7% | 51% | 42% |

For the purposes of this analysis, "continuous permafrost" is here defined as ground that has a temperature colder than -1°C at one meter depth (as projected by the SNAP/GIPL model in the Soil Thermal Dynamics, Section B-2). In the near term, a small but likely insignificant proportion of habitat (1-3%) is projected to shift across this threshold (Table D-32). However, by 2060, much more sweeping change is expected, with up to 1/3 of habitat thawing or partially thawing for some Aquatic Coarse-Filter CEs (Table D-32).

**Table D-32.** Aquatic Coarse-Filter CEs and predicted change in permafrost from current (2010s) to near-term (2025) and current to long term (2060) as percent of total CE area.

| Aquatic Coarse-Filter CEs | | Current continuous permafrost that changes to future discontinuous permafrost |
|---|---|---|
| Streams | Near Term | 1% |
| | Long Term | 14% |
| Disconnected Lakes | Near Term | 3% |
| | Long Term | 29% |
| Connected Lakes | Near Term | 1% |
| | Long Term | 12% |

## 3.7.  Literature Cited

Bogan, D. 2011. Early Detection Monitoring for Zebra and Quagga Mussels in Alaska Lakes. http://www.uaf.edu/files/ces/cnipm/annualinvasivespeciesconference/13thAnnualMeetingProceedings/BoganQZ_mussel_monitoring_alaska.pdf. CNIPM Conference, Alaska.

Bowden, W., M. Gooseff, A. Balser, A. Green, B. J. Peterson, and J. Bradford. 2008. Sediment and nutrient delivery from thermokarst features in the foothills of the North Slope, Alaska: Potential impacts on headwater stream ecosystems. Journal of Geophysical Research doi:10.1029/ 2007JG000470.

Brabets, T., and M. Walvoord. 2009. Trends in streamflow in the Yukon River Basin from 1944 to 2005 and the influence of the Pacific Decadal Oscillation. Journal Hydrology 271: 108-119.

Bunnell, D. B., C. P. Madenjian, J. D. Holuszko, J. V. Adams, and J. R. P. French III. 2009. Expansion of *Dreissena* into offshore waters of Lake Michigan and potential impacts on fish populations. Journal of Great Lakes Research 35: 74-80.

Buscemi, P. A. 1958. Littoral Oxygen Depletion Produced by a Cover of *Elodea canadensis*. Oikos 9: 239-245.

Carrasco, K. 2000. Coho pre-spawn mortalities in a flooded reed canarygrass habitat. *In:* Proceedings of the Reed Canarygrass Working Group, Northwest Chapter Society for Ecological Restoration. Pp. 1-2.

Coops, H., F. W. B. van der Brink, and G. van der Velde. 1996. Growth and morphological responses of four helophyte species in an experimental waterdepth gradient. Aquatic Botany 54: 11–24.

Cuhel, R. L., and C. Aguilar. 2013. Ecosystem Transformations of the Laurentian Great Lake Michigan by Nonindigenous Biological Invaders. *In:* C. A. Carlson and S. J. Giovannoni (eds.) Annual Review of Marine Science, Palo Alto. Annual Reviews 5: 289-320.

Dingman, S. 1973. Effects of permafrost on stream characteristics in the discontinuous permafrost zone of central Alaska. In Permafrost: North American Contribution to the Second International Conference, Washington, DC. National Academy of Sciences Pp. 447-453.

Hitt, N. P. 2003. Immediate effects of wildfire on stream temperature. Journal Freshwater Ecology 18: 171–173.

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

Hodgson, J. M. 1968. Chemical control of reed canarygrass on irrigation canals. Weed Science 16: 465–468.

Jakubowski, A. R., M. D. Casler, and R. D. Jackson. 2013. Genetic evidence suggests a widespread distribution of native North American populations of reed canarygrass. Biological Invasions 15: 261-268.

Larsen, A., and N. Lisuzzo. 2012. Changes in Arctic Grayling Fishery Following the Introduction of the Non-Native Aquatic Weed, *Elodea nuttallii*, Altered Flow Regimes and Changes in Management Policy. CNIPM Conference, Alaska.

Lavergne, S., and J. Molofsky. 2004. Reed canary grass (*Phalaris arundinacea*) as a biological model in the study of plant invasions. Critical Reviews in Plant Sciences 23: 415-429.

Lefor, M.W. 1987. *Phalaris arundinacea* L. (reed canary grasss, Gramineae) as an hydrophyte in Essex, Connecticut, USA. Environmental Management 11: 771–773.

Merz, J. E., J. R. Smith, M. L. Workman, J. D. Setka, and B. Mulchaey.2008. Aquatic Macrophyte Encroachment in Chinook Salmon Spawning Beds: Lessons Learned from Gravel Enhancement Monitoring in the Lower Mokelumne River, California. North American Journal of Fisheries Management 28: 1568-1577.

Moore, R. D., D. L. Spittlehouse, and A. Story. 2005. Riparian microclimate and stream temperature response to forest harvesting: a review. Journal American Water Resource Association 41:813–834.

Pettit, N., and R. Naiman. 2007. Fire in the riparian zone: characteristics and ecological consequences. Ecosystems 10: 673–687.

Pokorny, J., J. Kvet, J. P. Ondok, Z. Toul, and I. Ostry. 1984. Production ecological analysis of a plant community dominated by *Elodea canadensis* Michx. Aquatic Botany 19: 263-292.

Prowse, T. 2001. River-ice ecology. I: hydrology, geomorphic and water-quality aspects. Journal Cold Regions Engineering 15: 1–16.

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

Rorslett, B., D. Berge, and S. W. Johansen. 1986. Lake enrichment by submersed macrophytes – A Norwegian whole-lake experience with *Elodea* canadensis. Aquatic Botany 26: 325-340.

Rouse, W., M. Douglas, R. Hecky, G. Kling, L. Lesack, P. Marsh, M. McDonald, B. Nicholson, N. Roulet, and J. Smol. 1997. Effects of climate change on fresh waters of arctic and sub-Arctic North America. Hydrologic Processes 11: 873-902.

Schindler D., and J. Smol. 2006. Cumulative Effects of Climate Warming and Other Human Activities on Freshwaters of Arctic and Subarctic North America. Ambio 35: 160-168.

Walter K., L. Smith, and F. Chapin. 2007. Methane bubbling from northern lakes: present and future contributions to the global methane budget. Philosophical Transactions of the Royal Society 365: 1657-1676.

Wright, R. F. 1976. The impact of forest fire on the nutrient influxes to small lakes in northeastern Minnesota. Ecology 57: 649–663.

# 4. Aquatic Fine-Filter Conservation Elements

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**Summary**

Section D-4. *Aquatic Fine-Filter Conservation Elements* provides the detailed descriptions, methods, datasets, results, and limitations for the assessments of five fish species considered to be of high ecological importance in the region and potential impacts of CAs on these species.

## 4.1.    Introduction

Five regionally important fish species were selected as Aquatic Fine-Filter CEs to represent the variety of aquatic animal species of conservation concern and/or subsistence importance present in the YKL study area. For the purposes of the REA, Chinook and chum salmon are treated as representatives of all salmon species and sheefish are treated as representative of all whitefish. Northern pike represent a top level predator with the potential for significant bioaccumulation of toxins. Dolly Varden are included to encompass higher elevation and steeper gradient stream habitats.

We include a discussion of methods used in generating distribution maps and the generalized approach to assessing potential impacts of CAs on each Aquatic Fine-Filter CE. The results section includes brief descriptions of each CE, followed by an evaluation of predicted impacts to each CE. Following this section, applications of the outputs and limitations are discussed.  One MQ is addressed within the sections of relevant species and one MQ is addressed at the end of the section.

**Table D-33.** Aquatic Fine-Filter Conservation Elements selected for the YKL REA.

| Aquatic Fine-Filter CEs | Ecological Importance |
|---|---|
| Chinook salmon (*Oncorhynchus tshawytschaus*) | Nutrient inputs to both aquatic and terrestrial ecosystems, food resource for large predators |
| chum salmon (*Oncorhynchus keta*) | Nutrient inputs to both aquatic and terrestrial ecosystems, food resource for large predators |
| sheefish/inconnu (*Stenodus leucichthys*) | Predation in aquatic food webs: sheefish feed mostly on other fish and have both anadromous and resident populations, both of which tend to migrate over long distances |
| northern pike (*Esox lucius*) | Predation in aquatic food webs: northern pike are resident fish that feed on other fish resulting in bioaccumulation of contaminants |
| Dolly Varden (*Salvelinus malma*) | Top predator of headwater streams: Dolly Varden are typically found in the smallest reaches of the river network |

## 4.2.  Methods

**Distribution maps**

The information on the spatial distribution of anadromous fish species across the state is found in the Alaska Department of Fish and Game (ADF&G) Anadromous Waters Catalog (AWC). The AWC was used to develop the distribution maps for Chinook salmon, chum salmon, and sheefish using data attributed by species (Skip Repetto ADF&G, unpublished data; Table D-34).

The distribution for Dolly Varden is based on predictions from a random forests classification model developed from presence-absence data in the ADF&G Alaska Freshwater Fish Inventory Database (AFFID) and GIS-generated landscape predictors (Table D-35). A suite of 13 predictor variables that represent climatic, hydrologic, and topographic attributes of both the stream and watershed were used as inputs to the model. The final random forests model had a misclassification rate of 24.6% and a kappa of 0.50, indicating moderate model performance (Manel et al. 2001). To test the prediction accuracy of the model, 10 models were constructed using a random sample of 80% of the field data points and used to predict the remaining 20% of the field data points. Prediction accuracy was the same for both the validation and training datasets (~24%). The variable importance plots indicated that the most important predictors for Dolly Varden were mean watershed elevation, mean watershed slope over area ratio, and mean watershed slope. Dolly Varden were found to occur in stream reaches of higher elevation, with steeper slopes, higher annual precipitation, and smaller in area than those without Dolly Varden.

Distribution for northern pike is based on predictions from a random forests classification model developed from presence-absence data in the ADF&G Alaska Freshwater Fish Inventory Database (AFFID), telemetry points for northern pike from an ADF&G/BLM project in the Kuskokwim drainage, and GIS-generated landscape predictors. A suite of 14 predictor variables that represent climatic, hydrologic, and topographic attributes of both the stream and watershed were used as input to the model. The final random forests model had a misclassification rate of 11% and a kappa of 0.76, indicating strong model performance (Manel et al. 2001). To test the prediction accuracy of the model, 10 models were constructed using a random sample of 80% of the field data points and used to predict the remaining 20% of the field data points. Mean prediction accuracy was 10% for the validation datasets. The variable importance plots indicated that the most important predictors for northern pike were watershed area, stream order, stream elevation, lake density, and floodplains. Northern pike were predicted in stream reaches with connected floodplains, larger watersheds, higher stream order, lower elevation, and higher lake density than those without northern pike.

**Table D-34.** Source datasets for the distribution of chinook salmon, chum salmon, and sheefish.

| Dataset Name | Data source |
|---|---|
| Anadromous Waters Catalog (unpublished version attributed with species and life stages) | Skip Repetto, ADF&G |

**Table D-35.** Source datasets for the distribution of Dolly Varden and northern pike.

| Dataset Name | Data source |
|---|---|
| Alaska Freshwater Fish Inventory Points | Skip Repetto, ADF&G |
| Telemetry data for northern pike in the Kuskokwim Drainage | Matthew Albert, ADF&G |
| National Elevation Dataset Alaska 60m Digital Elevation Model (DEM) | USGS |
| Current Distribution of Floodplains in YKL Study Area | AKNHP, UAA |
| National Hydrography Dataset Waterbodies | USGS |

### Landscape condition

We assessed current, near-term (2025), and long-term (2060) status for each Aquatic Fine-Filter CE using the Landscape Condition Model (Section C). In the long-term (2060) we present a hypothetical scenario of a road along the Kuskokwim River, which should be noted is a distant possibility based on the construction of a natural gas pipeline adjacent to the Kuskokwim River. For each Aquatic Fine-Filter CE, landscape condition was determined using 60 m grid cell resolution. The status of each CE was determined by converting the polyline distributions for CEs to rasters, extracting the LCMs to the distribution rasters, and converting the extracted rasters back to polylines. The sum of impacts from all CAs on Aquatic Fine-Filter CEs was assessed using the species distributions maps we developed.

### CA and CE analyses

For each Aquatic Fine-Filter CE, the long-term potential (2010-2060) impacts from climate change were evaluated, when possible, based on the development of conceptual models and availability of spatial data sets. Assessing the potential for impacts of Invasive species, development, and fire on CEs in an explicitly spatial context did not appear to provide additional information useful in terms of informing management or research efforts beyond the conceptual model. Thus, for this report, we only included those CA and CE overlays that highlight where impacts and/or effects from CAs on CEs were most apparent on the landscape. However when invasive species or fire was perceived to be relevant they are discussed. Although we did not include all of the CA and CE overlays in this report, all GIS data are provided as a final product and available for future analyses.

**Table D-36.** Source datasets for CA and CE analysis.

| Dataset Name | Data source |
|---|---|
| Areas of Permafrost Change from 2010s to 2060s in Alaska | SNAP, UAF |
| Change in growing season from 2010s to 2060s | SNAP, UAF |
| Mean July Temperature from 2010s to 2060s | SNAP, UAF |
| Subsistence fish harvest data | ADF&G |
| Placer mine and hard rock mine data | Alaska Resource Data File, USGS |

## Management Questions (MQs)

There were two management questions specific to Aquatic Fine-Filter CEs. The first MQ related to how predicted changes in climate may impact Essential Fish Habitat (EFH; MQ #14). To answer this question spatially we used the current distribution maps we developed for Chinook salmon and chum salmon (EFH species), overlaid with projected changes in temperature data for 2010-2060. Additionally, the conceptual models provide a literature review of the potential impacts that climate change may have on salmon habitats and salmon populations throughout the YKL study area. These results are presented within the individual CE sections.

The second MQ was specific to how and where mineral resource development may affect fishery habitat within the YKL study area (MQ #14). To answer this question spatially we used the current distribution maps for important fisheries species that have adequate subsistence harvest data (Chinook salmon, chum salmon, sheefish, and northern pike), overlaid with current and future landscape condition, as well as mineral resource development data for the YKL study area. Additionally, the conceptual models we developed for salmon species, sheefish, and northern pike provide a literature review of the potential impacts that mineral resource development may have on subsistence and commercial harvest fish species throughout the YKL study area. We did not have current subsistence data for Dolly Varden and thus do not provide spatial results for this species.

## General Effects of CAs on Fish Species Conceptual Model

The conceptual model below (Figure D-90) is based on extensive literature review and describes the relationship between the various change agents and natural drivers for fish species in general. The boxes and arrows represent the state of knowledge about fish and its relationships to each attribute. Change Agents (CAs) and the environmental parameters that they affect, or drivers, have specific effects on particular fish species and general affects that will impact most fish species similarly. To differentiate clearly between specific and general impacts, we propose a base conceptual model that details the general interactions between CAs, drivers, and fish habitat and fish in general.

This base model forms the framework within which CE-specific effects can be understood. While we expect that most CEs will respond to similar drivers, the strength of responses is anticipated to differ among CEs. Differences in strength of responses are illustrated by the arrow and line width.
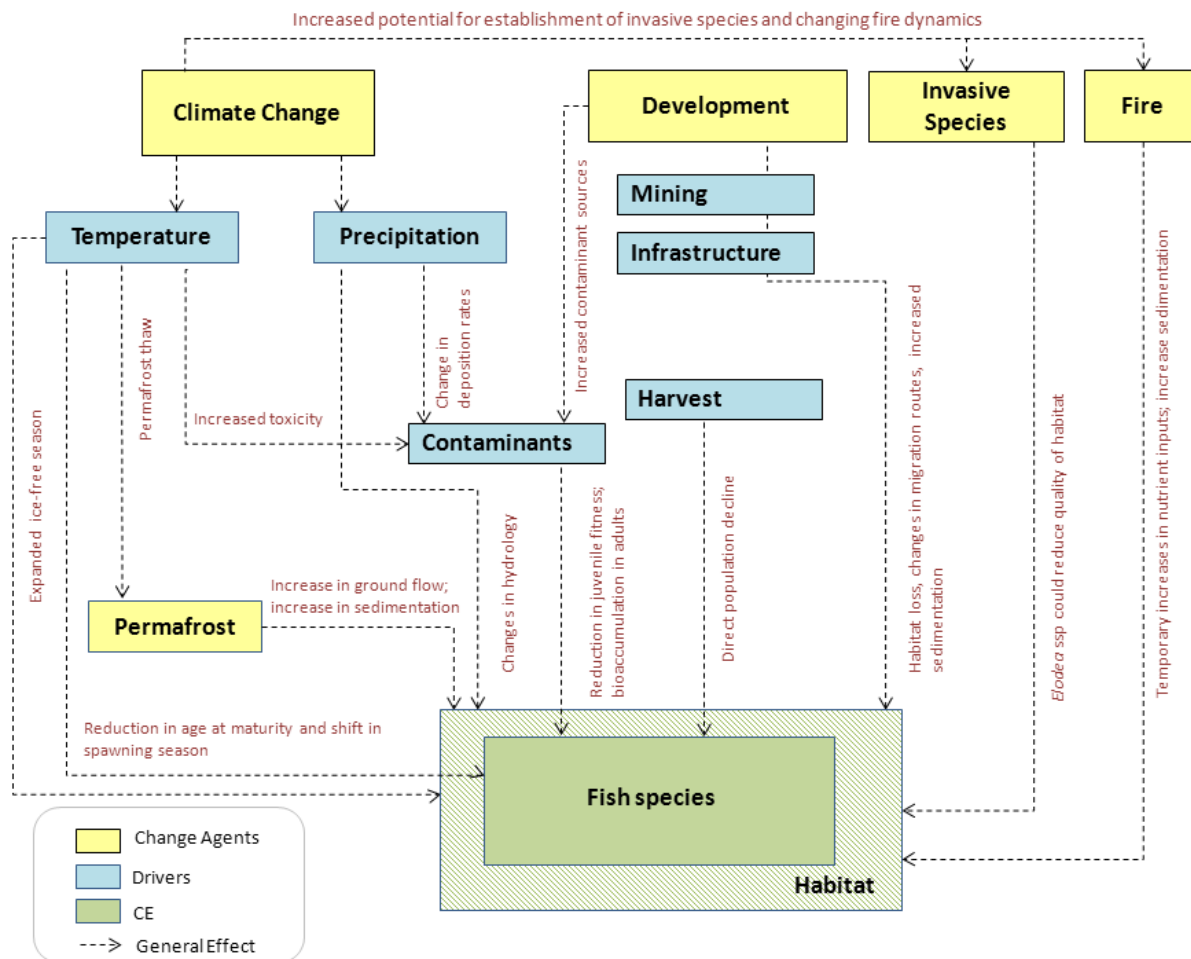
**Figure D-90.** Principal interactions among population drivers and change agents for fish species in the YKL study area.

### *Climate Change*

Climate change is expected to result in increased annual average temperatures for the YKL study area in the long term (see Section B-1). Although specific effects of climate change on water temperature are not clear, the warming trend will result in two phenomena that will likely have major impacts on fish habitat: increase in the duration of the ice-free season for lakes and streams and permafrost thaw. As areas remain ice-free for a longer period of time, the quality of feeding habitats will likely improve because fish will be able to feed more during any single year (Reist et al. 2006). Additionally, permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations. Increased nutrient input will improve the quality of fish feeding habitat with the direct or indirect increased abundance of prey species (Reist et al. 2006), at least temporarily. As a consequence, the age at maturity for fish is predicted to decrease (Brown et al. 2012). Spawning will shift later in the year for autumn spawners and earlier in the year for spring spawners to correspond with the time that water temperature approaches 0°C or the time that aquatic habitats become ice-free, respectively. However, increased permafrost thaw can result in erosion and sedimentation in streams. While higher stream temperatures are generally associated with increased primary production, higher stream turbidity may in fact reduce primary production and aquatic invertebrate populations, lowering the quality of

fish feeding habitat by reducing the abundance of prey species either directly or indirectly. Furthermore, recent studies have documented an increase in mercury contamination as a result of permafrost thaw within the Yukon River Basin (Schuster et al. 2011). Increased mercury contamination could negatively impact macroinvetebrates and fish as well as wildlife and humans that rely on these food resources.

### Fire

Fires strip stabilizing vegetation from the landscape and increase erosion and runoff, resulting in higher sediment inputs to streams and rivers. Increased runoff has the potential to decrease both primary productivity and aquatic invertebrate populations through increased turbidity. The increases in erosion and runoff in burned areas also increase nutrient inputs to aquatic habitats (Davis et al. 2013). These effects are temporary and are limited by the re-establishment of terrestrial and emergent vegetation.

### Development

Major construction, especially of roads, or mineral extraction operations increases erosion and runoff leading to increased stream turbidity and sedimentation, compounding the effects of permafrost thaw and fire. The construction of new roads may channelize river systems and hinder migration routes, at least in part. Furthermore, with increased road access increased fishing pressure is possible. Mining operations, especially those of a large scale, threaten to destroy feeding and spawning habitats. Placer mines are often located in upper reaches of drainages so placer mining most heavily impacts fish species that spawn in those areas (Brown et al. 2012).

### Contaminants

Areas naturally rich in heavy metals, including mercury (Hg), arsenic (As), and antimony (Sb), occur in the YKL study area (Matz 2012). These areas are naturally weathered, causing heavy metals to enter aquatic ecosystems. Development also increases the likelihood of contamination within the YKL study area. Development will likely contribute to an increasing presence of petrochemicals primarily through fuel/oil spills. Oil contamination has the largest impact on eggs, larvae, and juvenile fish because of their reduced capacity to leave the contaminated area (Brown et al. 2012). Mining has the potential to expose heavy metals that can enter into aquatic habitats. Furthermore, permafrost can act as a reservoir for Hg storage (Schuster et al. 2011). With projected increases in permafrost thaw, an increase in Hg contamination to aquatic ecosystems within the YKL study area is anticipated (Schulster et al. 2011). As water temperature increases, certain contaminants become more bioavailable (e.g., Hg) and exposure rates of fish to contaminants will likely increase (Dijkstra et al. 2013). Additionally, with increased precipitation the deposition rate of contaminants including Hg and organochlorines increases (Risch et al. 2012). Contaminants are an increasing threat to fish, especially piscivorous fish that eat other large fish. Adult predatory fish are more likely than juvenile fish of the same species to accumulate high concentrations of heavy metals (Matz 2012).

### Invasive species

Invasive species are not known from aquatic habitats in the YKL study area; however some species are recognized to occur elsewhere in Alaska and could cause impacts to these fish species. *Elodea* species are invasive aquatic macrophytes that currently have potential to spread to the YKL study area. *Elodea* is already established in the Tanana watershed just outside the study area and may spread downstream in the future.

Establishment of *Elodea* within the study area will likely reduce the quality of feeding and spawning habitat as it has elsewhere (Merz et al. 2008, Larsen and Lisuzzo 2012, and see Buscemi, 1958, Pokorny et. al., 1984, Rorslett et. al., 1986). Additionally, non-native cultivars of *Phalaris arundinacea* have the potential to impact fish species by alterations to stream habitats by clogging waterways (Lavergne and Molofsky 2004), which result in decreased stream velocities and increased sedimentation rates (Hodgson 1968, Lefor 1987). These and other invasive species are discussed in the Aquatic Coarse-Filter CE section 3.

### *Harvest*

Subsistence and personal use harvest of fish is largely unregulated within the YKL study area. While sport fishing in the area is currently relatively small, it has the potential to increase in the future with increased road development. Commercial fishing operations within the YKL study area are targeted at salmon species, but other species are caught incidentally.

## 4.3.    Chinook salmon (*Oncorhynchus tshawytscha*)
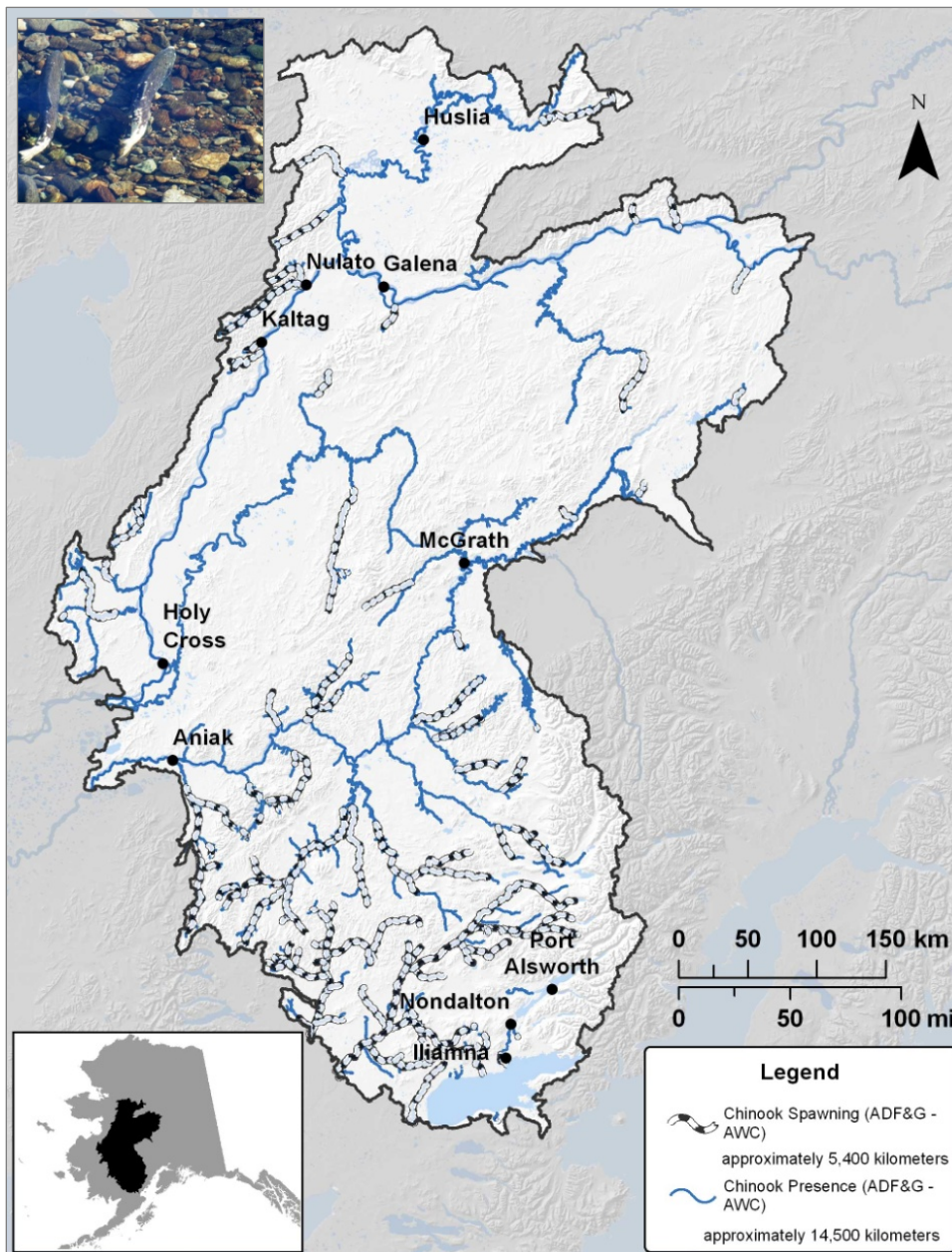


**Figure D-91.** Current distribution and spawning habitat of Chinook salmon within the YKL study area.

Chinook salmon spend 1 to 2 years in freshwater before migrating to the ocean, where they spend an additional 1 to 5 years feeding before returning to their natal stream to spawn. Within the YKL study area, Chinook salmon migrate upstream to their natal river in spring or summer, several months prior to spawning. Spawning takes place from July to early September. Females deposit eggs in gravel bottoms of clear, fast moving streams and rivers and the eggs usually hatch in late winter or early spring. Juvenile Chinook salmon feed on plankton and insects while in freshwater and adults feed mainly on fish while at sea.

Chinook salmon are well distributed through most of the major watersheds in the YKL study area (Figure D-91). The amount of spawning habitats is much higher in the Lime Hills and Kuskokwim Mountains study areas than in

the Yukon Flats (Eiler et al. 2004). Estimated total run sizes of Chinook salmon to the Kuskokwim River ranged from 100,000 to 400,000 fish for the period 1976 to 2011 (Bue 2012).

**Conceptual Model**

The conceptual model below (Figure D-92) is based on literature review and describes the relationship between the various change agents and natural drivers for Chinook salmon.



**Figure D-92.** Principal interactions among population drivers and change agents for Chinook salmon in the YKL study area.

**Climate Change Impacts on Essential Fish Habitat**

| | |
|---|---|
| **MQ 14** | How, where, and when could Essential Fish Habitat (EFH) be affected by predicted changes in climate? |

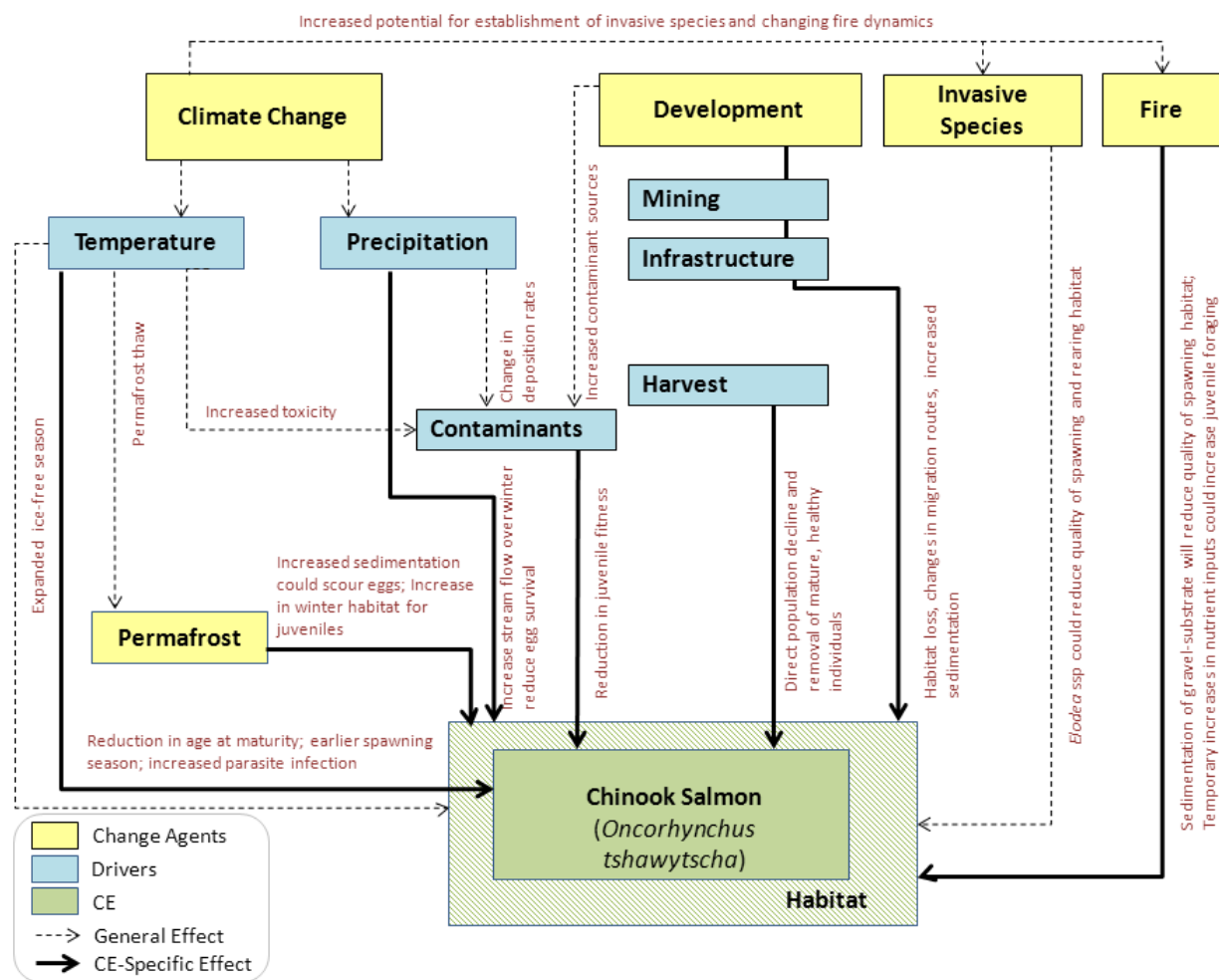Water temperature increases have been correlated with increased frequency of infection of *Ichthyophonus hoferi*, a microscopic parasite that infects Chinook salmon (Kocan et al. 2003; Zuray et al. 2012). Water temperatures above 15C° are known to be lethal for *Ichthyophonus*-infected fish (Okamoto et al. 1987). Prior to the 1980s, *Ichthyophonus* was unreported in Chinook salmon within the Yukon River (Kocan et al. 2003). Since the 1990s *Ichthyophonus*-infected Chinook salmon have increased to levels that warrant concern for subsistence harvest and commercial fishing in the Yukon River (Kocan et al. 2003). Rising average water temperatures in the Yukon River during the past three decades has been associated with an increase in disease and pre-spawning mortality among infected Chinook salmon (Zuray et al. 2012). During 1999 and 2001 when water temperatures within the Yukon River were at their highest, around 20°C, rates of infection of *Ichthyophonus hoferi* were also highest and in 2002, when temperatures were at their lowest (high around 16C°) infection rates were also lower (Kocan et al. 2003). With the projected increases in air temperature, water temperatures will likely increase and the proportion of disease and pre-spawning mortality among *Ichthyophonus*-infected fish could increase (Zuray et al. 2012). If pre-spawning mortalities continue to increase with increasing temperatures, greater restrictions on subsistence and commercial fishing would be necessary in order to meet higher escapement goals. This is especially true for Chinook salmon runs in the northern part of the YKL study area where air temperature increases are projected to be greatest (Figure D-93).
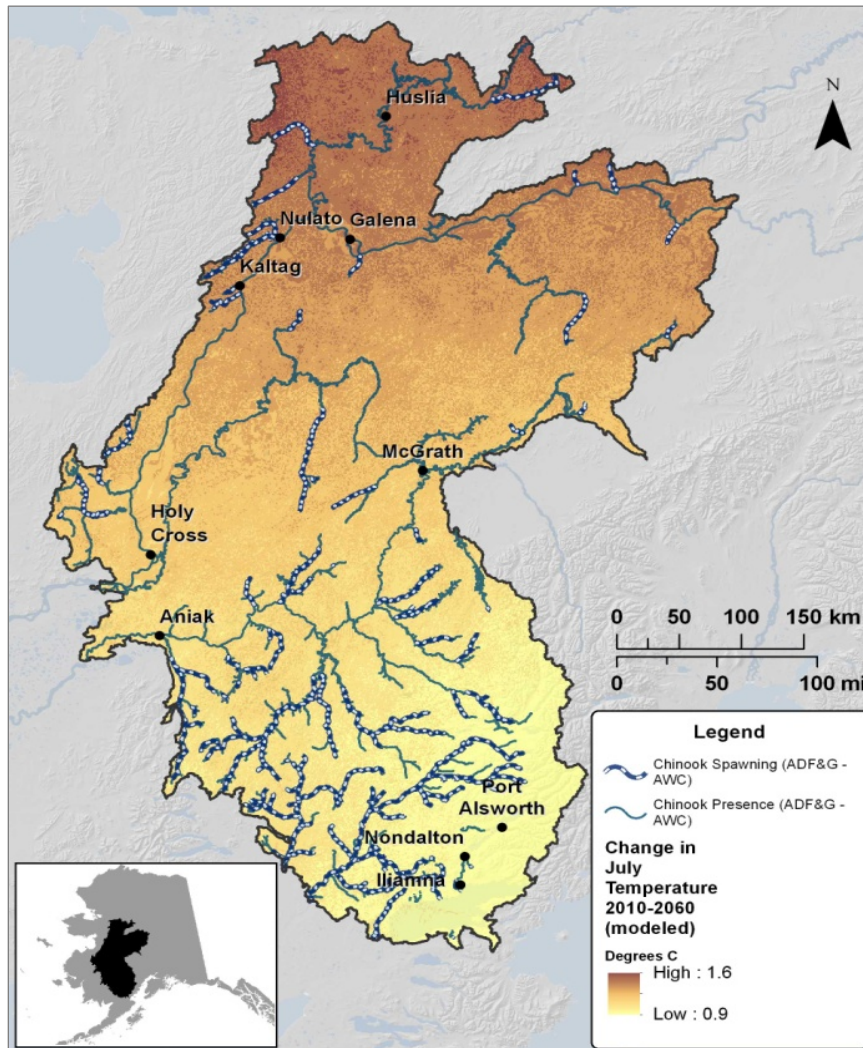
**Figure D-93.** Distribution and spawning habitat of Chinook salmon and modeled increase in July temperature change from 2010 - 2060 within the YKL study area.

Chinook salmon juveniles typically rear for 1 to 2 years in streams, thus they could potentially be more susceptible to changing hydrologic regimes than chum salmon which do not have a resident freshwater period. An increase in temperature may provide increased growth opportunities due to increased food resources and consequently, decrease the freshwater residence time of juvenile Chinook salmon (Sommer et al. 2001). However, if food resources do not increase at rates to match demand, growth will decrease and may affect overwintering survival (Reist et al. 2006). Additionally, increased temperatures have been shown to shift the spawning time to later in the year because less cumulative degree days are needed for egg incubation (Lisi et al. 2013). Chinook salmon within the YKL study area travel long distances to spawning grounds and increased temperatures increase energy costs related to migratory movements (Hinch and Rand 1998).

Permafrost thaw and increased winter precipitation will likely increase groundwater flows, improving Chinook salmon overwintering habitat in medium to small high gradient streams (Ficke et al. 2007). However, increases in maximum flows could have negative impacts on Chinook salmon habitat, such as scouring of redds, erosion of streambanks, and increased siltation which could impact the ability of salmon to reproduce successfully. Silt can

act as a stressor by preventing the flow of oxygenated water which is essential for developing eggs and larval fish. Because Chinook salmon are visual feeders, increased amounts of suspended sediments in the water could have negative effects on juvenile foraging abilities. Suspended sediments have also been known to reduce available habitat for macroinvertebrates, which are an important food resource for Chinook salmon (Kemp et al. 2011).

## Harvest

Chinook salmon is the primary fish species sought by commercial fishers and a crucial subsistence food source for rural residents. There are two major stocks that make up the majority of the Chinook salmon run in the Yukon River, which originate from the Tanana River and the upper Yukon tributaries in Canada and comprise 21% and 50% of the total run, respectively (Eiler et al. 2004). The Yukon River Chinook salmon stock was listed as a stock of yield concern in 2000, and commercial salmon fishing has been closed since 2008, with some restrictions on subsistence fishing as well. Through 2007, Chinook salmon runs continued to improve over the very poor runs of 1999–2000. However, in 2008 and continuing through 2013, the number of Chinook salmon returning to the Yukon River drainage was less than expected (Schindler et al. 2013).

Due to restrictions on harvest, the escapements in recent years can be used as an estimate of the relative production of Chinook salmon originating from the Yukon Flats study area. Total Chinook escapement to the Yukon River portion of the study area was estimated by starting with the total escapement below the Tanana and subtracting the escapement for the two populations monitored downstream of the study area (Andreafsky and Atchuelinguk rivers). For 2010, the total escapement in the Yukon River within the study area was 4,482 Chinook (Estensen et al. 2012). This is approximately 9% of the total 2010 escapement to the Yukon River. A radio telemetry study conducted from 2002-2004 found that stock groups from the middle and lower Yukon River comprised 8% of the total run (Koyukuk, Melozitna, Nowitna, Tozitna, Anvik and Nulato rivers). These estimates indicate that the tributaries to the Yukon River in the YKL study area are not large producers of Chinook salmon relative to watersheds draining to the upper Yukon River.

## Development

Major construction, especially of roads, or mineral extraction operations increase erosion and runoff leading to increased stream turbidity and sedimentation, compounding the effects of permafrost thaw and increased winter precipitation described above. The construction of new roads may channelize river systems and hinder migration routes. Furthermore, with increased road access there's the potential for increased fishing pressure and access to important spawning areas (Burr 2012).

The potential impacts of mining operations on Chinook and other fish species are discussed at greater length under MQ 15 (locations and impacts of mining on fishery habitats) at the end of this section. Briefly though, mining operations, especially those of a large scale, threaten to destroy feeding and spawning habitats. Small-scale placer mines are largely restricted to the north central and eastern part of the YKL study area and likely have localized impacts on spawning habitats. Large-scale mines (such as the proposed Pebble Mine and Donlin Mine; Figure D-111 ) are currently absent from the YKL study region, but have the greatest potential for disrupting salmon spawning habitat (U.S. EPA 2014). However, the location of the Donlin Mine (near the Kuskokwim River; Figure D-111) is significantly smaller in scale and economic value compared to that of the proposed Pebble Mine. Impacts of mining operations are discussed below under MQ 15.

**Current status and future landscape condition**

The majority of Chinook salmon habitat is currently classified as high landscape condition (Figure D-94). Areas of low landscape condition are localized near communities and are associated with human development in these areas. Future projections of landscape condition suggest that Chinook salmon habitat will remain relatively intact and in good condition (Figure D-94). However, Chinook habitat along the potential Kuskokwim road development are projected to go from current "high" quality landscape status to relatively "low" quality landscape status (Figure D-94).

**Applications**

The distribution maps created for Chinook salmon provide managers with baseline information on distribution and spawning habitat within the YKL study area. Given their increased susceptibility to infection of *Ichthyophonus* parasite, increases in mean July temperature are of particular concern for spawning Chinook salmon. This is especially true for Chinook salmon runs in the northern part of the YKL study area (within the Yukon River) where temperature increases are projected to be greatest (Figure D-93) and current water temperatures are at thresholds for which salmon become more susceptible to parasite infection. Thus, future management and research efforts would benefit from studies focused on understanding the impacts of increased water temperature on infection rates of Chinook salmon populations spawning throughout the YKL area and specifically within the Yukon River. Additionally, we provide conceptual models with information on the potential effects of climate change and anthropogenic development on Chinook salmon that will help direct future modeling efforts and aid in current and future management decision making.

**Limitations and Data Gaps**

Because we lack water temperature data for the YKL study area, air temperature was used as a proxy for water temperature changes for July temperature spatial analysis. Climate-linked aquatic models would benefit from future efforts that focused specifically on the impacts of increasing water temperatures on infection rates of *Icthyopyhonus* and Chinook salmon. Additionally, future climate modeling efforts should focus on the effects of permafrost thaw and increased winter precipitation on Chinook salmon habitat with the YKL study area.

Few data exist for long-term trends and temporal changes in fish populations, limiting our ability to assess population changes over time. Additional information on the impacts of subsistence and commercial fishing on salmon populations would be useful, in conjunction with an investigation into how climate might impact stream temperatures to better understand the overall potential for change in harvest of salmon populations.
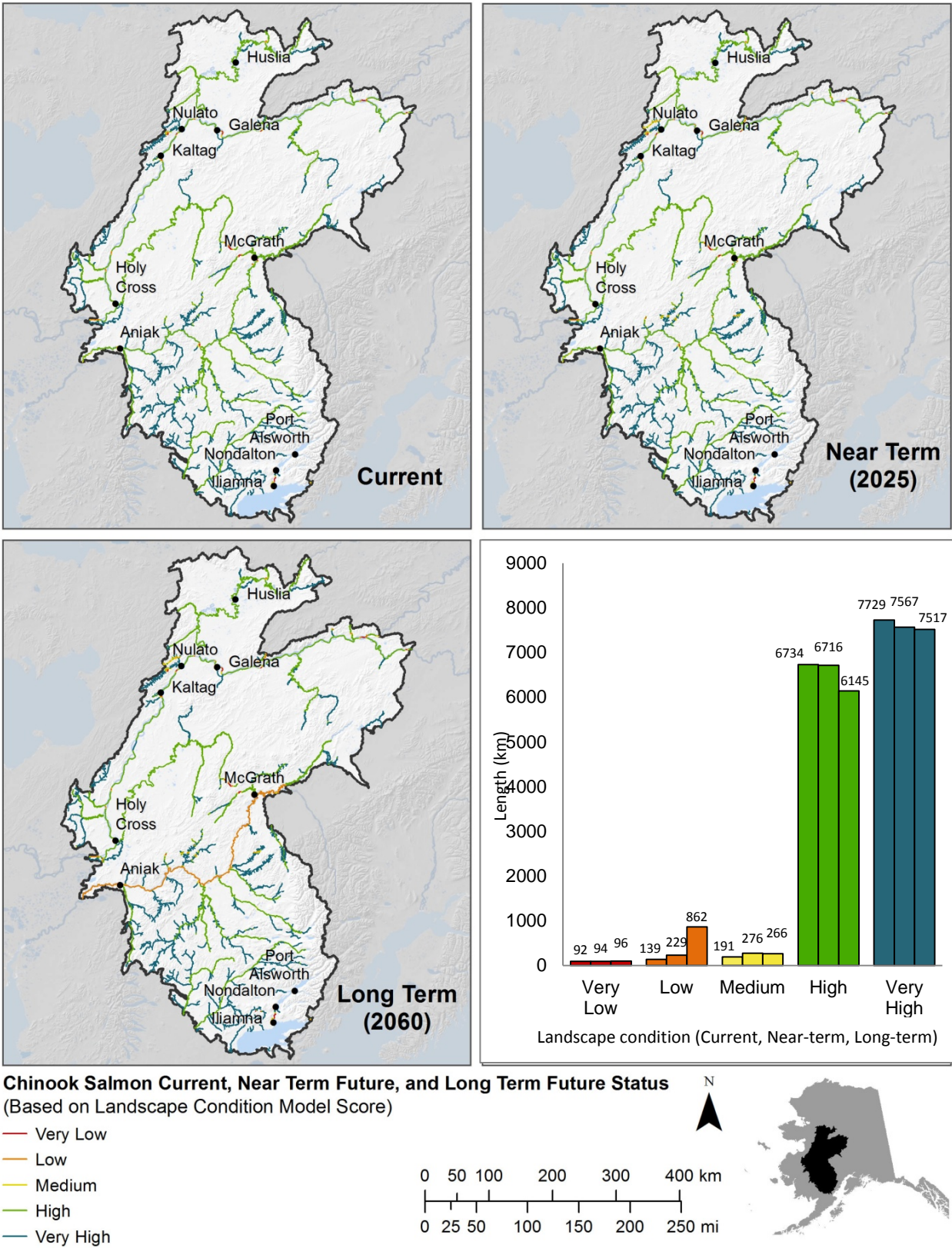
**Figure D-94.** Current, near-term future (2025), and long-term future (2060) landscape condition (summarized at the 5th level HUC) within current Chinook salmon habitat in the YKL study area.

## 4.4.    Chum salmon (*Oncorhynchus keta*)
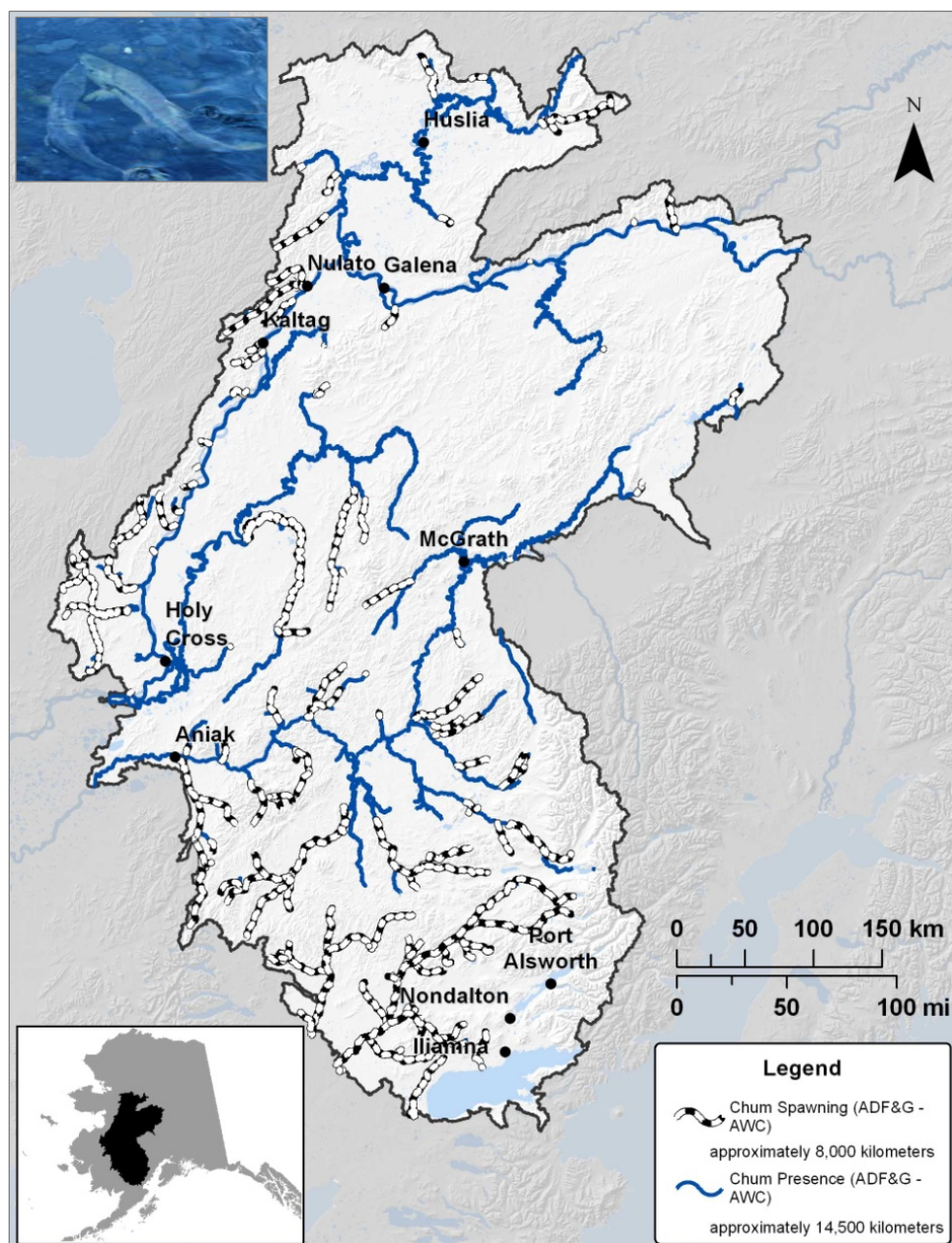


**Figure D-95.** Current distribution and spawning habitat of chum salmon within the YKL study area.

Chum salmon are the most abundant species of salmon spawning in the Yukon River drainage system (Figure D-95), and they support important subsistence use and commercial fisheries. There are two genetically distinct runs of chum salmon: summer and fall. Summer chum salmon enter the river between early June and July, and spawn mostly in shallow, clear, cold tributaries of the lower 500 miles of the Yukon River. Fall chum salmon enter the river from mid-July to late August and select spawning streams in the upper Yukon River drainage from the Tanana River confluence to the headwaters of the Yukon River. Studies using radio-telemetry indicate that a significant number of fall chum salmon returning to the Tanana River may be spawning in mainstem reaches (Cleary and Hamazaki, 2005).

Chum salmon do not have a period of freshwater residence after emergence of the fry, as do Chinook salmon. Chum salmon embryos hatch after 3–4 months, depending on water temperature and remain in the gravel while continuing to absorb nutrients from the egg yolk for an additional 60–90 days before emerging (Morrow 1980). Fry emerge from the gravel during spring (April-May) and migrate to the ocean within days or a few weeks after hatching (Salo 1991). Juvenile chum salmon that hatch far upriver begin feeding on insect larvae while still moving toward the sea. As adults, they almost always return to spawn in their natal stream.

## Conceptual Model

The conceptual model below (Figure D-96) is based on literature review and describes the relationship between the various change agents and natural drivers for chum salmon. Relationships expected to be of greatest relevance are changes in temperature, precipitation, and development. Not all relationships identified lend themselves well to measurement or monitoring, but are included to enhance our overall understanding of complex interactions.
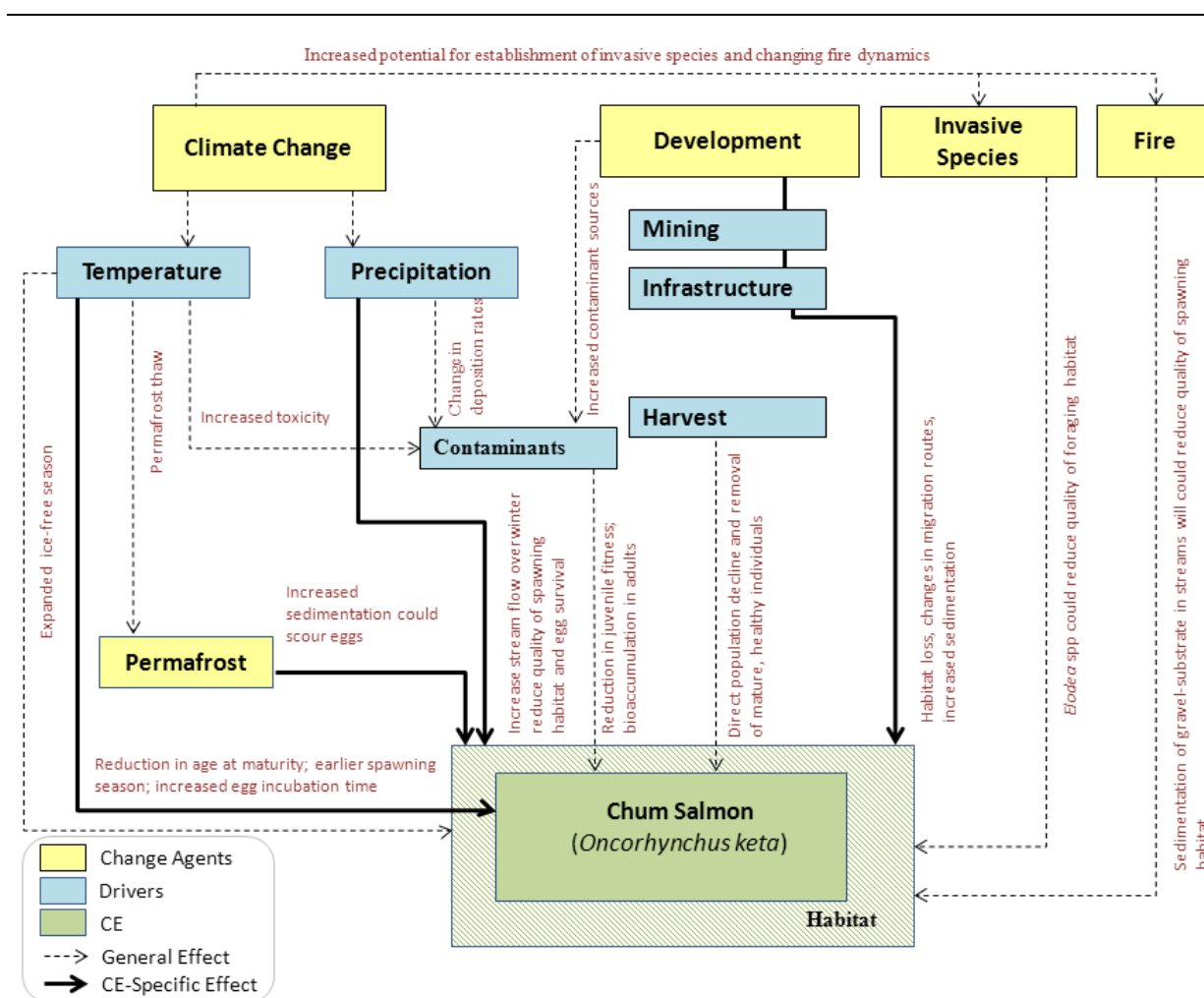


**Figure D-96.** Principal interactions among population drivers and change agents for chum salmon in the YKL study area.

**Climate Change Impacts on Essential Fish Habitat**

| MQ 14 | How, where, and when could Essential Fish Habitat (EFH) be affected by predicted changes in climate? |
|---|---|

Water temperature, water flow through the substrate, and dissolved oxygen concentration are important factors that influence redd site selection (Maclean, 2003). Chum salmon need initial incubation temperatures around 4.0 °C for successful early embryonic development (Raymond 1981; Beacham et al. 1988) and the time of fry emergence is related to temperature during the incubation period (Salo 1991). Thus, changes during the early part of incubation can affect time of emergence. For example, as temperatures increase egg incubation rates will likely increase and time to emergence and migration will therefore decline. Fall chum salmon in particular, may benefit more directly from increases in water temperatures because they tend to select warmer and stable water temperatures for spawning habitat (Maclean 2003). However, an increase in water temperatures (coupled with low flow as a consequence of decreased summer precipitation) could cause higher fish densities and depleted oxygen concentrations, resulting in high pre-spawning mortality (Murphy 1985). Changes in air temperature between 2010-2060 are projected to be greatest for the northern part of the study area (Figure D-97), thus chum salmon in the northern region may be impacted to a greater degree by increased temperatures, than chum salmon in the southern portion of the study area.
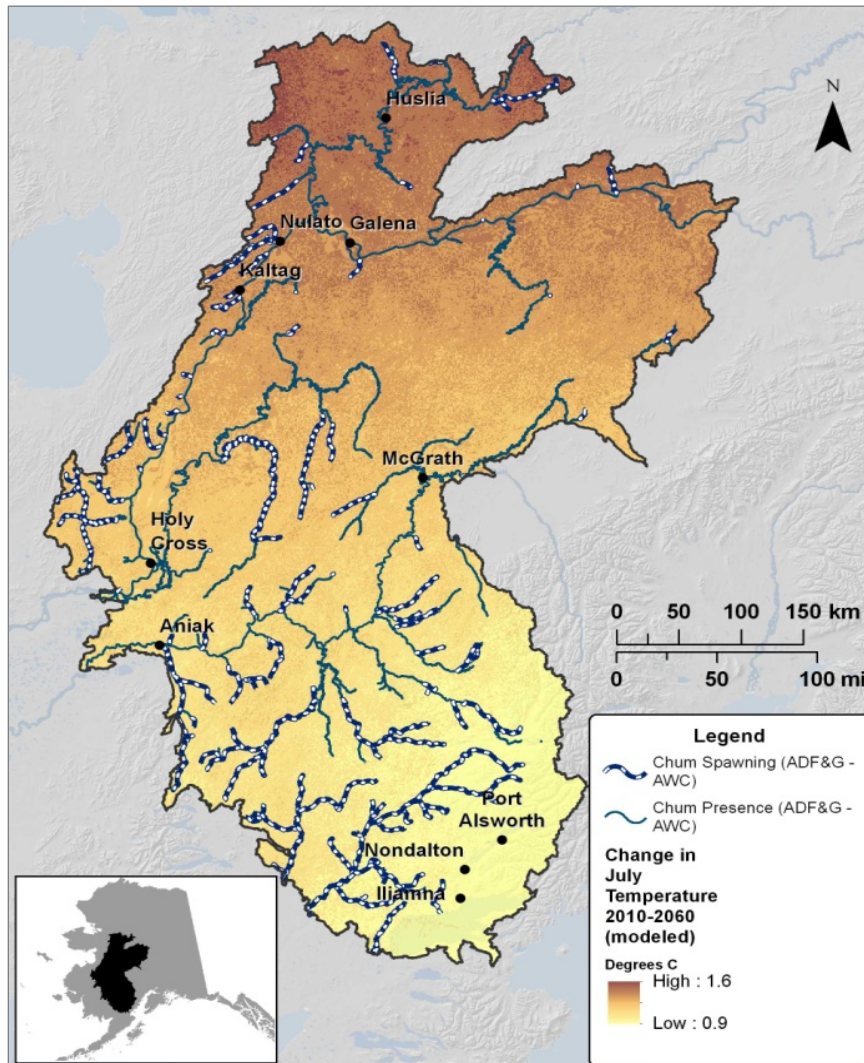
**Figure D-97.** Current distribution and spawning habitat of chum salmon and July (hottest month) projected temperature change from 2010-2060 for the YKL study area.

Increased permafrost thaw and snow melt may increase the rate of stream discharge and the potential for scour and sedimentation of chum salmon redds (Lisle 1989). Likewise, increased precipitation, especially in winter, could have similar negative impacts on chum salmon spawning habitat by increasing the potential scouring of redds and erosion of streambanks.

**Harvest**

Chum salmon are important subsistence and commercial species in the YKL study area. They provide an important year-round source of fresh and dried fish for subsistence and personal use purposes. In September 2000, the Yukon River summer chum salmon stock was classified as a management concern, and most of the Yukon River drainage fall chum salmon stock as a yield concern.

Annual sport harvests of chum salmon in the Yukon River drainage have historically been, and continue to be, primarily from streams of the Tanana River drainage (Brase and Baker 2012). Sport harvests are reported from

other streams and drainages in the Yukon River watershed, primarily from the Andreafsky, Anvik, and Koyukuk rivers and their tributaries. As of 2010, the mainstem Tanana River was classified as an important migration corridor.

## Development

The impacts from major construction, dams, and mining are expected to be similar for chum salmon as for Chinook salmon (see Section 4.2).

## Current status and future landscape condition

Majority of chum salmon habitat is currently classified as high landscape condition (Figure D-98). Areas of low landscape condition are localized near communities and are associated with human development in these areas. Future projections of landscape condition suggest that chum salmon habitat will remain relatively intact and in good condition (Figure D-98). However, similar to Chinook, chum salmon habitat along the potential Kuskokwim road development area are projected to go from current "high" quality landscape status to relatively "low" quality landscape status (Figure D-98).
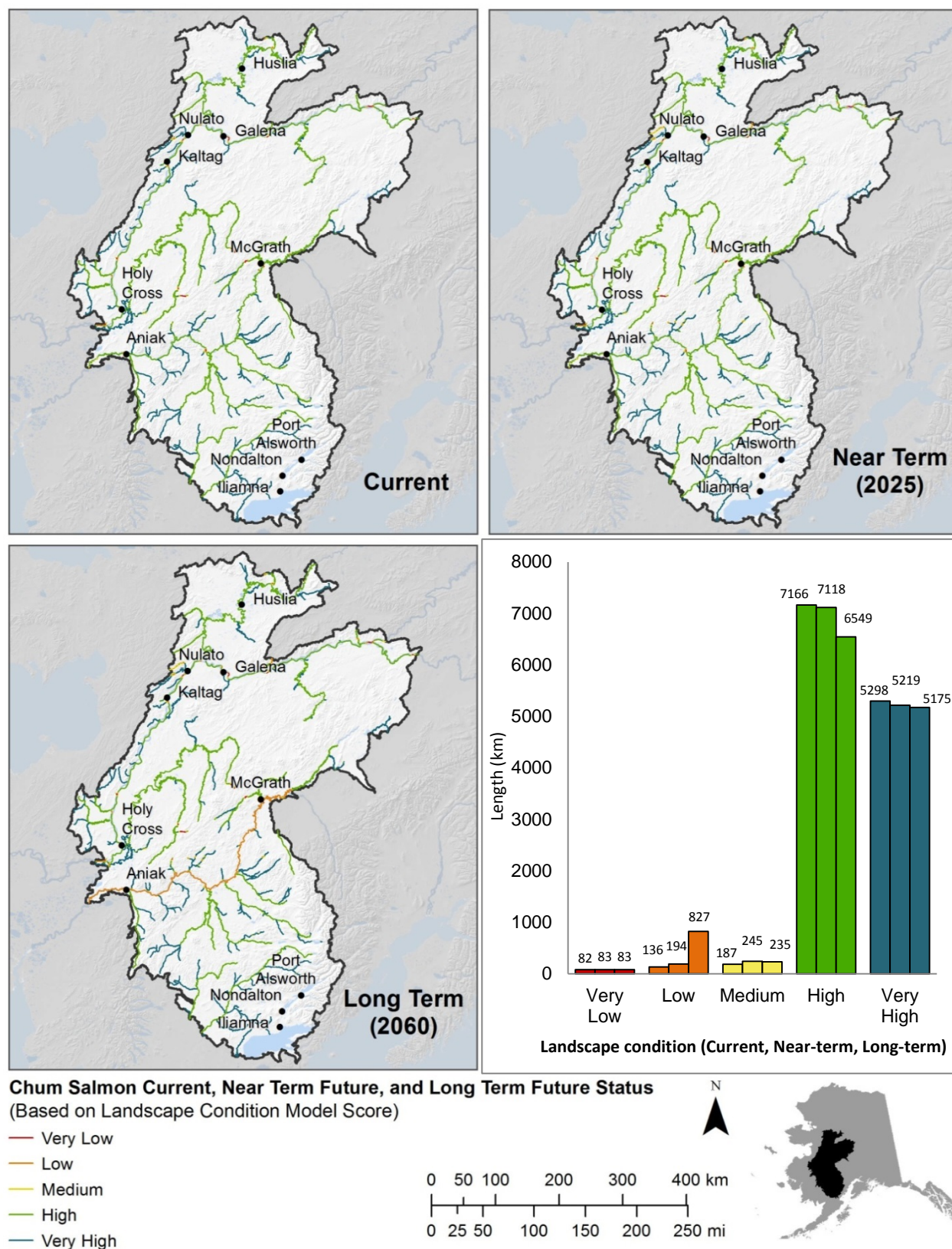
**Figure D-98.** Landscape condition modeled for current, near-term (2025), and long-term (2060) projections clipped to current chum salmon habitat in the YKL study area.

**Applications**

The distribution map created for chum salmon provide managers and researchers with baseline distribution information for the YKL study area. Additionally, we provide conceptual models with information on the potential effects of climate change and anthropogenic development to chum salmon that will help direct future modeling efforts and could aid in current and future management decision making. Since limited spatial data were available on climate change impacts to aquatic systems, most changes were qualitatively described based on literature reviews and incorporated into the conceptual models.

The greatest projected increases during the long-term in July air temperature are forecasted for the northern part of the YKL study area (Figure D-97). The Yukon River is an important spawning area for chum salmon. Future management and research studies should focus on the potential impacts of temperature increases on chum salmon spawning populations within the YKL area and specifically within the Yukon River.

**Limitations and Data Gaps**

Because we lack water temperature data for the YKL study area, air temperature was used as a proxy for water temperature changes for the July temperature spatial analysis. Given the lack of these data, future research efforts should focus on collection of water temperature data that would assist with long-term modeling efforts and that could aid in current and future management decision making.

Few data exist for long-term trends and temporal changes in fish populations, limiting our ability to assess population changes over time. Additional information on the impacts of subsistence and commercial fishing on salmon populations would be helpful, in conjunction with an investigation into how climate might impact stream temperatures to better understand the potential for change in harvest of salmon populations.

## 4.5.    Sheefish (*Stenodus leucichthys*)
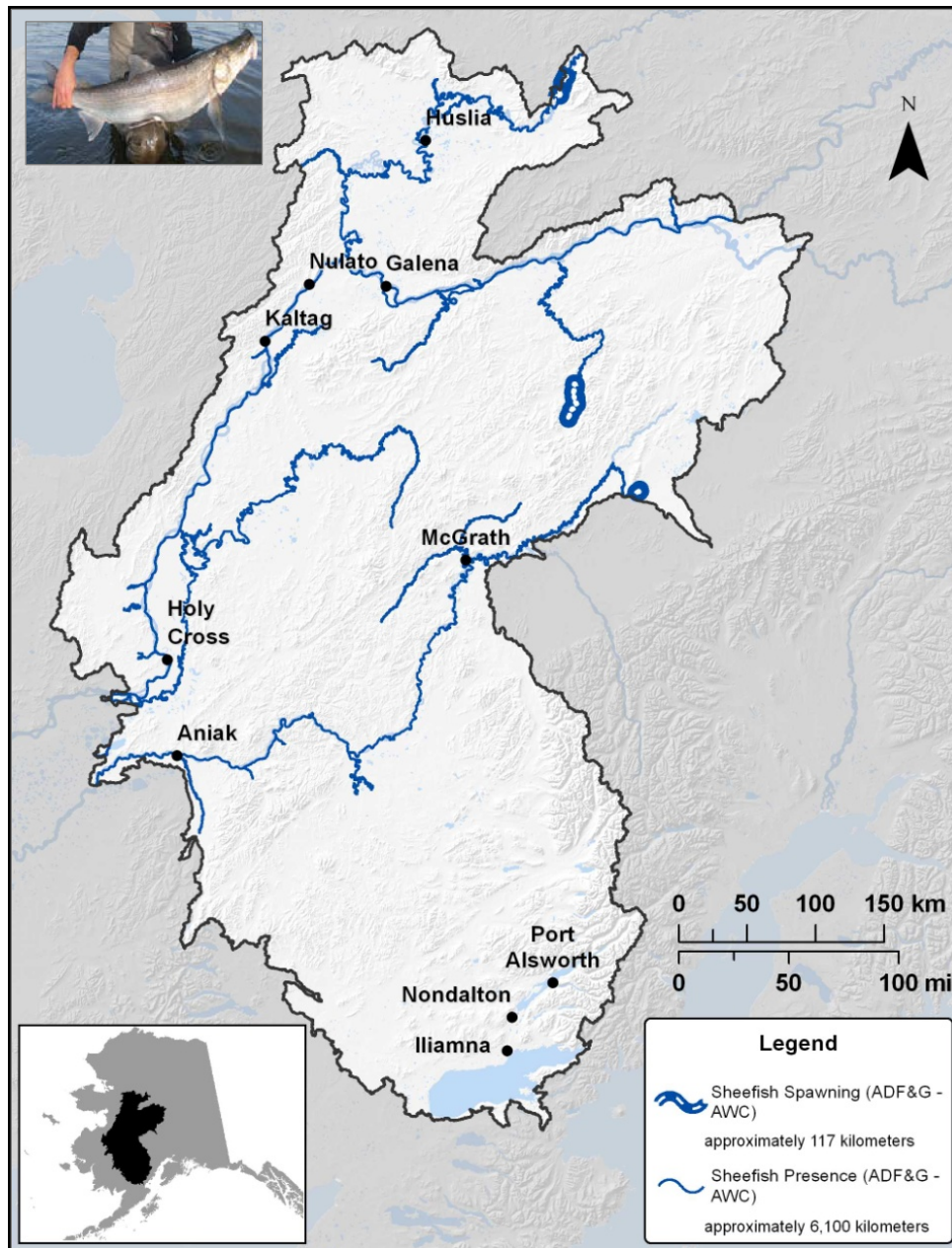


**Figure D-99.** Current known distribution and spawning habitat of sheefish within the YKL study area.

Sheefish overwinter predominantly in near-shore coastal waters and estuaries, as well as low gradient rivers within the YKL study area. In the YKL study area, sheefish feed at the mouths of major tributaries along the Kuskokwim and Yukon rivers during summer months. Sheefish annually make long migrations between overwintering habitat and feeding habitat (L. Stuby pers. comm.). Sheefish therefore migrate into and out of the YKL study area seasonally, as the study area does not include coastal waters or estuaries. However, a small number of spawning areas have been identified within the YKL study area (Figure D-99).

Spawning habitat is located in upstream, clear-water streams of moderate size with gravel-substrates and is confined to relatively small and specific areas (Stuby 2012). Spawning individuals sometimes arrive in low energy

waters near spawning sites a month or two before spawning to feed. Eggs are broadcast and settle into the gravel substrate of streams. After the one to two week spawning period, sheefish swim downstream to overwintering habitat (L. Stuby pers. comm.).

Juvenile sheefish feed on aquatic invertebrates and other small prey while adults feed predominantly on other fish (Brown et al. 2012). Sheefish mature at 6-9 years for males and 7-12 years for females. Once mature, sheefish spawn multiple times throughout their lifetimes at the same spawning site each time (Brown and Burr 2012). Because of the energy required for spawning, sheefish often do not spawn every year once mature, (Hander et al. 2008). Spawning coincides with the time at which the temperature of water approaches 0°C. In the main stem of the Yukon River, sheefish spawn from mid- to late October and in other spawning areas from late September to mid-October (Brown et al. 2012). Timing of hatch is not well known. The age at maturity and the timing of favorable temperature conditions for spawning determine when individuals will migrate from feeding habitats to spawning habitats.

## Conceptual Model

The conceptual model below (Figure D-100) is based on literature review and describes the relationship between the various change agents and natural drivers for sheefish. Relationships expected to be of greatest relevance are changes in temperature, precipitation, fire, development, contaminants, and harvest. Not all relationships identified lend themselves well to measurement or monitoring, but are included to enhance our overall understanding of complex interactions.
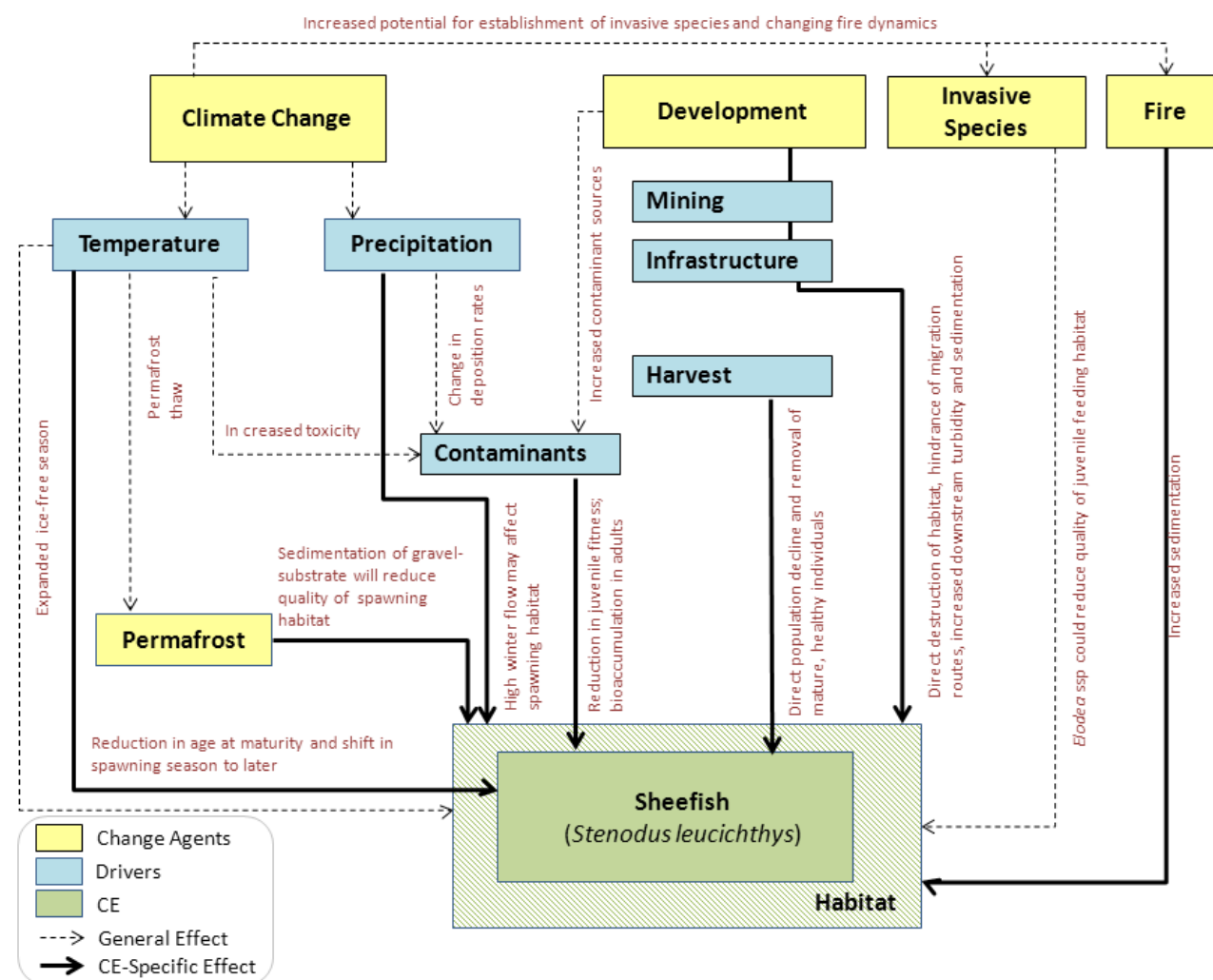
**Figure D-100.** Principal interactions among population drivers and change agents for sheefish in the YKL study area.

## Climate Change

Growing season length and mean annual temperature is not expected to see much change in the near term (2025). In the longer term, however (as represented by the change between the current decade and the 2060), growing season (surrogate for ice-free conditions) is expected to increase by at least a week within areas of sheefish spawning habitat and up to 3 weeks or more for sheefish habitat in general (Figure D-101).

With a projected increase in the growing season, hatch time may occur earlier in the season and spawning will likely shift to later in the year to correspond with the time that aquatic habitats become ice-free. Furthermore, during spring break up, many sheefish travel upriver to feed and the timing of these migrations may shift to earlier in the season.

As a consequence of permafrost thaw, sedimentation of gravel-substrate in streams could reduce the quality of spawning habitat (Brown et al. 2012). Additionally, heavy precipitation during spawning season may additionally increase sedimentation and flow rates, disturbing spawning activities (L. Stuby ADF&G, pers. comm.).
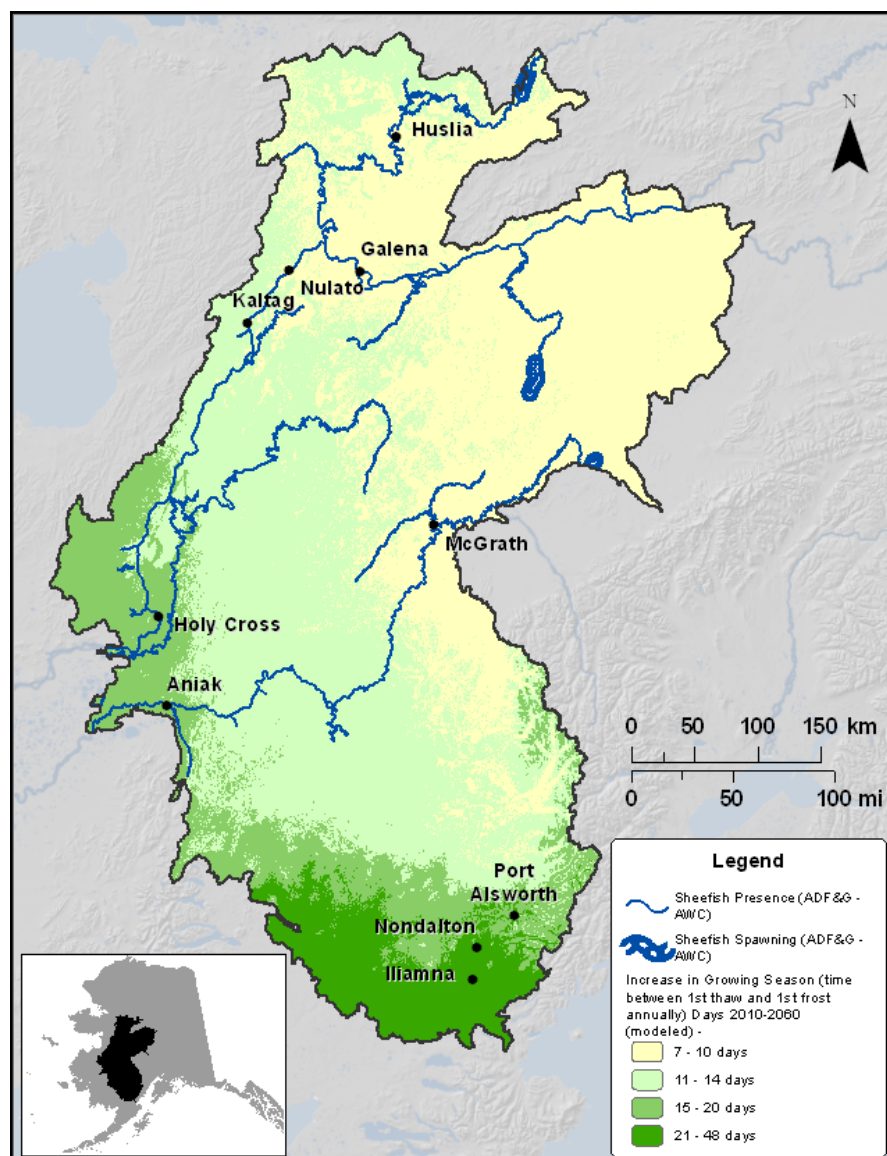
**Figure D-101.** Current known distribution and spawning habitat of sheefish and modeled change in growing season from 2010-2060 within the YKL study area.

### Invasive Species

We are not aware of impacts of invasive species on sheefish in the YKL study area or elsewhere in Alaska. However, if aquatic invasive plants capable of forming dense populations, such as *Elodea*, become established it would likely reduce the quality of sheefish habitat, especially if it invades lower gradient streams where water flow is already low (for more discussion, see Invasive Species sections in "General Effects of CAs on CEs" and in Aquatic Coarse-Filters, D-3).

### Harvest

Subsistence and personal use harvest of sheefish is largely unregulated within the YKL study area. Sheefish are harvested incidentally by commercial salmon fisheries operating in the area (Brown et al. 2012) and are

currently being subjected to increased harvest in subsistence fisheries (Burr 2012). The effects of harvest on population abundance within the YKL study area are largely unknown; however, it is possible that harvest is currently, or will become, unsustainable for some spawning populations.

## Development

Major construction, especially of roads, or mineral extraction operations will increase erosion and runoff leading to increased stream turbidity and sedimentation, compounding the effects of permafrost thaw and increased winter precipitation described above. Deposition of sediments in low gradient streams, which are commonly used by sheefish, is more likely because water flow is generally not sufficient enough to remove sediments that are deposited along streambeds.  Road construction, such as a proposed road that would cross the Alatna River near a known sheefish spawning area, is likely to negatively impact spawning habitat (Burr 2012). The construction of new roads may channelize river systems and hinder migration routes. Furthermore, with increased road access there's the potential for increased fishing pressure (Burr 2012).

## Current status and future landscape condition

Majority of sheefish habitat is currently classified as high landscape condition (Figure D-102). Future projections of landscape condition suggest that sheefish habitat will remain relatively intact and in good condition (Figure D-102). However, sheefish habitat along the potential Kuskokwim road area are projected to go from current "high" quality landscape status to relatively "low" quality landscape status (Figure D-102).

## Applications

The distribution map created for sheefish provides managers and researchers with baseline information for the YKL study area. Additionally, we provide conceptual models with information on the potential effects of climate change and anthropogenic development to sheefish that will help direct future modeling efforts and aid in current and future management decision making.

## Limitations and Data Gaps

Since limited spatial data were available on climate change impacts to aquatic systems, most changes were qualitatively described based on literature reviews and incorporated into the conceptual models. Climate-linked aquatic models would benefit future efforts that focused specifically on changes in the growing season in relation to sheefish habitat and life history strategies.

Few data exist for long-term trends and temporal changes in sheefish populations, limiting our ability to assess population changes over time in relation to CA's. Very little is known about sheefish spawning habitat in this region and studies focused on identifying additional spawning habitat would benefit future management and research efforts.  Additional information on the impacts of subsistence fishing on sheefish populations would be helpful, in conjunction with an investigation into how changes in stream and lake temperatures might impact spawning habitat and the movements of sheefish throughout the YKL REA study area. Further information on the impacts of mining and road development actives, especially near low-gradient streams, would benefit future sheefish management plans.
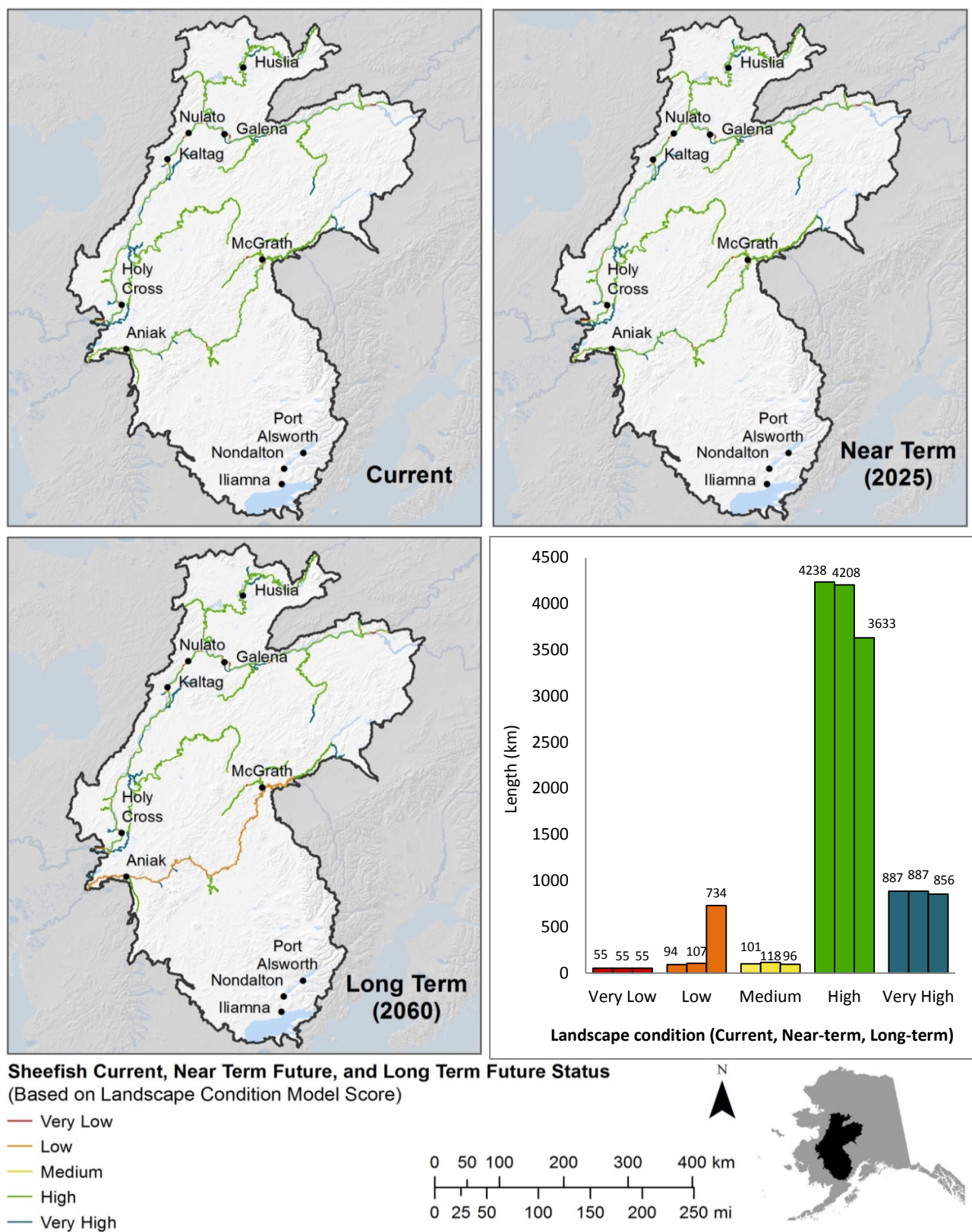
**Figure D-102.** Landscape condition modeled for current, near-term future (2025), and long term future (2060) projections clipped to current sheefish habitat in the YKL study area.

## 4.6. Northern pike (*Esox lucius*)
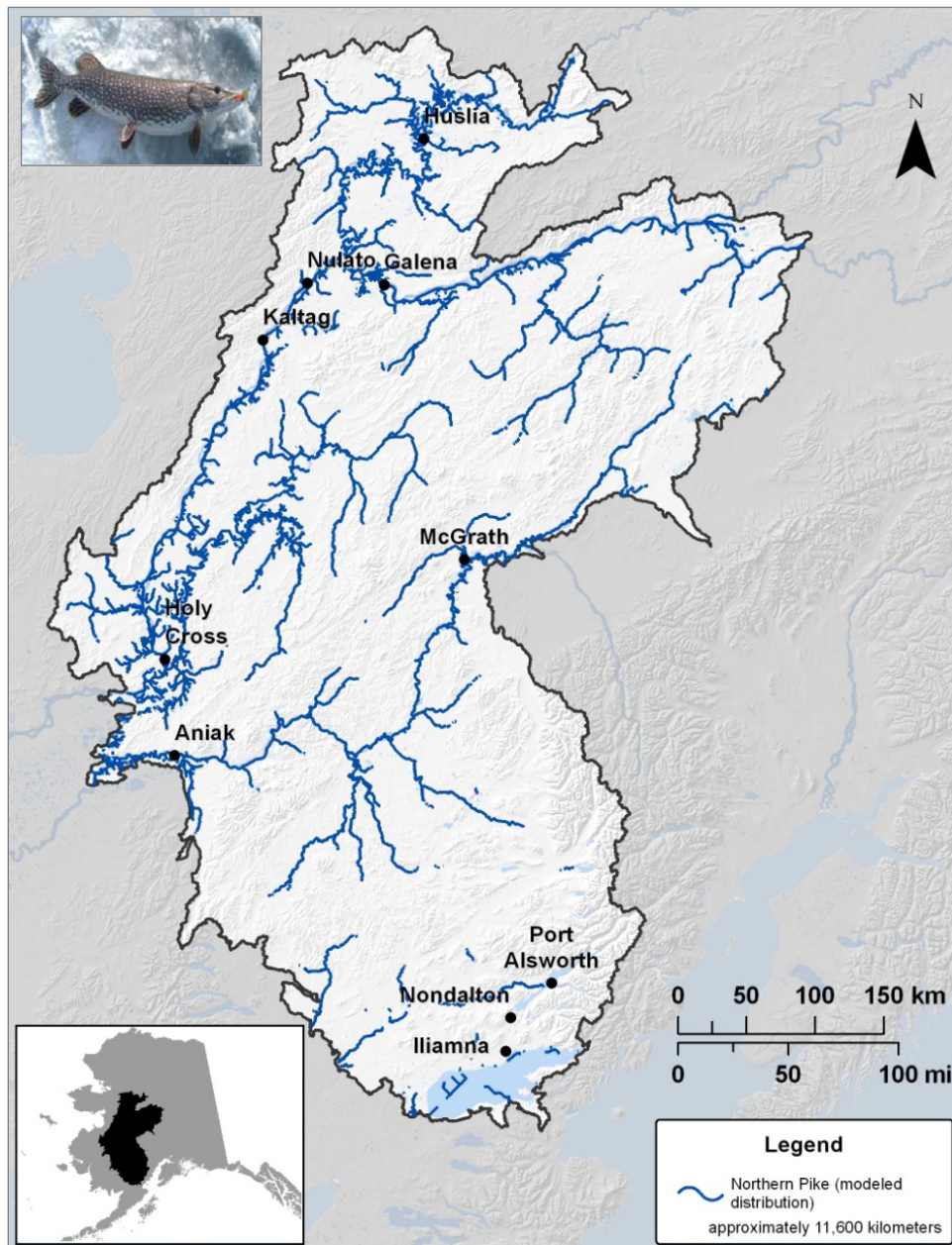


**Figure D-103.** Modeled distribution of northern pike habitat within the YKL study area.

Northern pike overwinter predominantly in deep, slow moving rivers of medium to large size, deep sloughs, and deep, connected lakes. Females lay eggs in vegetated margins of lakes, sloughs, and slow moving streams. Eggs can take up to 30 days to hatch. Pike migrate out of their overwintering habitat to spawn in the spring once the ice has melted off the water. Pike do not necessarily spawn in their native spawning area or in the same spawning area year to year, although some individuals have been documented to return to the same overwinter habitat (Scanlon 2009). After spawning, they migrate to feed in various locations throughout the ice-free season. Potentially, some individuals migrate into or out of the YKL study area while feeding. The modeled distribution of pike is shown in Figure D-103.

Juvenile pike feed on small invertebrates but quickly transition to consuming fish. Adult pike primarily consume other fish. Northern pike in Alaska usually reach maturity at 4-6 years of age; however, in extremely favorable conditions, pike have been observed to spawn after a single year. Individuals can live for over 20 years.

## Conceptual Model

The conceptual model below (Figure D-104) is based on literature review and describes the relationship between the various change agents and natural drivers for northern pike. Relationships expected to be of greatest relevance are changes in temperature, precipitation, development, contaminants, and harvest. Not all relationships identified lend themselves well to measurement or monitoring, but are included to enhance our overall understanding of complex interactions.
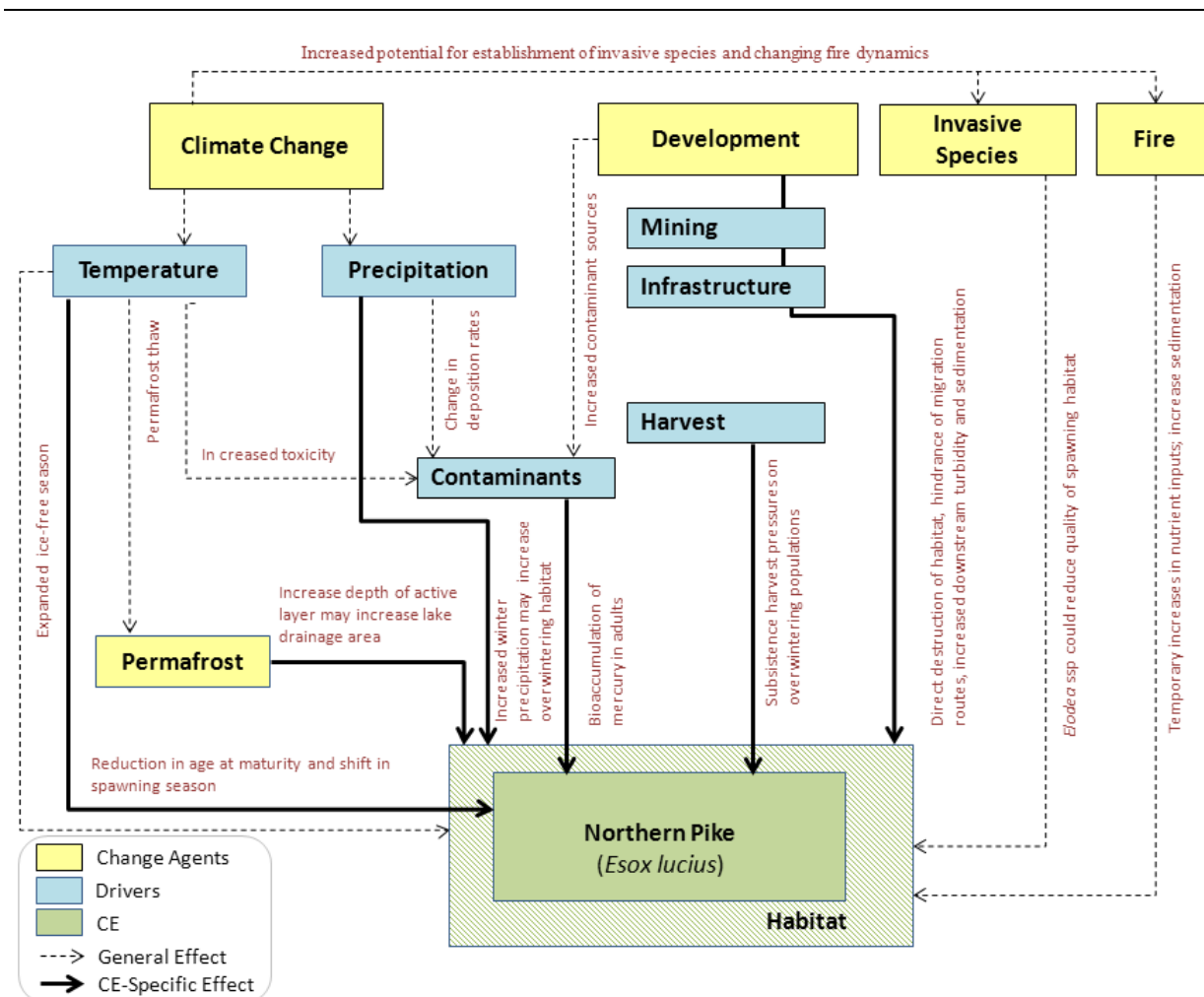


**Figure D-104.** Principal interactions among population drivers and change agents for northern pike in the YKL study area.

## Climate Change

Northern pike are resident species that are closely tied to changes in the growing season. With a projected increase in the length of the growing season by 2060 (see Section B-1), hatch time may occur earlier and spawning will likely shift to earlier in the year to correspond with the time that aquatic habitats become ice-free. The majority of northern pike habitat within the YKL study area is projected to undergo a 7-14 day increase in the length of the growing season from 2010-2060 (Figure D-105). However, the change in length of the growing season in the southern part of the study area near Lake Iliamna and the western part of the study area near Holy Cross are projected to increase by up to 48 days (Figure D-105).

A trend of lake drainage is likely to increase as the depth of the active layer increases (Rouse et al. 1997). Spawning grounds in lake margins will be reduced if lake drainage occurs or may become disconnected from river systems, resulting in an overall reduction of spawning habitat.



**Figure D-105.** Modeled distribution of northern pike and modeled change in growing season from 2010-2060 within the YKL study area.

Spawning habitat in sloughs and slow, large streams, however is unlikely to be affected. The drainage of lakes will partially reduce available overwintering habitat, although sloughs and deep rivers suitable for overwintering will likely remain intact.
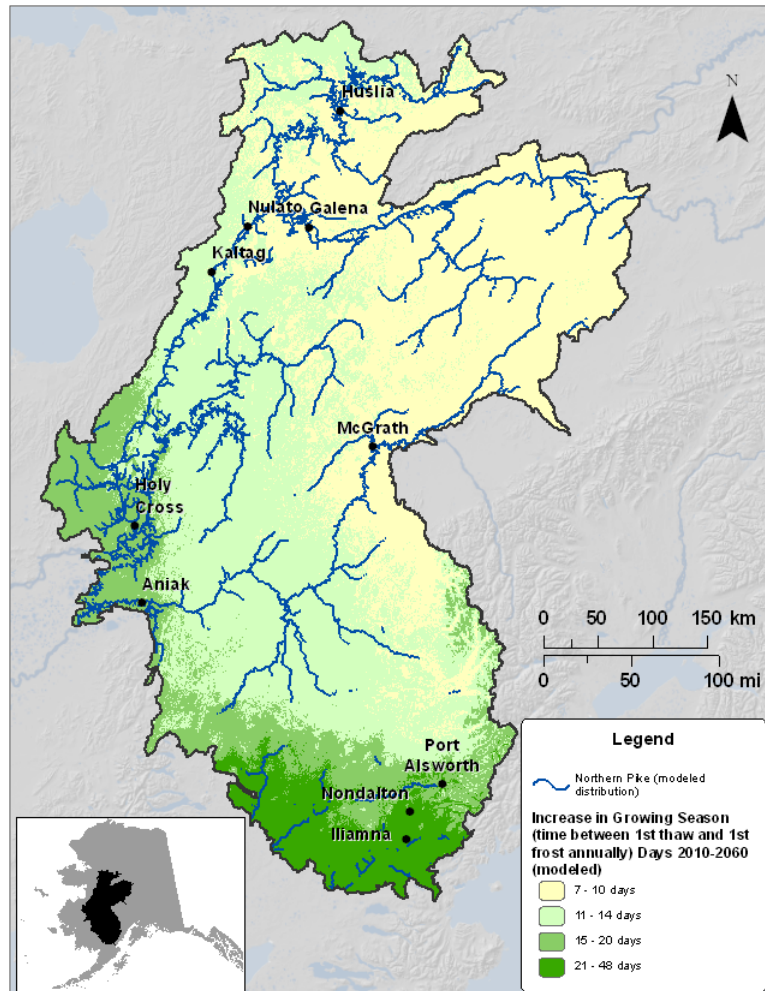
## Contaminants

Adult northern pike accumulate high concentrations of methylated mercury (a toxic organic form of mercury) through their diet of other large fish. Bioaccumulation of mercury has implications for subsistence use of pike: based on current mercury concentrations in northern pike from western Alaska, adults should consume no more than one pike meal per month (Jewett and Duffy 2007). With continued depressed salmon runs, subsistence users are likely to become increasingly reliant on resident fish species, such as northern pike (Matt Varner, BLM, pers communication). Future increases in mercury concentrations in aquatic habitats could reduce the value of pike as a subsistence resource or render it unfit for human consumption. This is a growing concern within the YKL study area due to the potential for increased mercury contamination related to permafrost thaw (Schuster et al. 2011), to increased fire frequency (Kelley et al. 2006), to cinnabar deposits and mining activities (Matz et al. 2012), and to atmospheric deposition (AMAP 2002).

## Invasive Species

We are not aware of impacts of invasive species on northern pike in the YKL study area. Northern pike populations and habitats are perceived to be less sensitive to establishment of aquatic invasive plants capable of forming dense populations, such as *Elodea*. While northern pike can occupy numerous habitats, they often feed and spawn in vegetated areas of lakes and slow streams and have in fact been documented to move to use *Elodea canadensis* stands during later spawning periods (see Raat 1988).  Further, introduced populations of pike have become established in lakes with dense *Elodea* populations in southcentral Alaska (Carlson pers. obs.). For more discussion, see Invasive Species sections in "General Effects of CAs on CEs" and in Aquatic Coarse-Filters, D-3.

## Harvest

Northern pike are not subject to commercial fisheries in the YKL study area and are not caught incidentally in the salmon commercial fisheries in significant numbers. During the ice-free season, pike are subject to increasing sport fishing. Although the sport fishing regulations are very generous, sport fishing does not currently place substantial pressure on populations (Burr and Roach 2003, Scanlon 2009; Burr 2012). Subsistence harvesting is unregulated and occurs predominantly during the winter when pike are concentrated in their overwintering habitats. It is possible that subsistence harvest currently impacts some overwintering populations, but no data are available to assess subsistence harvest trends (Scanlon 2009; Burr 2012).

## Development

See Development discussion in previous sections (Chinook Section D-4.2) for a synopsis of known and perceived impacts. Northern pike are piscivorous, thus any impacts to other fish habitat are expected to be reflected up the food chain and ultimately impact northern pike populations.

## Current status and future landscape condition

The majority of northern pike habitat is currently classified as high condition (Figure D-106). Future projections of landscape condition suggest that northern pike habitat will remain relatively intact and in good condition (Figure D-106). However, as with the other fish species, northern pike along the potential Kuskokwim road development area are projected to go from current "high" quality landscape status to relatively "low" quality landscape status (Figure D-106).
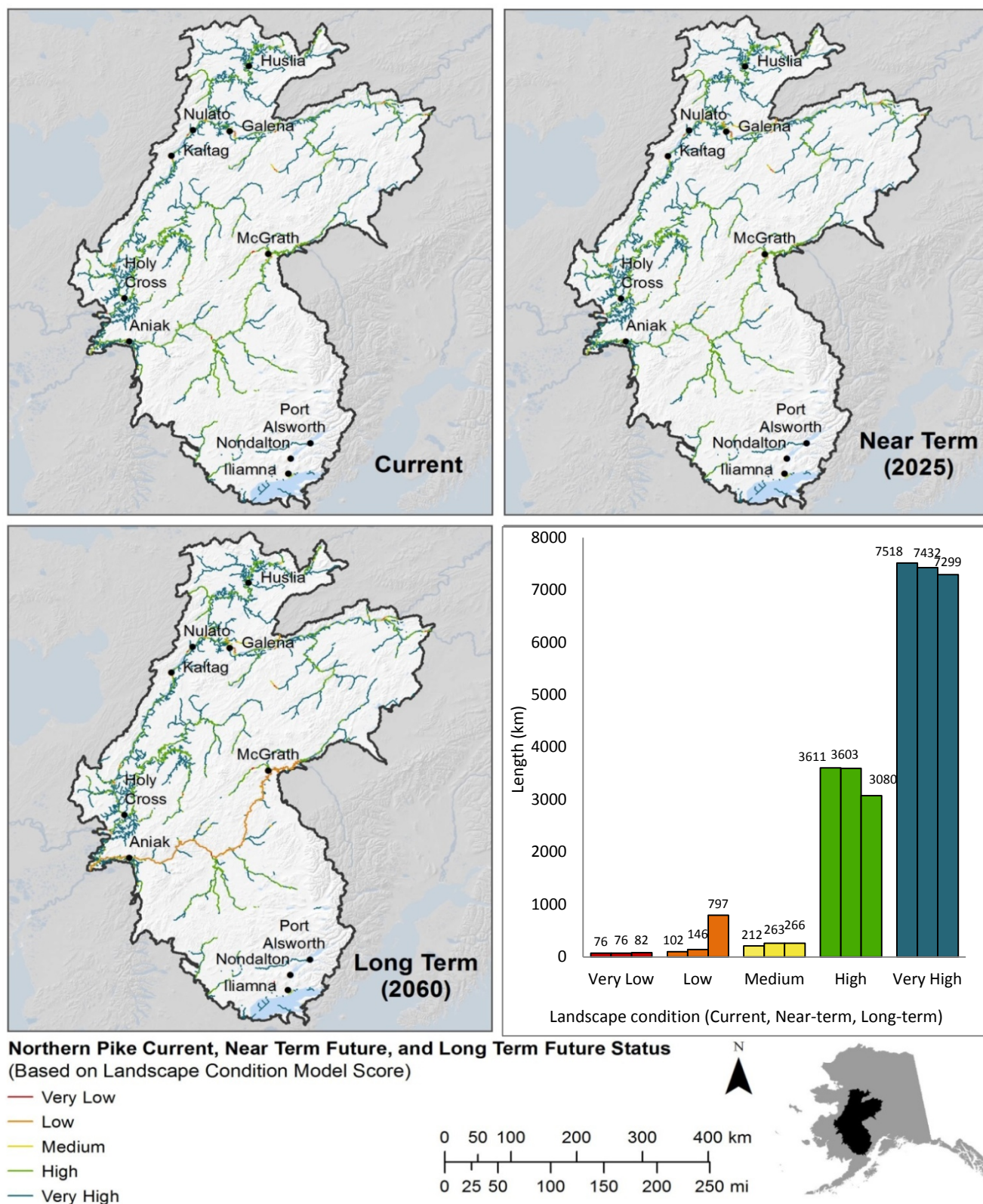
**Figure D-106.** Landscape condition modeled for current, near term future (2025), and long term future (2060) projections clipped to landscape condition within current northern pike habitat in the YKL study area.

**Applications**

We provide the first map of modeled distribution of northern pike for the YKL study area. This map will provide managers and researchers with baseline distribution information for northern pike within the YKL study area. Additionally, we provide conceptual models with information on the potential effects of climate change and anthropogenic development on northern pike that will help direct future modeling efforts and that will aid in current and future management decision making.

**Limitations and Data Gaps**

Since limited spatial data were available on climate change impacts to aquatic systems, most changes were qualitatively described based on literature reviews and incorporated into the conceptual models. Climate-linked aquatic models for northern pike would benefit future efforts that focused specifically on how changes in the growing season might impact spawning and fry emergence as well as migration timing from overwintering habitat to spawning habitat. Additionally, studies focused on the effects of permafrost thaw within lakes used for overwintering and spawning habitat would benefit future northern pike management efforts.

Few data exist for long-term trends and temporal changes in fish populations, limiting our ability to assess population changes over time in relation to CA's. Additional information on the impacts of subsistence fishing on northern pike populations would be useful in conjunction with an investigation into how climate might impact water temperatures and northern pike populations.

## 4.7.    Dolly Varden (*Salvelinus malma*)
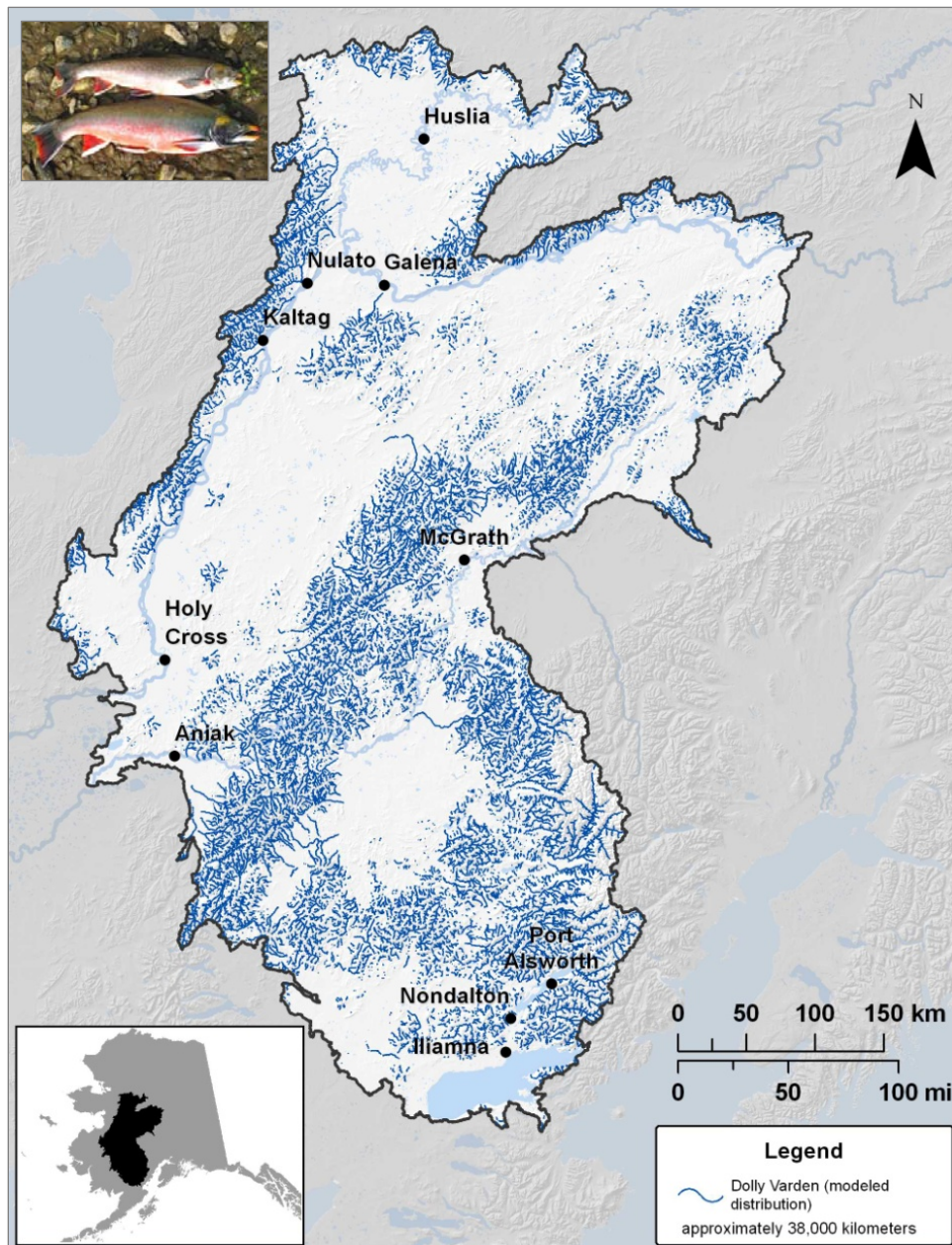


**Figure D-107.** Modeled distribution of Dolly Varden within the YKL study area.

Two forms of Dolly Varden occur in Alaska: a northern form and a southern form, which differ in size and longevity. Throughout most of the YKL study area, it is assumed that the northern form is more common, thus most of the data given here refers to the northern form. Dolly Varden in the YKL study area occur in both resident and anadromous populations (Chythlook 2012). Figure D-107 shows the modeled distribution of Dolly Varden in the YKL study region. Resident individuals occupy lakes or headwater streams, sometimes in drainages that also support anadromous populations (Palmer and King 2005). Resident individuals are often dwarfed in size and mature earlier compared to anadromous individuals. Individuals of resident populations that occur in or near large lakes, such as Lake Iliamna, or in rivers with influx of marine resources can grow as large as anadromous Dolly Varden (Jaecks 2010).

Dolly Varden mature around 5-9 years of age and at 16-24 inches long. Dolly Varden overwinter predominantly in headwater rivers, although in the southern portion of the study area they may also overwinter in lakes. In spring, Dolly Varden migrate to main channels of rivers (Krauthoefer et al. 2007). Individuals spawn multiple times throughout their lifetimes. Spawning individuals may migrate to the ocean and then to spawning areas or may migrate directly from overwintering habitat to spawning areas. Spawning along the Firth River in northern Yukon occurred over a relatively long period of time, from mid-august to early October (DFO 2003). In the Kvichak River, just southwest of the YKL study area, Dolly Varden spawn in October and November (Krieg et al. 2005). Spawning in the Iliamna River occurs in September and October (Jaecks 2010). Females lay eggs in small, dugout nests in the gravel substrates of headwater streams.

Juvenile fish emerge from the gravel in late spring and spend one to three years in their headwater streams, after which anadromous individuals will migrate to the ocean around April to June (Krieg et al. 2005). Juvenile fish feed on invertebrates in slow-flowing river and stream banks. Larger juvenile and adult fish consume out-migrating salmon fry, salmon eggs, invertebrates, and small fish.

**Conceptual Model**

The conceptual model below (Figure D-108) is based on literature review and describes the relationship between the various change agents and natural drivers for Dolly Varden. Relationships expected to be of greatest relevance are changes in temperature, precipitation, and development. Not all relationships identified lend themselves well to measurement or monitoring, but are included to enhance our overall understanding of complex interactions.
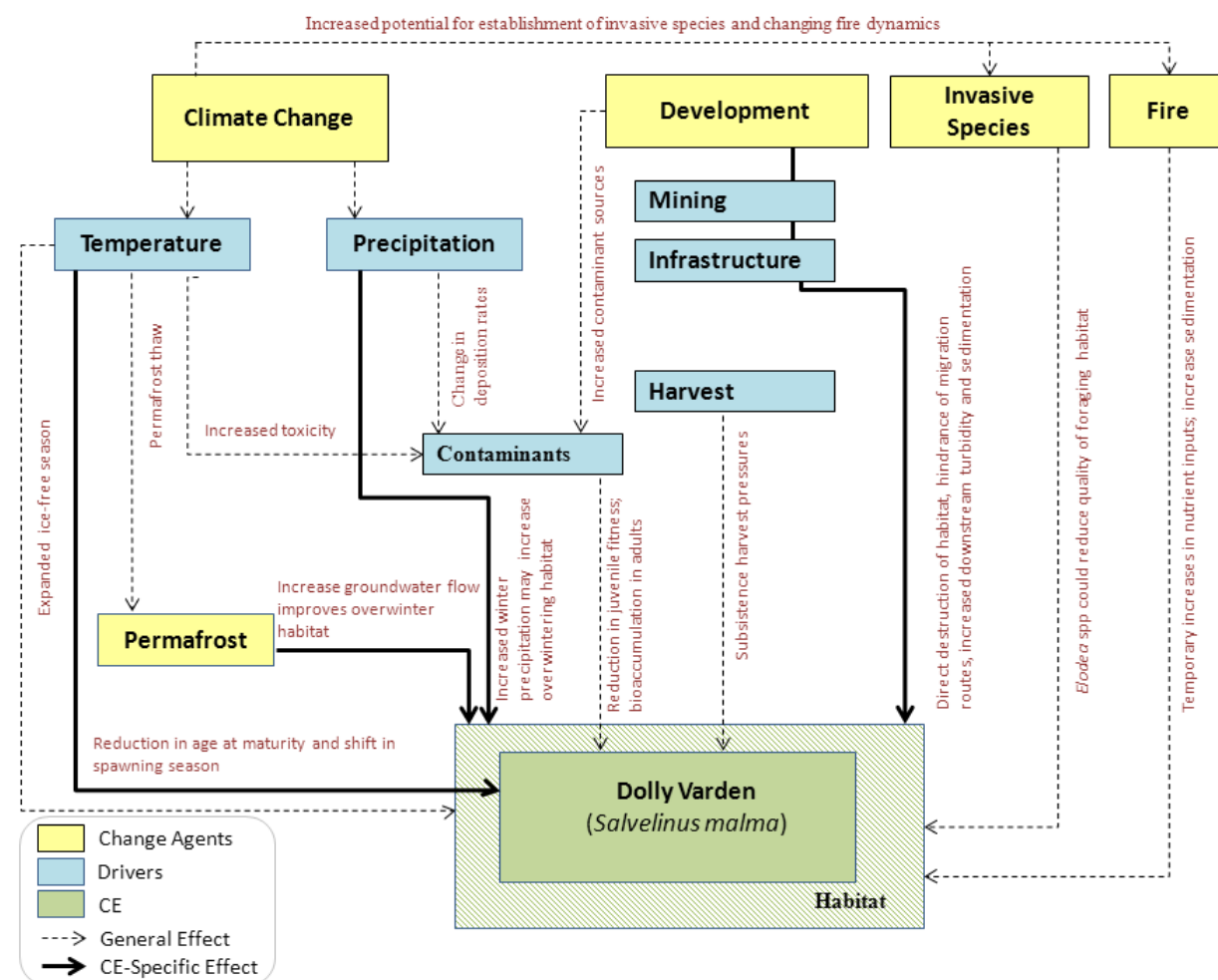
**Figure D-108.** Principal interactions among population drivers and change agents for Dolly Varden in the YKL study area.

## Climate Change

Increasing annual temperatures will cause a general trend of permafrost thaw on the landscape level, increasing the depth of the soil active layer and mean annual ground temperature (see Section B-3). Lake drainage, as a consequence of permafrost thaw, will likely reduce available habitat for resident lake populations of Dolly Varden, especially in the northern part of the study area where permafrost retreat is projected to be greatest in the long-term (Figure D-109). On the other hand, permafrost thaw may increase groundwater flows in winter improving overwintering habitat and increasing overwintering survival for Dolly Varden.

Permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations (Bowden et al. 2008). Increased nutrient input improves the quality of fish feeding habitat with the direct or indirect increased abundance of prey species (Reist et al. 2006). However, permafrost thaw could cause erosion and runoff into lakes and streams. Increased sedimentation in streams reduces the quality of spawning habitat for Dolly Varden because they rely on gravel substrate to hide their eggs.

With projected increased temperatures, the duration of the ice-free season will likely increase which will improve the quality of feeding habitats as those habitats will remain ice-free for a longer period of time (Reist et al. 2006). Consequently, the age at maturity for Dolly Varden could decrease as growth rates increase. Spawning may shift to later in the fall to correspond with the changes in the duration of the ice-free season. Warmer waters may also increase the prevalence of diseases and parasites (Reist et al. 2006).

A predicted increase in winter precipitation could potentially increase available overwintering habitat directly (by increasing the volume of water) and indirectly through the loss of snow insulation which would reduce ice thickness. Increased precipitation could also result in increased run-off and sedimentation to Dolly Varden habitat.
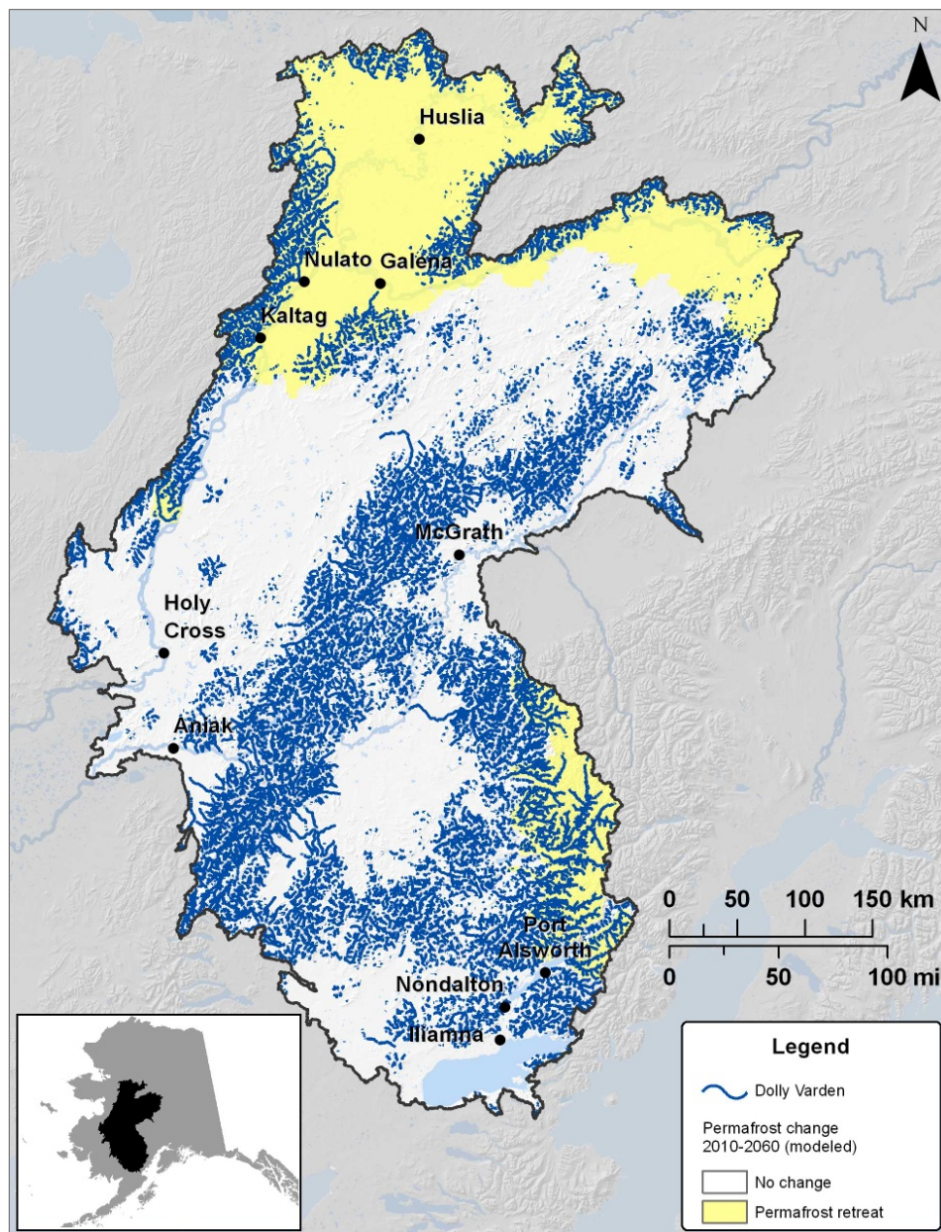
**Figure D-109.** Modeled distribution of Dolly Varden and predicted changes in mean annual ground temperature from 2010 to 2060 within the YKL study area.

## Invasive Species

We do not anticipate that invasive species are likely to have a major impact on Dolly Varden in the near or long term. Future establishment of invasive riparian species, such as *Phalaris arundinacea*, could impact headwater habitats (see the General Effects of CAs on CEs Invasive species section above for more discussion).

## Harvest

Sport harvest of Dolly Varden in the Kuskokwim River drainage is currently estimated to be within sustainable limits, a trend which will likely continue unless regulations are made less restrictive (Chythlook 2012). However,

subsistence harvesters have noted in the past 20 years a decline in the number of large Dolly Varden individuals in the YKL study area (Krauthoefer et al. 2007).

## Contaminants

Because Dolly Varden can be piscivorous during the juvenile and adult freshwater stages, they have the propensity to bioaccumulate and biomagnify organochlorine and heavy metal contaminants. Biomagnification and bioaccumulation of mercury in particular, has implications for subsistence use of Dolly Varden (Jewett and Duffy 2007). Future increases in mercury concentrations in aquatic habitat could reduce the value of Dolly Varden as a subsistence resource or potentially render it unfit for human consumption. This is a growing concern within the YKL study area due to the potential for increased mercury contamination related to permafrost thaw (Schuster et al. 2011), to increased fire frequency (Kelley et al. 2006), to cinnabar deposits and mining activities (Matz et al. 2012), and to atmospheric deposition (AMAP 2002).
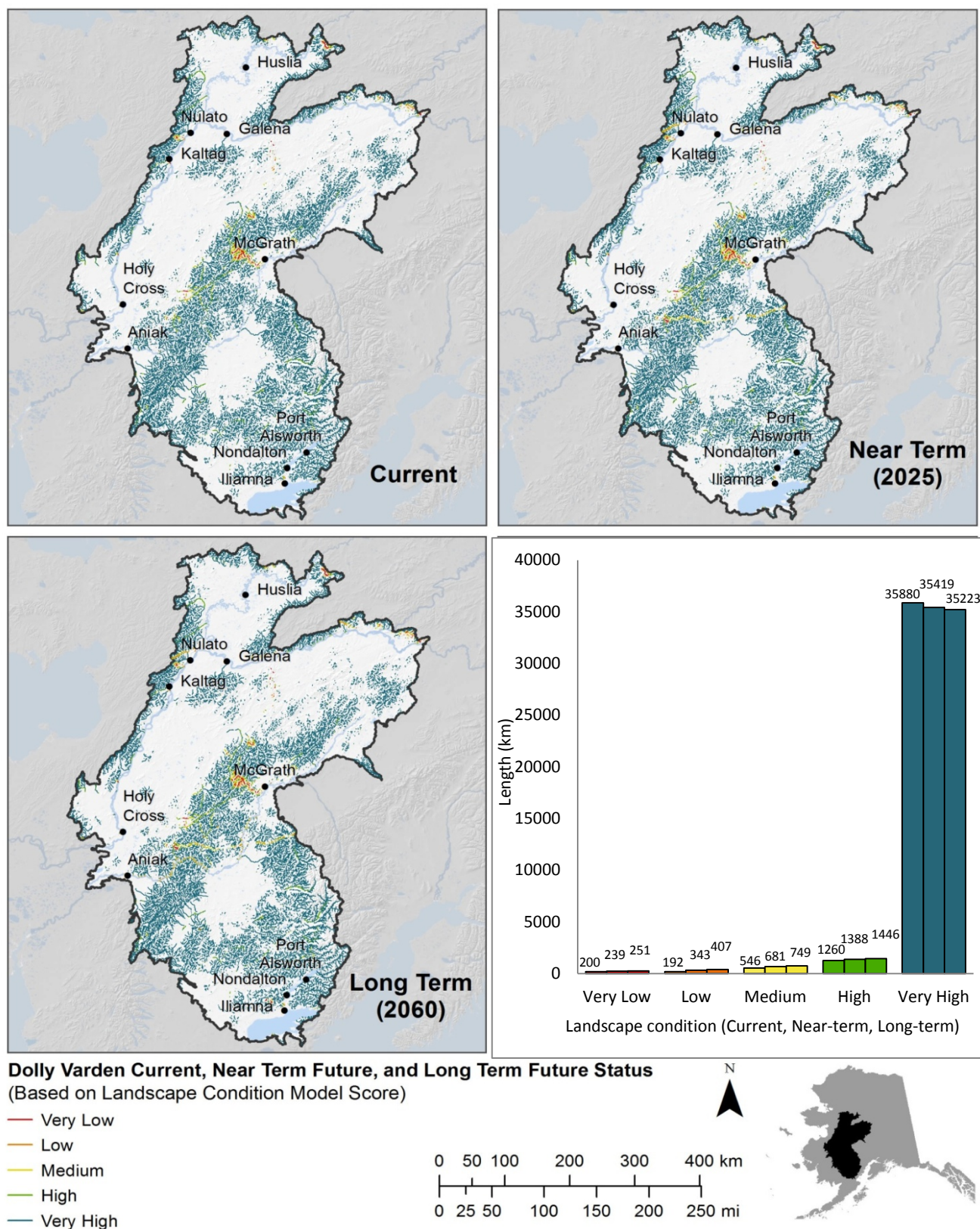
## Development

Major construction, especially of roads, or mineral extraction operations which is more likely to occur in headwater streams where Dolly Varden are common, will increase erosion and runoff leading to increased stream turbidity and sedimentation. The construction of new roads may channelize river systems and hinder migration routes, at least in part. Furthermore, with increased road access there's the potential for increased fishing pressure and access to important spawning areas (Burr 2012). Mining operations, especially those of a large scale, threaten to destroy feeding and spawning habitats.

## Current status and future landscape condition

The majority of Dolly Varden habitat is currently classified as high landscape condition (Figure D-110). Areas of low landscape condition are localized near communities and generally associated with anthropogenic development. Future projections of landscape condition suggest that Dolly Varden habitat will remain relatively intact and in good condition. However, Dolly Varden along the potential Kuskokwim road development area are projected to go form from current "high" quality landscape status to relatively "low" quality landscape status. Although the impact from road development is much less on Dolly because it is a headwaters fish and the road would be on higher order rivers.

Anthropogenic activities to consider in future land-use planning include mining. Placer mining throughout the YKL study area and hard rock mining in Nushagak and Kvichak watersheds just north of Iliamna could have negative effects on Dolly Varden spawning, overwintering, and rearing habitat due to the large amounts of silt deposited in streams and the potential for direct destruction of habitat.  Impacts to Dolly Varden could be much higher due to the colocation of resident populations with potential hard rock mining sites within the Lake Iliamna area.

**Figure D-110.** Landscape condition modeled for current, near term (2025), and long term (2060) projections clipped to current Dolly Varden habitat in the YKL study area.

**Applications**

We provide the first map of modeled distribution of Dolly Varden for the YKL study area. This map will provide managers and researchers with baseline distribution information for Dolly Varden within the YKL study area. Additionally, we provide conceptual models with information on the potential effects of climate change and anthropogenic development on Dolly Varden that will help direct future modeling efforts and aid in current and future management decision making.

**Limitations and Data Gaps**

Since limited spatial data were available on climate change impacts to aquatic systems, most changes were qualitatively described based on literature reviews and incorporated into the conceptual models. Climate-linked aquatic models would benefit future efforts that focused specifically on increased water temperature and permafrost change around lakes used by Dolly Varden for overwintering and spawning habitat.

Few data exist for long-term trends and temporal changes in fish populations, limiting our ability to assess population changes over time in relation to CA's. Additional information on the impacts of subsistence and commercial fishing on Dolly Varden populations would be useful to better understand the potential for change in harvest of this species in the long-term.

## 4.8. Impacts of Mineral Resource Development on Fishery Habitat

| MQ 15 | Where and how might mineral resource development affect fishery habitat? |
|-------|--------------------------------------------------------------------------|

Mining and its associated activities have the potential to cause adverse effects to important fishery habitat within the YKL study area. Mineral resource development can involve several activities including: exploration, mine development, mining and milling, waste management, and reclamation (NMFS 2005, American Fisheries Society 2000). Mineral resource development within riverine habitats may result in direct impacts to fish species and habitats at the mining site, but also within surrounding areas and downstream from mining activities.

**Methods**

To answer this question spatially, we overlaid the current distribution maps for important fisheries species that also have adequate subsistence harvest data (Chinook salmon, chum salmon, sheefish, and northern pike) with current and future landscape condition, as well as mineral resource development data for the YKL study area. The conceptual models we developed for salmon species, sheefish, and northern pike provide information on the potential impacts that mineral resource development may have on subsistence and commercial harvest fish species throughout the YKL study area. Additionally, Section B-5.3 Anthropogenic Agents provides a thorough review of current and potential mining activities and provides detail on the methods for designating placer mining sites within the YKL study area.

**Results**

The potential adverse effects of mineral resource development depend on the type, extent, and location of the activities. Infrastructure and development for placer and hard rock mining sites, such as road construction and culverts, have been reported to have detrimental effects on salmon spawning habitat. In particular, road construction has the potential to cause high sediment loads in streams that can adversely affect embryo survival (Everest et al. 1987), fry emergence, and increased predation (Chapman 1988; Chapman and McLeod 1987; Weaver and Fraley 1993). Similarly, stream culverts at road crossings may impede migration routes. Additional impacts may include mining-related pollution, acid mine drainage, habitat fragmentation, altered temperature regimes, and pollution (NMFS 2008; U.S. EPA 2014).

Placer mining within the YKL study area (Figure D-111, Figure D-112) and hard rock mining in Nushagak and Kvichak watersheds just north of Iliamna (Figure D-111, Figure D-112) could have negative effects on chum and Chinook salmon spawning and rearing habitat mostly due to the large amounts of silt deposited in streams and the potential for direct destruction of habitat (U.S. EPA 2014). Additionally, studies have documented increased heavy metal exposure (e.g., mercury, arsenic, and antimony) from mining practices in other parts of Alaska (Matz 2012). Given that chum salmon juveniles only spend a couple of weeks within the YKL study area before migrating to the ocean, exposure to heavy metal contaminants is less a concern as it is for Chinook salmon and resident fish species. Since juveniles do not rear in streams and given the majority of the life of chum salmon occurs in the marine environment, the largest impact from development of roads and mining operations would affect spawning habitat.

Only a small portion of overall distribution of sheefish is located near potential placer mining areas (Figure D-113). The potential adverse effects of mineral resource development depend on the type, extent, and location

of the activities and are expected to be similar to those for Chinook and chum salmon. However, sheefish predominately use low-gradient streams which are more susceptible to increased sedimentation (due to lower stream flow) from mining and road development activities. Placer mining near or upstream of sheefish habitat (Figure D-113) and hard rock mining in Nushagak and Kvichak watersheds just north of Iliamna (Figure D-113) could have negative effects on sheefish habitat.

Placer mining in the Nushagak and Kvichak watersheds (Figure D-114) could also have negative effects on northern pike spawning and rearing habitat. Northern pike are resident species, thus impacts from mineral resource development could have negative impacts on all life stages of this species.

**Figure D-111.** Chinook salmon current, near-term (2025), and future (2060) landscape condition, subsistence use areas, and areas of current and potential mineral resource development within the YKL study area.
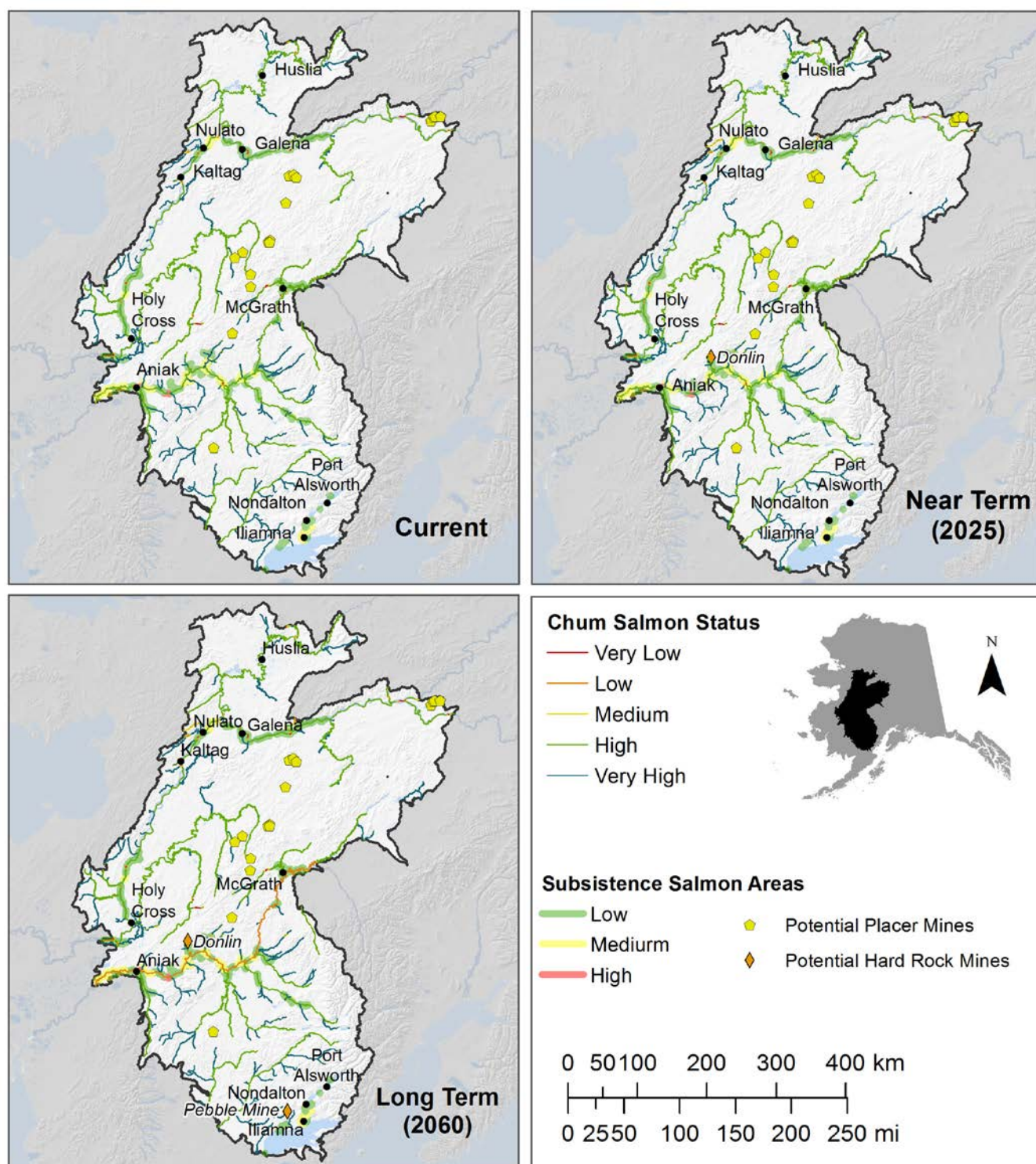
**Figure D-112.** Chum salmon current, near-term (2025), and future (2060) landscape condition, subsistence use areas, and areas of current and potential mineral resource development within the YKL study area.
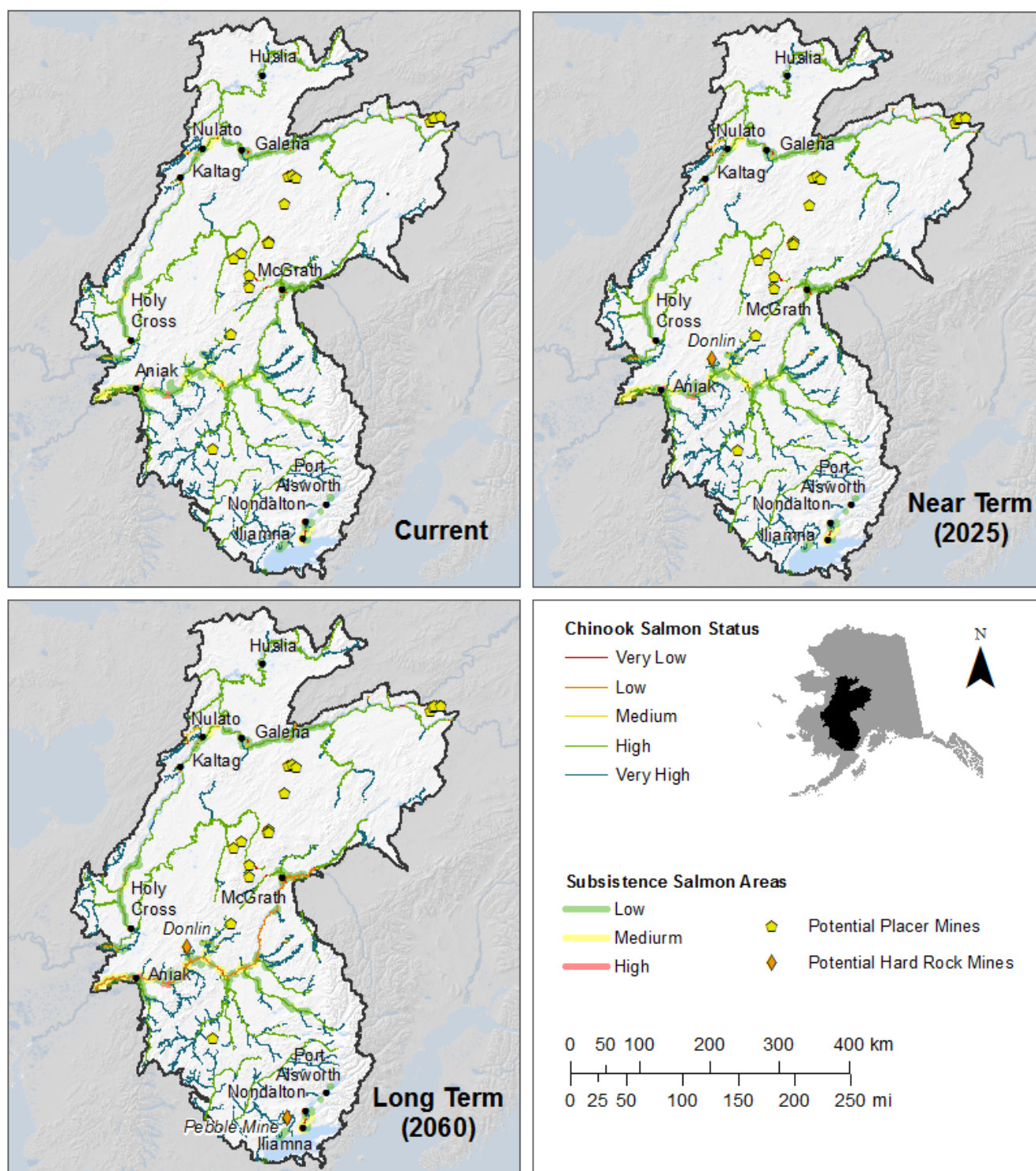
**Figure D-113.** Sheefish current, near-term (2025), and future (2060) landscape condition, subsistence use areas, and areas of current and potential mineral resource development within the YKL study area.

**Figure D-114.** Northern pike current, near-term (2025), and future (2060) landscape condition, subsistence use areas, and areas of current and potential mineral resource development within the YKL study area.
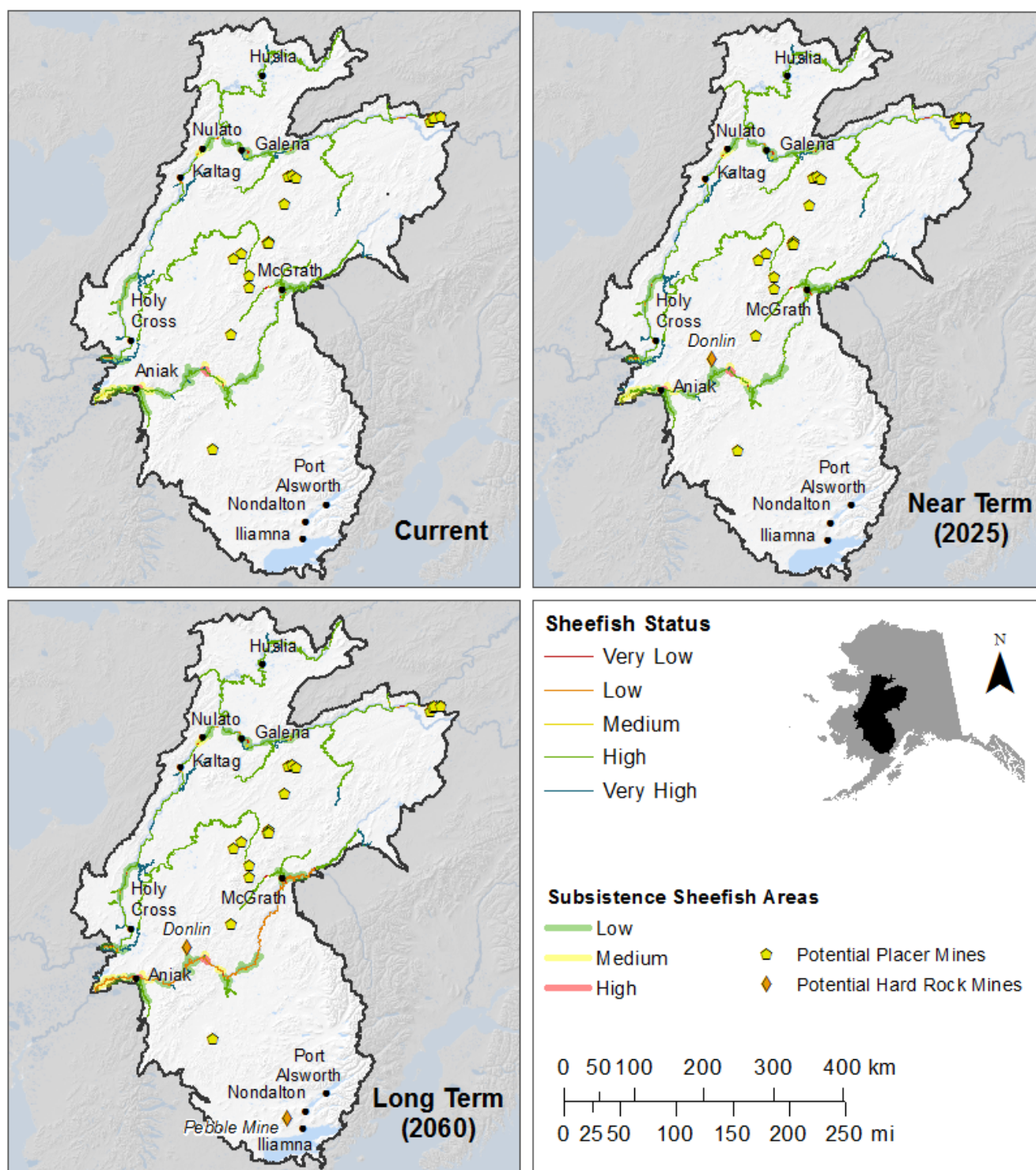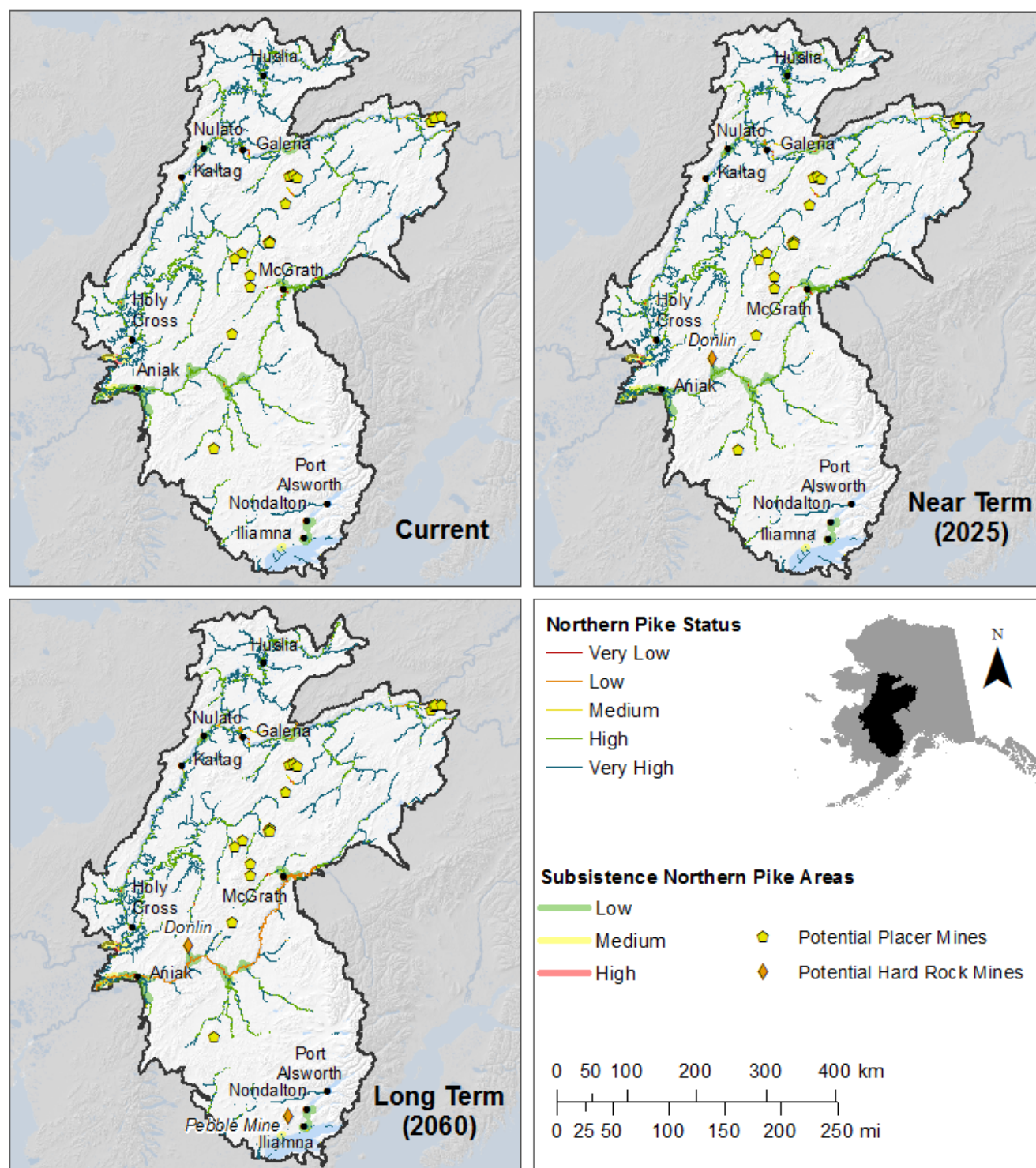
## 4.9.    Literature Cited

AMAP 2002: Persistent Organic Pollutants, Heavy Metals, Radioactivity, Human Health, Changing Pathways. Oslo, Norway: Arctic Monitoring and Assessment Programme.

American Fisheries Society. 2000. AFS Policy Statement #13: Effects of Surface Mining on Aquatic Resources in North America (Revised). http://www.fisheries.org/afs/docs/policy_13f.pdf.

Beacham, T. D., C. B. Murray, and R. E. Withler. 1988. Age, morphology, developmental biology, and biochemical genetic variation of Yukon River fall chum salmon, *Oncorhynchus keta*, and comparisons with British Columbia populations. Fishery Bulletin 86: 663-674.

Brase, A. and B. Baker. 2012. Fishery management report for recreational fisheries in the Tanana River management area, 2011. Alaska Department of Fish and Game, Fishery Management Report No. 12-46, Anchorage, Alaska.

Brown, R., and J. Burr. 2012. A Radiotelemetry Investigation of the Spawning Origins of Innoko River Inconnu (Sheefish). Fishery Data Series No. 12-54. Division of Sport Fish and Commercial Fisheries, Alaska Department of Fish and Game. Anchorage, Alaska. 20 pp.

Brown, R., C. Brown, N. Braem, W. Carter III, N. Legere, and L. Slayton. 2012. Whitefish Biology, Distribution, and Fisheries in the Yukon and Kuskokwim River Drainages in Alaska: a Synthesis of Available Information. Alaska Fisheries Data Series Number 2012-4. Fairbanks Field Office, Fish and Wildlife Service, U.S. Department of the Interior. Fairbanks, Alaska. 316 pp.

Buckwalter, J., J. Kirsch, and D. Reed. 2010. Fish Inventory and Anadromous Cataloging in the Lower Yukon River Drainage, 2008. Fishery Data Series Number 10-76. Divisions of Sport Fish and Commercial Fisheries, Alaska Department of Fish and Game. 595 pp.

Bue B.G., K.L. Schaberg, Z. Willer, D.B. Molyneaux. 2012. Estimates for the historic run and escapements for the Chinook salmon stock returning to the Kuskokwim River, 1976-2011. Alaska Department of Fish and Game, Fishery Data Series N. 12-49, Anchorage, Alaska.

Burr, J. 2012. Fishery Management Report for Sport Fisheries in the Yukon Management Area, 2011. Fishery Management Report Number 12-44. Divisions of Sport Fish and Commercial Fisheries, Alaska Department of Fish and Game. Anchorage, Alaska. 49 pp.

Burr, J., and S. Roach. 2003. Abundances, Length and Age Compositions, and CPUE of Northern Pike Within Selected Sloughs of the Nowitna River, 1997. Fishery Data Series Number 03-16. Division of Sport Fish, Alaska Department of Fish and Game. Anchorage, Alaska. 25 pp.

Buscemi, P. A. 1958. Littoral Oxygen Depletion Produced by a Cover of *Elodea canadensis*. Oikos 9: 239-245.

Chapman, D. W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117: 1-21.

Chapman, D. W., and K. P. McLeod. 1987. Development of criteria for fine sediment in the Northern Rockies Ecoregion. U.S. Environmental Protection Agency. Seattle, Washington.

Chythlook, J. 2012. Fishery Management Report for Sport Fisheries in the Kuskokwim-Goodnews Management Area, 2011. Fishery Management Report Number 12-43. Divisions of Sport Fish and Commercial Fisheries, Alaska Department of Fish and Game. 62 pp.

Cleary, P. and T. Hamazaki. 2005. Fall chum salmon mark-recapture abundance estimation on the Tanana and Kantishna Rivers, 2004: Anchorage, Alaska Department of Fish and Game, Fisheries Data Series No. 05-76.

Cutler, D. R., T. C. Edwards, K. H. Beard, A. Cutler, and K. T. Hess. 2007. Random forests for classification in ecology. Ecology 88: 2783-2792.

Davis, J., C. Baxter, E. Rosi-Marshall, J. Pierce, and B. Crosby. 2013. Anticipating Stream Ecosystem Responses to Climate Change: Toward Predictions that Incorporate Effects Via Land-Water Linkages. Ecosystems 16: 909-922.

DFO. 2003. Firth River Dolly Varden. DFO Science. Stock Status Report D5-63 (2002). Central and Arctic Region, Fisheries and Oceans Canada.

Dijkstra J. A., K. L. Buckman, D. Ward, D. W. Evans M. Dionne, and C. Y. Chen. 2013. Experimental and Natural Warming Elevates Mercury Concentrations in Estuarine Fish. PLoS ONE: doi:10.1371/journal.pone.0058401.

Eiler, J. H., T. R. Spencer, J. J. Pella, M. M. Masuda, and R. R. Holder. 2004. Distribution and movement patterns of Chinook salmon returning to the Yukon River basin in 2000-2002. U. S. Dept. Commer, NOAA tech memo NMFMS-AMSC-148, 99 pp.

Eiler, J., M. Masuda, J. Pella, and T. Spencer. 2007. Stock Composition, Run Timing, and Movement Patterns of Chinook Salmon Returning to the Yukon River Basin in 2004. Alaska Department of Fish and Game, Anchorage, Alaska. http://hdl.handle.net/123456789/6400.

Estensen, J. L., S. Hayes, S. Buckelew, D. Green, and D. J. Bergstrom. 2012. Annual Management Report Yukon and Northern Areas 2010. Alaska Department of Fish and Game, Anchorage, Alaska.

Everest, F. H., R. L. Beschta, J. S. Scrivener, K. V. Koski, J. R. Sedell, and C. J. Cedarholm. 1987. Fine sediment and salmonid production: a paradox. Pp. 98-142, *In*: J. Colt and R.J. White (eds.) Streamside management: forestry and fishery interactions. Contrib. No. 57. Seattle, WA. Instit. of For. Res., Univ. WA.

Ficke, A. D., C. A. Myrick, and L. J. Hansen. 2007. Potential impacts of global climate change on freshwater fisheries. Reviews in Fish Biology and Fisheries 17: 581-613.

Hander, R., R. Brown, and T. Underwood. 2008. Comparison of inconnu spawning abundance estimates in the Selawik River, 1995, 2004, and 2005, Selawik National Wildlife Refuge. Alaska Fisheries Technical Report Number 99. Fairbanks Field Office, Fish and Wildlife Service, U.S. Department of the Interior. Fairbanks, Alaska. 20 pp.

Hinch, S. G., and P. S. Rand. 1998. Swim speeds and energy use of upriver-migrating sockeye salmon (*Oncorhynchus nerka*): role of local environment and fish characteristics. Canadian Journal of Fisheries and Aquatic Sciences 55: 1821–1831.

Hodgson, J. M. 1968. Chemical control of reed canarygrass on irrigation canals. Weed Science 16: 465–468.

Jacobson, K. C., M. R. Arkoosh, A. N. Kagley, E. R. Clemons, T. K. Collier, and E. Casillas. 2003. Cumulative effects of natural and anthropogenic stress on immune function and disease resistance in juvenile Chinook salmon. J. Aquat. Anim. Health 15: 1–12.

Jaecks, T. 2010. Population Dynamics and Trophic Ecology of Dolly Varden in the Iliamna River, Alaska: Life History of Freshwater Fish Relying on Marine Food Subsidies. Thesis for fulfillment of requirements of Master of Science. University of Washington. 82 pp.

Jewett, S., and L. Duffy. 2007. Mercury in fishes of Alaska, with emphasis on subsistence species. Science of the Total Environment 387: 3-27.

Kelly, E. N., D. W. Schindler, V. L. St. Louis, D. B. Donald, and K. E. Vladicka. 2006. Forest fire increases mercury accumulation by fishes via food web restructuring and increased mercury inputs. PNAS doi:10.1073/pnas.0609798104.

Kemp, P. S., D. A. Sear, A. L., Collins, P. Naden, and J. I. Jones. 2011. The impacts of fine sediment on riverine fish. Hydrological Processes doi:10.1002/hyp.7940.

Kocan, R., P. Hershberger, and J. Winton. 2003. Effects of Ichthyophonus on Survival and reproductive success of Yukon River Chinook Salmon. Federal Subsistence Fishery Monitoring Program, Final Project Report No. FIS 01-200. U. S. Fish and Wildlife Service, Office of Subsistence Management, Fishery Information Services Division, Anchorage, Alaska.

Krauthoefer, T., J. Simon, M. Coffing, M. Kerlin, and W. Morgan. 2007. The Harvest of Non-salmon Fish by Residents of Aniak and Chuathbaluk, Alaska, 2001-2003. Division of Subsistence, Alaska Department of Fish and Game. Juneau, Alaska. 107 pp.

Krieg, T., M. Chythlook, P. Coiley-Kenner, D. Holen, K. Kamletz, and H. Nicholson. 2005. Freshwater Fish Harvest and Use in Communities of the Kvichak Watershed, 2003. Technical Paper Number 297. Division of Subsistence, Alaska Department of Fish and Game. Juneau, Alaska. 237 pp.

Larsen, A., and N. Lisuzzo. 2012. Changes in Arctic Grayling Fishery Following the Introduction of the Non-Native Aquatic Weed, *Elodea nuttallii*, Altered Flow Regimes and Changes in Management Policy. CNIPM Conference, Alaska.

Lavergne, S., and J. Molofsky.  2004. Reed canary grass (*Phalaris arundinacea*) as a biologicalmodel in the study of plant invasions. Critical Reviews in Plant Sciences 23: 415-429.

Lefor, M.W. 1987. *Phalaris arundinacea* L. (reed canary grasss, Gramineae) as an hydrophyte in Essex, Connecticut, USA. Environmental Management 11: 771–773.

Liaw, A., and M. Wiener. 2002. Classification and regression by randomForest. R News 2/3: 18–22.

Lisi, P., D. Schindler, K. Bentley, and G. Pess. 2013. Association between geomorphic attributes of watersheds, water temperature, and salmon spawn timing in Alaskan streams. Geomorphology 185: 78-86.

Lisle, T. 1989. Sediment transport and resulting deposition in spawning gravels, north coastal California. Water Resources Research 25: 1303-1319.

Maclean, S. 2003. Influences of hydrological processes on the spatial and temporal variation in spawning habitat quality for two chum salmon stocks in interior Alaska. M.S. thesis, University of Alaska Fairbanks. 93 pp.

Matz, A. 2012. Mercury, Arsenic, and Antimony in Aquatic Biota from the Middle Kuskokwim River Region, Alaska, 2010-2011. Alaska State Office, Bureau of Land Management, U.S. Department of the Interior. Anchorage, Alaska. 44 pp.

Merz, J. E., J. R. Smith, M. L. Workman, I. D. Setka, and B. Muichaey. 2008. Aquatic macrophyte encroachment in Chinook salmon spawning beds: lessons learned from gravel enhancement monitoring in the lower Mokelumne River, Cailfornia. North American Journal of Fisheries Management 28: 1568-1577.

Morrow, J. 1980. The freshwater fishes of Alaska. Alaska Northwest Publishing, Anchorage, Alaska.

Murphy, M. 1985. Die-offs of pre-spawn adult pink salmon and chum salmon in southeastern Alaska. North American Journal of Fish Management 5: 302–308.

NMFS. 2005. Final Environmental Impact Statement for Essential Fish Habitat Identification and Conservation in Alaska, Appendix G Non-fishing Impacts to Essential Fish Habitat and Recommended Conservation Measures.

NMFS. 2008. Impacts to Marine Fisheries Habitat from Nonfishing Activities in the Northeastern United States. Northeast Regional Office Gloucester, Massachusetts NOAA Technical Memorandum NMFS-NE-209.

Okamoto, N., K. Nakase, and T. San. 1987. Relationships between water temperature, fish size, infective dose and *Ichthyophonus* infection in rainbow trout. Bulletin of the Japanese Society of Scientific Fisheries 53: 581-584.

Palmer, D., and B. King. 2005. Migratory patterns of different spawning aggregates of Dolly Varden in the Kenai River watershed. Alaska Fisheries Technical Report Number 86. Kenai Field Office, Fish and Wildlife Service, U.S. Department of the Interior. Kenai, Alaska. 30 pp.

Pokorny, J., J. Kvet, J. P. Ondok, Z. Toul, and I. Ostry. 1984. Production ecological analysis of a plant community dominated by *Elodea canadensis* Michx. Aquatic Botany 19(3-4): 263-292.

Raat, A. J. 1988. Synopsis of Biological Data on the Northern Pike: *Esox* Lucius Linnaeus, 1758. Food and Agriculture Organization of the United Nations.

Raymond, J. 1981. Incubation of fall chum salmon *Oncorhynchus keta* (Walbaum) at Clear Air Force Station, Alaska: Alaska Department of Fish and Game, Information Leaflet No. 189.

Reist, J., F. Wrona, T. Prowse, M. Power, J. Dempson, J. King, and R. Beamish. 2006. An Overview of Effects of Climate Change on Selected Arctic Freshwater and Anadromous Fishes. Ambio 35: 381-38.

Risch, M. R., D. A. Gay, K. K. Fowler, G. J. Keeler, S. M. Backus, P. Blanchard, J. A. Barres, J. T. Dvonch. 2012. Spatial patterns and temporal trends in mercury concentrations, precipitation depths, and mercury wet deposition in the North American Great Lakes region, 2002–2008. Environmental Pollution 161: 261– 27.

Rorslett, B., D. Berge, and S. W. Johansen . 1986. Lake enrichment by submersed macrophytes – A Norwegian whole-lake experience with *Elodea* canadensis. Aquatic Botany 26: 325-340.

Rouse, W., M. Douglas, R. Hecky, A. Hershey, G. Kling, L. Lesack, P. Marsh, M. McDonald, B. Nicholson, N. Roulet, and J. Smol. 1997. Effects of Climate Change on the Freshwaters of Arctic and Subarctic North America. Hydrological Processes 11: 873-902.

Salo, E. 1991. Life history of chum salmon (Oncorhynchus keta). *In:* C. Groot and L.

Margolis (eds.) Pacific salmon life histories. University of British Columbia Press, Vancouver, B. C. Canada. Pp. 223-309.

Scanlon, B. 2009. Movements and Fidelity of Northern Pike in the Lower Innoko River Drainage, 2002-2004. Fishery Data Series Number 09-45. Divisions of Sport Fish and Commercial Fisheries, Alaska Department of Fish and Game. Anchorage, Alaska. 44 pp.

Schindler, D., C. Krueger, P. Bisson, M. Bradford, B. Clark, J. Conitz, K. Howard, M. Jones, J. Murphy, K. Myers, M. Scheuerell, E. Volk, and J. Winton. 2013. Arctic-Yukon-Kuskokwim Chinook Salmon Research Action Plan: Evidence of Decline of Chinook Salmon Populations and Recommendations for Future Research. Prepared for: AYK Sustainable Salmon Initiative (Anchorage, Alaska). 70 pp.

Schuster, P. F., R. G. Striegl, G. R. Aiken, D. P. Krabbenhoft, J. F. Dewild, K. Butler, B. Kamark, and M. Dornblaser. 2011. Mercury export from the Yukon River Basin and potential response to climate change. Environmental Science and Technology 45: 926-9267.

Sommer, T. R., M. L. Nobriga, W. C. Harrell, W. Batham, and W. J. Kimmerer. 2001. Floodplain rearing of juvenile Chinook salmon: evidence of enhanced growth and survival. Canadian Journal of Fisheries and Aquatic Sciences 58: 325-333.

Stuby, L. Research Biologist, Division of Sport Fish, Alaska Department of Fish and Game. 1300 College Road, Fairbanks, Alaska. Tel: (907) 459-7347 – pers. comm.

Stuby, L. 2012. Spawning Locations, Seasonal Distributions, and Migratory Timing of Kuskokwim River Sheefish using Radiotelemetry, 2007-2011. Fishery Data Series Number 12-65. Divisions of Sport Fish and Commercial Fisheries, Alaska Department of Fish and Game. Anchorage, Alaska. 64 pp.

U.S. EPA. 2014. An Assessment of Potential Mining Impacts on Salmon Ecosystems of Bristol Bay, Alaska (Final Report). U.S. Environmental Protection Agency, Washington, DC, EPA 910-R-14-001A-C, ES, 2014.

Weaver, T. M., and J. J. Fraley. 1993. A method to measure emergence success of westslope cutthroat trout fry from varying substrate compositions in a natural stream. North American Journal of Fisheries Management 13: 817-822.

Zuray, S., R. Kocan, and P. Hershberger. 2012. Synchronous cycling of *Ichthyophoniasis* with Chinook salmon density revealed during the annual Yukon River spawning migration. Transactions of the American Fisheries Society 141: 615-623.

# Data Request Method

Rapid Ecoregional Assessments (REAs)—National Operations Center, CO

Individual REA data layers and some other products are still available but are no longer being published.

If you would like to obtain more information, including data and model zip files* (containing Esri ModelBuilder files for ArcGIS 10.x and relevant Python scripts), please email **BLM_OC_REA_Data_Portal_Feedback_Team@blm.gov**.
*Note that a few models require software that BLM does not provide such as R, Maxent, and TauDEM.

Models associated with individual REAs may require data links to be updated to function properly. REA reports, technical appendices, and model overviews (for some REAs) contain detailed information to determine what products are available and what datasets are necessary to run a certain model.

Please include the report name and any specific data information that you can provide with your request.

Other BLM data can be found on the Geospatial Business Platform Hub (https://gbp-blm-egis.hub.arcgis.com).