

Central Yukon Rapid Ecoregional Assessment



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

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Acronyms Used in This Document:

A2	Emissions scenario selected for this assessment, called "A2" by IPCC
ACCS	Alaska Center for Conservation Science
ACEC	Area of Critical Environmental Concern
ACRC	Alaska Climate Research Center
ACS	American Community Survey
ADEC	Alaska Department of Environmental Conservation
ADEED	Alaska Department of Education and Early Development
ADFG	Alaska Department of Fish and Game
ADLWD	Alaska Department of Labor and Workforce Development
ADNR	Alaska Department of Natural Resources
ADOT	Alaska Department of Transportation
AEA	Alaska Energy Authority
AET	Actual EvapoTranspiration
AFS	Alaska Fire Service
AHDR	Arctic Human Development Record
AIAN	American Indian and Alaska Native
AKEPIC	Alaska Exotic Plants Information Clearinghouse
AKGAP	Alaska Gap Analysis Program
AKNHP	Alaska Natural Heritage Program
AKVM	Vegetation Map of Northern, Western, and Interior Alaska
ALARI	Alaska Local And Regional Information (of ADLWD)
ALFRESCO	ALaska FFrame-based EcoSystem COde
ALT	Active Layer Thickness
AMIRA	Autoregressive Integrated Moving Average
AMLIS	Abandoned Mine Land Inventory System
AMT	Assessment Management Team
ANCSA	Alaska Native Claims Settlement Act
ANILCA	Alaska National Interest Lands Conservation Act
ANTHC	Alaska Native Tribal Health Consortium
AR4	fourth assessment report of the IPCC
ARDF	Alaska Resource Data File
ASGDC	Alaska State Geo-spatial Data Clearinghouse
ASI	Arctic Social Indicators
ATV	All-Terrain Vehicle
AUC	Area-Under-Curve
AVCP	Alaska Village Council Presidents
AVEC	Alaska Village Electric Cooperative
AWC	Anadromous Waters Catalog
BGEPA	Bald and Golden Eagle Protection Act
BIOTICS	conservation data framework developed by NatureServe
BISON	Biodiversity Serving Our Nation
BLM	Bureau of Land Management
BpS	Biophysical Setting
CA	Change Agent
CART	Classification And Regression Tree
CBVM	Circumboreal Vegetation Map

CE	Conservation Element
CMIP	Coupled Model Intercomparison Project
CPI	Consumer Price Index
CRU	Climate Research Unit
CS	Classification Success
CSIS	Community Subsistence Information System
CuCarb	carbonate-hosted copper deposits
CYR	Central Yukon
DEM	Digital Elevation Model
DEW	Distant Early Warning
DMTS	Delong Mountain Transportation System
DOF	Date of Freeze
DOT	Date of Thaw
DU	Ducks Unlimited
ECHAM5	an atmospheric general circulation model
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
ESRI	Environmental Services Research Institute
FAA	Federal Aviation Administration
FNSB	Fairbanks North Star Borough
FUDS	Formerly Used Defense Sites
GBIF	Global Biodiversity Information Facility
GCM	Global Circulation Model
GDD	Growing Degree Days
GDP	Gross Domestic Product
GIPL	Geophysical Institute Permafrost Lab
GIS	Geographic Information System
GMU	Game Management Unit
GTLF	Ground Transportation Linear Feature
HDR	HDR, Inc. (engineering and environmental consulting firm)
HF	Heating Fuel
HUC	Hydrologic Unit Code
IC	Interim Conveyed
IEM	Integrated Ecosystems Model
IfSAR	Interferometric Synthetic Aperture Radar
IK/AK	Indigenous Knowledge/Aboriginal Knowledge
IPCC	Intergovernmental Panel on Climate Change
IR	Invasiveness Rank
ISER	Institute of Social and Economic Research
LANDFIRE	LANDscape Fire and REsource management planning
LCM	Landscape Condition Model
LEK	Local Ecological Knowledge
LIB	Large Intact Block
LK	Local Knowledge
LOGS	Length Of Growing Season
MAGT	Mean Annual Ground Temperature
MaxEnt	Maximum Entropy (a statistical method for probability distribution)
MCA	Medieval Climate Anomaly
mph	miles per hour

MPI	Max Planck Institute
MQ	Management Question
MS	Material Site
NALCMS	North American Land Change Monitoring System
NANA	Northwest Arctic Native Association
NCES	National Center for Education Statistics
NDVI	Normalized Difference Vegetation Index
NED	National Elevation Dataset
NEPA	National Environmental Policy Act
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NoAK	Northern Alaska subsections map
NOC	National Operations Center (of BLM)
NPR-A	National Petroleum Reserve-Alaska
NPS	National Park Service
NVC	National Vegetation Classification
NWAB	NorthWest Arctic Borough
NWR	National Wildlife Refuge
PA	Plant Association
PAR	Partitioning Around Medoids
PCE	Power Cost Equalization
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PET	Potential EvapoTranspiration
PGE	Platinum Group Element
Placer	placer and paleoplacer gold
PRISM	Parameter-elevation Regressions on Independent Slope Models
REA	Rapid Ecoregional Assessment
REE	Rare Earth Elements
REF	Renewable Energy Fund
RS	Revised Statute
SandU	Sandstone Uranium
SDF	Snow Day Fraction
SDM	Species Distribution Model
SNAP	Scenarios Network for Alaska and Arctic Planning
SnGranite	tin-tungsten-molybdenum-flourspar deposits associated with specialized granites
STATSGO	STATE Soil GeOgraphic dataset
SWI	Summer Warmth Index
TA	Tentative Approval
TAZ	Traffic Analysis Zone
Tech Team	Technical Team
TEK	Traditional Ecological Knowledge
TEM	Terrestrial Ecosystem Model
TIGER	Topologically Integrated Geographic Encoding and Referencing
TK	Traditional Knowledge
TNC	The Nature Conservancy
TTL	Tribal Traditional Lifeways
UA	University of Alaska
UAF	University of Alaska Fairbanks

UAM	University of Alaska Museum
USD	United States Dollar
USDA	United States Department of Agriculture
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey

Note on Structure of the Final Report

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

Section A. Cover Sheet

Section B. Introduction

Section C. Abiotic Change Agents

Section D. Biotic Change Agents

Section E. Anthropogenic Change Agents

Section F. Landscape and Ecological Integrity

Section G. Terrestrial Coarse-Filter Conservation Elements

Section H. Terrestrial Fine-Filter Conservation Elements

Section I. Aquatic Coarse-Filter Conservation Elements

Section J. Aquatic Fine-Filter Conservation Elements

Section K. Data Gaps and Omissions

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

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

B. Introduction to the Final Report

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Summary

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

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1. What is a Rapid Ecoregional Assessment?

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

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

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

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

Four REAs have recently been completed in Alaska. These include the Seward Peninsula (Harkness et al. 2012), Yukon Lowlands–Kuskokwim Mountains–Lime Hills (Trammell et al. 2014), the North Slope (Trammell et al. 2015), and the Central Yukon (*current document*).

2. Approach and Process

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

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

MQs focus the REAs on pertinent management and planning concerns for the region. MQs are used to select CEs and CAs by identifying critical resources and management concerns for the study area. CEs are also identified by an Ecoregional Conceptual Model (see Section B.3.9. Ecoregional Conceptual Model). Although a basic list of CAs is provided by the BLM, MQs can also identify regionally-specific CAs to be considered in the analysis. An important strength of this approach is the integration of current management concerns and current scientific understanding into a comprehensive and forward-looking regional assessment.

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

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

2.1. Change Agents (CAs)

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

2.2. Conservation Elements (CEs)

Conservation Elements (CEs) are defined as biotic constituents (e.g., vegetation classes and wildlife species, or species assemblages), abiotic factors (e.g., soils) of regional importance in

major ecosystems and habitats across the ecoregion, or high biodiversity priority sites (e.g., designated Important Bird Areas). CEs are meant to represent key resources that can serve as surrogates for ecological condition across the ecoregion.

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

Coarse-Filter Conservation Elements

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

Fine-Filter Conservation Elements

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

Table B-1. Change Agents and Conservation Elements selected for the Central Yukon REA.

Change Agents (CAs)	Conservation Elements (CEs)	
	Coarse-Filter CEs	Fine-Filter CEs
Climate	Terrestrial Coarse-Filter	Terrestrial Fine-Filter
Precipitation	Alpine and Arctic Tussock Tundra	beaver (<i>Castor canadensis</i>)
Temperature	Alpine Dwarf Shrub Tundra	caribou (<i>Rangifer tarandus</i>)
Thaw Date	Floodplain Forest and Shrub	golden eagle (<i>Aquila chrysaetos</i>)
Fire	Lowland Woody Wetland	Swainson's thrush (<i>Catharus ustulatus</i>)
Return Interval	Upland Low Shrub Tundra	Dall sheep (<i>Ovis dalli</i>)
Vegetation Response	Upland Mesic Spruce Forest	snowshoe hare (<i>Lepus americanus</i>)
Permafrost	Upland Mesic Spruce-Hardwood Forest	trumpeter swan (<i>Cygnus buccinator</i>)
Ground Temperature	Aquatic Coarse-Filter	Aquatic Fine-Filter
Active Layer Thickness	Rivers and Large Streams	chinook salmon (<i>Oncorhynchus tshawytscha</i>)
Invasive Species	Small Streams (including Headwater streams)	chum salmon (<i>Oncorhynchus keta</i>)
Insect and Disease	Large Connected Freshwater Lakes	Dolly Varden (<i>Salvelinus malma</i>)
Anthropogenic Uses	Small Connected Freshwater Lakes	humpback whitefish (<i>Coregonus pidschian</i>)
Subsistence		northern pike (<i>Esox lucius</i>)
Natural Resource Extraction		sheefish/inconnu (<i>Stenodus leucichthys</i>)
Transportation and Communication Infrastructure		
Recreation		
Energy Development		

2.3. Management Questions

Management Questions (MQs) provide regional managers the opportunity to highlight specific concerns relevant to the larger ecoregions, and provide a tangible way in which these REA efforts can be translated into management plans and actions. The University of Alaska (UA) team received an initial list of Management Questions from the BLM Central Yukon Field Office, who spent substantial time and effort identifying regionally important resource questions.

Through our conversations with the BLM, the UA Team parsed out original multi-part questions into distinct questions. Additionally, all of the original management questions from BLM had overarching questions of “How reliable are these predictions? Are there other data/models which provide information that is different than the output presented?” These questions will be addressed as a standard component to all analyses throughout the REA. Overall this process produced a list of 78 potential MQs. The original list of MQs can be reviewed in Section K of this report.

Given the rapid nature of the REA, the BLM locally suggested we limit the number of MQs to around 20 (with a maximum of 30). Based on the success of the North Slope REA MQ selection process using the Delphi survey method (Hess and King 2002, Scolozzi et al. 2012, O'Neill et al. 2008) to prioritize and focus our MQs, the UA team employed the same approach for the Central Yukon REA. The UA team asked AMT members to rank which 20 questions were their top questions, which 20 additional questions were next priority (mid), and which questions were of lowest priority to them (remove).

Each AMT member was asked to consider the following guidance from the BLM National Operations Center (NOC) on how to craft an appropriate Management Question:

- Is the MQ about large-scale, region-wide issues?
- Can the MQ be answered by available geospatial information, remote sensing, or acceptable surrogates at the landscape scale?
- If the MQ cannot be addressed spatially, would a literature review be an appropriate use of the REA?
- If it is an inventory question, can it be addressed within the timeframe of the REA?
- Does the MQ inform a specific practical management decision or resource allocation to be made? (i.e., Which areas due to resource vulnerability require protection as ACECs? Which areas should be avoided for authorization of new roads or utility corridors?)
- Does the MQ identify the potential subsequent decision process and or action associated with the answer to the question?
- Has the MQ been answered in another recently completed ecoregional assessment and is there additional information that warrants reexamining this issue?

Ten responses were received from the first ranking by the AMT, 18 MQs surfaced as being the top or mid priority MQs by the majority of the voting members of the AMT Responses were

presented to the AMT and Technical Team members during the first AMT meeting on September 5, 2014. Additional MQs were provided by the AMT and an additional round of ranking was done to ensure the first ranking was agreed upon by the majority of the AMT.

The second round of MQ surveys resulted in seven responses. The results were tallied based on ranks for each question then reordered based on those tallies. Questions that were consistently ranked as either Top 20 or Mid 20 by over half of the voting AMT members were selected as our final list of MQs (Table B-2). In addition to the 20 MQs we also identified 12 alternative MQs with almost half of the AMT agreeing on these questions being either top 20 or mid 20 MQs. These questions were considered as replacement MQs if any of the final MQs cannot be adequately addressed by the UA team, pending AMT approval. Alternative MQs can be reviewed in CYR Memorandum I (AKNHP et al. 2014).

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

Abiotic Change Agents (Section C)	
A1	How is climate change likely to alter the fire regime in the dominant vegetation classes and riparian zones?
B1	How is climate change likely to alter permafrost distribution, active layer depth, precipitation regime, and evapotranspiration in this region?
B2	What are the expected associated changes to dominant vegetation communities and CE habitat in relation to altered permafrost distribution, active layer depth, precipitation regime, and evapotranspiration?
C1	How will changes in precipitation, evapotranspiration, and active layer depth alter surface water availability and, therefore, ecosystem function (dominant vegetation classes)?
E1	How is climate change affecting the timing of snow melt and snow onset, spring breakup and green-up, and growing season length?
F3	How are major vegetation successional pathways likely to change in response to climate change, with special emphasis on increased shrub cover and treeline changes?
Anthropogenic Change Agents (Section E)	
Q1	Which subsistence species (aquatic and terrestrial) are being harvested by whom and where is harvest taking place?
U1	Compare the footprint of all types of landscape and landscape disturbances (anthropogenic and natural changed) over the last 20 and 50 years.
U3	How and where is the anthropogenic footprint most likely to expand 20 and 50 years into the future?
Terrestrial Coarse-Filter Conservation Elements (Section G)	
AH1	What rare, but important habitat types that are too fine to map at the REA scale and are associated with coarse- (or fine-) filter CEs that could help identify areas where more detailed mapping or surveys are warranted before making land use allocations (such as steppe bluff association with dry aspect forest)?
G1	Where are refugia for unique vegetation communities (e.g., hot springs, bluffs, sand dunes) and what are the wildlife species associated with them?

G2	Which unique vegetation communities (and specifically, which rare plant species) are most vulnerable to significant alteration due to climate change?
Terrestrial Fine-Filter Conservation Elements (Section H)	
AE1	Where is primary waterfowl (black scoter or trumpeter swan) habitat located?
L1	What are caribou seasonal distribution and movement patterns?
N3	How might sheep distribution shift in relation to climate change?
T1	The introduction of free-ranging reindeer herds to this region has been proposed. What areas would be most likely to biologically support a reindeer herd?
X1	What have the past cumulative impacts of road construction and mineral extraction been on terrestrial CE habitat and population dynamics?
X2	How might future road construction and mineral extraction infrastructure (e.g., both temporary and permanent roads [Umiat, Ambler, Stevens Village], pads, pipeline, both permanent and temporary) affect species habitat, distribution, movements and population dynamics (especially caribou, moose, sheep)?
Aquatic Conservation Elements (Sections I and J)	
W2	How might future road construction and mineral extraction infrastructure (e.g., both temporary and permanent roads, pads, pipeline) affect fish habitat, fish distribution, and fish movements (especially chinook, chum, sheefish)?
V1	How does human activity (e.g., mineral extraction, gravel extraction) alter stream ecology and watershed health (i.e., water quantity, water quality, outflow/stream connectivity, fish habitat, and riparian habitat)?

2.4. Conceptual Models

Conceptual models represent the state of knowledge about the relationships between the CEs, CAs, and other resources. Not all relationships identified lend themselves well to measurement or monitoring, but they are important to include because they add to the understanding of complex interactions (Bryce et al. 2012).

For each CE we produced a conceptual model that contains:

1. a textual description of the interrelationships between/among the CE, CA, and other resources and their associated forms and processes;
2. a diagrammatic representation of the model, which includes information on how we anticipate the model being use for the REA. Specifically, the diagrams will address those relationships with the CAs that we will be able to assess in a spatial framework;
3. the basis and scientific support for the model; and
4. detailed conceptual models have been developed for each CE and are supported and referenced by scientific literature.

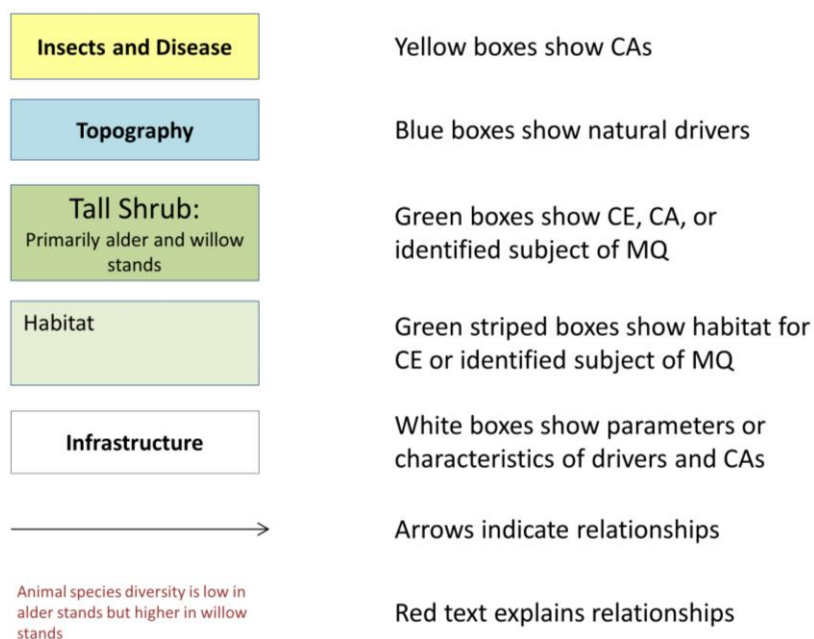


Figure B-1. Conventions for conceptual models.

Conceptual models are diagramed according to the conventions outlined in Figure B-1 above. The boxes indicate CEs, CAs, and drivers and arrows indicate regionally important interactions known to occur in the CYR study area. Text in dark red is positioned next to arrows to indicate the most likely relationships between constituents.

2.5. Attributes and Indicators

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

Attributes and indicators are a critical component of the core analysis as they help to define the relationships between conservation elements (CEs) and change agents (CAs), and, where possible, thresholds associated with these relationships.

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

Categorization of attributes/indicators has been adopted as a required element for all REAs. Categorization allows data from a variety of sources to be organized similarly, whether the original data were collected in categories or were collected as numerical measurements. It also allows communication of information generated by complex REA analyses in an elegantly simple but meaningful manner, and helps to provide consistency in assessing and reporting across the variety of BLM resources, landscapes, and ecoregions.

We did not include attributes and indicators for Coarse-filter CEs. Alternatively, Coarse-filter CEs status will be assessed using Landscape Condition Models and Cumulative Climate Impacts.

Here we provide an example (Figure B-2) of an attribute and indicator table for trumpeter swan (*Cygnus buccinator*). This information is provided in summary table format for all Fine-filter CEs, and is included with the individual CE conceptual model write-ups.

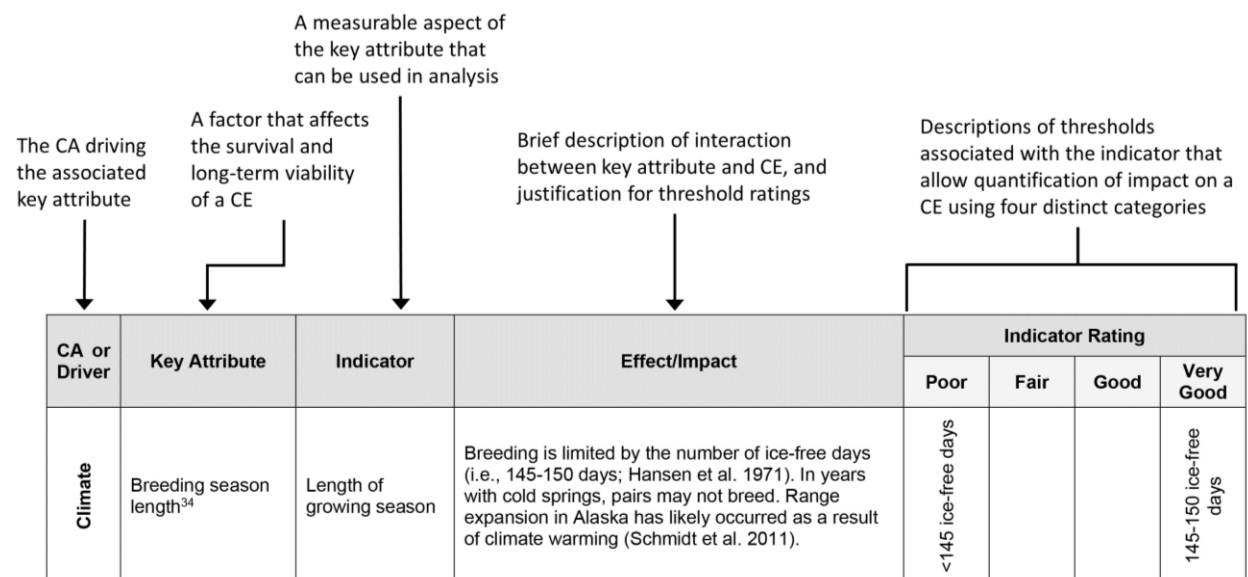


Figure B-2. Explanation and example of attributes and indicators tables.

2.6. CE × CA Analyses

The purpose of the CE specific assessment is to evaluate the current status of each CE at the ecoregional scale and to investigate how its status may change in the future as a result of future development and climate change. The conceptual model for each CE helps guide the selection of key ecological attributes and indicators that will assist us in assessing current and future status. Ecological attributes and associated indicators, at the Fine-filter level, provide measures of the acceptable range of variation for each ecological attribute to further assist with assessment of status and trends.

In each of the Fine-filter CE conceptual models, we have presented in **bold lines** those relationships that we intend to analyze spatially based on available datasets (measureable effects) as described in the attributes and indicators tables (Figure B-3). Although these analyses will differ on a CE by CE basis, this process generally involves overlaying the distribution model for each CE with the measureable CA indicator (e.g., invasive species may alter this vegetation community composition if frequent disturbance of the CE occurs.).

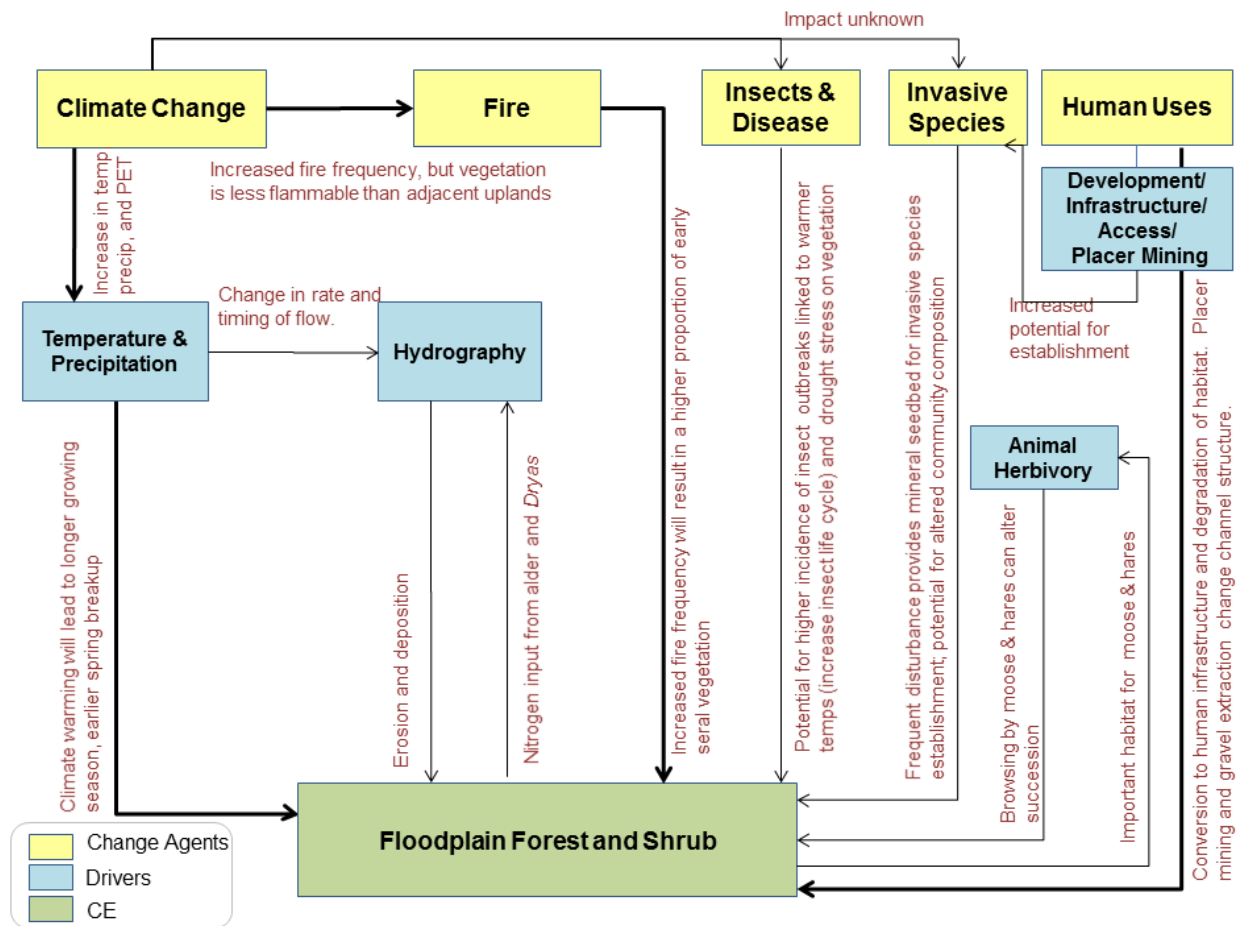


Figure B-3. Example conceptual model for Floodplain Forest and Shrub CE.

2.7. Process Models

While conceptual models help inform the ecological relationships between ecosystem components, drivers, and processes, process models illustrate computational relationships or logical decisions within the context of a spatial or mathematical model to produce an output. Process models diagram data sources, geoprocessing procedures, and workflows, providing analytical transparency and allowing for repeatability of processes in the future (Bryce et al. 2012). Process models have been developed to represent the analysis of each CA and MQ, and they helped provide guidance for data discovery.

Process models are diagrammed according to the conventions in Figure B-4 below (Bryce et al. 2012). Each process model will contain the following:

1. A diagram illustrating data and methods. These are key elements (datasets representing key attributes of CEs, CAs, and MQs) and procedures in the computational process, the relationship among them, and the flow of information and analyses.
2. Descriptive text explaining the diagram. Methods for developing process models for all MQs are similar: source datasets are computationally or spatially related to produce outputs that are further related to produce final products.

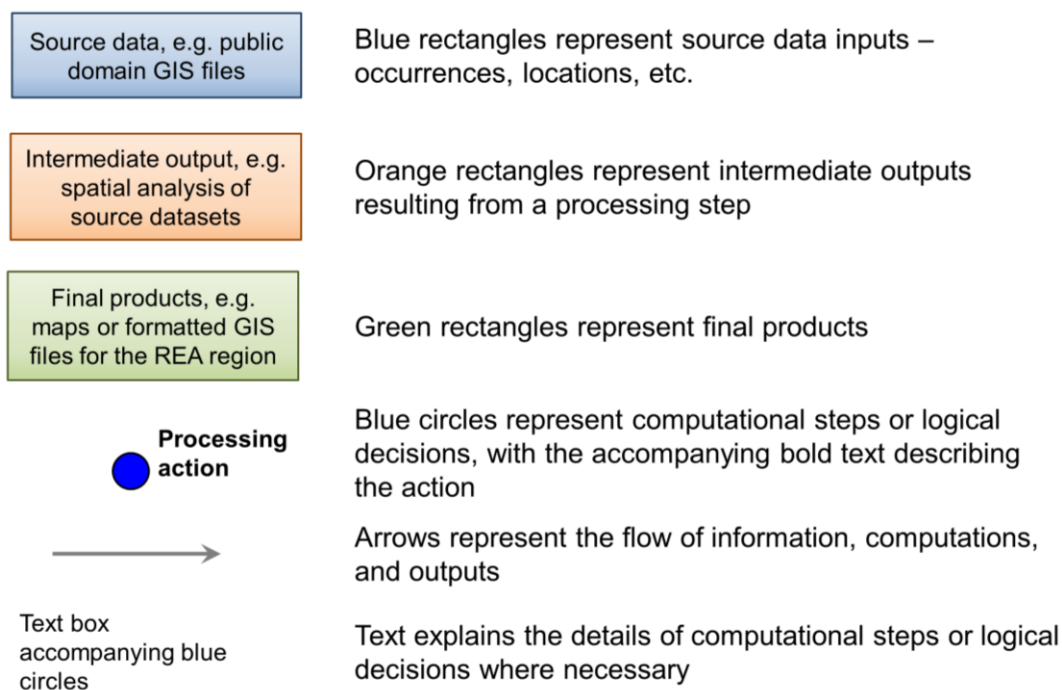


Figure B-4. Conventions for Process Models.

2.8. Land Owners and Stakeholders

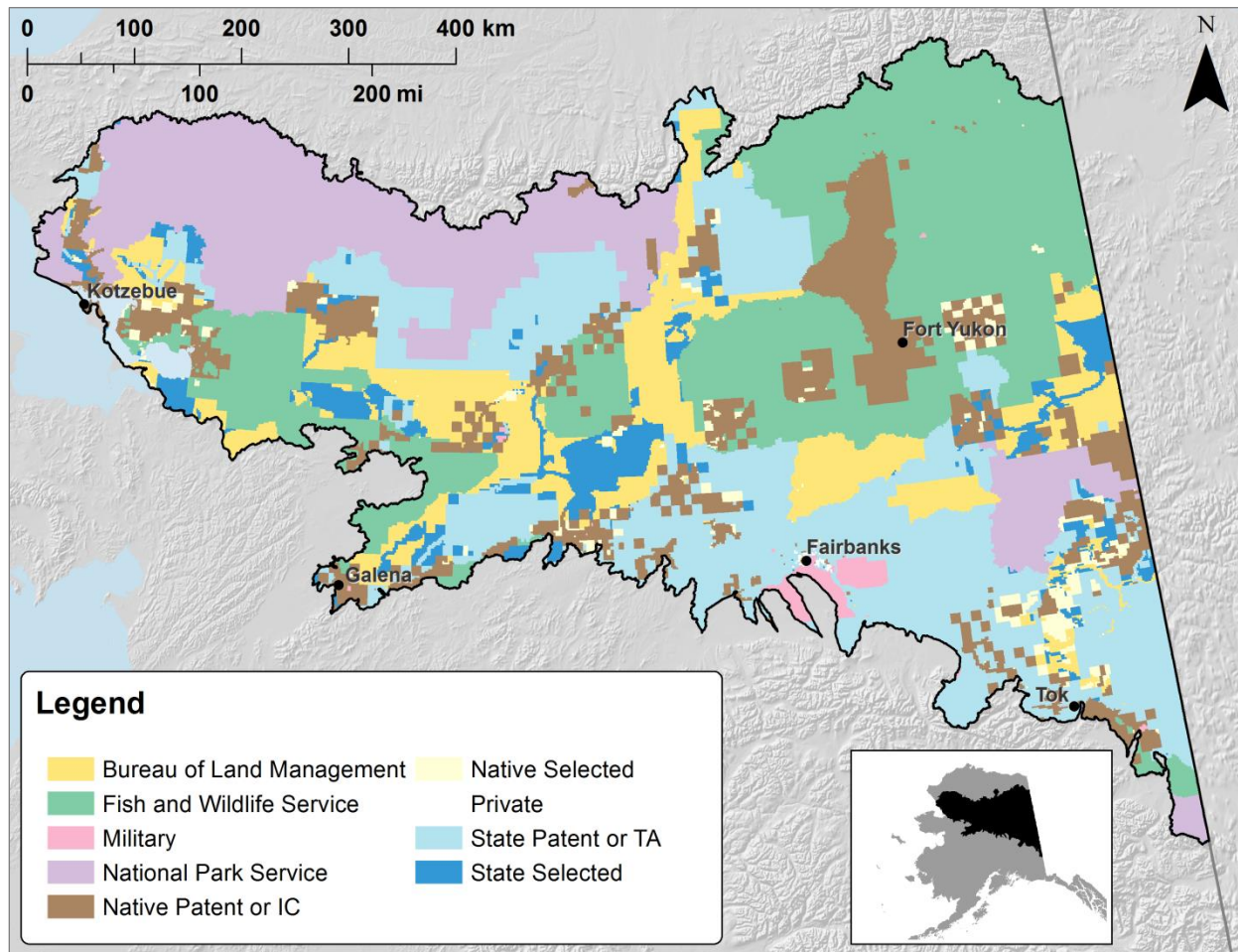


Figure B-5. Land management status in the Central Yukon study area in 2015.

Community meetings were an important part of this REA to ensure broader regional stakeholders were included and informed about the effort. The UA team and BLM State and Field offices coordinated informational meetings with the Fairbanks North Star Borough Planning Commission as part of a series of three community meetings: the 1st meeting was held on 17 March 2015, the 2nd meeting was held 27 October 2015, and the 3rd meeting will be held after completion of the project, tentatively scheduled for June 2016. The Planning Commission was chosen for our community meetings, as Fairbanks holds the largest population of the region and has the largest impact of individuals that can attend. An additional community meeting may be presenting final results to a Resource Advisory Council meeting held 3–4 times a year across the state and is attended by stakeholders from various interest groups such as tourism, energy, Alaska Native organizations, environmental interest groups, and the public. During these meetings the UA team informed the planning commission about the REA process, its expected outcomes, and gathered input on CEs, CAs, and MQs.

A larger stakeholder group was also informed on the status of the assessment through a series of four newsletters (spring 2015, summer 2015, fall 2015, and anticipated delivery summer 2016).

Each newsletter was delivered by hard copy via the postal service and through e-mail, reaching a group of almost 270 interested parties ranging from local business owners to state government officials.

Additional stakeholder engagement came from the representatives of various state and federal agencies that manage land parcels within the Central Yukon study area (Figure B-5) that served on the Assessment Management Team (AMT) and Technical Team (Tech Team). The AMT and Tech Team provided guidance and direction to the objectives of the assessment through regular project communication and meetings (interim project memos and presentations can be accessed [online](#)¹). A full list of AMT and Technical Team members is included after the cover page. The U.S. Fish and Wildlife Service, State of Alaska, National Park Service, Native groups, and Bureau of Land Management are the primary land management agencies by area in the Central Yukon study area (Table B-3).

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

Land Ownership	Area (km ²)	Percent of Total Study Area
Fish and Wildlife Service	103,004	26%
State Patent or TA	93,758	24%
National Park Service	66,959	17%
Native Patent or IC	49,510	13%
Bureau of Land Management	48,318	12%
State Selected	20,108	5%
Native Selected	7,223	2%
Water	3,665	0.9%
Department of Defense	3,034	0.8%
Private	238	0.06%

We used the most recent land ownership status data provided by the BLM at the start of this REA analysis in 2014. By the completion of this project, land status changed in the CYR study area where the State of Alaska relinquished approximately 700,000 acres of state-selected lands in the upper Black River area. We recognize land status is constantly ever-changing and readers should be aware of the limitations of all data used in our analyses.

2.9. Project Team

The Alaska Center for Conservation Science (ACCS) served as the lead for this REA, with close collaboration from the Scenarios Network for Alaska and Arctic Planning (SNAP), and Institute of Social and Economic Research (ISER). ACCS was formally known as the Alaska Natural Heritage Program (AKNHP), but changed structure within the University of Alaska during the CYR assessment. Throughout this document this team is collectively referred to as the University of Alaska (UA) Team. The UA Team as a whole was responsible for assessing the current and potential future status of CEs at the ecoregional scale and their relationships to CAs, as well as

¹ See <http://accs.uaa.alaska.edu/rapid-ecoregional-assessments/central-yukon-rea-documents>

addressing the Management Questions (MQs), identifying data gaps, and delivering data to the BLM. Project leads are identified for the various sections reflecting the multi-disciplinal expertise and knowledge used in assessing this region.

3. Description of Rapid Ecoregional Study Area

The assessment area, referred to in this REA as the Central Yukon (CYR) study area, includes a core of seven ecoregions selected by BLM: Brooks Range (south of the ridge crest), Davidson Mountains, Kobuk Ridges and Valleys, North Ogilvie Mountains, Ray Mountains, Yukon–Old Crow Basin, and Yukon-Tanana Uplands (Figure B-6). Ecoregions in this assessment were defined by Nowacki et al. (2001) and represent a unified mapping approach that blends traditional approaches (e.g., Bailey et al. 1994, Omernik 1987) with regionally-specific knowledge and ecological goals. Following BLM guidelines, the study area was formed by buffering the selected ecoregions by any 5th-level hydrologic units that intersected the ecoregion boundaries. Additionally, at the request of the BLM, the assessment boundary includes key lands surrounding the Dalton Highway on the north edge of the study area. Most of the Kotzebue Sound Lowlands are included in the study area because of the buffer region. The buffer region additionally causes the inclusion of small portions of several ecoregions along the southern boundary of the study area: these portions have been modified into a conglomerate unique to this REA referred to as the Tanana-Kuskokwim-Yukon Lowlands.

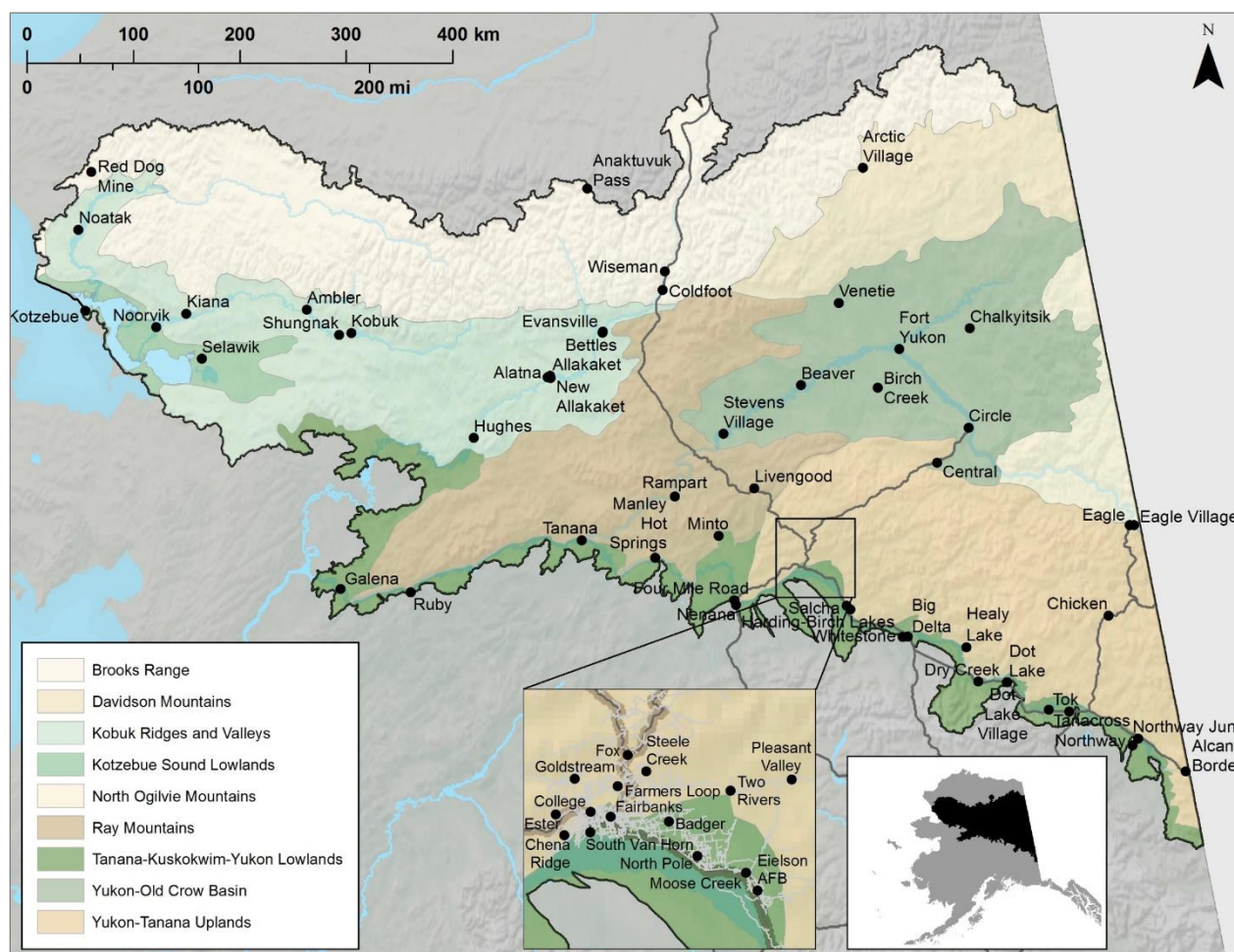


Figure B-6. Ecoregions included in the CYR study area.

This region has a boreal climate, with long cold winters and relatively brief but warm summers. Climate varies depending primarily upon elevation, proximity to the coast, and latitude. Although in general the most extreme cold occurs at high elevations, some areas experience localized temperature inversions. With mean annual temperatures below freezing in most areas, but above freezing in others, permafrost is discontinuous. This discontinuity occurs at both fine scales and broader scales. The following narratives for each ecoregion are paraphrased from Nowacki et al. (2001). They provide general descriptions of ecosystem resources and drivers.

3.1. Brooks Range

This east-west range is the northernmost extension of the Rocky Mountains and includes the Brooks Range, British Mountains, and Richardson Mountains. Many of the mountains are comprised of steep, angular summits flanked by rubble and scree (Figure B-7). On the western and eastern ends of the range, the topography becomes less rugged. Rivers and streams cut narrow ravines into the terrain. During the Pleistocene, glaciers covered the higher portions of the range. Only a few small cirque glaciers remain. A dry, polar climate dominates the land. Winters are long and cold, and summers are short and cool. Air temperatures decrease rapidly with increased elevation. Permafrost is mostly continuous south of the ridge crest. Dominant vegetation classes on the south side of the range are sedge tussocks and shrubs in valleys and lower slopes, sparse conifer-birch forests in large valleys, and alpine tundra and barrens at higher elevations. The ecoregion provides habitat for Dall sheep, caribou, marmots, gray wolves, and brown bears. Groundwater fed springs and streams provide habitat for Arctic grayling.

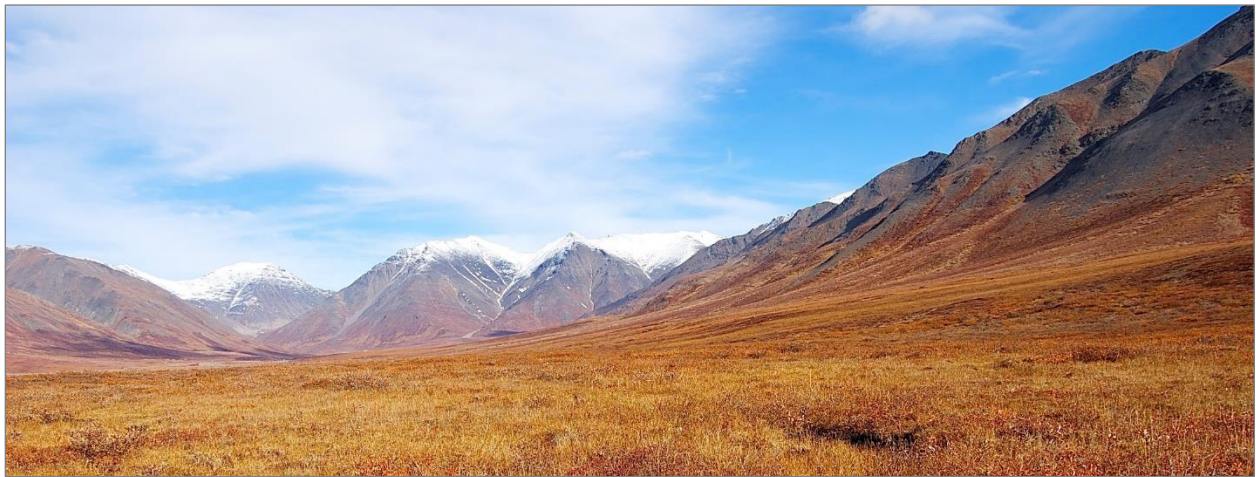


Figure B-7. Chandalar Shelf of the Brooks Range.

3.2. Davidson Mountains

Mountains with coarse rubble slopes are interspersed with broad floodplains underlain by unconsolidated glacial and alluvial sediments. Thin to thick permafrost underlies the majority of the ecoregion. Climate is continental with cold winters and short, cool summers. Dominant vegetation classes are black spruce woodlands; white spruce and balsam poplar along rivers; and white spruce, resin birch, and quaking aspen in uplands. Shrub communities of willow, alder,

and birch are also common. Forest fires are frequent. Moose, bears, and wintering caribou are common.

3.3. Kobuk Ridges and Valleys

The Kobuk ridges and valleys ecoregion is comprised of a series of paralleling ridges and valleys that radiate south from the Brooks Range, created partially by high-angle reverse faults and interceding troughs. In the past, ice sheets descending from the north covered the area. Broad valleys are covered with alluvial and glacial sediments while intervening ridges are covered with rubble (Figure B-8). Climate is dry continental with long, cold winters and short, cool summers. During winter, cold air drains from the Brooks Range into the valleys. Permafrost is thin to moderately thick throughout much of the area. Forests and woodlands dominate much of the area. Trees become increasingly sparse in the west. Tall and short shrub communities of birch, willow, and alder occupy ridges.



Figure B-8. Kiana Hills and the Squirrel River.

3.4. North Ogilvie Mountains

Flat-topped hills and a plain are primarily underlain by calcareous sedimentary rock. The ecoregion was not glaciated and is, therefore, heavily eroded. Ridges and upper slopes are barren and jagged rock outcrops are common (Figure B-9). Shallow soils cover the rocky colluvial deposits of slopes that are subject to frequent landslides and debris flows. Lower and more stable slopes have developed deeper soils that are extensively underlain by permafrost. Low shrub tundra with willow, alder, and birch and spruce woodlands occur at lower elevations. The streams originating in the North Ogilvie Mountains feed the Porcupine, Yukon, and Peel rivers. Few lakes exist. Climate is continental with cold winters and short, cool summers. Brown bears, wolverine, Dall sheep, caribou, lemmings, and pikas are common.



Figure B-9. Calcareous rock outcrops and ridges in the North Ogilvie Mountains.

3.5. Ray Mountains

The Ray Mountains are comprised of compact, east-west oriented ranges. Metamorphic bedrock is covered with rubble, and soils are shallow and rocky. During the Pleistocene, the Ray Mountains remained largely unglaciated. Climate is continental with dry, cold winters and somewhat moist, warm summers. Permafrost is discontinuous and ranges from thin to moderately thick. Dominant vegetation classes are black spruce woodlands; white spruce, birch, and aspen on south-facing slopes; white spruce, balsam poplar, alder, and willows on floodplains; and shrub birch and *Dryas*-lichen tundra at higher elevations. Clear headwater streams are important habitat for Arctic grayling. Moose, brown bears, gray wolves, red fox, lynx, and marten are common.

3.6. Yukon–Old Crow Basin

Mountain toeslopes around the Porcupine River form a basin comprised of depositional fans, terraces, and pediments. The region was largely unglaciated and is heavily eroded. Surrounding the flats, surficial deposits of colluvial, alluvial, and aeolian origins are deep and underlain by continuous permafrost. The poorly drained flats contain extensive wetlands with many thaw lakes and ponds. Deltaic fans, river terraces, and floodplains are common on the landscape (Figure B-10). Climate is dry continental with large seasonal temperature fluctuations. Winters are cold and dry because of dominant Arctic high pressure systems. Common vegetation ranges from wet herbaceous marshes to open black spruce forests to closed spruce-deciduous forests on well-drained uplands. The wetland complexes formed by the Yukon River support large numbers of waterfowl and other migratory birds. Moose, bears, northern pike, and salmon are common.



Figure B-10. Floodplain and extensive flats along the Porcupine River.

3.7. Yukon-Tanana Uplands

Broad, rounded mountains of moderate height are underlain by metasedimentary volcanic crust blocks and continental shelf deposits. Surficial deposits are bedrock and rubble on ridges and upper slopes, colluvium on lower slopes, and alluvium in the narrow valleys. The region is underlain by discontinuous permafrost thick on north-facing slopes and thin in valleys. Climate is continental with cold winters and warm summers. White spruce, resin birch, and quaking aspen dominate south-facing slopes (Figure B-11). North-facing slopes are primarily black spruce woodland or forest while valleys are dominated by black spruce woodlands and tussock bogs. Low birch-ericaceous shrub and *Dryas*-lichen tundra are common at the uppermost elevations. Forest fires are very common in this region resulting in a patchwork of forest ages. Caribou, moose, snowshoe hare, marten, lynx, black bears, and brown bears are common. Abundant cliffs provide habitat for peregrine falcons. Chinook, chum, and coho salmon spawn in the clear headwater streams.

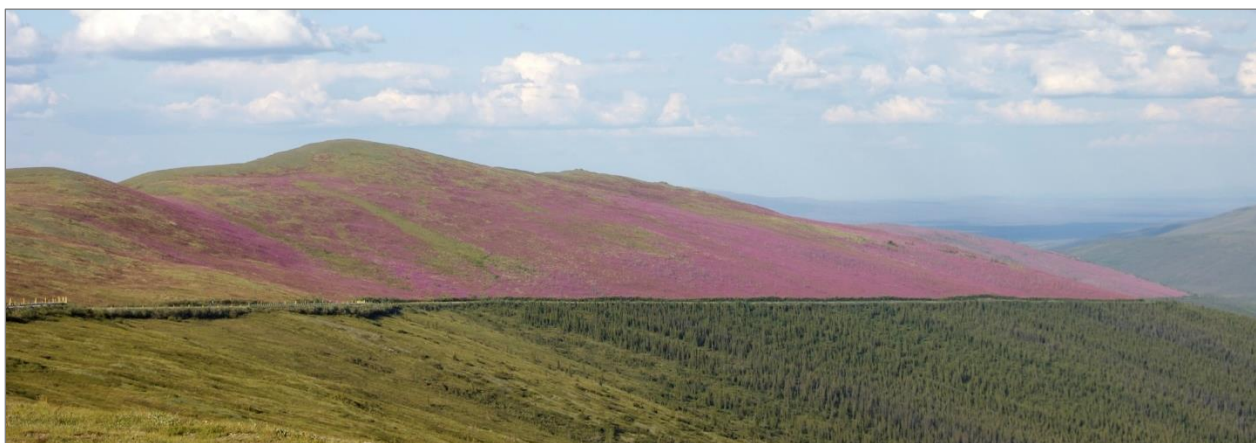


Figure B-11. Eagle Summit area in the White Mountains.

3.8. Assessment Boundary and Scale

As per BLM guidance, reporting units for the Central Yukon REA will be at the landscape level in scale and intent. For most analyses, the BLM has specified that data be reported at the 5th-level

10-digit hydrologic unit code (HUC) with raw data being provided at 30-m grid cells for raster data or other native resolution as appropriate. Climate data will be provided at a resolution of 771-m grid cells and, therefore, any climate related questions will be answered at this scale as well. Many of the primary landscape level datasets for Alaska are also coarser than the 30-m pixel resolution recommended by the BLM (for example, the best available resolution for Digital Elevation Model is 60-m grid cells). Therefore, the ultimate reporting unit of each analysis will be limited by the coarsest resolution of the data. In general, however, raw data will be provided at 60-m grid cell resolution, and results will be reported at the 5th-level HUCs.

3.9. Ecoregional Conceptual Model

The Ecoregional Conceptual Model portrays an understanding of critical ecosystem components, processes, and interactions necessary for the maintenance of sustainable ecosystems. By summarizing existing information and hypotheses on the structure and function of ecosystems, the Ecoregional Conceptual Model provides the framework to assess ecological conditions and trends. The complex interactions of ecosystem resources, ecological drivers, and CAs is simplified in the Ecoregional Conceptual Model to clearly show ways in which ecosystem resources interact with one another and the relationships between ecosystem resources, CAs, and ecosystem drivers. The model provides the scientific justification for the selection of CAs and informs the selection of CEs by capturing representative ecosystem resources and their processes.

The Ecoregional Conceptual Model for the Central Yukon study area (Figure B-12) provides a coarse-scale interpretation of key ecological resources, drivers, and CAs of the seven constituent ecoregions. The model is divided into the following components:

- **Principal ecosystem resources**, including vegetation, animals, soil resources, freshwater resources, and ocean (coastal zone).
- **Ecosystem drivers**, including climate and atmospheric conditions (i.e., precipitation, temperature, cloud cover etc.) and landscape setting (i.e., geology, elevation, and proximity to ocean).
- **Anthropogenic** (land use, commercial/sport harvests, recreation) and **non-anthropogenic CAs** (climate change, fire, and invasive species).
- **Relationships between ecosystem resources** with interactions between them identifying key ecosystem processes and functions (for example, soils resources provide habitat for animals).
- **Relationships of ecosystem drivers and CAs** as external forces for ecosystem resources (for example, climate change alters composition, structure, and productivity of ecosystem resources and climatic conditions provide carbon and nitrogen setting providing essential components to the ecosystem resources).

The Conceptual Ecoregional Model will serve as a framework for measuring the cumulative impacts of all the CAs on all the CEs, providing a measure of overall current and future landscape and ecological integrity.

Section B. Introduction

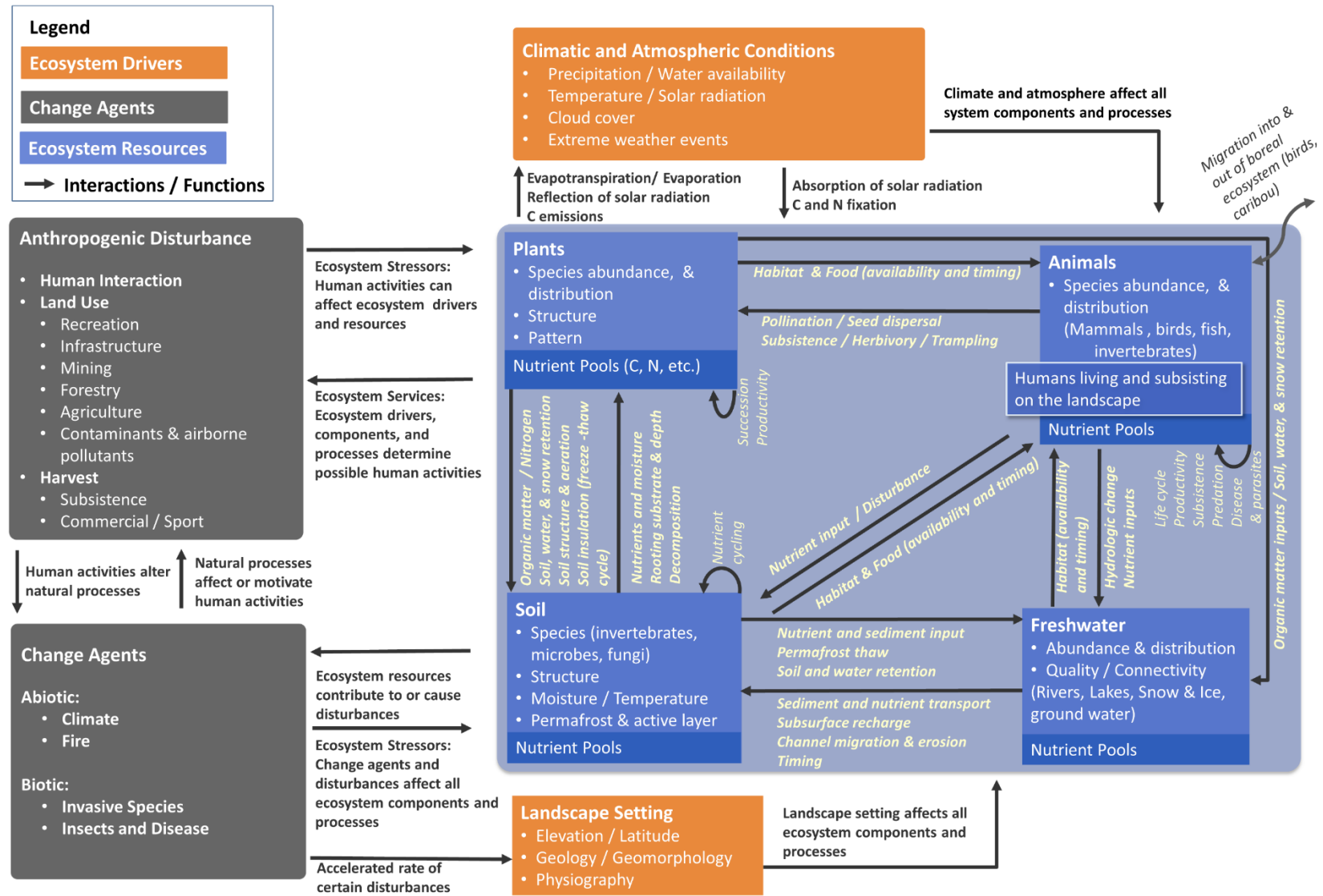


Figure B-12. Ecoregional Conceptual Model for the Central Yukon study area.

4. Assessing Current and Future Conditions

In addition to performing the core analysis between CEs and CAs, we examined the general landscape to describe overall conditions. Key to this assessment was an evaluation of landscape integrity. Landscape integrity is derived from modeling landscape condition and intactness. Landscape condition examines the level of human modification on the landscape, while intactness provides a measure of fragmentation across the region. When taken in combination with CE distributions (Figure B-13), our assessment can be used to infer overall ecological integrity of the region.

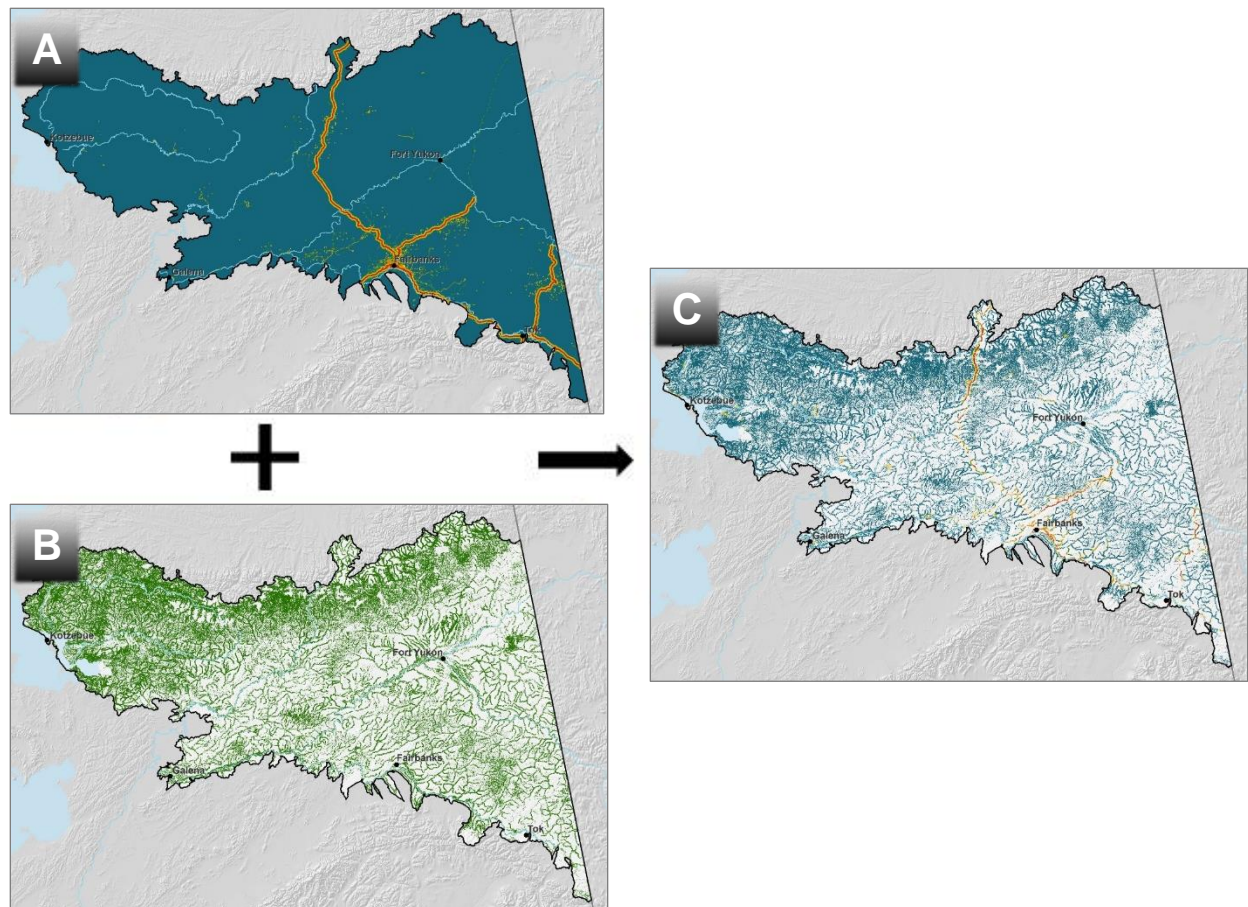


Figure B-13. Example process of assessing status of a Conservation Element (CE). Landscape condition (A) is extracted to the distribution of a CE (B) to generate the CE status (C). Warmer colors in the CE status represent areas of lower expected ecological condition.

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

5. Scope, Intent, and Limitations

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

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

Another key source of uncertainty is the inherent uncertainty in predicting future conditions. Specifically, human behavior and land use is very hard to predict, especially in the long-term. Thus, any future land use should only be considered as potential land uses. A more robust approach of future land use would require an examination of multiple scenarios to bracket the uncertainty associated with all future human land use and development. This assessment is designed to provide a model of possible future conditions, but should not be considered a prediction, nor do we assign any probability or likelihood that any given land use would happen in the future.

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

6. Literature Cited

- Bailey, R. G., P. E. Avers, T. King, and W. H. McNab (eds.) 1994. Ecoregions and subregions of the United States. U.S. Forest Service. Washington, D.C.
- BLM. 2014. The BLM's landscape approach for managing public lands. Available: http://www.blm.gov/wo/st/en/prog/more/Landscape_Approach.html
- Bryce, S., J. Strittholt, B. Ward, and D. Bachelet. 2012. Colorado Plateau rapid ecoregional assessment final report. Prepared for: National Operations Center, Bureau of Land Management, U.S. Department of the Interior. Dynamac Corporation and Conservation Biology Institute. Denver, Colorado. 183 pp.
- Harkness, M., M. Reid, N. Fresco, S. Martin, H. Hamilton, S. Auer, S. Marchenko, J. Bow, I. Varley, P. Comer, P. Crist, and L. Kutner. 2012. Seward Peninsula – Nulato Hills – Kotzebue Lowlands rapid ecoregional assessment report. Prepared for: U.S. Department of the Interior, Bureau of Land Management.
- Hess, G. R., and T. J. King. 2002. Planning open spaces for wildlife I. Selecting focal species using a Delphi survey approach. *Landscape and Urban Planning* 58:25-40.
- Jenkins, R. E. 1976. Maintenance of natural diversity: approach and recommendations. Pages 441-451 in K. Sabol, ed. *Transactions—Forty-First North American Wildlife and Natural Resources Conference*; 1976 March; Washington, D.C.
- Nowacki, G., P. Spencer, M. Fleming, T. Brock, and T. Jorgenson. 2001. Ecoregions of Alaska: 2001. U.S. Geological Survey Open-File Report 02-297 (map).
- Omerik, J. M. 1987. Ecoregions of the conterminous United States. *Annals of the Association of American Geographers* 77:118–125.
- O'Neill, S. J., T. J. Osborn, M. Hulme, I. Lorenzoni, and A. R. Watkinson. 2008. Using expert knowledge to assess uncertainties in future polar bear populations under climate change. *Journal of Applied Ecology* 45:1649–1659.
- Scolozzi, R., E. Morri, and R. Santolini. 2012. Delphi-based change assessment in ecosystem service values to support strategic spatial planning in Italian landscapes. *Ecological Indicators* 21:134–144.
- Trammell, E. J., M. L. Carlson, N. Fresco, T. Gotthardt, M. L. McTeague, and D. Vadapalli (eds.) 2015. North Slope rapid ecoregional assessment. Prepared for: the Bureau of Land Management, U.S. Department of the Interior. Anchorage, Alaska.
- Trammell, E. J., M. L. McTeague, K. W. Boggs, M. L. Carlson, N. Fresco, T. Gotthardt, L. Kenney, and D. Vadapalli. 2014. Yukon Lowlands – Kuskokwim Mountains – Lime Hills rapid ecoregional assessment technical supplement. Prepared for: the U.S. Department of the Interior, Bureau of Land Management. Denver, Colorado.

C. Abiotic Change Agents

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Summary

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

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1. Climate Change

Climate was selected as a Change Agent (CA) for all Rapid Ecoregional Assessments (REAs) by the Bureau of Land Management (BLM). Current projected climate and future changes in projected climate are assessed in this section using landscape scale model outputs. Feedback relationships between climate and other CAs (fire and permafrost) and between climate and Conservation Elements (CEs) are also addressed in this section. Climate variables assessed in this section include temperature, precipitation, summer warmth index, snow day fraction, date of freeze, date of thaw, and climate clusters (“cliomes”) that are based on monthly temperature and precipitation data. Other strongly climate-linked factors, including fire and permafrost, are addressed in Sections C.2 and C.3, respectively.

1.1 Introduction to Climate Change

The climate of far northern ecosystems is changing rapidly, resulting in thawing permafrost, altered hydrology, and shifting biological processes; warming is predicted to continue to be more extreme at high latitudes relative to almost anywhere else on the planet. Predicting the magnitude and effects of these changes is crucial to planning and adapting (Hinzman et al. 2005). Not only are Arctic and sub-Arctic systems vulnerable to climate shifts, but they are also central to feedbacks important to global systems (Chapin et al. 2005). Climate change will likely drive multiple types of change in the Central Yukon (CYR) study area. Climate variables can directly impact Coarse-filter and Fine-filter CEs, but are also part of feedback loops with other CAs, such as fire and invasive species.

Computer models that simulate relationships between climate, vegetation, and fire are important tools for understanding and projecting environmental change (Kittel et al. 2000, Rupp et al. 2007). Baseline data (1981–2010) provided information on recent climate in the CYR study area. We employed simulation models to assess current, near-term future, and long-term future climate change. Current, near-term future, and long-term future time frames were defined as decadal averages for the 2010s, 2020s, and 2060s, respectively. Throughout this assessment, seasons were defined based on standardized definitions: “winter” is December–February, “spring” is March–May, “summer” is June–August, and “fall” (autumn) is September–November. Climate data were primarily derived from datasets created and managed by the Scenarios Network for Alaska and Arctic Planning (SNAP), with subsets of the available data selected based on the needs of the project.

Historical Climate

Historical weather station data for the CYR study area were limited, particularly in the north and higher elevations, where the coldest conditions might be expected. Winter temperatures were coldest in Circle and warmest in Kotzebue, due to coastal influences, with a difference of about 6 °C. In contrast, Kotzebue stood out as the coldest community in the spring. In summer, Fairbanks was the warmest site, but variation in summer temperatures was low among regions. Annual precipitation was relatively uniform—and quite low—across the study area. Seasonally, however, patterns varied. For example, while Tok was the driest site, it received the highest precipitation in June and July. Kotzebue, in contrast, received more precipitation annually but was very dry in early summer. Mean monthly temperature and precipitation from climate

stations in the CYR study area for the period of 1981–2000 are presented in Table C-1 and Table C-2 (historical climate station data from [Alaska Climate Research Center](http://climate.gi.alaska.edu/), ACRC¹).

Table C-1. Mean monthly temperature from climate stations in the CYR study area for the period of 1981–2010 (°C).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Circle	-25.9	-23.5	-17.1	-3.4	7.2	13.7	15.0	11.0	4.2	-7.4	-19.8	-24.1	-5.7
Fairbanks	-22.2	-18.5	-11.4	0.3	9.7	15.8	16.9	13.4	7.2	-4.3	-16.3	-20.1	-2.4
Galena	-22.9	-18.4	-13.1	-3.3	7.4	14.8	15.9	12.4	6.7	-4.7	-15.3	-19.9	-3.3
Kotzebue	-19.3	-18.2	-17.2	-10.4	-0.1	7.6	12.6	10.9	5.7	-4.3	-12.7	-16.5	-5.1
Tok	-24.1	-19.2	-12.1	-0.3	7.9	13.5	15.3	12.1	5.8	-5.6	-17.9	-22.6	-3.9

Table C-2: Mean monthly precipitation from climate stations in the CYR study area for the period of 1981–2010 (rainwater equivalent in mm).

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Circle	14.0	10.4	6.4	8.6	16.0	52.3	47.8	48.3	29.7	23.4	16.3	16.8	289.8
Fairbanks	14.7	10.7	6.4	7.9	15.2	34.8	54.9	47.8	27.9	21.1	17.0	16.3	274.6
Galena	16.8	16.8	14.5	7.9	10.2	36.3	50.0	56.6	36.1	26.9	19.6	22.6	314.2
Kotzebue	15.7	16.8	11.2	13.7	10.4	14.7	36.8	55.4	40.1	25.7	19.6	19.3	279.4
Tok	8.6	5.3	5.3	4.3	16.8	52.3	55.4	27.2	21.8	15.2	15.5	12.2	240.0

1.2 Methods

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

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

Averages of the five best-performing GCMs were downscaled to 771-m resolution for Alaska using the Delta method (Fowler et al. 2007, Prudhomme et al. 2002) and PRISM (Parameter-

¹ See <http://climate.gi.alaska.edu/>

elevation Regressions on Independent Slopes Model) interpolated data (Daly et al. 2008), which takes into account slope, elevation, aspect, and distance to coastlines. The five GCM average was selected to minimize uncertainty resulting from model bias, and to match other climate change work done in Alaska. The downscaling method was calibrated based on historical climate data from 1971–2000. Decadal averages were generated instead of using data for single years to reduce error resulting from the stochastic nature of GCM outputs, which mimic the true inter-annual variability of climate.

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

This assessment focused on the A2 emissions scenario, which describes a heterogeneous world with high population growth, slow economic development, and slow technological change. As such, it ultimately predicts high carbon emissions, as less developed nations are driven to higher burning rates of dirty fuels, with few population checks or cleaner technologies to temper these emissions. However, the most rapid change does not occur until later in this century, with considerable lag time, since slow economic development suggests few immediate increases in worldwide fuel use. Several recent studies show that many factors that are likely to increase greenhouse gas concentrations now appear greater than they were originally calculated to be for the A2 scenario. These include biological and geological carbon-cycle feedbacks, such as the weakening of the oceanic carbon sink and the acceleration of release of methane from thawing permafrost, and actual measurable increases in greenhouse gas emissions, which have accelerated recently (Fussel 2009). The A2 scenario outputs fall between those of RCP 6 (a mid-range pathway in which emissions peak around 2080, then decline) and RCP 8.5, the most extreme pathway, in which emissions continue to rise throughout the 21st century (Rogelj et al. 2012).

In this report, we examine the relationship between current, near-term, and long-term climate variables. Due to the formatting of climate data as decadal means, current climate was represented by model output for the decade 2010–2019, near-term climate was represented by the decade 2020–2029, and long-term climate was represented by the decade 2060–2069. All data presented in map form in the Results section have been served in raw form at 771-m resolution. It was determined that producing tabular output for all 5th-level HUCs would be cumbersome and of little use to managers. However, given the particular interest in changing climate in communities and immediately surrounding areas, we extracted data for all 5th-level HUCs that contain communities. Some of these outputs are presented in tabular form.

The REA included a comparison of the distribution of CEs with the status of CAs, termed the core analysis, and a management-driven analysis of specific questions, termed Management Questions (MQs). For the purposes of addressing both the MQs and the core analysis, we provided both primary and derived climate data as described above and as listed below in Table C-3. These datasets were used in the discussion and analysis of climate change. A subset of these data was also selected to analyze the potential impacts of climate change on CEs, based on attributes and indicators determined from the literature. These datasets were used in

conjunction with CE distributions as the basis for the spatial analysis of the potential impacts of CAs on CEs.

Table C-3. Climate source data used in the REA analysis.

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

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

Temperature

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

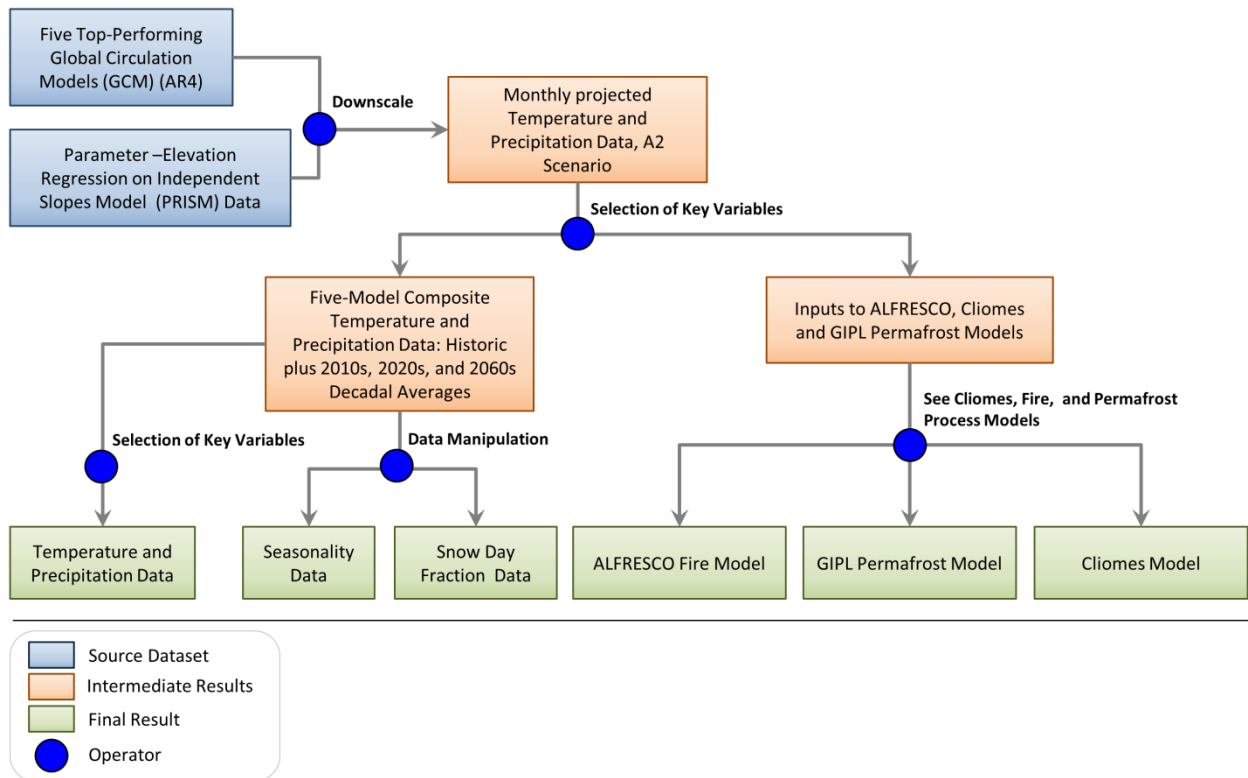


Figure C-1. Process model of downscaled climate products.

Precipitation and Snow Day Fraction

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

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

Date of Freeze, Date of Thaw, and Length of Growing Season

Estimated ordinal days of freeze (DOF) and thaw (DOT) are calculated by assuming a linear change in temperature between consecutive months. Mean monthly temperatures are used to represent daily temperature on the 15th day of each month. When consecutive monthly midpoints have opposite sign temperatures, the day of transition (freeze or thaw) is the day between them on which temperature crosses 0 °C. These calculations are only an estimate of

the true occurrence of freeze and thaw. True transitions across the freezing point may occur several times in a year, or not at all. Moreover, it should be kept in mind that these metrics are not equivalent to notions of freeze and thaw (or “freeze-up” and “breakup”) in common parlance, since these generally refer to the behavior of river ice, sea ice, or frozen soils. Lag times can be expected before these occurrences take place, and these lag times will vary based on characteristics of the water body in question. However, changes in these metrics between time periods can be used as estimates or proxies for changes in ecologically important variables that depend on seasonal timing or season length.

The length of growing season refers to the number of days between the days of thaw and freeze. It is measured in units of time (days). Although length of growing season (LOGS) does not correspond exactly to any ecological or social metric of summer season length, the term is used in this assessment in order to maintain consistency with source datasets and with other REA reports, which use the same terminology. Selecting a single metric and associated term to represent the length of the warm season is problematic, because different thresholds and lag times apply to different variables. With regard to most management questions, projected changes in LOGS may prove more pertinent than total number of days. Changes over time can serve as a proxy for equivalent changes in several related metrics, including actual growing season length for given species of vegetation and number of ice-free days on various waterbodies.

Summer Warmth Index

Summer warmth index (SWI) was calculated as the sum of mean monthly temperatures $> 0^{\circ}\text{C}$. SWI is an index that has been used to measure linkages between climate change and changes in vegetation. SWI can be used instead of DOT, DOF, LOGS, and July temperature data or in conjunctions with these metrics to determine potential impacts to CEs, depending on whether a species or assemblage is more dependent on the duration, extremes, timing, or overall warmth of the summer season. While LOGS is measured in units of time, SWI is measured in units of degrees Celsius.

Cliomes

Climate-biomes, or “cliomes,” were initially created as part of a collaborative effort between multiple agencies in Alaska and Canada (SNAP 2012). Cliomes refer to climate groupings derived by clustering regions of greatest similarity based on baseline climate variables (12 months of downscaled temperature data and 12 months of downscaled precipitation data for the period of 1971–2000). At the core of the project was the idea of using progressive clustering methodology, existing land cover classifications, and historical and projected climate data to identify areas likely to undergo ecological pressure, given climate change. Cliome results and data are intended to serve as a framework for research and planning by land managers and other stakeholders with an interest in ecological and socioeconomic sustainability.

Using climate projection data from SNAP and input from project leaders and participants (SNAP 2012), the project modeled projected changes in cliomes. The 18 Cliomes used in this project were identified using the combined Random Forests™ and Partitioning Around Medoids clustering algorithms, which are defined by 24 input variables (monthly mean temperature and precipitation) used to create each cluster.

This overview focuses on defining these clusters as characteristic climate types, rather than as vegetation-linked or biome-linked groupings, although managers may be able to draw some

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

Cliomes are climate groupings that land managers—or others familiar with the current landscape—may associate with broad species assemblages or communities, although they are not directly biologically linked. However, projections from the cliomes model serve as indicators of potential change and/or stress to ecosystems, and can be used as a proxy for the magnitude of climate change expected. Cliomes were spatially compared to four different land cover designation systems (see SNAP 2012) to help define the prevailing conditions of each cliome.

A projected shift from one cliome to another indicates that systems are likely to experience stress due to changes in climate conditions. As a result, species assemblage may change. A one-to-one correspondence between cliome change and species assemblages is not expected, however, since they represent very different ways of looking at habitat. While all 18 cliomes were created so as to be as mathematically disparate as possible, the difference between mean values (“medoids”) for any two clusters varies. A shift from cluster 1 to cluster 18 represents the greatest possible change, within the confines of the original clustering area. If this difference is defined by a value of approximately 1.0, the relative magnitude of all other possible shifts can be compared in terms of that difference. Table C-4 shows the relative distances between clusters.

Table C-4. Relative differences of mean values (“medoids”) between 18 cliomes (climate clusters).

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

Uncertainty

Uncertainty and stochasticity are inherent to the predictive models used to create climate projections. Predictions are imperfect for several reasons, including uncertainty related to future human behavior and future releases of greenhouse gases; uncertainty related to the complexity of creating global circulation models; and uncertainty related to the inherent variability of weather, even in the face of clear climate trends.

Uncertainty related to human behavior is addressed by the IPCC via differing RPCs, but, as described under Datasets, divergence in model outputs remains minor until late in the century, beyond the scope of this project. Uncertainty related to disparities in modeling methods, assumptions, and accuracy are addressed, also as described under Datasets, by using a composite of the five regionally-best-performing GCMs. Our methods for addressing the third source of uncertainty—that is, uncertainty related to the models’ propensity to mimic the natural month-to-month, year-to-year, and even decade-to-decade variability seen in real climate data—will be discussed further below, in the separate Temperature and Precipitation sections.

1.3 Results

Due to the resolution of the climate data and the most appropriate and manageable level to discuss and analyze it, some outputs were given in tabular form at the resolution of ecoregions. These ecoregions were carefully selected, based on examination of the published literature and additional application of expert opinion, in order to capture east-west ecological zones as well as north-south delineations (Nowacki et al. 2001). Nine such ecoregions were defined within the CYR study area, as shown in Figure C-2. In cases where the CYR study area included only small portions of ecoregions as defined by Nowacki et al. (2001), regional analysis would not have offered enough data to be meaningful. Thus, we combined these fragments into larger regions with some similar ecological characteristics, e.g. the Tanana-Kuskokwim-Yukon lowlands.

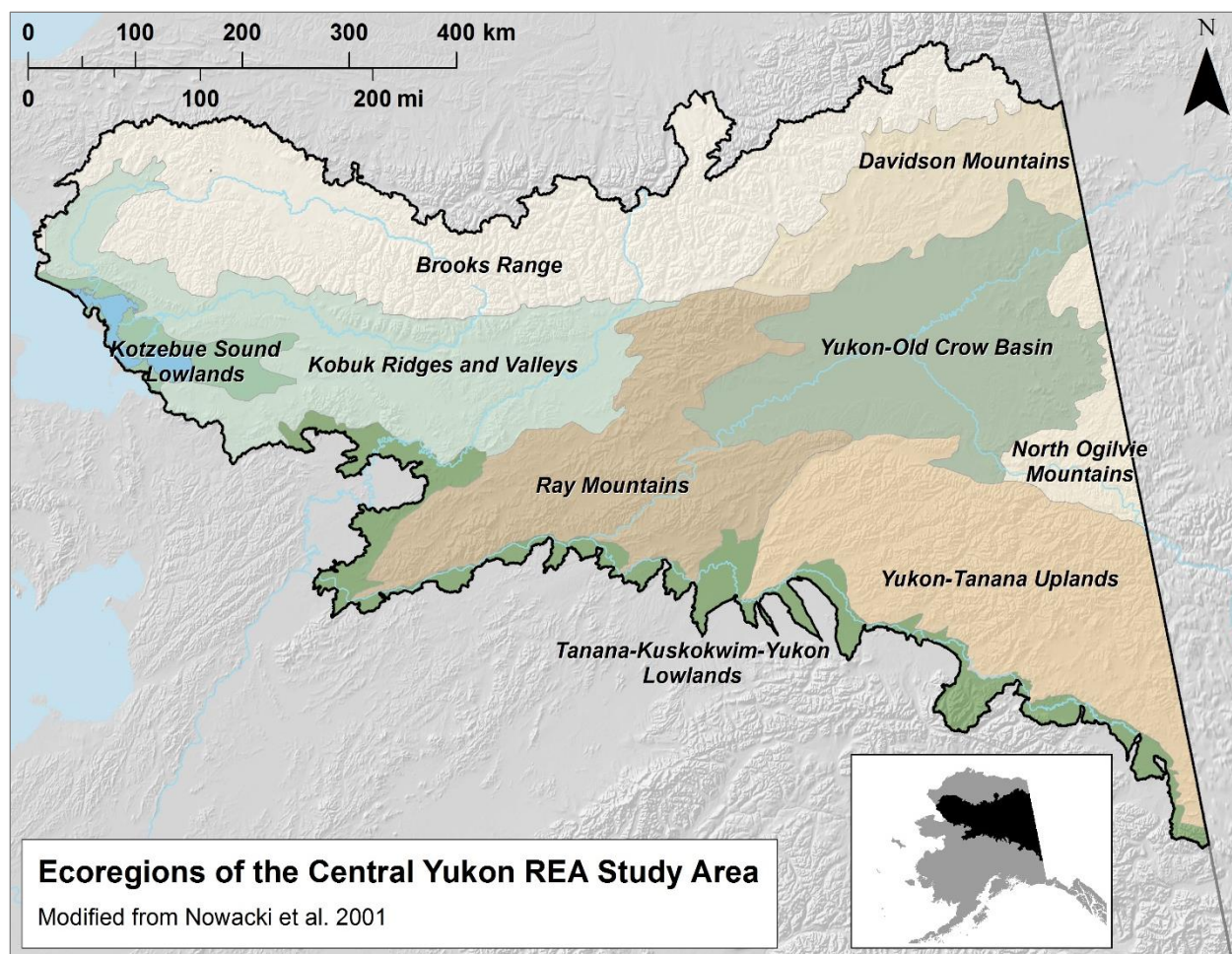


Figure C-2. Ecoregions modified from Nowacki et al. (2001) within the CYR study area.

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

Temperature Uncertainty Analysis

As described under Methods, some of the major sources of uncertainty in temperature projections were addressed via model selection. However, we additionally sought a way to address the uncertainty associated with the natural stochasticity built into all GCMs. Each of the five models used to create the composite model has its own built-in variability that mimics the natural fluctuations of weather patterns across relatively short time frames. GCMs are designed to replicate accurate mean values for climate variables, as well as normal variability in weather patterns attributable to such factors as daily and monthly weather variations and longer-term fluctuations such as the Pacific Decadal Oscillation. In any given model, some months will be warmer than expected, and some cooler. Thus, the standard deviation among model outputs can serve as a measure of uncertainty. Assessments based on mean GCM values can be considered to be more robust if trends in those mean values fall outside at least one standard

deviation of the means of multiple models, suggesting a greater than two-thirds likelihood that a trend is attributable to climate change rather than to weather variability.

Cross-model standard deviations for temperature are shown in Table C-5. These values are calculated across decades and across all pixels in the study area. Inter-model variability is higher in winter and spring months than in summer and autumn. When averaged across all twelve months, inter-model variability is fairly consistent across decades. Using a single averaged value helps the potential variation for any given cell is, on average, 1.2 °C (Table C-5). Thus, projected shifts in temperature greater than 1.2 °C are likely (68%) to actually be observed, while changes of less than 1.2 °C could be due to model variability and may not represent actual changes. Changes of more than 2.4 °C (two standard deviations) represent actual changes that are likely (95%) to be significant.

Table C-5. Inter-model variability (one standard deviation) for monthly temperature projections by decade.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	mean
2010s	2.6	1.2	2.3	1.6	0.7	1.2	0.8	0.7	0.6	0.8	1.8	0.9	1.3
2020s	1.8	2.5	1.7	1.4	0.9	0.8	0.5	0.5	0.4	0.4	1.1	2.2	1.2
2030s	2.0	2.3	1.2	1.4	0.4	0.7	1.4	0.8	0.6	1.3	2.2	1.4	1.3
2040s	1.2	1.9	1.8	1.3	1.1	1.0	1.2	1.0	0.7	1.3	1.2	2.5	1.4
2050s	2.5	1.7	1.0	1.4	0.8	1.0	1.6	0.9	0.6	0.9	0.7	0.9	1.2
2060s	2.5	1.3	1.7	0.8	0.6	1.3	1.2	1.0	0.8	0.8	1.1	1.3	1.2
mean	2.1	1.8	1.6	1.3	0.8	1.0	1.1	0.8	0.6	0.9	1.4	1.5	1.2

Temperature

Results are presented region-wide and by ecoregion, including maximum and minimum values at the 771-m pixel resolution used in the model.

Model outputs show warming trends for the warmest month of the year (Figure C-3). Trends are more pronounced in the long-term future than in the near-term future. When analyzed by ecoregion (Figure C-4), it becomes clear that variability across regions is high, and variability is particularly pronounced within regions (range of values shown by bars).

In the coldest month, trends are more pronounced than in the summer, and are also more pronounced in the long-term future than in the near-term future (Figure C-5). Figure C-6 shows these trends by ecoregion.

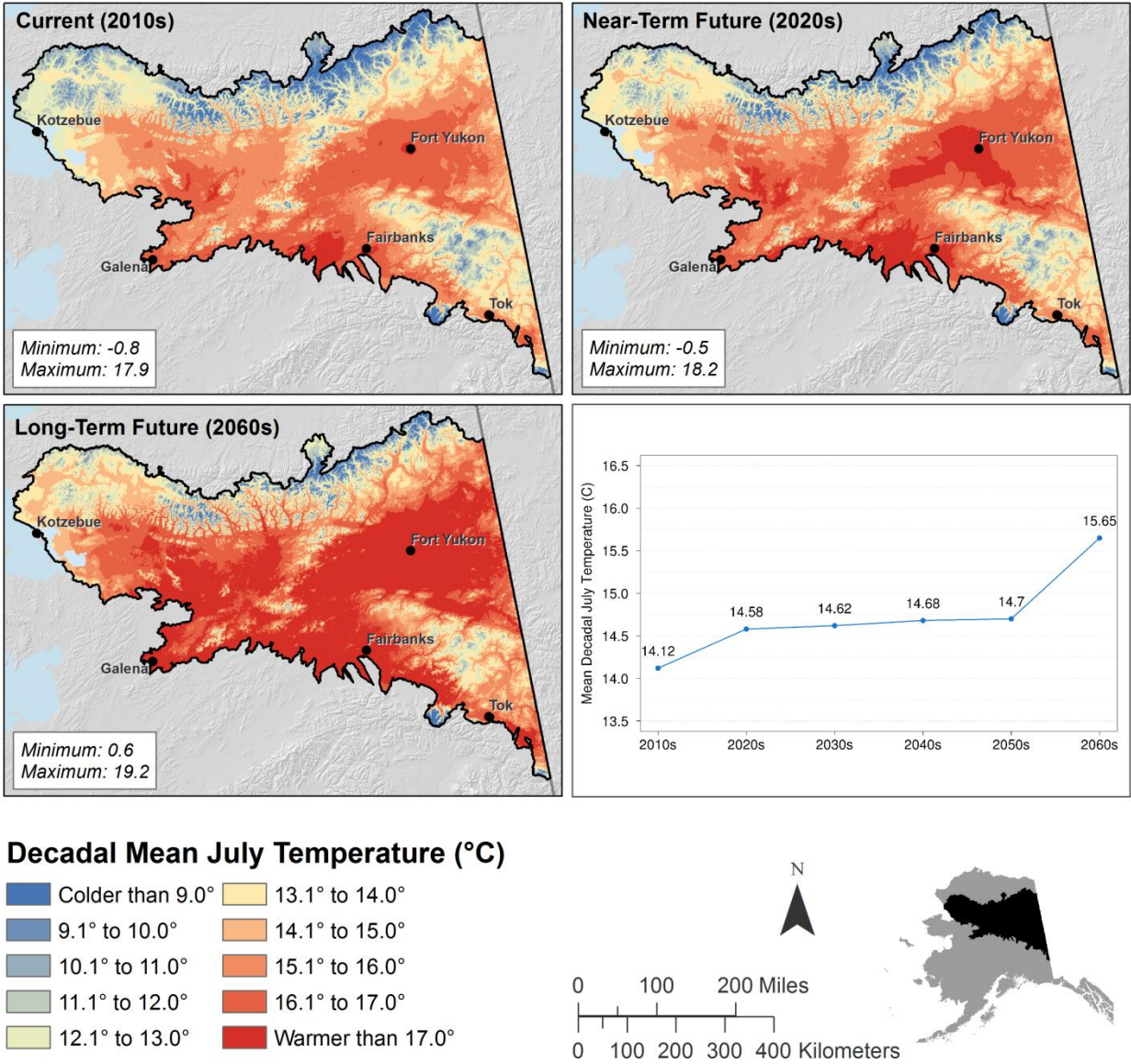


Figure C-3. Current, near-term, and long-term mean July temperature (°C) in CYR study area.

Section C. Abiotic Change Agents

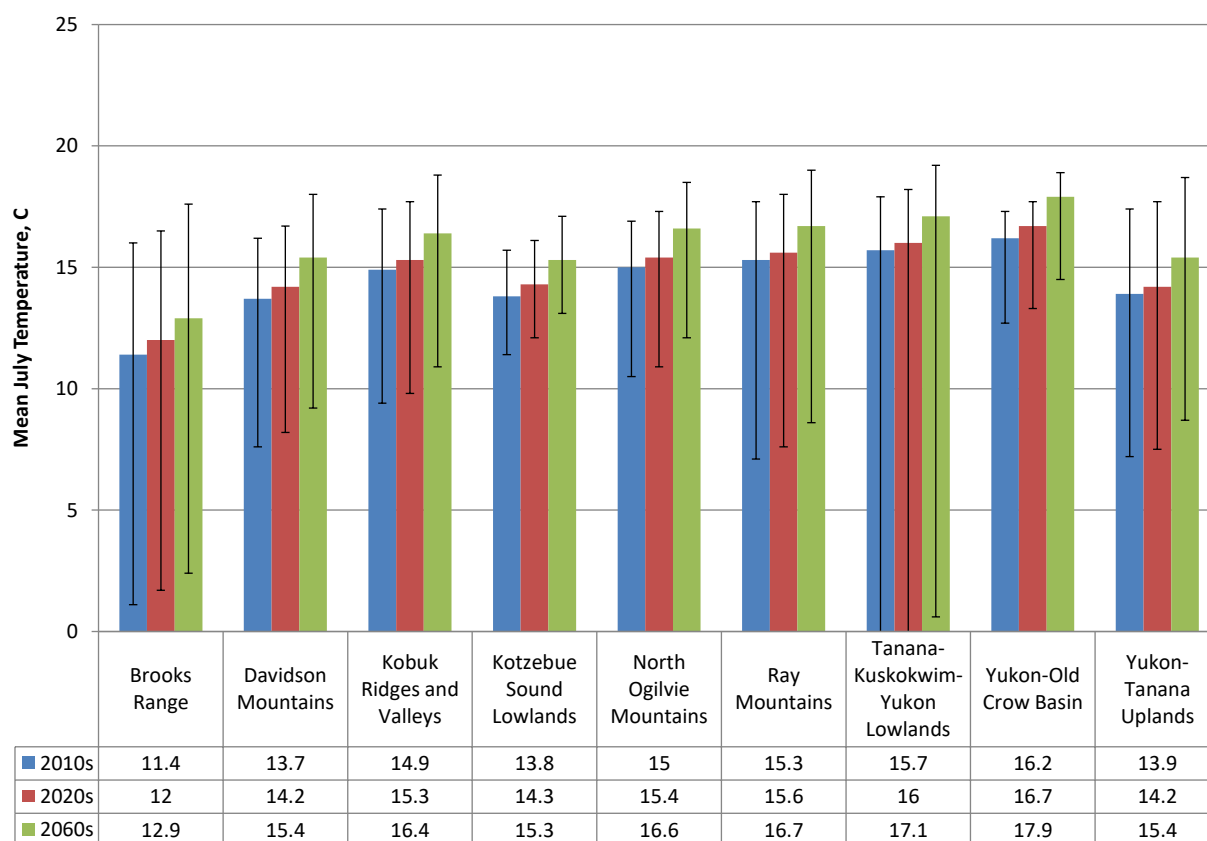


Figure C-4. Mean July temperature projections (°C) by ecoregion. Colored bars represent mean values, and bars show the full range of values for all pixels.

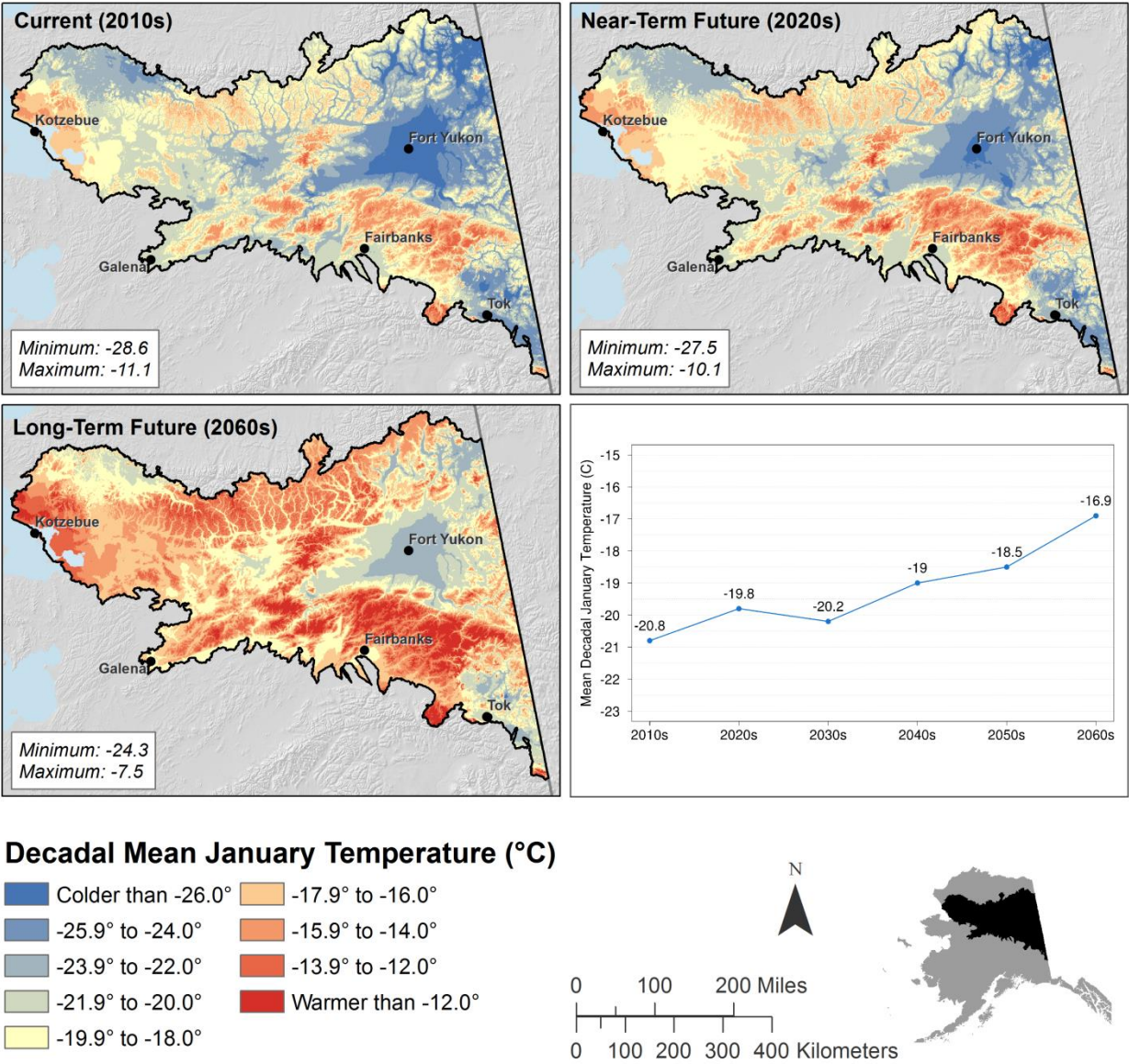


Figure C-5. Current, near-term, and long-term mean January temperature (°C) of the CYR study area.

Section C. Abiotic Change Agents

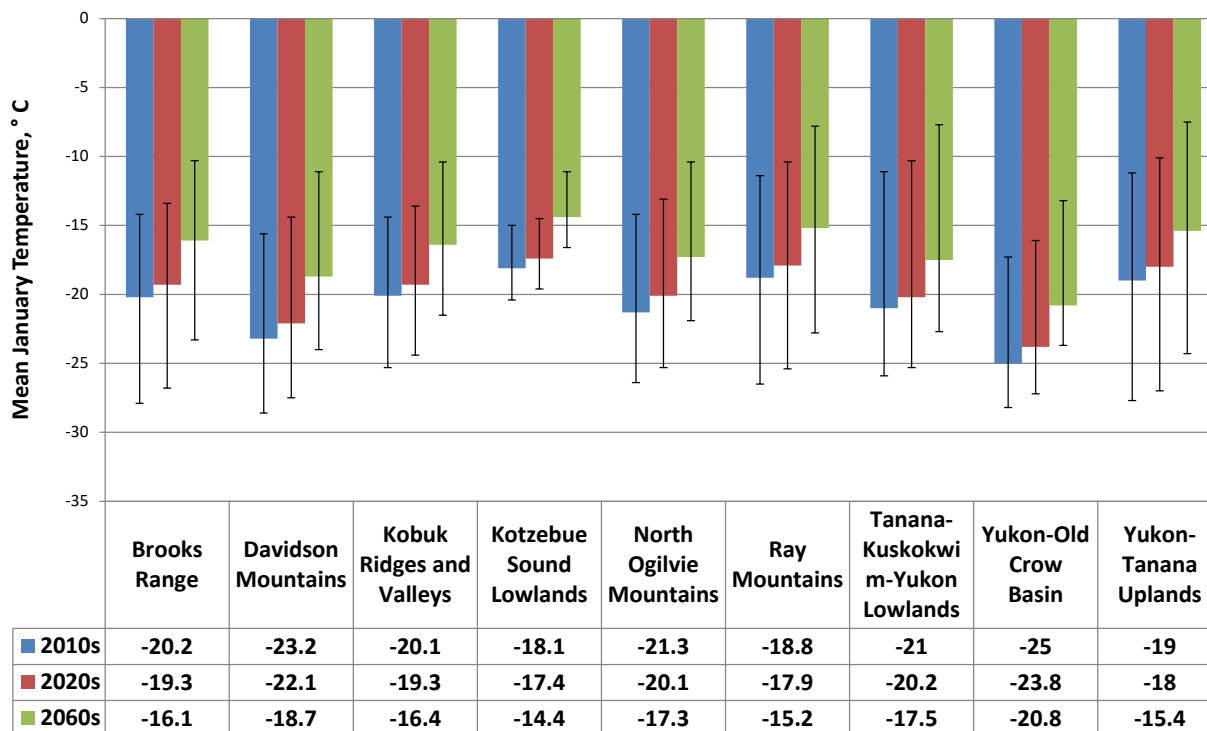


Figure C-6. Mean January temperature projections (°C) by ecoregion. Colored bars represent mean values, and bars show the full range of values for all pixels.

Summer Warmth Index

SWI ranges widely across the study area: from colder ecoregions, such as Brooks Range (33.4 °C), to the warmest ecoregions, such as Yukon-Old Crow (57.6 °C) (Figure C-7). Increases in SWI of between 6 and 7 °C are projected across the REA. Changes in SWI are expected to be relatively similar among ecoregions in the REA; however, the ecological results of these changes may be quite different.

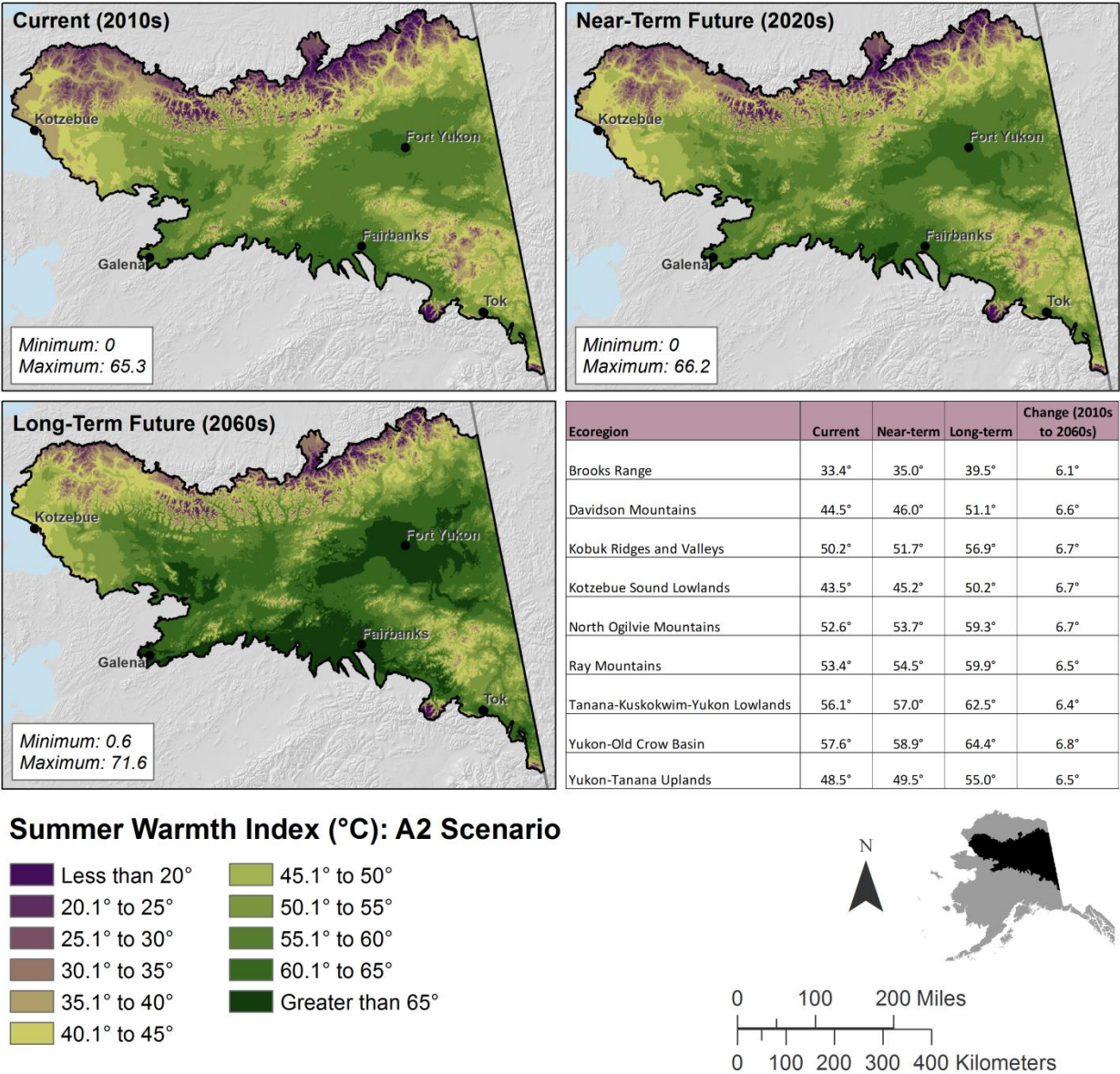


Figure C-7. Current, near-term, and long-term SWI in the CYR study area. Table summarizes mean SWI values by ecoregion with total long-term change.

Precipitation Uncertainty Analysis

As for temperature projections, assessments based on mean GCM values can be considered more robust if trends in those mean values fall outside at least one standard deviation of the means of multiple models. Because precipitation is more variable than temperature across space and time, variability and uncertainty tend to be greater for precipitation than for temperature.

Cross-model standard deviations for precipitation are shown in Table C-6. These values are averaged across decades and across all pixels in the study area. The potential variation for any given cell is, on average, 5.5 mm (Table C-6). Thus, shifts greater than 5.5 mm are likely (68%) to represent actual change due to shifting climate rather than just variability in weather patterns.

Changes of more than 11 mm (two standard deviations) are highly likely (95%) to be attributable to climate change. This, however, should be viewed as an estimate as inter-model variability appears to be higher in summer months than the rest of the year.

Table C-6. Inter-model variability (standard deviation) for monthly precipitation projections by decade.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	mean
2010s	3.8	2.2	2.4	1.7	3.3	9.3	5.8	8.1	8.5	4.0	2.8	3.9	4.7
2020s	4.4	2.9	2.3	2.4	2.7	13.9	6.8	12.2	7.4	3.8	4.5	5.2	5.7
2030s	5.9	3.2	2.9	3.3	3.3	5.1	8.3	10.3	6.6	4.9	5.9	3.5	5.3
2040s	2.9	3.9	2.0	1.8	4.4	8.1	7.7	8.5	8.4	4.1	4.1	6.3	5.2
2050s	4.7	2.9	3.3	3.7	4.6	8.3	7.2	11.5	10.4	5.8	4.9	4.2	6.0
2060s	6.5	3.1	2.5	3.7	3.2	10.4	11.4	12.0	8.8	4.2	3.7	5.9	6.3
mean	4.7	3.0	2.6	2.8	3.6	9.2	7.9	10.4	8.4	4.5	4.3	4.8	5.5

Precipitation

Currently, precipitation varies widely across the region, from a minimum of about 220 mm of annual rainwater equivalent to a maximum of about 1900 mm. The wettest values are represented by only a very small number of pixels, in high mountain areas; the majority of the region does not experience more than 550 mm annually. The driest zones cover a relatively large area of the Interior flats, centered around Fort Yukon.

Model outputs project slight increases in precipitation over time, across all seasons. Annual precipitation (Figure C-8) is projected to increase fairly steadily, but not dramatically, over time. When these results are broken down by ecoregion and by season (Figure C-9, Figure C-10), it can be seen that near-term increases in summer precipitation are slight or absent, while long-term changes are more noticeable, although more pronounced to the north, and less so to the south and east. In general, greater increases are expected in areas that are already wetter, suggesting that increases are fairly proportional across the entire region. Winter precipitation is also expected to see larger increases to the north, but in this case, increases are more pronounced in the near-term, and seem to level off in the long-term.

These model results suggest that near-term increases in summer precipitation could be offset by changes in seasonality and evaporation (due to temperature increases), changes in drainage (due to permafrost changes), or changes in transpiration (due to shifts in vegetation). Thus, total water availability during crucial fire-prone months may actually be lower than historical levels. And, as will be discussed under snow day fraction, increases in winter precipitation may not translate to increases in snowpack. However, it should be repeated that uncertainty in precipitation projections is relatively high.

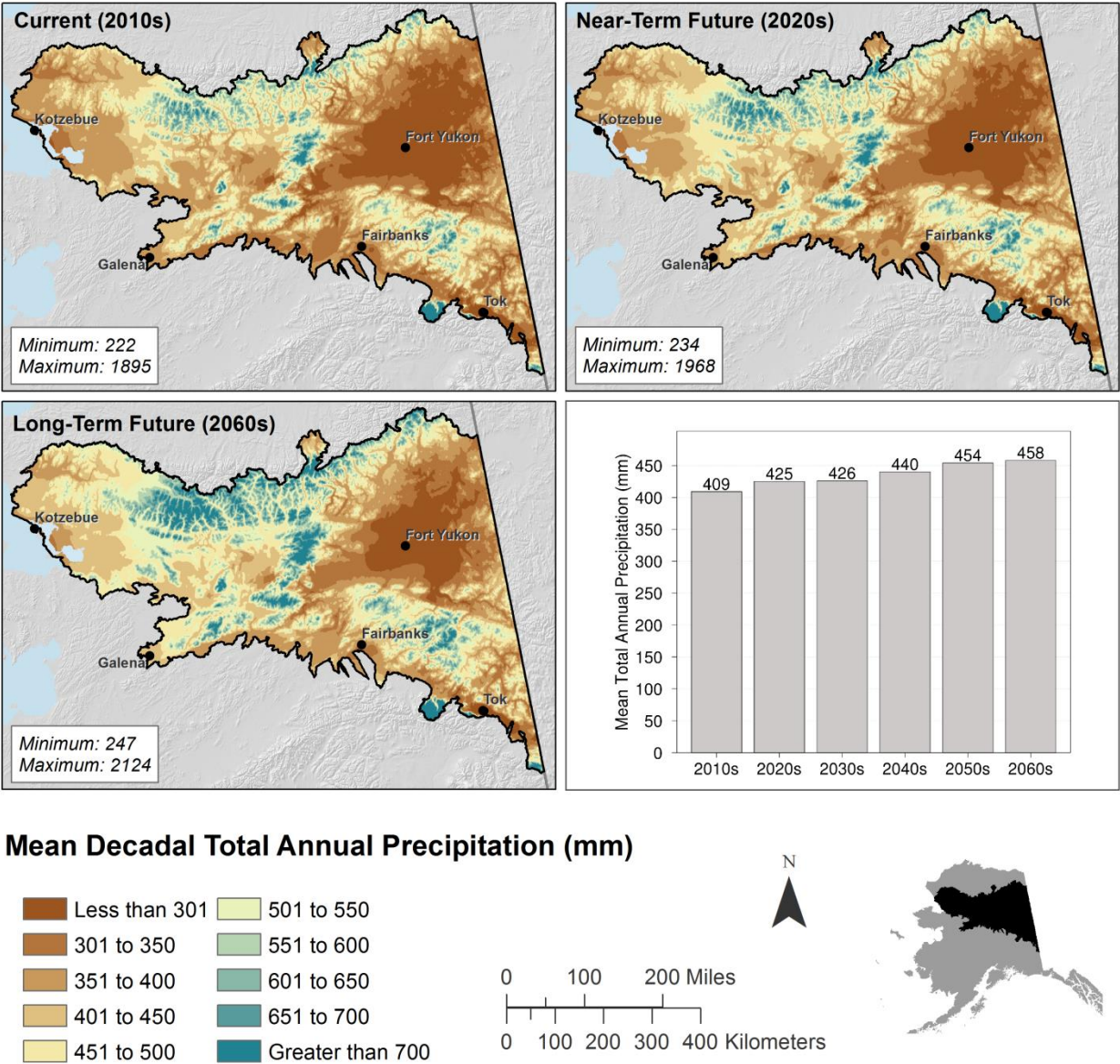


Figure C-8. Current, near-term, and long-term total mean annual decadal precipitation (mm) in the CYR study area.

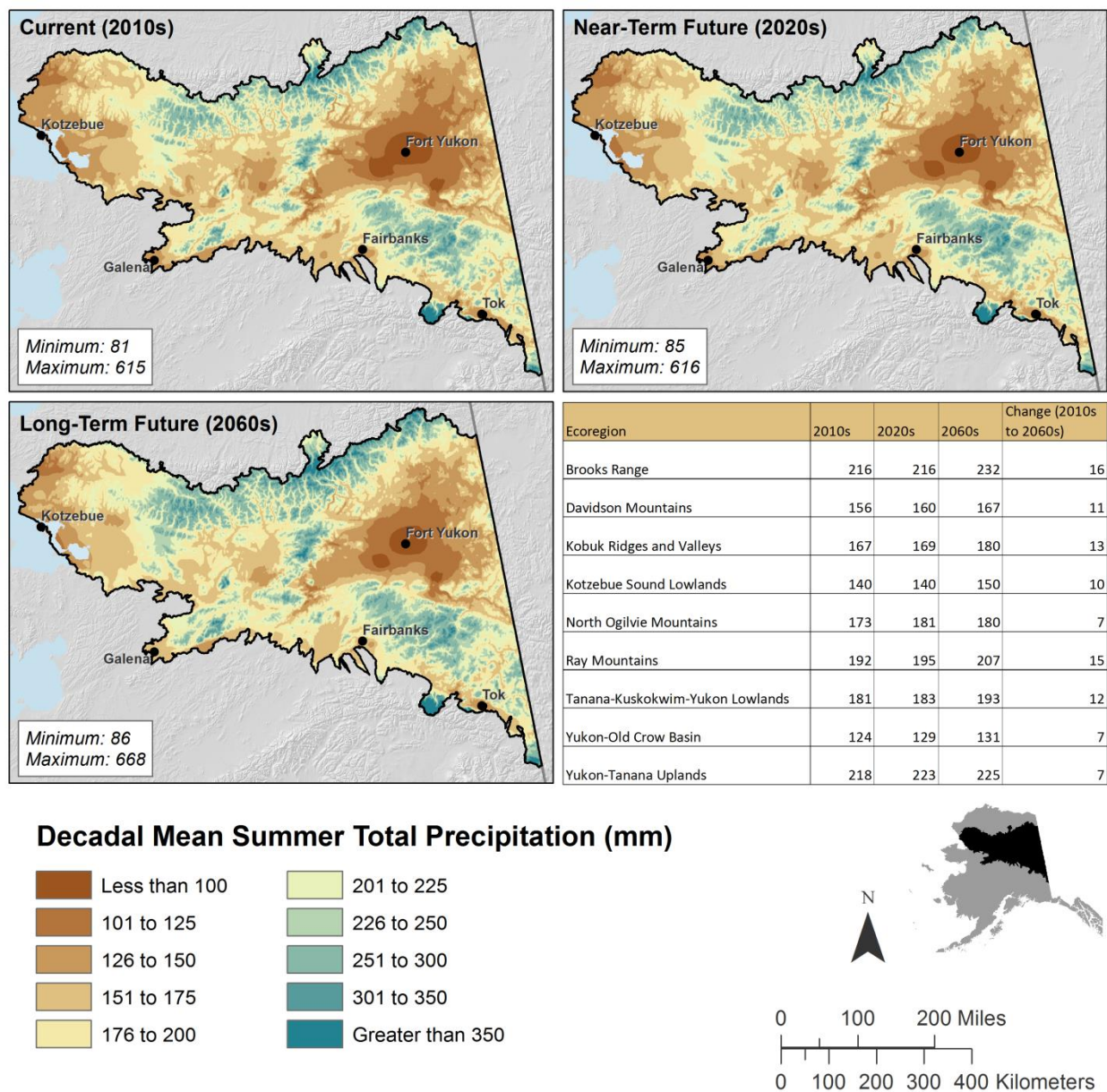


Figure C-9. Current, near-term, and long-term total mean summer decadal precipitation (mm) in the CYR study area. Table summarizes mean precipitation (mm) by ecoregion with overall change in mean precipitation.

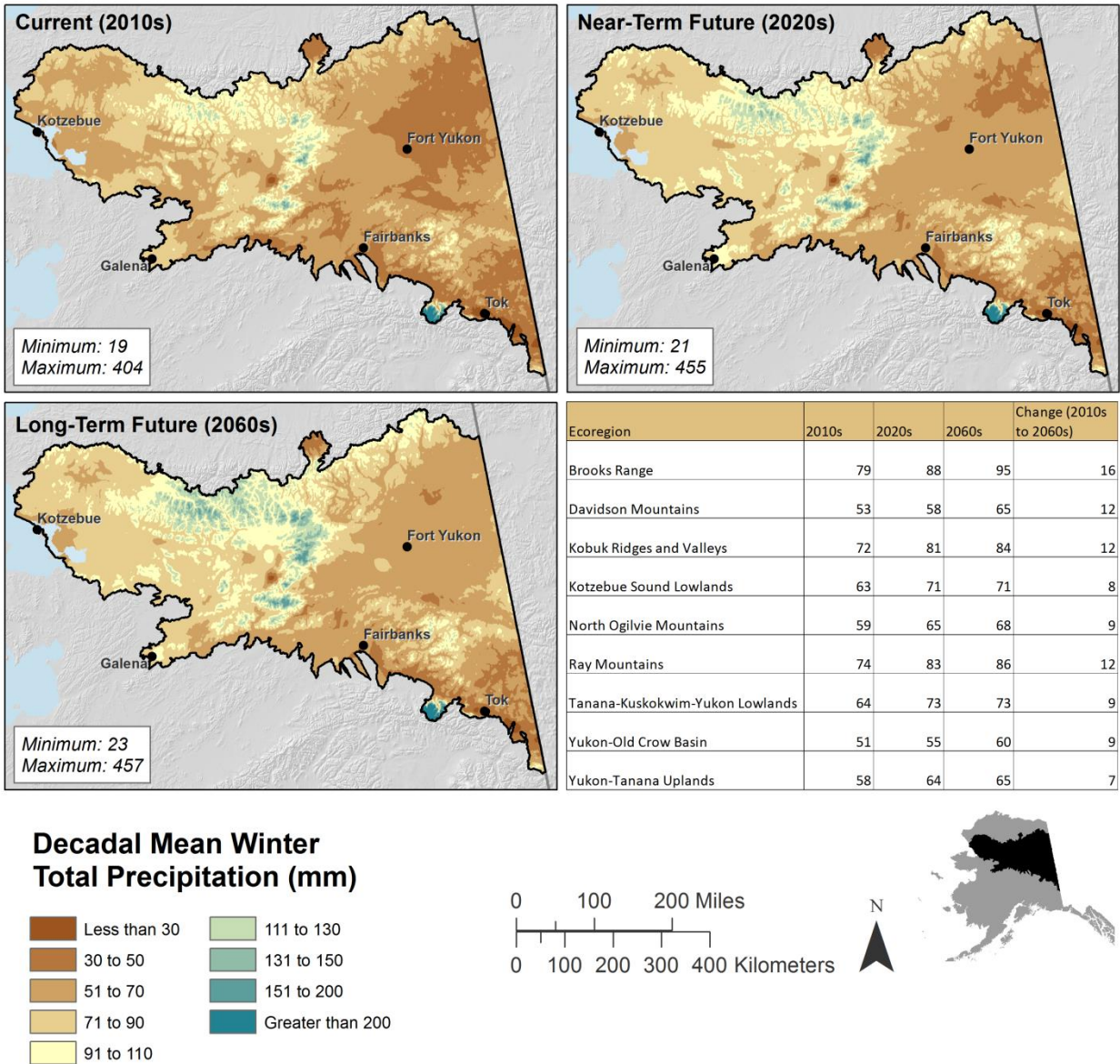


Figure C-10. Current, near-term, long-term total mean winter decadal precipitation (mm) in the CYR study area. Table summarizes mean precipitation (mm) by ecoregion with overall change in mean precipitation.

Snow Day Fraction and winter rainfall

Figure C-11 shows snow day fraction (SDF) for the shoulder season months, May and September. Snow day fraction represents the fraction of days on which precipitation would be expected to occur as snow, if it were to occur at all. Most noticeable shifts in SDF are expected in the shoulder seasons, with snow arriving later in the season, and disappearing sooner in the spring. For example, in the greater Kotzebue area, the maps show that on any many as half of all days in May on which precipitation falls, it currently arrives as snow. However, by the 2060's that percentage is expected to drop to less than 20%. Likewise, across the broad lowlands surrounding Fort Yukon, during the current decade, on 10% to 20% of days in September in which precipitation occurs, that precipitation is likely to be snow. By the 2060s, that percentage is expected to fall below 10%.

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Almost all precipitation in other months is expected to continue to occur as snow. However, even small amount of rainfall during winter months (rain on snow events) can have profound ecological impacts (Wilson et al. 2013). Figure C-12 shows the projected winter rainfall (sum of totals for November through March) for each ecoregion in the study area. Substantial increases are expected over time.

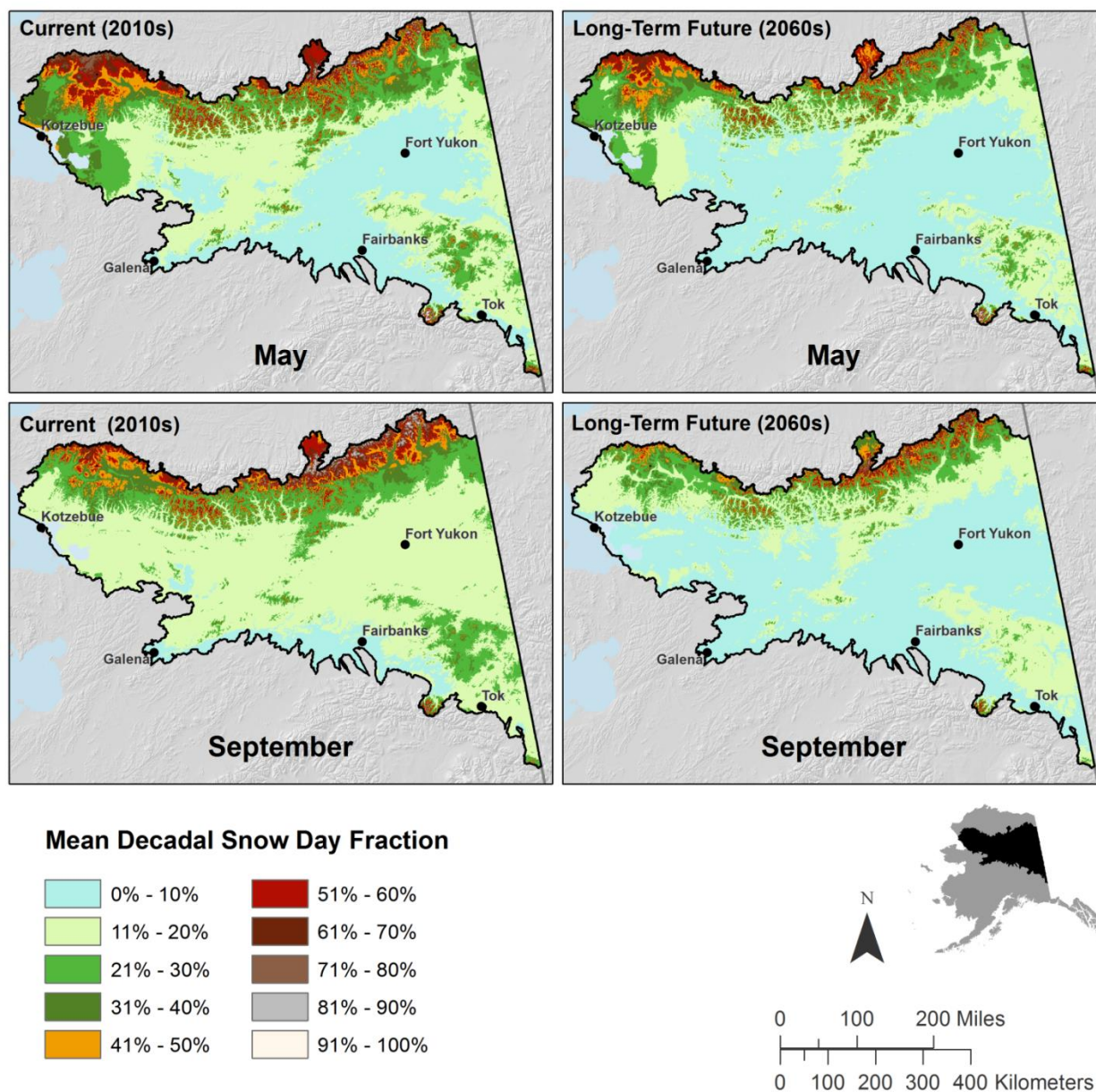


Figure C-11. Current and long-term mean decadal snow day fraction in shoulder season months May and September in the CYR study area.

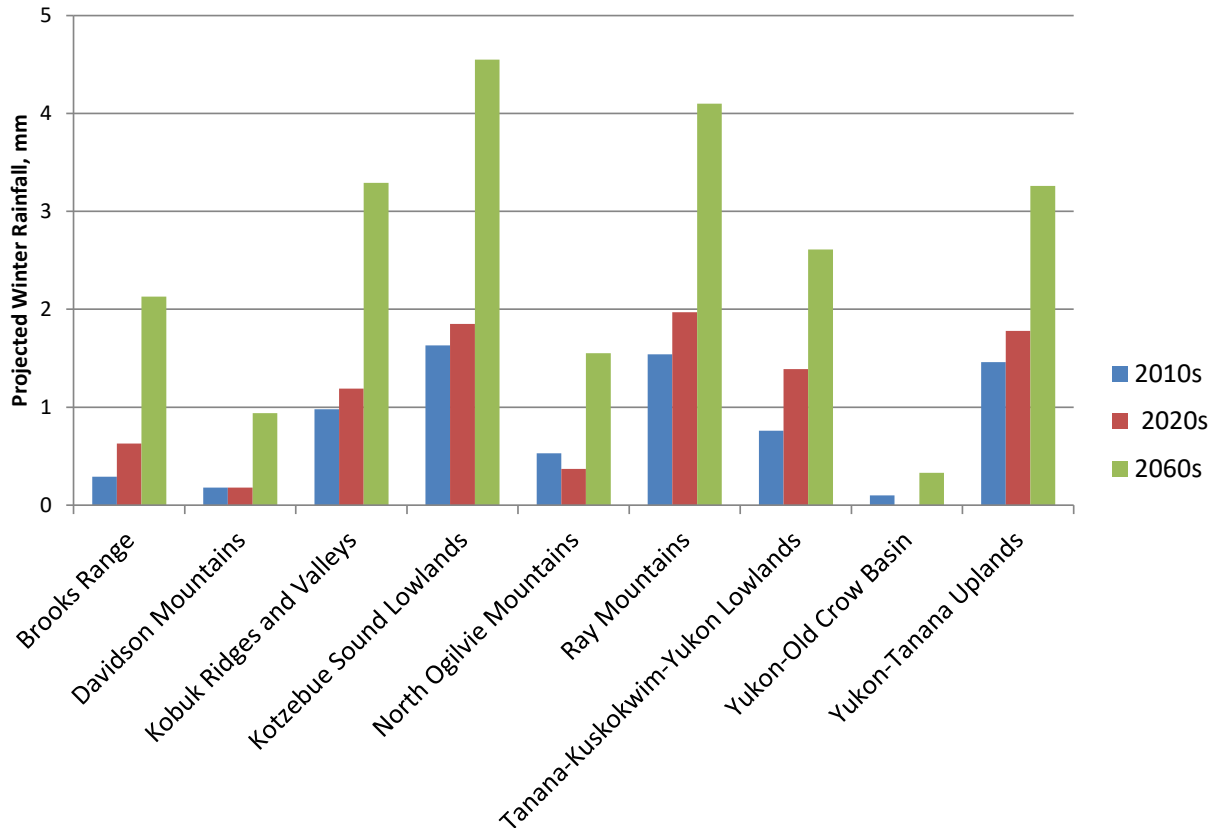


Figure C-12. Projected rainfall (mm) during the five most snow-dominated months (November-March) by ecoregion and decade.

Date of Freeze, Date of Thaw, and Length of Growing Season

Mean decadal DOF is projected to shift marginally between the current decade (2010s) and the near-term future. A change of six or seven days in the fall is projected by the long-term future, as can be seen in Figure C-13.

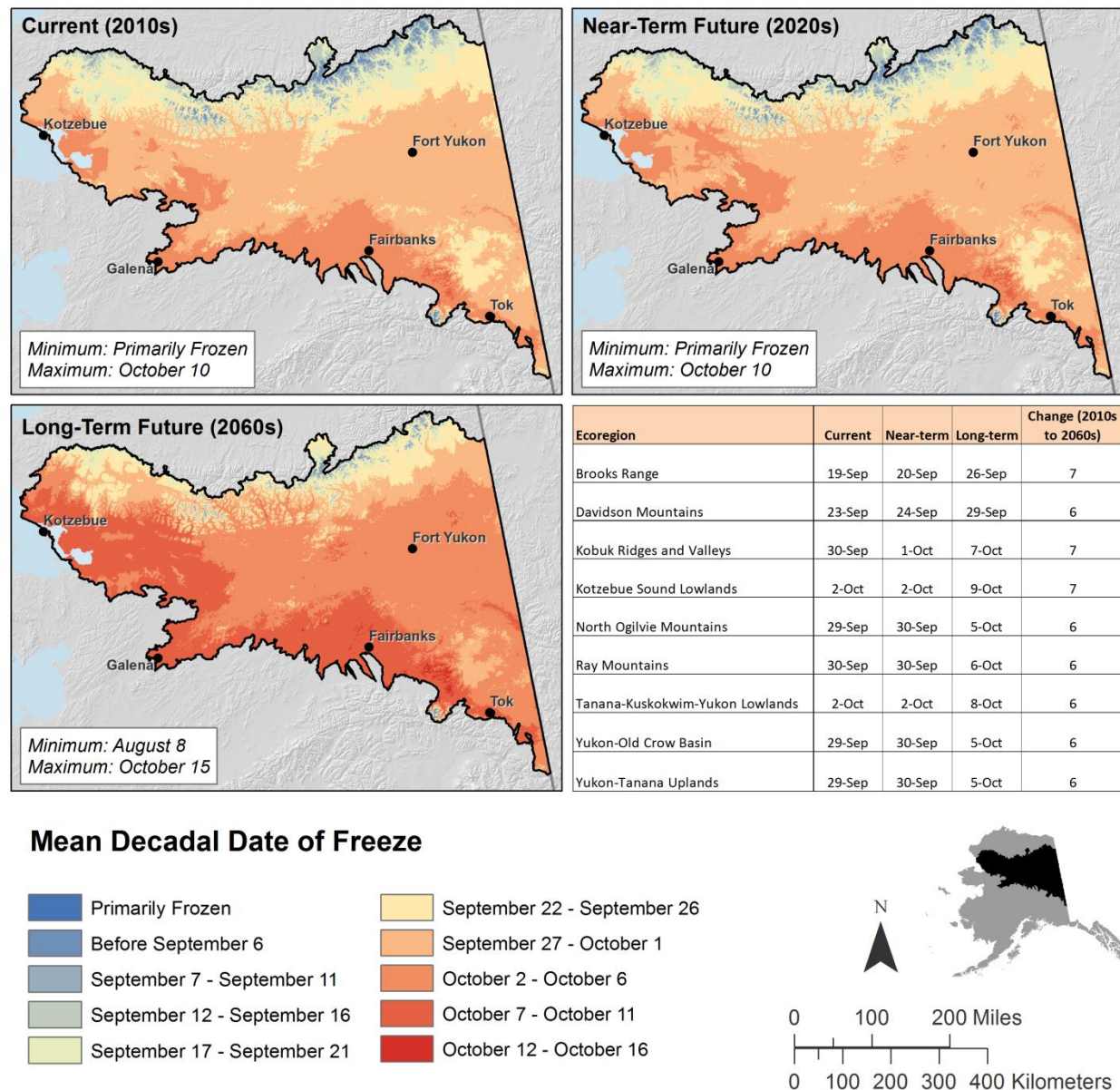
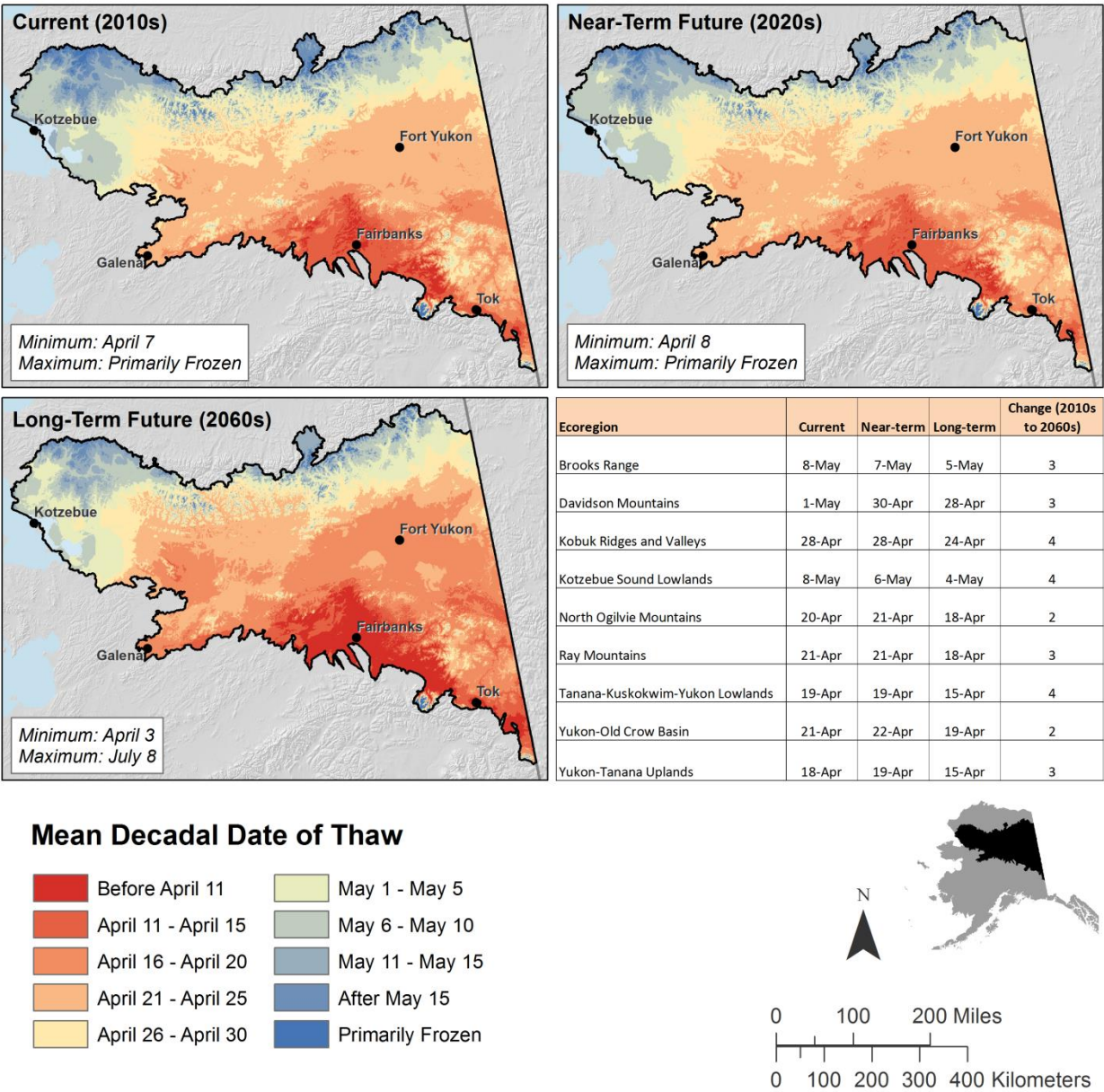


Figure C-13. Current, near-term, and long-term mean decadal date of freeze in the CYR study area.

Date of thaw is projected to shift slightly earlier between the current decade (2010s) and the near-term future as well as between near-term future and the long-term future (Figure C-14). The total change by the 2060s, 2–4 days, is less than that projected for DOF.

Length of growing season is projected to increase across the CYR study area, with subtle in the near-term future and marked shifts by the long-term future (Figure C-15). Total change in LOGS is expected to be anywhere from 6–14 days, varying spatially (Figure C-16). When analyzed by ecoregion (Table C-7), the greatest changes are noted in the Kotzebue Sound Lowlands, the Kobuk Ridges and Valleys, and the Brooks Range.

In this region with a short summer season, small changes in these LOGS are expected to trigger changes in vegetation distribution and phenology, impacting wildlife suitability and habitat.



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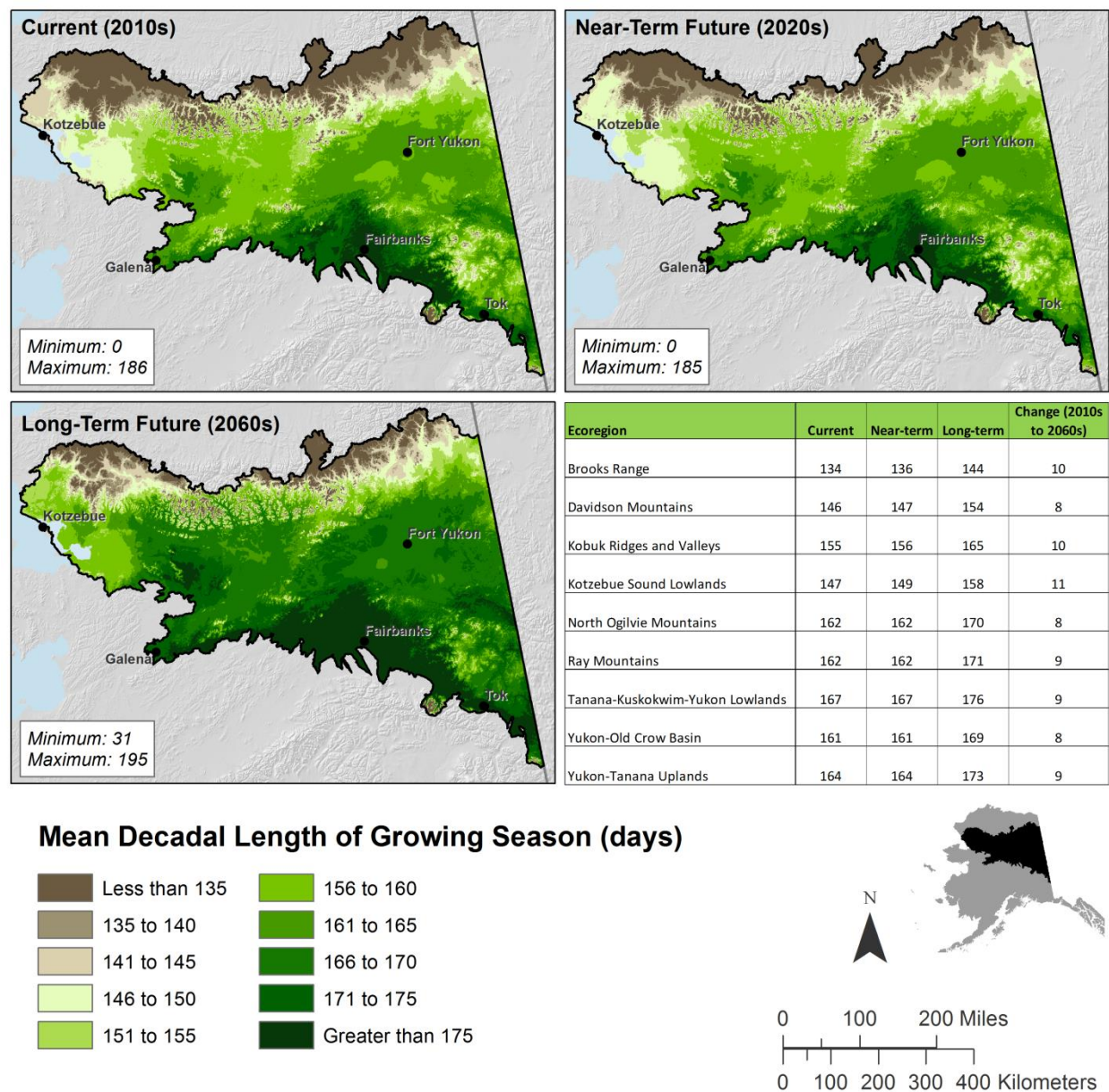


Figure C-15. Current, near-term, and long-term mean decadal length of growing season in the CYR study area. Table summarizes length of growing season by ecoregion.

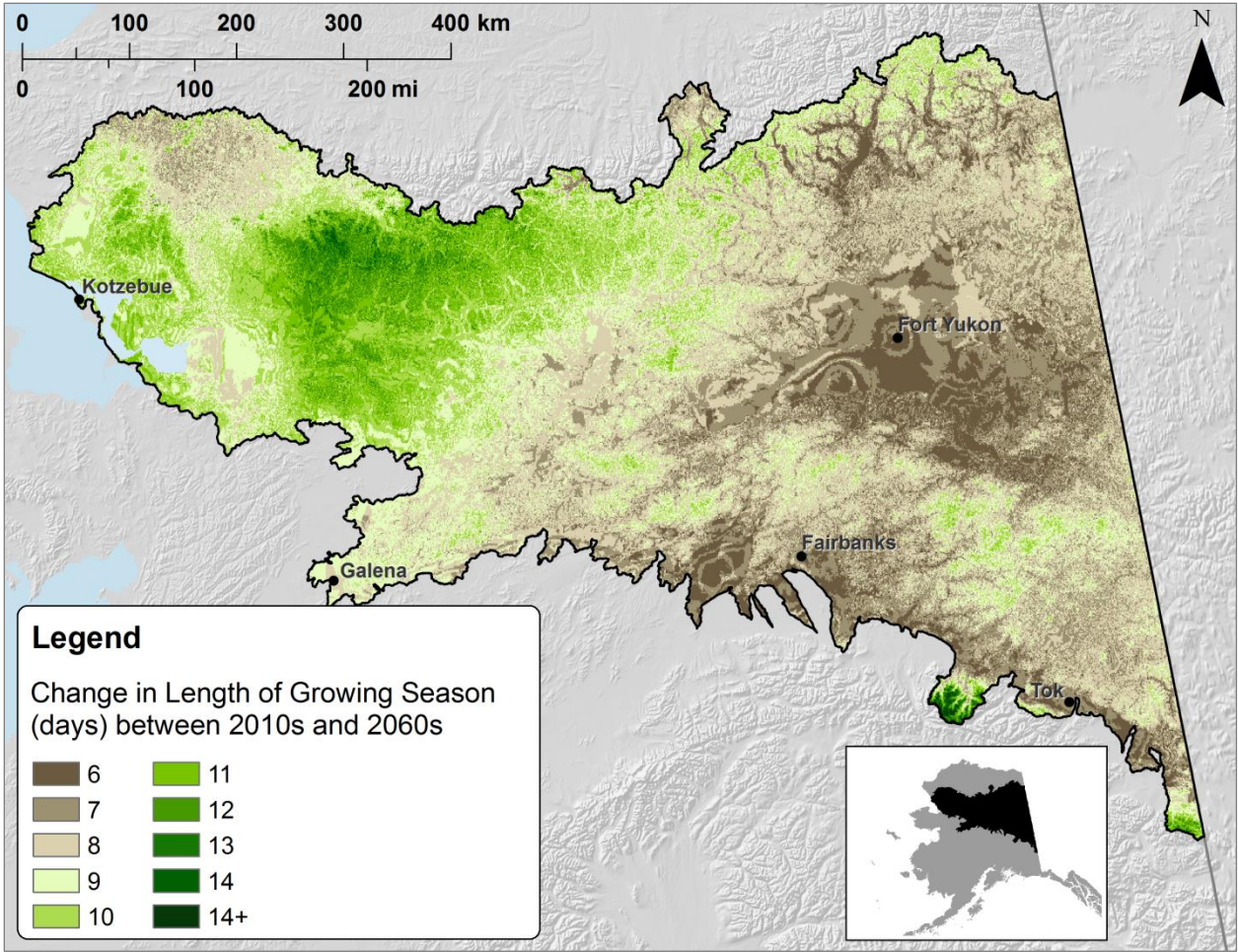


Figure C-16. Change in length of growing season (in days) from current to long-term future in the CYR study area.

Table C-7. Summary of change in DOF, DOT, and LOGS by ecoregion.

	Ecoregion	Brooks Range	Davidson Mountains	Kobuk Ridges and Valleys	Kotzebue Sound Lowlands	North Ogilvie Mountains	Ray Mountains	Tanana-Kuskokwim-Yukon Lowlands	Yukon-Old Crow Basin	Yukon-Tanana Uplands
Date of Freeze	Current	19-Sep	23-Sep	30-Sep	2-Oct	29-Sep	30-Sep	2-Oct	29-Sep	29-Sep
	Near-term	20-Sep	24-Sep	1-Oct	2-Oct	30-Sep	30-Sep	2-Oct	30-Sep	30-Sep
	Long-term	26-Sep	29-Sep	7-Oct	9-Oct	5-Oct	6-Oct	8-Oct	5-Oct	5-Oct
	Change (2010s to 2060s)	7	6	7	7	6	6	6	6	6
Date of Thaw	Current	8-May	1-May	28-Apr	8-May	20-Apr	21-Apr	19-Apr	21-Apr	18-Apr
	Near-term	7-May	30-Apr	28-Apr	6-May	21-Apr	21-Apr	19-Apr	22-Apr	19-Apr
	Long-term	5-May	28-Apr	24-Apr	4-May	18-Apr	18-Apr	15-Apr	19-Apr	15-Apr
	Change (2010s to 2060s)	3	3	4	4	2	3	4	2	3
Length of Growing Season	Current	13-May	25-May	3-Jun	26-May	10-Jun	10-Jun	15-Jun	9-Jun	12-Jun
	Near-term	15-May	26-May	4-Jun	28-May	10-Jun	10-Jun	15-Jun	9-Jun	12-Jun
	Long-term	23-May	2-Jun	13-Jun	6-Jun	18-Jun	19-Jun	24-Jun	17-Jun	21-Jun
	Change (2010s to 2060s)	10	8	10	11	8	9	9	8	9

Cliomes

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

The inset map of Alaska and western Canada depicts the original area across which 18 cliomes were originally defined. All but one of the 18 cliomes are present in the CYR REA region in the current, near-term, and long-term projections.

Projected shifts in cliome can serve as a proxy variable for overall climate shift, as it might affect large-scale landscape variables such as biome composition. However, cliome shift cannot be considered directly analogous to biome shift. Projections show marked shifts by 2060 along the western coastal portion of the REA, as well as the loss of cliomes in the sub-Arctic areas in the northern part of the CYR study area.

Cliome Descriptions

Each cliome can be viewed in terms of the 24 input variables used to create it, and described in these terms.

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

- **Cliome 1:** This cliome is the coldest and driest of all 18, with a mean annual temperature of -15.9 °C, an above-freezing season length of only 73 days, and a total of 61 mm and 55 mm or rainfall-equivalent in the below-freezing and above-freezing months, respectively. As such it can be considered a high Arctic desert. With only 216 Growing Degree Days (GDD) and 116 mm of precipitation, this cliome can be expected to be severely limited in the vegetation it can support.
- **Cliome 2:** Cliome 2 is not found in this region.
- **Cliome 3:** This Arctic cliome has an unfrozen season length of 110 days. Mean annual precipitation is 198 mm. The cold dry climate in this cliome is vegetation-limiting. However, less harsh winters might be expected to allow encroachment by species that would not be adequately cold-tolerant to survive in Cliome 1.
- **Cliome 4:** This cliome is characterized by dry conditions similar to other Arctic cliomes. Winters are similar to cliome 3, with mean January temperatures of about -28 °C. Summer temperatures are warmer, however, with July mean temperatures of about 10 °C, more than 5 °C warmer than Cliome 1 and 2 °C warmer than Cliome 3.
- **Cliome 5:** This Arctic cliome shows some Interior influences, with cold winters, late springs, and relatively warm summers. Precipitation is greater than in any of the preceding cliomes (about 20% higher than Cliome 4 and more than 100% higher than Cliome 1), and precipitation totals 243 mm annually. Fall precipitation accounts for most of this difference. The above freezing season is a mere 114 days, shorter than that of Cliome 4 and equivalent to that of Cliome 3.
- **Cliome 6:** This cliome displays slightly warmer and wetter Interior-Arctic climate conditions, with 12% more precipitation than Cliome 5 and a mean annual temperature 2 °C warmer (-9.9 °C). While the number of ice-free days in this cliome compares to that in Cliome 4, it exceeds all preceding cliomes in GDD by at least 18%, with a total of 945.
- **Cliome 7:** This climate grouping can be considered the first of the sub-Arctic or boreal cliomes. These all feature summer temperatures that average about 10 °C for all three summer months and precipitation exceeding 10 mm for all months. Warmer summers in these cliomes mean that about 60% of total precipitation is expected to fall as rain. Of cliomes 7–12, Cliome 7 has the coldest winters and driest summers, with January temperatures and July precipitation not dissimilar to Cliomes 3–6. However, spring

comes much sooner in this cliome and, yielding April and May temperatures roughly 5 °C warmer than any of the first six cliomes, and 1260 GDD.

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

- **Cliome 14:** This cliome is warm and fairly wet, with the most moderate winters and the highest precipitation of any cliome other than the extremely wet coastal rainforest cluster. Mean annual temperature is above freezing (1.0 °C).
- **Cliome 15:** This is a sub-boreal cliome that experiences the same wide summer-winter temperature range seen in the boreal zone (-19 °C to +17 °C), but a much warmer mean annual temperature (0.5 °C), meaning that Cliome 15 is likely to have limited permafrost. Precipitation is moderate (474 mm annually) three quarters of which falls as rain.
- **Cliome 16:** This cliome is similar to Cliome 15 in temperature patterns throughout the year, although winters are somewhat colder, with January temperatures generally between -20 and -25 °C. Precipitation is fairly high, although dwarfed by that of Cliome 17. Mean annual temperatures are below freezing here, suggesting more permafrost than Cliome 15.
- **Cliome 17:** This cliome is the most distinct of all 18 cliomes defined. Its characteristics are those of coastal rainforest, with 2248 mm of annual precipitation—vastly more than any other cliome. Moreover, the temperature-modifying effects of the ocean mean that Cliome 17 has mild winters, with January temperatures averaging -5.2 °C. Summers are also ocean-moderated, and much cooler than surrounding cliomes
- **Cliome 18:** This is the hottest cliome, with a mean annual temperature of 3.6 °C, making this cliome appropriate for a wide range of agricultural uses, as well as temperate native species characteristic of prairies or grasslands. Hot summers coupled with only 442 mm of precipitation annually are likely to make this system water-limited. Cliomes 17 and 18 are the only two identified that are likely to be free of permafrost.

Projected Cliome Shifts

Cliomes are expected to change in the near-term and long-term, as illustrated in Figure C-17. The most marked long-term change is apparent in western (coastal) areas and in northern (mountainous) areas. Figure C-18 shows areas of greatest and least change, based on the projected number of times a cliome shifted to any other cliome between current, near-term, and long-term. Areas shown in blue might be expected to experience less ecological stress than those shown in red.

Projected shifts (Figure C-19) include declines in Cliome 9 (currently found in the southern Brooks Range and Yukon/Old Crow Basin) and Cliome 11 (high Brooks Range), and corresponding increases in Cliome 10 (now found on the southern Seward Peninsula and coastal areas further south), and 14, 15, and 16 (northern portions of Canada's prairie provinces).

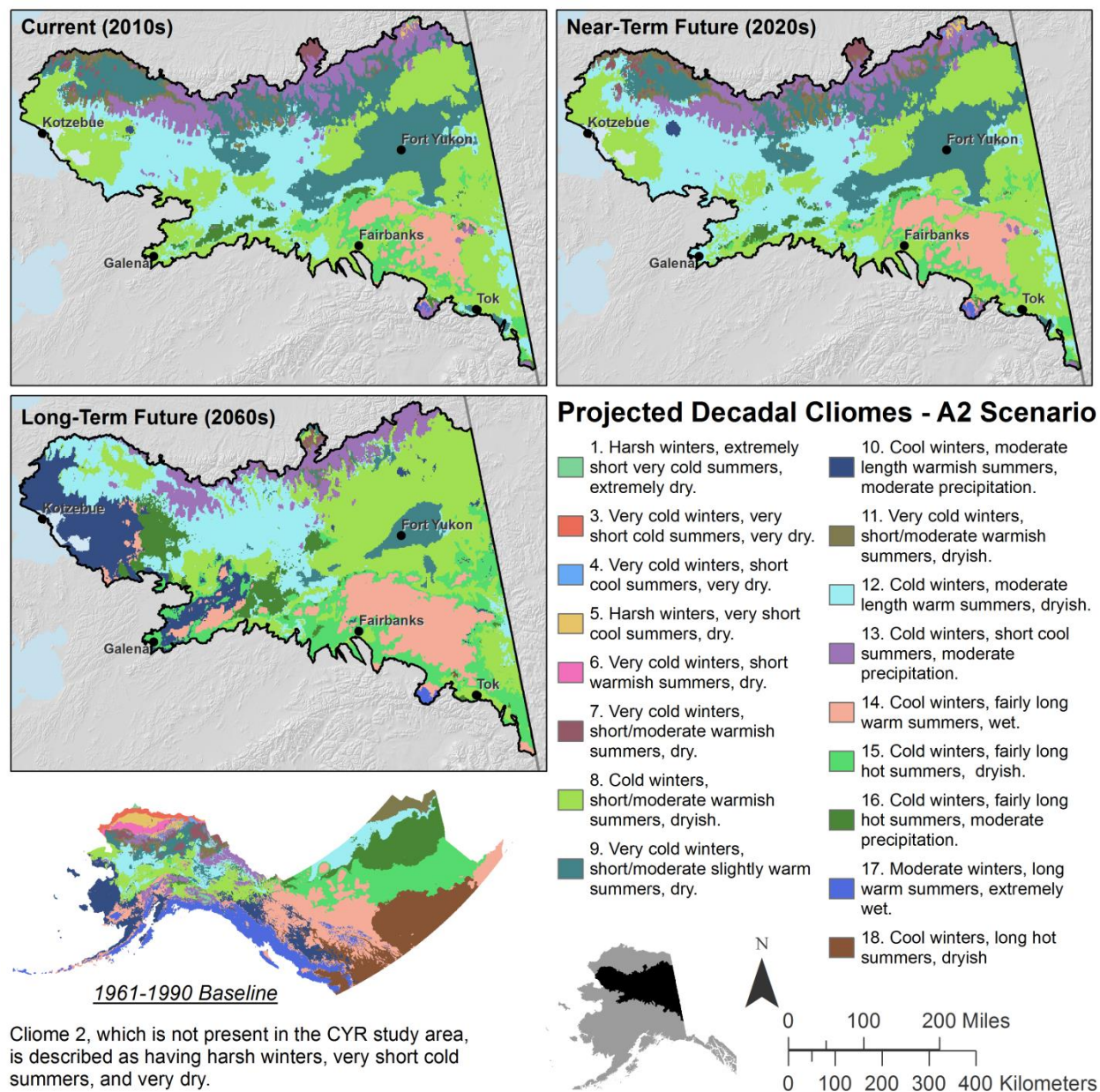


Figure C-17. Current, near-term, and long-term cliomes in CYR study area.

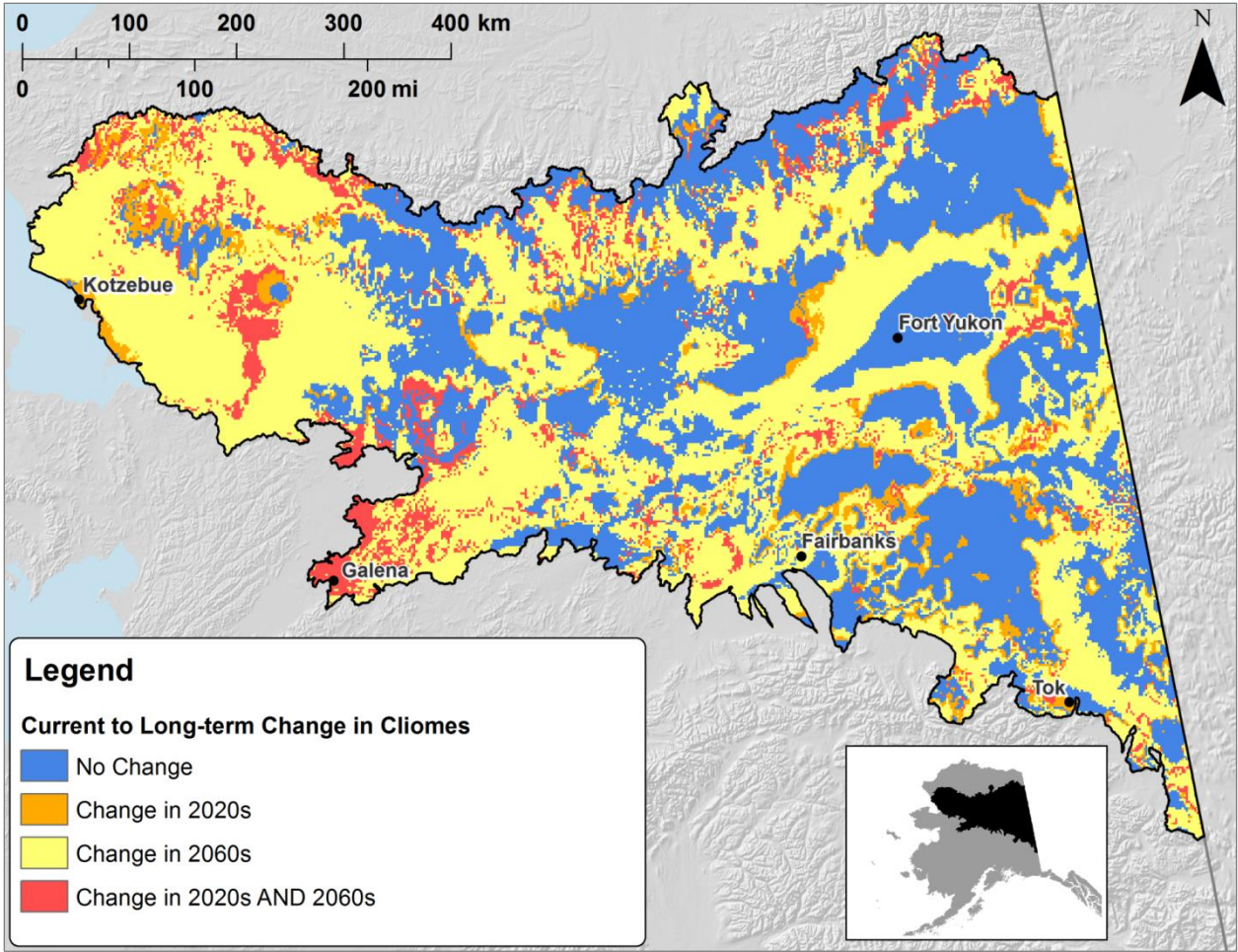


Figure C-18. Number of times a cliome shifted to any other cliome in each of the possible time steps.

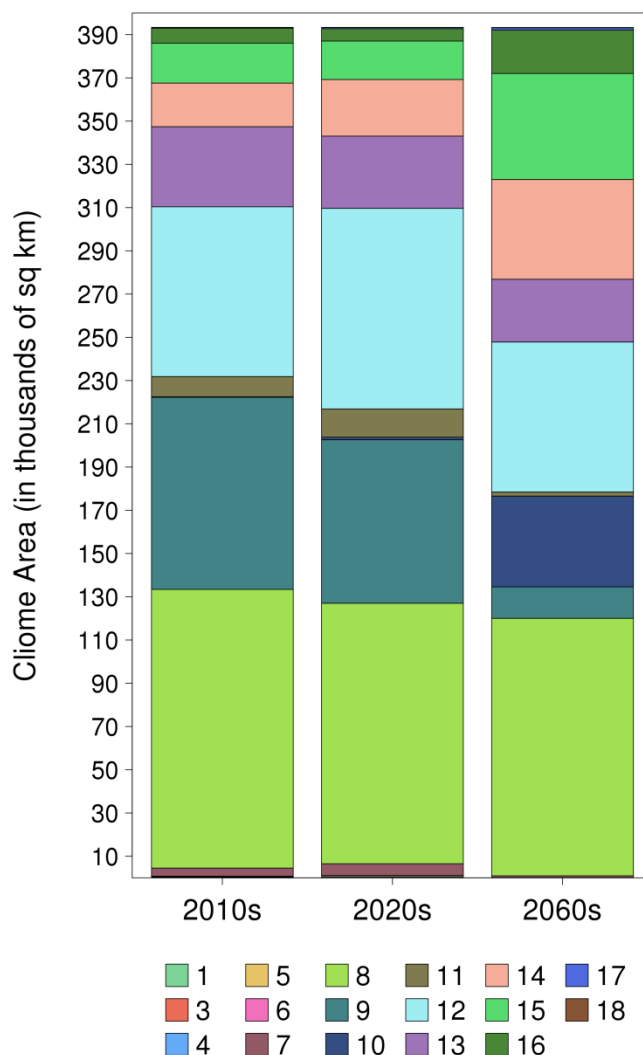


Figure C-19. Projected change in proportion of each cliome across the CYR study area.

1.4 Discussion

Overall, long-term climate shifts are expected to be significant across the CYR study area, for all climate variables examined. However, some times of change, and some regions of change are likely to be more pronounced than others. In particular, coastal areas and high elevation areas may see changes not experienced elsewhere.

Cliome results suggest greater ecological shift is likely in western coastal areas. Large portions of the Kotzebue Sound Lowlands are projected to shift to a climate pattern most closely matched with Cliome 10—a cliome that is currently entirely absent from the CYR study area. Cliome 10 is characteristic of current conditions in coastal areas further south.

The same conclusion—that change may be greatest on the coast—is hinted at by greater increases in LOGS in those areas. Changes in the seasonality of land-fast ice may be linked to these changes. This has strong implications for coastal erosion.

In northern and high elevation areas, treeline advance may be a threshold shift. This is further explored in the Fire section, but it should be noted here that treeline advance of balsam poplar on the North Slope is strongly linked with SWI (Breen 2014). For 80% of observed stands, SWI was greater than 25 °C. A 5 °C increase in SWI along an Arctic climate gradient corresponded to an increase in the normalized difference vegetation index (NDVI) of approximately 0.07, with particularly marked SWI-driven changes in areas of graminoid tundra (Raynolds et al. 2008). This is in keeping with the findings of Epstein et al. (2008) who calculated that both total biomass and shrub biomass increased monotonically with increasing SWI, but that changes in mosses and lichen were more complex. Comparison between the effects of changing SWI in Arctic regions versus sub-Arctic boreal zones (Verbyla 2008) suggests contrasting trends. Although increases in SWI drove corresponding increases in NDVI in the tundra, in warm and dry Interior boreal forest areas, increases in SWI actually correlated with decreasing in NDVI, perhaps due to drought stress. Northern and high elevation areas may also be the nexus for pronounced change with regard to snow day fraction and rain-on-snow events. Other report sections specifically examine the effects of these variables on CEs.

Applications

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

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

1.5 Limitations

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

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

Temperature

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

Precipitation

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

Snow Day Fraction

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

Date of Freeze and Date of Thaw

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

1.6 Literature Cited

- Breen, A. L. 2014. Balsam poplar (*Populus balsamifera* L.) communities on the Arctic Slope of Alaska. *Phytocoenologia* 44:1–17.
- Chapin, III, F. S., M. Sturm, M. C. Serreze, J. P. McFadden, J. R. Key, A. H. Lloyd, A. D. McGuire, T. S. Rupp, A. H. Lynch, J. P. Schimel, J. Beringer, W. L. Chapman, H. E. Epstein, E. S. Euskirchen, L. D. Hinzman, G. Jia, C.-L. Ping, K. D. Tape, C. D. C. Thompson, D. A. Walker, J. M. Welker. 2005. Role of land-surface changes in Arctic summer warming. *Science* 310:657–660.
- Daly, C., M. Halbleib, J. I. Smith, W. P. Gibson, M. K. Doggett, G. H. Taylor, J. Curtis, and P. A. Pasteris. 2008. Physiographically-sensitive mapping of temperature and precipitation across the conterminous United States. *International Journal of Climatology* 28:2031–2064.
- Epstein, H. E., D. A. Walker, M. K. Reynolds, G. J. Jia, and A. M. Kelley. 2008. Phytomass patterns across a temperature gradient of the North American Arctic tundra. *Journal of Geophysical Research- Biogeosciences* 113(G3).
- Fowler, H. J., S. Blenkinsop, and C. Tebaldi. 2007. Linking climate change modelling to impacts studies: recent advances in downscaling techniques for hydrological modelling. *International Journal of Climatology* 27:1547–1578.
- Fussler, H. M. 2009. An updated assessment of the risks from climate change based on research published since the IPCC Fourth Assessment Report. *Climatic Change* 97:469–482.
- Hinzman, L. D., N. D. Bettez, W. R. Bolton, F. S. Chapin, M. B. Dyurgerov, C. L. Fastie, B. Griffith, R. D. Hollister, A. Hope, H. P. Huntington, A. M. Jensen, G. J. Jia, T. Jorgenson, D. L. Kane, D. R. Klein, G. Kofinas, A. H. Lynch, A. H. Lloyd, A. D. McGuire, F. E. Nelson, W. C. Oechel, T. E. Osterkamp, C. H. Racine, V. E. Romanovsky, R. S. Stone, D. A. Stow, M. Sturm, C. E. Tweedie, G. L. Vourlitis, M. D. Walker, D. A. Walker, P. J. Webber, J. M. Welker, K. S. Winker, and K. Yoshikawa. 2005. Evidence and implications of recent climate change in northern Alaska and other Arctic regions. *Climatic Change* 72:251–298.
- Hope, A. G., E. Waltari, D. C. Payer, J. A. Cook, and S. L. Talbot. 2013. Future distribution of tundra refugia in northern Alaska. *Nature Climate Change* 3:931–938.
- IPCC SRES. 2000. N. Nakićenović, and R. Swart, (eds.) Special report on emissions scenarios: a special report of working group III of the Intergovernmental Panel on Climate Change (book), Cambridge University Press.
- Kittel, T. G. F., W. L. Steffen, and F. S. Chapin, III. 2000. Global and regional modelling of Arctic-boreal vegetation distribution and its sensitivity to altered forcing. *Global Change Biology* 6:1–18.
- McAfee, S. A., J. Walsh, and T. S. Rupp. 2013. Statistically downscaled projections of snow/rain partitioning for Alaska. *Hydrological Processes* 28:3930–3946.
- New, M., D. Lister, M. Hulme, and I. Makin. 2002. A high-resolution dataset of surface climate over global land areas. *Climate Research* 21:1–25.
- Nowacki, G., P. Spencer, M. Fleming, T. Brock, and T. Jorgenson. 2001. Ecoregions of Alaska: 2001. U.S. Geological Survey Open-File Report 02-297 (map).
- Prudhomme, C., N. Reynard, and S. Crooks. 2002. Downscaling of global climate models for flood frequency analysis: where are we now? *Hydrological Processes* 16:1137–1150.
- Reynolds, M. K., J. C. Comiso, D. A. Walker, and D. Verbyla. 2008. Relationship between satellite-derived land surface temperatures, Arctic vegetation types, and NDVI. *Remote Sensing of Environment* 112:1884–1894.
- Rogelj, J., M. Meinshausen, and R. Knutti. 2012. Global warming under old and new scenarios using IPCC climate sensitivity range estimates. *Nature Climate Change* 2:248–253.
- Rupp, T. S., X. Chen, M. Olson, and A. D. McGuire. 2007. Sensitivity of simulated boreal fire dynamics to uncertainties in climate drivers. *Earth Interactions* 11:1–21.

Section C. Abiotic Change Agents

- Scheffer, M., M. Hirota, M. Holmgren, E. H. Van Nes, and F. S. Chapin, III. 2012. Thresholds for boreal biome transitions. *Proceedings of the National Academy of Sciences of the United States of America* 109:21384–21389.
- SNAP. 2008. Validating SNAP climate models. Technical Report. Available: http://www.snap.uaf.edu/resource_page.php?resourceid=6
- SNAP. 2012. Predicting future potential climate-biomes for the Yukon, Northwest Territories, and Alaska. Prepared by the Scenarios Network for Arctic Planning and the EWHALE lab, University of Alaska Fairbanks on behalf of The Nature Conservancy's Canada Program, Arctic Landscape Conservation Cooperative, The U.S. Fish and Wildlife Service, Ducks Unlimited Canada, Government Canada, and Government Northwest Territories. Available: <http://www.snap.uaf.edu/attachments/Cliomes-FINAL.pdf>
- Verbyla, D. 2008. The greening and browning of Alaska based on 1982-2003 satellite data. *Global Ecology and Biogeography* 17:547–555.
- Western Regional Climate Center (WRCC). 2011. Climate Summaries. Available: <http://www.wrcc.dri.edu/climate-summaries/>
- Wilson, R. R., A. Bartsch, K. Joly, J. H. Reynolds, A. Orlando, and W. M. Loya. 2013. Frequency, timing, extent, and size of winter thaw-refreeze events in Alaska 2001-2008 detected by remotely sensed microwave backscatter data. *Polar Biology* 36:419–426.

2. Fire

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

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

2.1 Introduction to Fire

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

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

Driven by warming summers in recent years, fire appears to be increasing in frequency (Kelly et al. 2013) and intensity (Genet et al. 2013), resulting in altered ecosystems and processes (Wolken et al. 2011). However, complex feedbacks between increased fire frequency, resulting vegetation shifts, and subsequent fire are poorly understood and require further study (Balshi et al. 2009). Data on vegetative regrowth after tundra fires are particularly scarce, given the relative rarity of such fires (Barrett et al. 2012). Moreover, tundra fires may be poorly recorded and understood (Jones et al. 2013).

Connecting Past, Present, and Future

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

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

4. direct modeling of potential vegetation change within the fire model.

The Role of Modeling

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

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

2.2 Methods

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

ALFRESCO simulates the responses of vegetation to transient climatic changes (Figure C-20). The model assumptions reflect the hypothesis that fire regime and climate are the primary drivers of landscape-level changes in the distribution of vegetation in the circumpolar Arctic/boreal zone. Furthermore, the model assumes that vegetation composition and continuity serve as a major determinant of large, landscape-level fires.

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

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

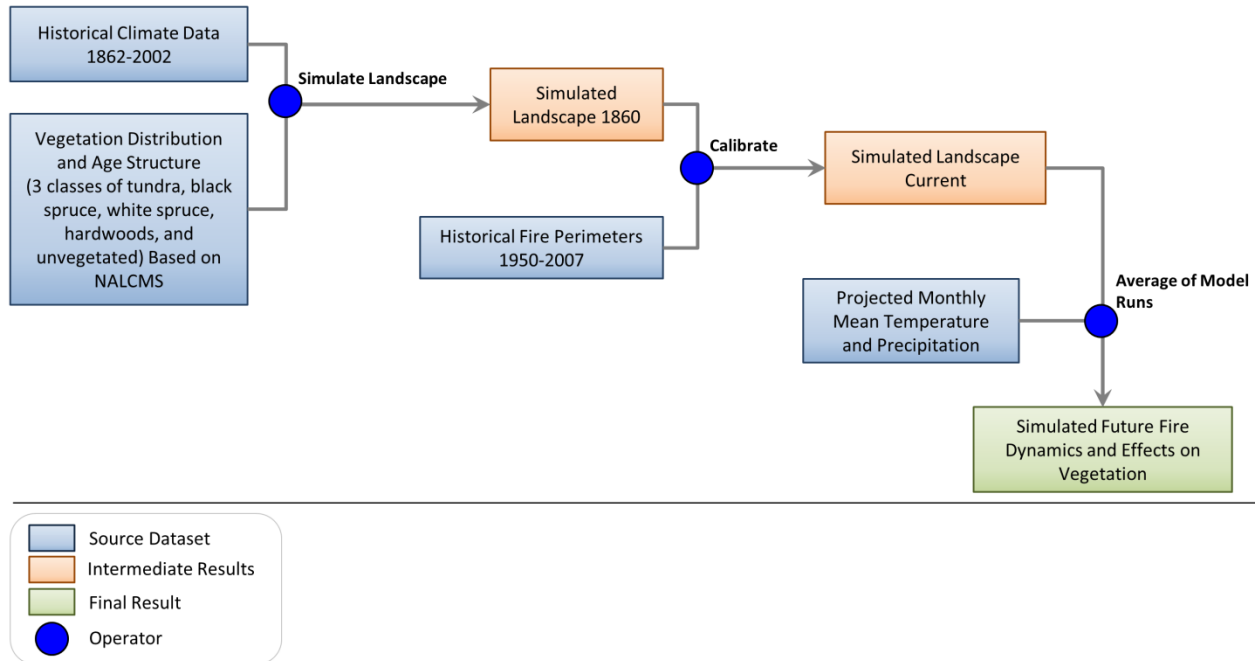


Figure C-20. Process model of ALFRESCO fire simulation methodology.

The model focuses on system interactions and feedbacks. The fire regime is simulated stochastically and is driven by climate, vegetation type, and time since last fire (Rupp et al. 2007). ALFRESCO employs a cellular automaton approach, where simulated fire may spread to any of the eight surrounding pixels. “Ignition” of a pixel is determined as a function of the flammability value of that pixel and starts are assigned randomly (Rupp et al. 2002). The flammability of each pixel is a function of vegetation type and age, meaning that ignitions will be concentrated in pixels with the most flammable type and age of vegetation and the hottest, driest climate conditions in spring and summer. Fire spread depends on the flammability (i.e., fuel loading and moisture) of the receptor pixel, and the model is calibrated to replicate observed historical fire patterns. Thus, fire is most likely to spread in older stands of black spruce and white spruce, and much less likely in deciduous stands, graminoid tundra, and shrub tundra. Some pixels (e.g., non-vegetated areas and large water bodies) do not burn and, thus, serve as fire breaks. Anthropogenic suppression activities were not simulated.

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

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

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

Model Stochasticity and Implementation

The “distribution” of varying fire frequencies is intimately tied to vegetation, as well as climate, but also involves stochastic elements such as the exact location of lightning strikes and the variability of weather patterns at finer time scales than are available to modelers. Thus, multiple individual model runs yield varying results. Therefore, fire distributions per se were not modeled; rather we modeled projected average fire frequency and extent across the landscape (Figure C-8). We also modeled some key changes in vegetation patterns and distribution. Some results are presented by ecoregions, derived from Nowacki et al. (2001). Outputs included projected average area burned per year across the target time periods and fire return intervals on an ecoregional basis.

Table C-8. Source datasets used in the analysis of fire as a CA for the CYR REA.

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

Model Inputs

ALFRESCO inputs include elevation, slope, aspect, and slope complexity data obtained from the PRISM climate group, as well as climate and vegetation variables (Table C-9). Historical climate data are derived from Climate Research Unit (CRU) data, and projected climate data are derived from SNAP downscaled climate projections.

ALFRESCO is calibrated based on fire history grids (0 = no fire, 1 = fire) produced directly from the BLM Alaska Fire Service database and the Canadian National Fire Database. They are simply a 1×1-km raster representation of their fire history polygon database that can be obtained from the Alaska Interagency Coordination Center (AICC 2016) and the Canadian Wildland Fire Information System (CWFIS 2016).

ALFRESCO vegetation classes are based on NALCMS 2005 land cover map (NALCMS 2016), although these vegetation classes are re-grouped and adapted to meet the needs of the model, as described below. Original NALCMS classes found in the CYR study area are listed below. A crosswalk of ALFRESCO vegetation classes with chosen CYR Terrestrial Coarse-Filter CEs are summarized in Section G. Terrestrial Coarse-Filter Conservation Elements.

1. Temperate or sub-polar needleleaf forest

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

2. Sub-polar taiga needleleaf forest

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

5. Temperate or sub-polar broadleaf deciduous forest

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

6. Mixed Forest

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

8. Temperate or sub-polar shrubland

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

10. Temperate or sub-polar grassland

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

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

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

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

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

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

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

14. Wetland

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

15. Barren Lands

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

16. Urban and Built-up

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

17. Water

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

18. Snow and Ice

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

For the purposes of ALFRESCO, classes were regrouped and/or reclassified. The process is summarized below, and the results can be seen in Table C-9.

Classes 15, 16, 17, and 18 were grouped as no vegetation; Classes 1 and 2 were combined as a spruce; classes 5 and 6 were grouped as deciduous; Classes 10 and 12 became graminoid tundra; and class 11 was re-classed as shrub tundra.

The wetland class was divided into coastal wetlands and Interior spruce bogs (spruce class) based on a coastal/Interior division derived from land classes defined by Nowacki et al. (2001) and Schut and Ballard (1999). The newly derived coastal wetland layer was further divided into wetland tundra or no vegetation based on average temperature for May–August from the downscaled 1961–1990 PRISM climatology, with a threshold value of 6.5 °C (warmer areas are wetland tundra). The same threshold was used to divide Class 8 into deciduous or shrub tundra (warmer areas are deciduous). The value 6.5 °C was selected based on Korner and Paulen's work (2004) determining vegetation threshold temperatures.

The combined spruce class was divided into black spruce if on a north-facing slope or white spruce if on a south-facing slope. Finally, suspect NALCMS pixels that placed spruce trees on the North Slope were redefined based on the most common class of 16 neighboring pixels.

Table C-9. Grouping of ALFRESCO land cover classes according to their North American Land Cover (NALCMS) class.

NALCMS category	ALFRESCO class
1. Temperate or sub-polar needleleaf forest	White Spruce or Black Spruce, depending on aspect.
2. Sub-polar taiga needleleaf forest	
5. Temperate or sub-polar broadleaf deciduous forest	Deciduous
6. Mixed Forest	
8. Temperate or sub-polar shrubland	Deciduous or Shrub tundra, depending on growing season temperature.
10. Temperate or sub-polar grassland	Graminoid tundra

NALCMS category	ALFRESCO class
11. Sub-polar or polar shrubland-lichen-moss	Shrub tundra
12. Sub-polar or polar grassland-lichen-moss	Graminoid tundra
14. Wetland	Wetland tundra, No vegetation, White spruce, or Black spruce, depending on coastal/Interior, aspect, and growing season temperature.
15. Barren Lands	No vegetation
16. Urban and Built-up	
17. Water	
18. Snow and Ice	

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

Vegetation Transitions within ALFRESCO

Transitions from one vegetation class to another within ALFRESCO can occur post-fire, but can also be driven by other variables such as climate, even in the absence of fire. The potential transitions and factors that drive these transitions are shown in and Figure C-21 and Figure C-22.

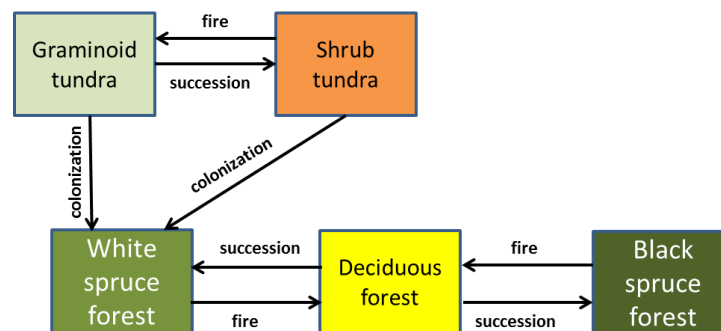


Figure C-21. Schematic of potential vegetation transitions within the ALFRESCO model.

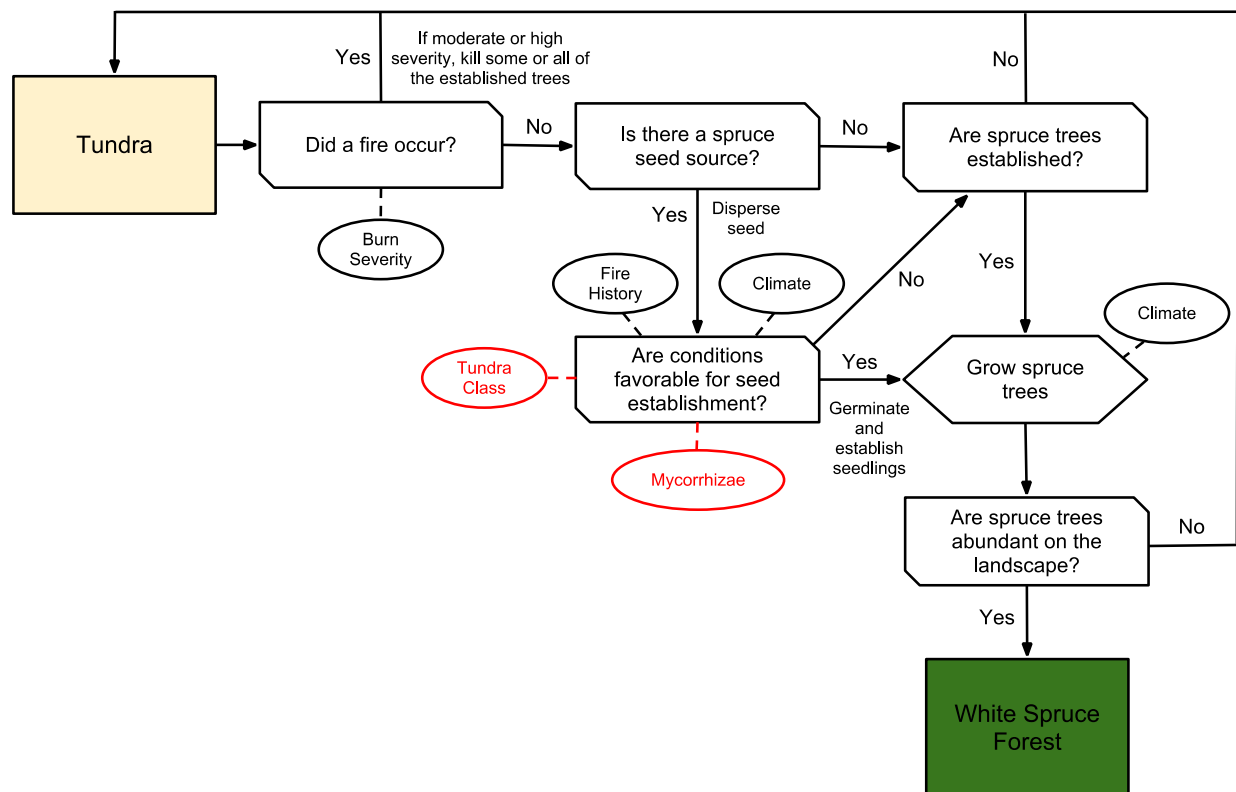


Figure C-22. Decision tree showing one potential type of vegetation transition, from Tundra to White Spruce Forest. Similarly, complex decision trees govern other transitions.

The variables and thresholds that drive these transitions are complex, and form a large part of the core of the code that is ALFRESCO (Epstein et al. 2004a, Epstein et al. 2004b). This code will be publicly available by SNAP in the near future. While this code is complex, some general rules are summarized below. Transition rules between classes are built into ALFRESCO code and calibrated based on hundreds of stochastic model runs. Indeed, some transitions occur only post-fire while others are climate driven or can occur at other times, depending on algorithms described below. All transition arrows in Figure C-21 not labeled “fire” represent transitions that may occur at times other than post-fire (at age zero). Most transitions are probabilistic, based on the variables that govern the model as a whole and each cover type in particular.

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

Transitions from graminoid to shrub tundra are governed by multiple factors, including time since fire, mean July temperature, and SWI. Although tundra fire can promote shrub expansion (Racine et al. 2004), shrubification can also occur without fire (Naito and Cairns 2015).

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

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

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

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

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

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

Fire History

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

At the time of this REA, ALFRESCO did not have any inputs or outputs simulating the effects of fire suppression. Kasischke et al. (2005) suggest that the changing effects of suppression in the past may have subtly affected area burned and forest composition, not so much at the landscape level, where lightning is the chief cause of fire and weather the chief driver, but in areas closest to human habitation, where current policies effect the highest levels of suppression. Thus, ALFRESCO outputs may be less reliable at the urban/wildland interface.

2.3 Results

Figure C-23 shows historical and modeled area burned across the study area. Annual values are based on decadal smoothing (averaging across decades) for the entire region, for the 1920s to 2010s. Modeled data represent the average (mean) of 200 runs using each of the 5 GCMs (1000 total ALFRESCO runs) for the A2 emissions scenario. As can be seen from the slope of the trendlines, historical trends are slightly more extreme than modeled trends. However, it should be noted that neither trendline achieves statistical significance ($p = 0.30$ and $p = 0.44$ for historical and modeled regressions, respectively). The variability and associated uncertainty of trend in the historical data underscores the difficulty of modeling and predicting a variable that has, innately, such enormous variability over space and time, and that also has a relatively short history of reliable data-keeping.

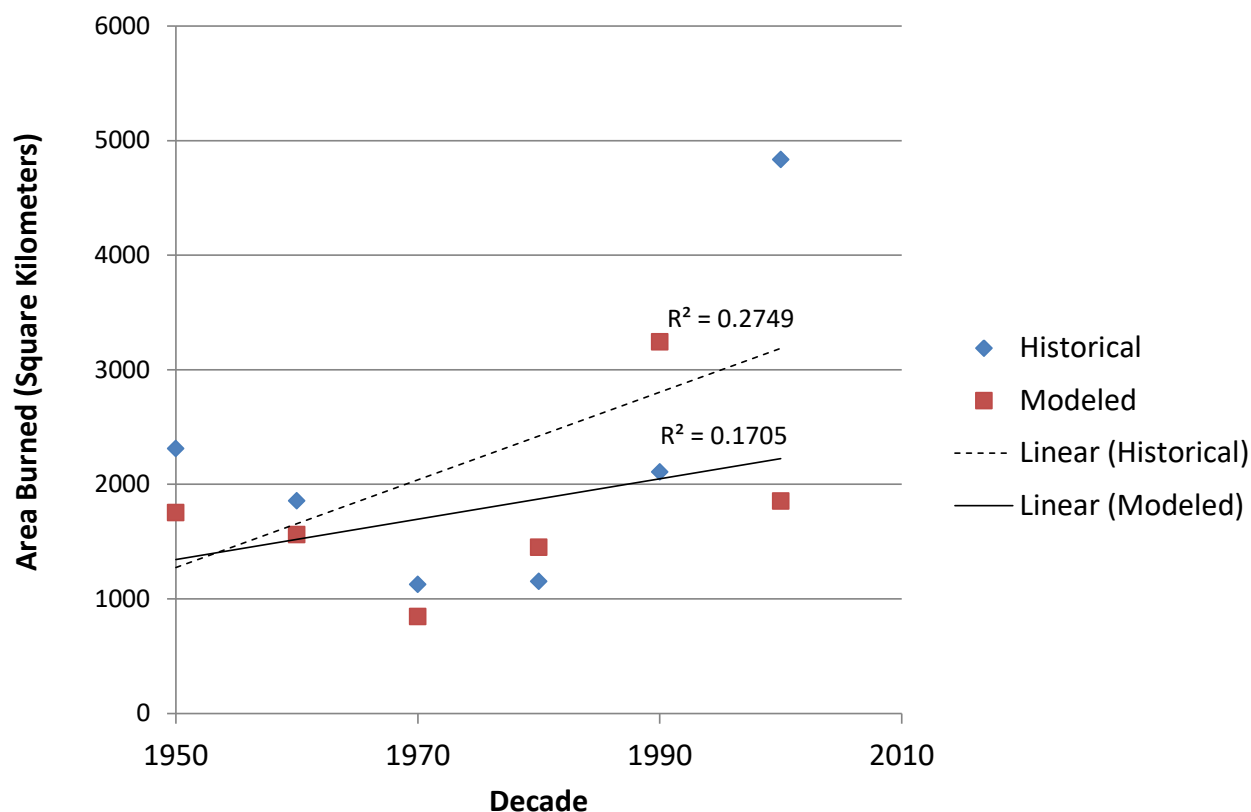


Figure C-23. Historical and modeled area burned, by decade.

Area Burned

Annual values for total area burned are based on decadal smoothing (averaging across decades) by ecoregion. These outputs are modeled data only—representing the average (mean) of 200 runs using each of the 5 GCMs, for the A2 emissions scenario. Thus, a total of 1000 ALFRESCO runs are averaged. While running the model even more times might marginally reduce uncertainty, there would be diminishing returns in relation to the computing time and effort required. The model's ability to achieve greater accuracy over short time periods would not be meaningfully increased.

The chances that any given pixel will burn in any given year are low, even in this fire-prone region, and very few pixels would be expected to burn more than once in the timeframe in question (between the 2010s and the 2060s). Despite low chances of a fire in any particular year for any particular model run, the relative flammability of each pixel (km²) in the CYR study area can be compared spatially by assessing how many times it is projected to burn in a 100-year time span. Figure C-24 compares relative flammability for a historical century-long set of model outputs representing 1900–1999 and a set of model outputs for this century. Each map represents data averaged across 1000 model runs. The historical time period cannot, thus, be expected to exactly match fire records, and the current and future time period is spatially representative, rather than spatially precise. Comparing these two maps, the most pronounced change occurs in areas where very low fire probability (green) is expected to have shifted or to be currently shifting to much higher flammability. This change corresponds with changes in treeline and shrubline at high altitudes and northern latitudes. Regions that have not been fire-driven systems in the past are depicted as becoming fire-driven in the future.

Empirical evidence suggests that these changes are already occurring, and are climate-related. Duffy et al. (2005) determined that 79% of the variability in the natural logarithm of the annual area burned by lightning-caused fires from 1950 to 2003 can be attributed to weather variables, particularly June temperature.

Subtle shifts toward greater flammability in areas that are already fire-driven systems are difficult to detect on these maps. The reason for this becomes clearer when we examine fire behavior. Despite averaging data across decades and across so many model runs, Figure C-25 demonstrates the high degree of variability in both real and modeled fire data. This may be due to a strong "leveraging" effect from the last decade of historical burns. Thus, although it is clear that fire frequency is increasing on the landscape, it can be very hard to reliably predict location and timing of this shift.

Although these data can be used to create tables or maps of fire return interval for the CYR study area (Table C-10), care must be taken to interpret these data so that they are not be misleading to land managers. The terms "fire cycle" or "return interval" generally only have meaning relative to a specific vegetation classes or mixed-species forest stands. Although the inverse of flammability can be expressed in units of years as "fire return interval," as in this table, the fact that these data are averaged across regions that include not only forest stands but also non-forest vegetation tends to yield numbers much higher than those typically referenced by foresters, who considered only timber stands. Nonetheless, the change in these projected fire return intervals from the previous century to the current one suggests landscape change in all ecoregions.

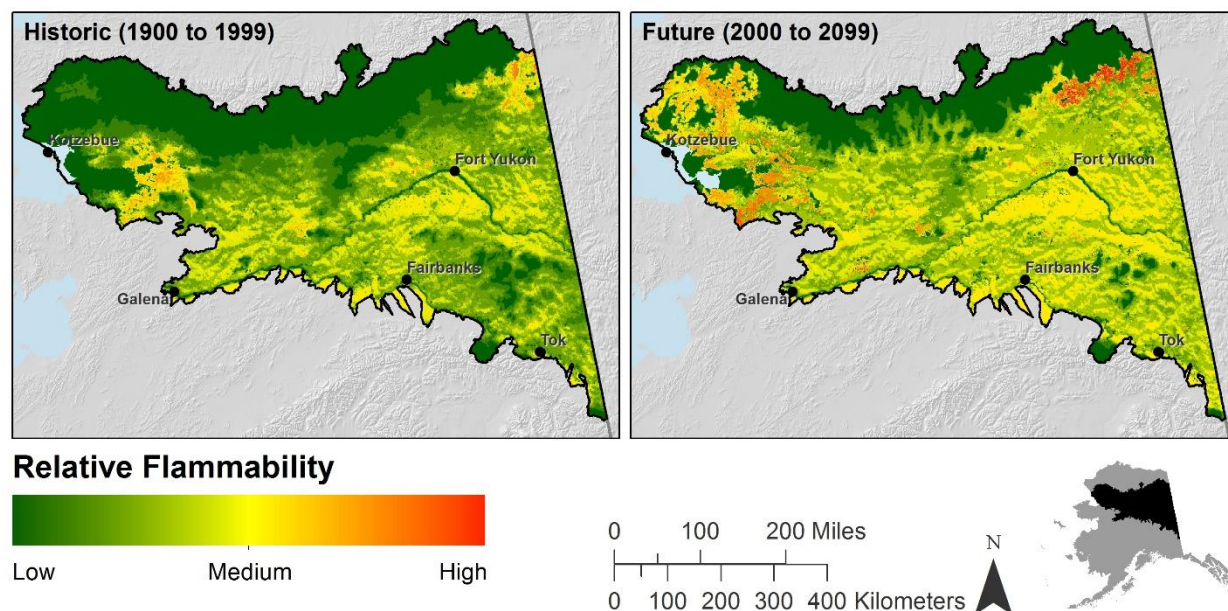


Figure C-24. Relative flammability across the CYR study area, for 1900–1999 and 2000–2099 based on outputs from 1000 ALFRESCO model runs.

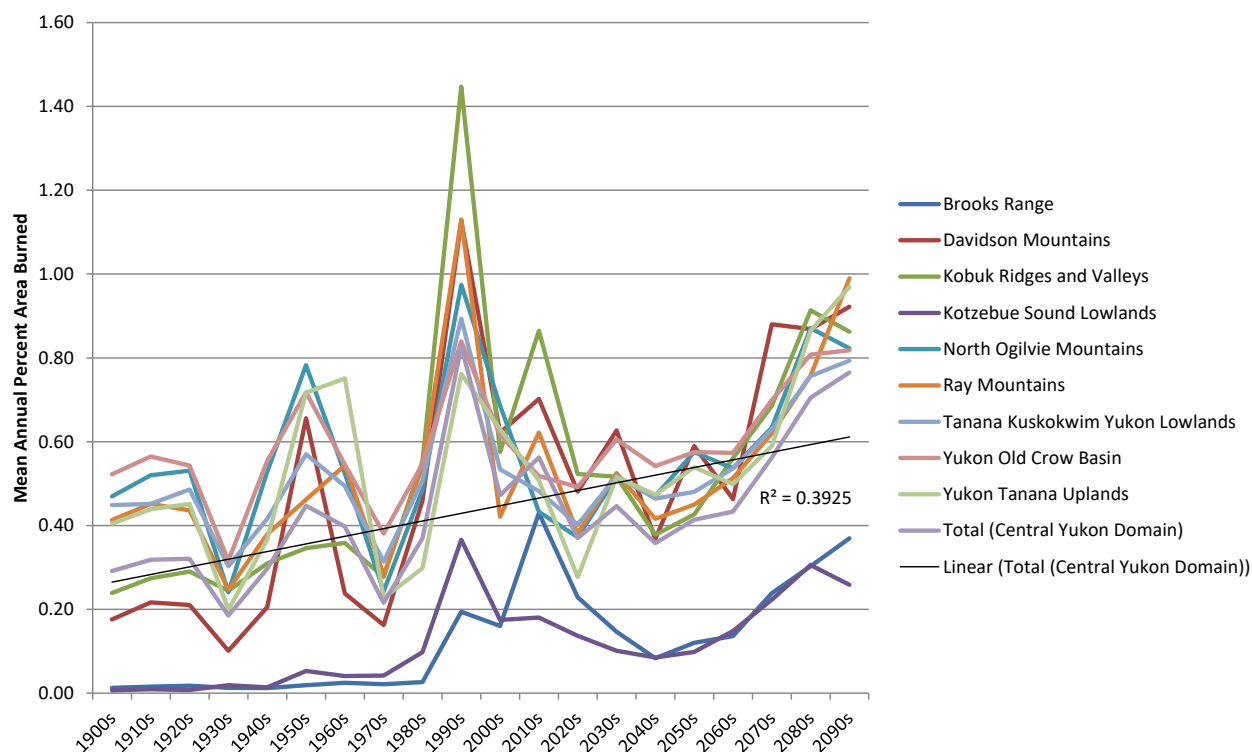


Figure C-25. Projected annual area burned by ecoregion within the CYR study area, averaged across decades.

Table C-10: Projected fire return intervals by decade and century, calculated by ecoregion. Note that because each ecoregion includes both forested and unforested pixels, return intervals are much longer than they would be if applied only to forest stands.

	Brooks Range	Davidson Mountains	Kobuk Ridges and Valleys	Kotzebue Sound Lowlands	North Ogilvie Mountains	Ray Mountains	Tanana Kuskokwim Yukon Lowlands	Yukon Old Crow Basin	Yukon Tanana Uplands	Total (Central Yukon Domain)
1900s	7621	568	418	13600	213	242	223	192	247	343
1910s	6255	461	365	10385	192	222	221	177	228	314
1920s	5524	475	344	13188	188	229	206	184	221	312
1930s	7716	984	409	5146	415	405	330	316	501	540
1940s	7969	487	323	7167	189	264	240	181	273	336
1950s	5273	152	289	1893	128	217	175	139	139	224
1960s	4020	421	279	2425	191	184	202	183	133	251
1970s	4595	614	361	2378	411	355	319	262	441	463
1980s	3764	218	181	1022	206	185	197	183	335	270
1990s	514	89	69	273	103	88	112	119	131	121
mean 1900s	5325	447	304	5748	224	239	223	194	265	318
2000s	622	161	174	572	146	237	187	163	159	212
2010s	233	142	116	553	231	161	207	193	197	178
2020s	437	208	191	731	269	262	249	203	361	270
2030s	682	160	193	989	194	190	193	165	194	224
2040s	1198	272	265	1173	213	240	215	185	211	279
2050s	832	170	234	1014	174	222	208	174	185	242
2060s	734	216	178	673	186	195	187	174	200	231
2070s	419	114	146	448	158	161	159	143	170	178
2080s	330	115	109	327	115	132	132	124	116	142
2090s	271	108	116	386	122	101	126	122	103	131
mean 2000s	576	167	172	687	181	190	186	165	190	209

Vegetation Change

Vegetation shifts predicted by ALFRESCO must be viewed only on a broad scale and across long time-frames, due to the extremely high variability in natural fire behavior, as noted with regard to Figure C-23. Thus, although the focus of this REA was from the 2010s to the 2060s, the following graphs include back-cast data back to 1900 and modeled data out to 2100, in order to provide a broader perspective on change.

As can be seen in Figure C-26, shifts are modeled to have started occurring in the latter decades of the twentieth century. Best-fit lines are quadratic rather than linear due to the assumption—borne out by the data—that change was absent or minimal in the early 1900s and then accelerated. These modeled shifts are corroborated by empirical evidence (Kasischke et al. 2010, Mann et al. 2012). Mann et al. (2012) find that the vegetation shift began circa 1990, and suggest that it may reach a new equilibrium around 2040. Kasischke et al. (2010) offer a more complex set of projections that include suggestions for fire suppression and management, but likewise suggest that a new vegetation equilibrium may be reached later this century.

Projected changes include a sharp increase in deciduous forest and a modest increase in shrub tundra, with corresponding decreases in white spruce, black spruce, and graminoid tundra. These simultaneous shifts likely indicate several ongoing changes.

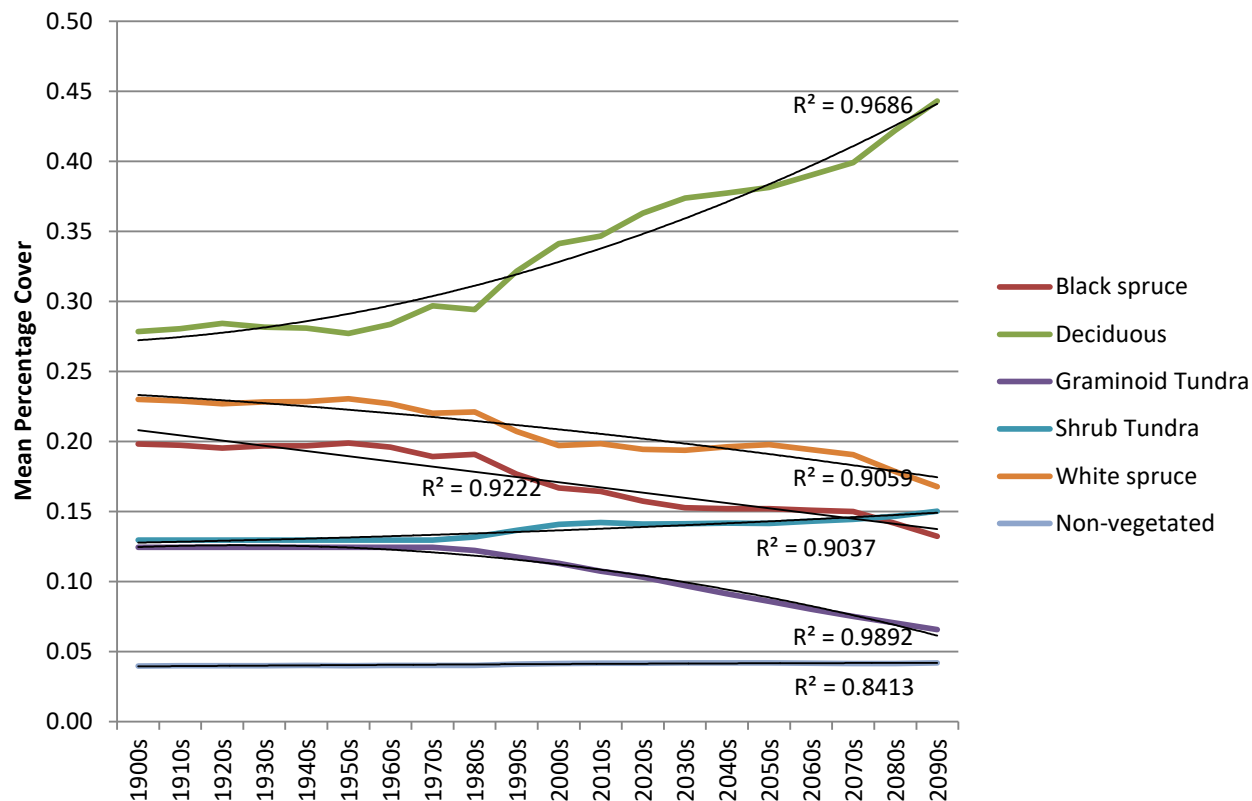


Figure C-26. Projected vegetation change across the CYR study area with modeled change and fitted quadratic line.

First, without even considering fire as a driver of change, warming temperatures and longer growing seasons are triggering a shift from graminoid tundra to shrub tundra, and a subsequent (and simultaneous) shift from shrub tundra to forest. This advance in treeline, in both altitude and latitude, has been well documented (Okano and Bret-Harte 2015, Ropars and Boudreau 2012). At the same time, warming temperatures are increasing fire frequency and area burned, and this change is resulting in a marked shift from older forest vegetation (mainly black spruce and white spruce) to earlier-succession forest vegetation (deciduous species, mainly willow, birch, and aspen).

Examining these trends by ecoregion sheds some light on how these simultaneous changes are playing out in different areas (Figure C-27). In the Brooks Range, treeline advance is projected to cause a loss of graminoid tundra and an increase in both shrub tundra and deciduous vegetation. In the Davidson Mountains, this change is even more pronounced.

The Kobuk Ridges and Valleys have very little graminoid tundra; thus, the expected changes are mostly seen in a shift from coniferous to deciduous vegetation. In contrast, the Kotzebue Sound Lowlands include a large amount of land that is either non-vegetated or not classified within this version of ALFRESCO because it is non-burnable wetland. The biggest shift projected in this area is from shrub tundra to forest.

The North Ogilvie Mountains currently have little tundra, but are likely to see a pronounced shift to earlier-succession (deciduous) forest. Similar patterns of change can be seen in the Ray Mountains, the Tanana-Kuskokwim-Yukon Valleys, the Yukon Old Crow Basin, and the Yukon

Tanana Uplands, although each region offers a slightly different story with regard to the timing and percentages of change.

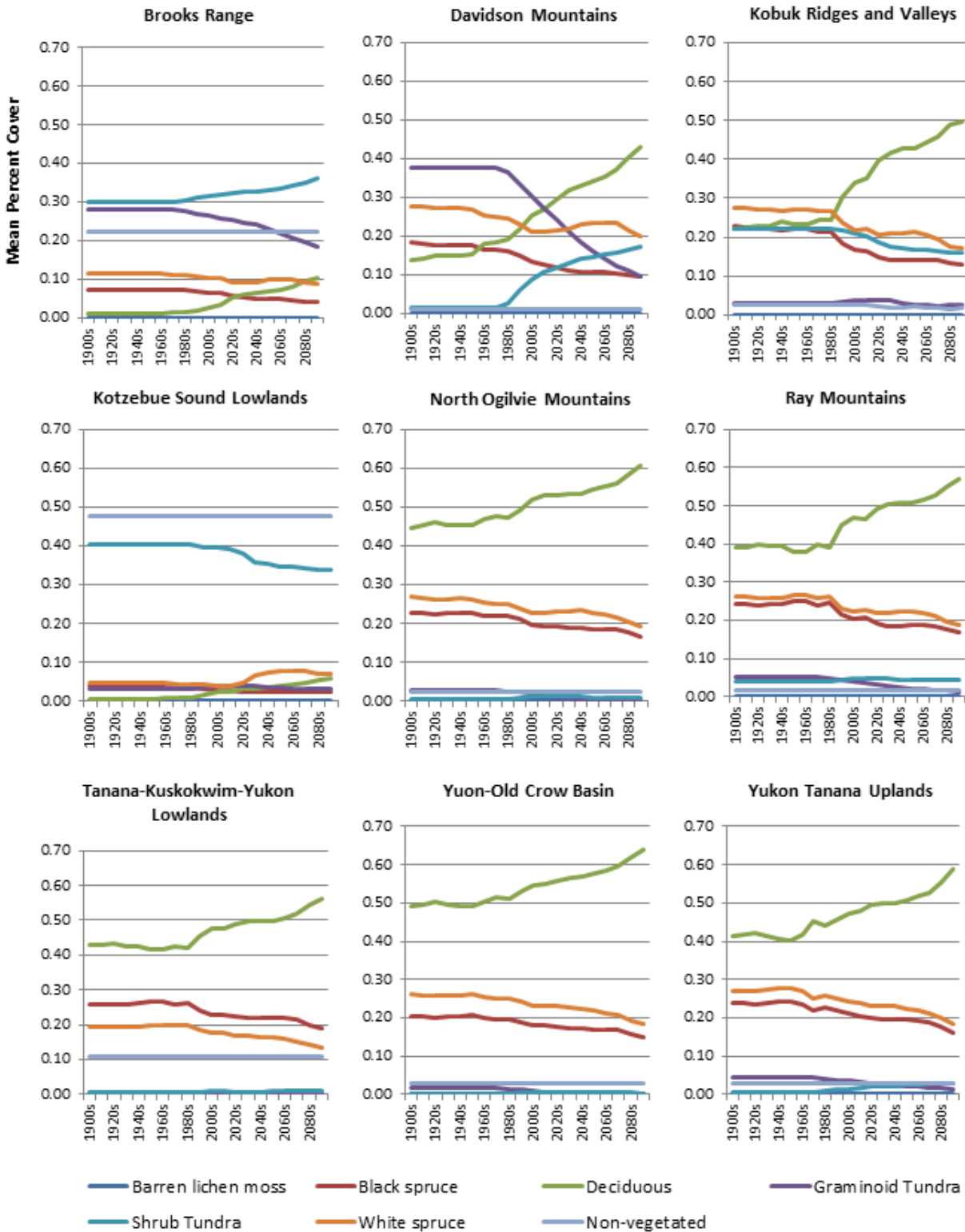


Figure C-27. Modeled mean percent cover of ALFRESCO vegetation classes for each of the nine ecoregions in the CYR study area.

Shrubline and Treeline Shifts

All of the above ALFRESCO outputs were created as described in the methods section by averaging 1000 different model runs. However, as an example to create a visual estimate of landscape-level change, we present a single ALFRESCO run hand-picked as a “best replicate”—a model run that falls as close as possible to the average of all runs, based on area burned across time. Indeed, a single model run cannot inform land managers about fire behavior at the micro level; the behavior of each pixel is stochastic. However, as can be seen in Figure C-28 and Figure C-29, the resulting maps of treeline shift and shrubline shift offer a sense of where and when these changes may occur.

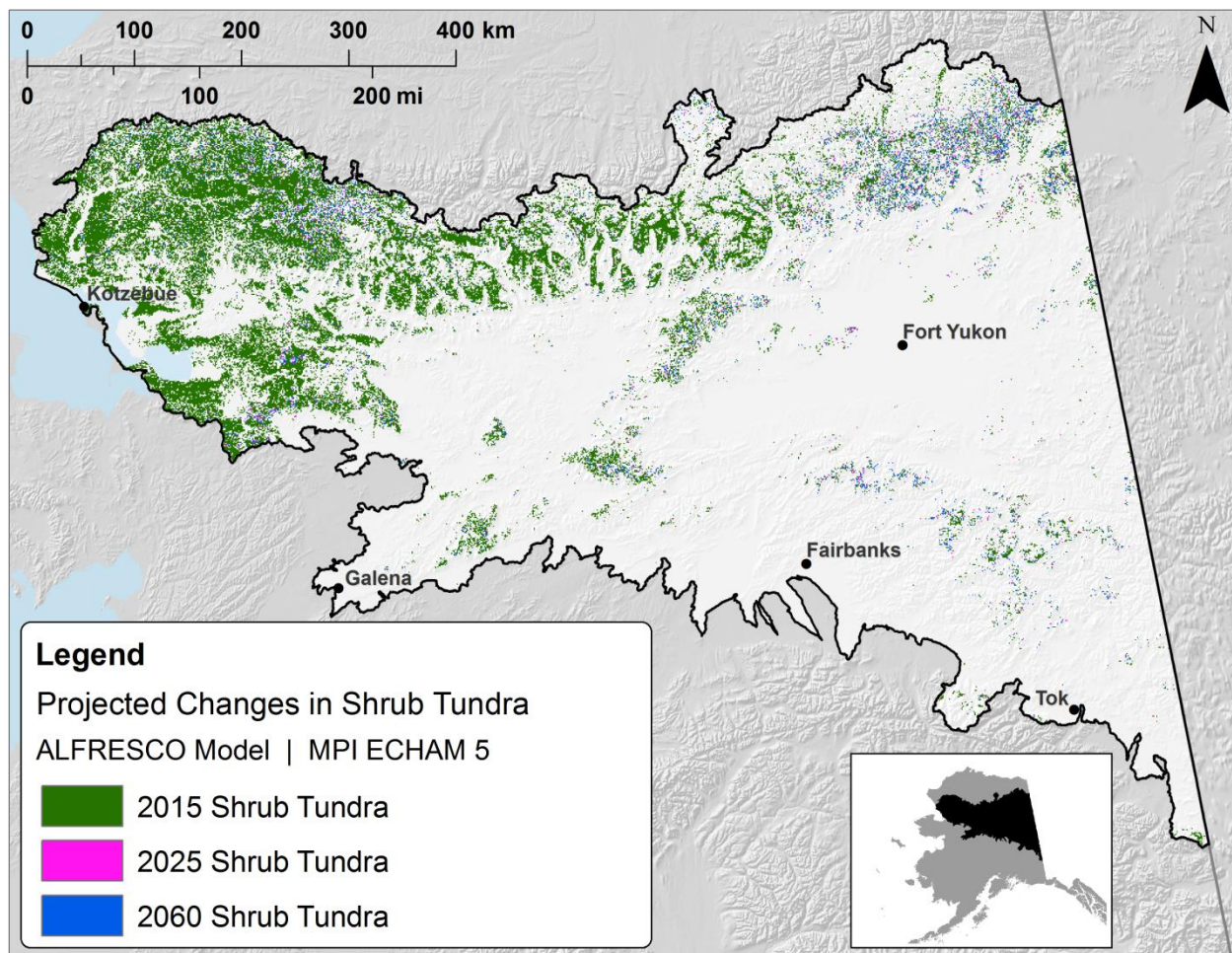


Figure C-28. Shrubline advance as predicted by a single "best replicate" run of the ALFRESCO model. Pink and blue pixels represent new projected shrub tundra. Outputs show singles years rather than decadal averages.

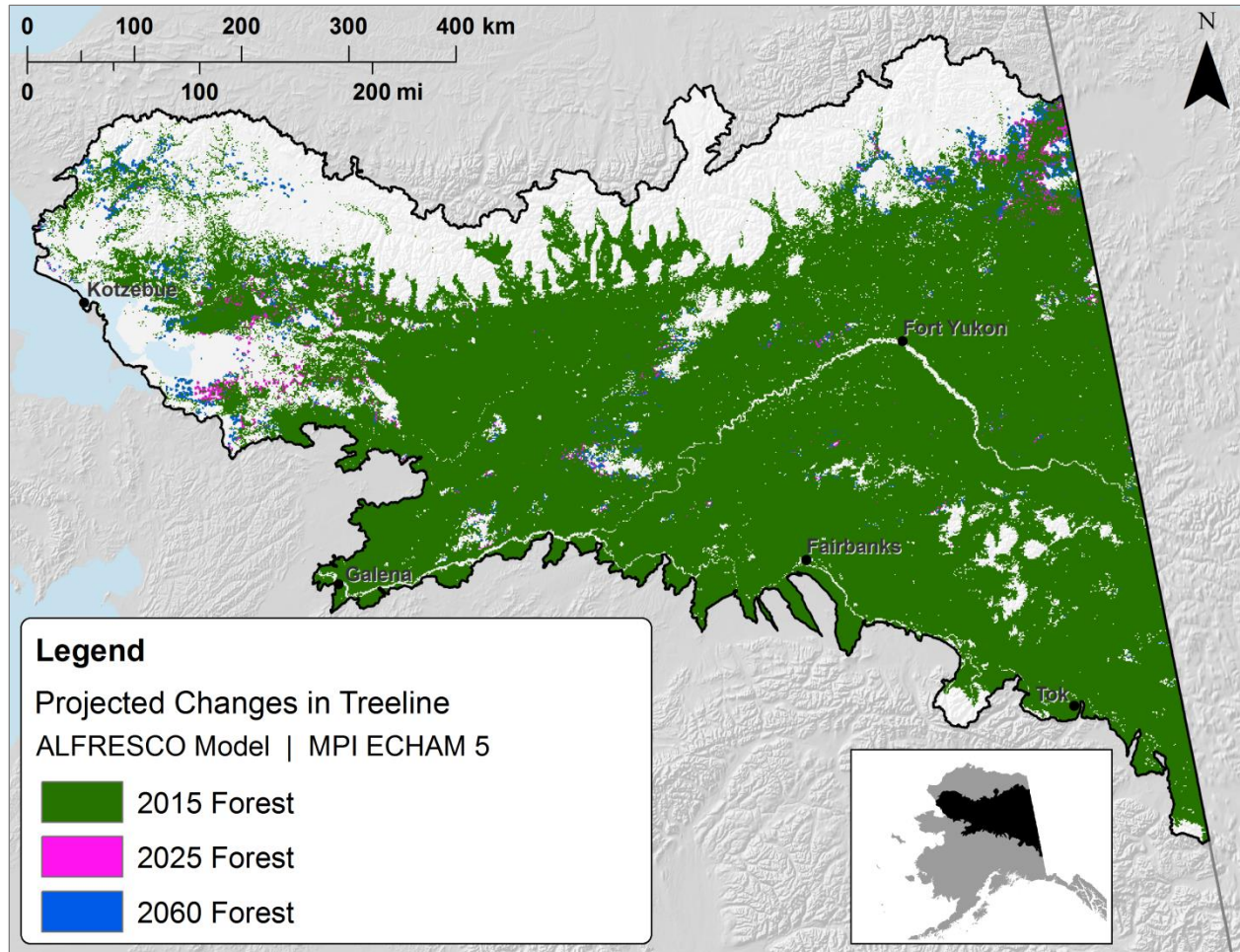


Figure C-29. Treeline advance as predicted by a single "best replicate" run of the ALFRESCO model. Pink and blue pixels represent new projected treeline.

2.4 Discussion

ALFRESCO outputs show a clearer trend over time with regard to vegetation change than area burned. This can be attributed to the fact that while fire behavior is highly stochastic, vegetation change is driven by both fire and temperature. Temperature data are much less “messy” than fire data, leading to a smoother pattern of change. Nonetheless, modeling area burned does suggest that fire is likely to increase to levels much higher than historical levels before dropping back to a “new normal.” In the long-term future, higher flammability (driven by higher temperatures) may be somewhat curtailed by younger mean age of vegetation. Whether the peak of this shift has already occurred, is occurring now, or will occur in the near future remains unclear.

Vegetation change is likely to vary by ecoregion, as described in the results. The overall pattern is toward shrubification of graminoid tundra, treeline advance in shrub tundra, and a shift from coniferous to deciduous tree cover, due to shorter fire cycles. Because all these changes are co-occurring, they can sometimes obscure one another when averaged across landscapes. For example, some new shrub tundra may appear, while other shrub tundra is lost, yielding no net gain.

Thus, although examining outputs from a single replicate of ALFRESCO is not a perfect solution, it helps elucidate some of the subtleties that may be missed by averaging across runs. While changes in treeline and shrubline depicted in Figure C-28 and Figure C-29 may appear small at first glance, the proliferation of pink pixels (change by 2025) and blue pixels (change by 2060) indicate important trends—and, in some locales, fairly radical change. In the eastern Brooks Range and Davidson Mountains, shrub tundra is projected to become far more common. Notably in the Davidson Mountains, treeline advance is likely to be marked in the long-term. Less change can be seen in the central portions of the Brooks Range, but to the west, long-term shrubline and treeline shifts are apparent. Meanwhile, ALFRESCO also appears to project treeline encroachment in both the near-term and long-term in a very different ecological zone, in the Kotzebue Sound Lowlands and Kobuk Ridges and Valleys. Finally, a “closing in” of high elevation pixels in the more southerly portions of the CYR study area suggests a substantial loss of isolated high-elevation vegetation islands.

2.5 Limitations

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

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

2.6 Literature Cited

- Alaska Interagency Coordination Center (AICC). 2016. Predictive Services: Maps/Imagery/Geospatial. Available: <http://fire.ak.blm.gov/predsvcs/maps.php>
- Balshi, M. S., A. D. McGuire, P. Duffy, M. Flannigan, J. Walsh, and J. Melillo. 2009. Assessing the response of area burned to changing climate in western boreal North America using a Multivariate Adaptive Regression Splines (MARS) approach. *Global Change Biology* 15:578–600.
- Barrett, K., A. Rocha, M. J. van de Weg, and G. Shaver. 2012. Vegetation shifts observed in Arctic tundra 17 years after fire. *Remote Sensing Letters* 3:729–736.
- Breen, A. L., A. Bennett, R. Hewitt, T. Hollingsworth, H. Genet, E. S. Euskirchen, T. S. Rupp, and A. D. McGuire. 2013. Tundra fire and vegetation dynamics: simulating the effect of climate change on fire regimes in Arctic ecosystems. American Geophysical Union, Fall Meeting 2013, abstract #B33I-0592.
- Canadian Wildland Fire Information System (CWFIS). 2016. Canadian National Fire Database. Available: <http://cwfis.cfs.nrcan.gc.ca/ha/nfdb>
- Chapin, III, F. S., T. S. Rupp, A. M. Starfield, L. O. DeWilde, E. S. Zavaleta, N. Fresco, J. Henkelman, and A. D. McGuire. 2003. Planning for resilience: modeling change in human-fire interactions in the Alaskan boreal forest. *Frontiers in Ecology and the Environment* 1:255–261.
- Chapin, III, F. S., M. Sturm, M. C. Serreze, J. P. McFadden, J. R. Key, A. H. Lloyd, A. D. McGuire, T. S. Rupp, A. H. Lynch, J. P. Schimel, J. Beringer, W. L. Chapman, H. E. Epstein, E. S. Euskirchen, L. D. Hinzman, G. Jia, C.-L. Ping, K. D. Tape, C. D. C. Thompson, D. A. Walker, and J. M. Welker. 2005. Role of land-surface changes in Arctic summer warming. *Science* 310:657–660.
- Clark, J. S. 1998. Why trees migrate so fast: confronting theory with dispersal biology and the paleorecord. *American Naturalist* 152:204–224.
- Duffy, P. A., J. E. Walsh, J. M. Graham, D. H. Mann, and T. S. Rupp. 2005. Impacts of large-scale atmospheric-ocean variability on Alaskan fire season severity. *Ecological Applications* 15:1317–1330.
- Epstein, H. E., J. Beringer, W. A. Gould, A. H. Lloyd, C. D. Thompson, F. S. Chapin, III, G. J. Michaelson, C. L. Ping, T. S. Rupp, and D. A. Walker. 2004a. The nature of spatial transitions in the Arctic. *Journal of Biogeography* 31:1917–1933.
- Epstein, H. E., M. P. Calef, M. D. Walker, F. S. Chapin, III, and A. M. Starfield. 2004b. Detecting changes in Arctic tundra plant communities in response to warming over decadal time scales. *Global Change Biology* 10:1325–1334.
- Genet, H., A. D. McGuire, K. Barrett, A. Breen, E. S. Euskirchen, J. F. Johnstone, E. S. Kasischke, A. M. Melvin, A. Bennett, M. C. Mack, T. S. Rupp, A. E. G. Schuur, M. R. Turetsky, and F. Yuan. 2013. Modeling the effects of fire severity and climate warming on active layer thickness and soil carbon storage of black spruce forests across the landscape in Interior Alaska. *Environmental Research Letters* 8:045016.
- Greene, D. F., and E. A. Johnson. 1999. Modelling recruitment of *Populus tremuloides*, *Pinus banksiana*, and *Picea mariana* following fire in the mixed wood boreal forest. *Canadian Journal of Forest Research* 29:462–473.
- Higuera, P. E., M. L. Chipman, J. L. Barnes, M. A. Urban, and F. S. Hu. 2011. Variability of tundra fire regimes in Arctic Alaska: millennial-scale patterns and ecological implications. *Ecological Applications* 21:3211–3226.
- Johnstone, J. F., T. N. Hollingsworth, F. S. Chapin, III, and M. C. Mack. 2010. Changes in fire regime break the legacy lock on successional trajectories in Alaskan boreal forest. *Global Change Biology* 16:1281–1295.
- Joly, K., P. A. Duffy, and T. S. Rupp. 2012. Simulating the effects of climate change on fire regimes in Arctic biomes: implications for caribou and moose habitat. *Ecosphere* 3:1–18.

Section C. Abiotic Change Agents

- Jones, B. M., A. L. Breen, B. V. Gaglioti, D. H. Mann, A. V. Rocha, G. Grosse, C. D. Arp, M. L. Kunz, and D. A. Walker. 2013. Identification of unrecognized tundra fire events on the North Slope of Alaska. *Journal of Geophysical Research-Biogeosciences* 118:1334–1344.
- Kasischke, E. S., and J. F. Johnstone. 2005. Variation in post-fire organic layer thickness in a black spruce forest complex in Interior Alaska and its effects on soil temperature and moisture. *Canadian Journal of Forest Research* 35(9).
- Kasischke, E. S., D. L. Verbyla, T. S. Rupp, A. D. McGuire, K. A. Murphy, R. Jandt, J. L. Allen, E. E. Hoy, P. A. Duffy, M. Calef, and M. R. Turetsky. 2010. Alaska's changing fire regime: implications for the vulnerability of its boreal forests. *Canadian Journal of Forest Research* 40:1313–1324.
- Kelly, R., M. L. Chipman, P. E. Higuera, I. Stefanova, L. B. Brubaker, and F. S. Hu. 2013. Recent burning of boreal forests exceeds fire regime limits of the past 10,000 years. *Proceedings of the National Academy of Sciences of the United States of America* 110:13055–13060.
- Korner, C., and L. Jensen. 2004. A worldwide study of high altitude treeline temperatures. *Journal of Biogeography* 31:713–732.
- Larsen, J. A. 1980. *The boreal ecosystem*. Academic Press, New York, New York, USA.
- Lloyd, A. H., C. L. Fastie, and H. Eisen. 2007. Fire and substrate interact to control the northern range limit of black spruce (*Picea mariana*) in Alaska. *Canadian Journal of Forest Research* 37:2480–2493.
- Mann, D. H., T. S. Rupp, M. A. Olson, P. A. Duffy. 2012. Is Alaska's boreal forest now crossing a major ecological threshold? *Arctic Antarctic and Alpine Research* 44:319–331.
- Naito, A. T., and D. M. Cairns. 2015. Patterns of shrub expansion in Alaskan Arctic river corridors suggest phase transition. *Ecology and Evolution* 5:87–101.
- North American Land Change Monitoring System (NALCMS). 2016. USGS Land Cover Institute (LCI). Available: <http://landcover.usgs.gov/nalcms.php>
- Nowacki, G., P. Spencer, M. Fleming, T. Brock, and T. Jorgenson. 2001. *Ecoregions of Alaska: 2001*. U.S. Geological Survey Open-File Report 02-297 (map).
- Okano, K., and M. S. Bret-Harte. 2015. Warming and neighbor removal affect white spruce seedling growth differently above and below treeline. *Springerplus* 4.
- Racine, C. H., R. R. Jandt, C. R. Meyers, and J. Dennis. 2004. Tundra fire and vegetation change along a hillslope on the Seward Peninsula, Alaska, U.S.A. *Arctic, Antarctic, and Alpine Research* 36:1–10.
- Rocha, A. V., M. M. Loranty, P. E. Higuera, M. C. Mack, F. S. Hu, B. M. Jones, A. L. Breen, E. B. Rastetter, S. J. Goetz, and G. R. Shaver. 2012. The footprint of Alaskan tundra fires during the past half-century: implications for surface properties and radiative forcing. *Environmental Research Letters* 7:044039.
- Roland, C. A., J. H. Schmidt, and E. F. Nicklen. 2013. Landscape-scale patterns in tree occupancy and abundance in sub-Arctic Alaska. *Ecological Monographs* 83:19–48.
- Ropars, P., and S. Boudreau. 2012. Shrub expansion at the forest-tundra ecotone: spatial heterogeneity linked to local topography. *Environmental Research Letters* 7:015501.
- Rupp, T. S., A. M. Starfield, and F. S. Chapin, III. 2000. A frame-based spatially-explicit model of sub-Arctic vegetation response to climatic change: comparison with a point model. *Landscape Ecology* 15:383–400.
- Rupp, T. S., A. M. Starfield, F. S. Chapin, and P. Duffy. 2002. Modeling the impact of black spruce on the fire regime of Alaskan boreal forest. *Climatic Change* 55:213–233.
- Rupp, T. S., X. Chen, M. Olson, and A. D. McGuire. 2007. Sensitivity of simulated boreal fire dynamics to uncertainties in climate drivers. *Earth Interactions* 11:1–21.
- Schut, P. H., and M. Ballard. 1999. *Ecozones and ecoregions of Canada (a national ecological framework for Canada: attribute data)*. Marshall, I.B., Agriculture and Agri-Food Canada, Research Branch, Centre for Land and Biological Resources Research, and Environment Canada, State of the Environment Directorate, Ecozone Analysis Branch, Ottawa/Hull.

- Szeicz, J. M., and G. M. MacDonald. 1996. A 930-year ring-width chronology from moisture-sensitive white spruce (*Picea glauca* Moench) in northwestern Canada. *Holocene* 6:345–351.
- Walker, D. A. 2000. Hierarchical subdivision of Arctic tundra based on vegetation response to climate, parent material and topography. *Global Change Biology* 6:19–34.
- Walker, H. J., and P. F. Hudson. 2003. Hydrologic and geomorphic processes in the Colville River delta, Alaska. *Geomorphology* 56:291–303.
- Volken, J. M., T. N. Hollingsworth, T. S. Rupp, F. S. Chapin, S. F. Trainor, T. M. Barrett, P. F. Sullivan, A. D. McGuire, E. S. Euskirchen, P. E. Hennon, E. A. Beever, J. S. Conn, L. K. Crone, D. V. D'Amore, N. Fresco, T. A. Hanley, K. Kielland, J. J. Kruse, T. Patterson, E. A. G. Schuur, D. L. Verbyla, and J. Yarie. 2011. Evidence and implications of recent and projected climate change in Alaska's forest ecosystems. *Ecosphere* 2:1–35.

3. Soil Thermal Dynamics

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

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

3.1 Introduction to Soil Thermal Dynamics

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

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

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

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

Historical and current conditions

Current permafrost conditions vary within the CYR study area (Kittel et al. 2011, Jorgenson et al. 2013). In some areas permafrost is continuous, while in others it is discontinuous or absent, particularly around water bodies, in coastal areas, on south-facing slopes, and in the southern portion of the REA area.

Permafrost thaw can result in vegetation changes, hydrologic changes, and changes in soil carbon balance; however, the impacts of permafrost thaw tend to be highly site-specific and time-specific (Jorgenson et al. 2013). Coastal thaw has serious ramifications in terms of erosion, which can affect both human infrastructure and ecosystems (Barnhart et al. 2014, Kittel et al. 2011). In the boreal forest, impacts depend on the type and percentage of ice in the permafrost and on soil drainage conditions, and can range from little change to complete ecosystem destruction (Osterkamp et al. 2000).

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

3.2 Methods

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

GIPL Permafrost Model

The main components of the permafrost model are represented in the general ecosystem conceptual model. As shown in Figure C-30, permafrost modeling incorporated both SNAP climate projections and the Geophysical Institute Permafrost Laboratory (GIPL) permafrost model for Alaska, which relies on spatial data related to soil, vegetation, and climate. GIPL model outputs include mean annual ground temperature at 1-m depth (MAGT) and a dataset that includes both active layer thickness (ALT—the thin layer above permafrost that seasonally freezes and thaws) and seasonal soil freeze-thaw depth, linked by appropriate algorithms, as described below. In order to maintain consistency with pre-existing terminology, this latter dataset is referred to as ALT, although it also includes seasonal freeze-thaw data for areas that are unfrozen at 1-m depth.

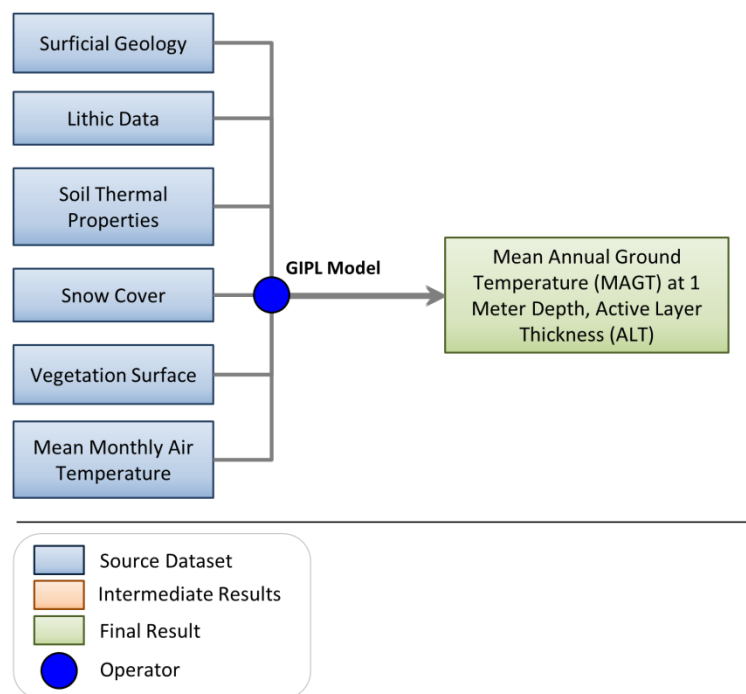


Figure C-30. Process model of permafrost modeling techniques.

The GIPL model was developed specifically to predict the effect of changing climate on permafrost. GIPL model is a quasi-transitional, spatially distributed equilibrium model for calculating the ALT and mean annual ground temperature. The GIPL model was ground-truthed and validated using cores from around the state.

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

Mean annual ground temperature is a relatively straightforward metric, since temperatures below freezing represent permafrost and those above freezing indicate unfrozen ground. For this assessment, areas of permafrost were defined as cells where MAGT at 1-m depth is $\leq 0^{\circ}\text{C}$ and areas of non-permafrost were defined as cells where mean annual ground temperature at 1-m depth is $> 0^{\circ}\text{C}$. However, it should be noted that extensive deeper permafrost may still occur in areas projected to be thawed at one meter. Such deep permafrost has smaller impacts on vegetation and draining than shallow permafrost. Furthermore, temperatures projected to be slightly below freezing could still result in permafrost thaw in areas that receive direct sunlight.

Active layer thickness is the depth of thaw that occurs during summer months in the surface layer of permafrost-influenced soils. As noted, this dataset also includes seasonal soil freeze-thaw depth: the depth of freeze that occurs during winter months in the surface layer of non-permafrost influenced soils. Thus, this dataset includes ALT in cells where MAGT at 1-m depth is $\leq 0^{\circ}\text{C}$ and seasonal soil freeze-thaw depth in cells where mean annual ground temperature at 1-m depth is $> 0^{\circ}\text{C}$. Mean annual ground temperature, ALT, and seasonal freeze-thaw depth all have strong implications for what plant species can persist in a given area.

Algorithms to determine MAGT and ALT are dependent on calculations of the insulating properties of varying ground cover and soil types, as well as on climate variables, and vary spatially across the landscape at a resolution of 1 km. Surface vegetation data are derived from the Global Land Cover Characteristics Database, Version 2.0 (GLCC 2016). Land cover categories used to define organic matter thermal properties are derived from the National Atlas of the United States of America, 1985, and soil types come from the U.S. Geological Survey 1997 Surficial Geology Map of Alaska. Outputs provide a general approximation of areas likely to undergo some degree of thaw and associated hydrologic changes.

Integrated Ecosystem Modeling-Thermokarst Model

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

The Integrated Ecosystem Modeling thermokarst model (Figure C-31) relies on the hypothesis that thermokarst occurs in lowland peatland with ice-rich permafrost sites. Lowlands were defined as areas surrounding local elevational minima with a slope less than or equal to four degrees.

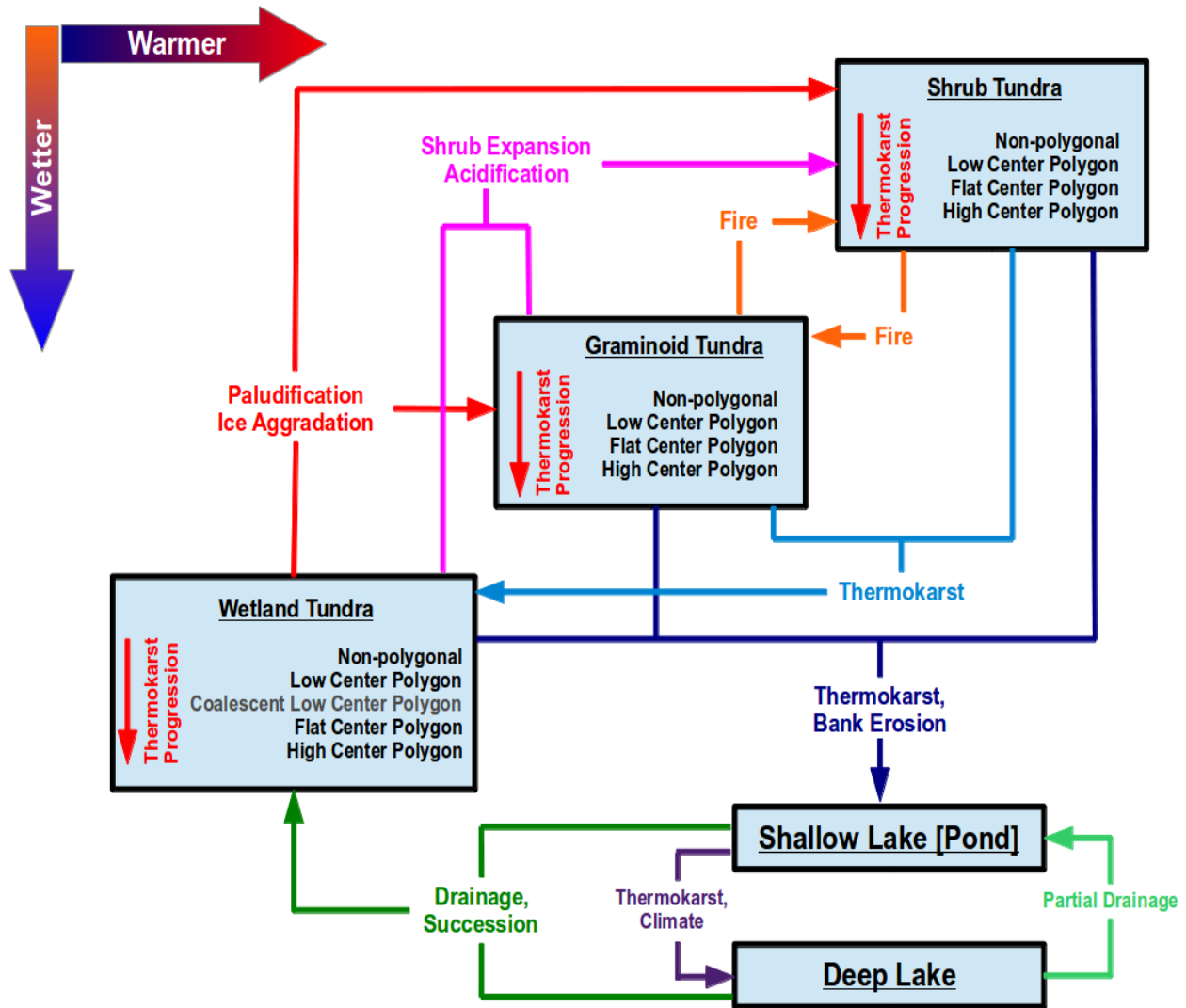


Figure C-31. Impacts of thermokarst and feedback to other landscape processes.

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

As such, outputs from the thermokarst model reflect the risk of thermokarst in the case of permafrost thaw (or partial thaw). Thus, when coupled with outputs of the GIPL model, these outputs can shed light on which areas of change may be most dramatically affected at the regional and landscape level. Datasets used in both of the above models are listed in Table C-11.

Table C-11. Source datasets for the analysis of permafrost and associated thermokarst as a CA in the CYR study area.

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

3.3 Results

Mean Annual Ground Temperature

Projections show a relatively steady increase in MAGT across the region over time, with acceleration as the century progresses. Because permafrost conditions are highly site-specific at fine resolution, actual conditions are likely to vary within pixels. Thus, these outputs must be viewed at a coarser level.

Ground temperature is expected to remain below freezing at most sites through near-term future (2020s), but projections show a notable shift to above-freezing temperatures in the southern half of the REA by the long-term. The “Change in Permafrost” map (Figure C-34) illustrates this shift in permafrost, while Figure C-35 pulls out the areas where MAGT changes from below-freezing to above-freezing between the current and the long-term.

When summarized by ecoregion (Figure C-33), it becomes clear that a shift from predominantly below-freezing conditions to predominantly thawed conditions may occur across broad areas, particularly in the Yukon-Tanana Uplands, North Ogilvie Mountains, and Tanana-Kuskokwim-Yukon Lowlands. Table C-12 breaks this down further, ranking every community in the REA according to MAGT. Community values are based on average MAGT in the 5th-level hydrologic units that contains each settlement.

It should be noted that true variability in ground temperature is even greater than can be discerned from these maps, since it also occurs at scales much finer than 1 km. For example, localized processes such as deep snow accumulation in riparian zones can allow for year-round liquid water below beaded stream pools, with the development of thaw bulbs or taliks (Arp et al. 2015).

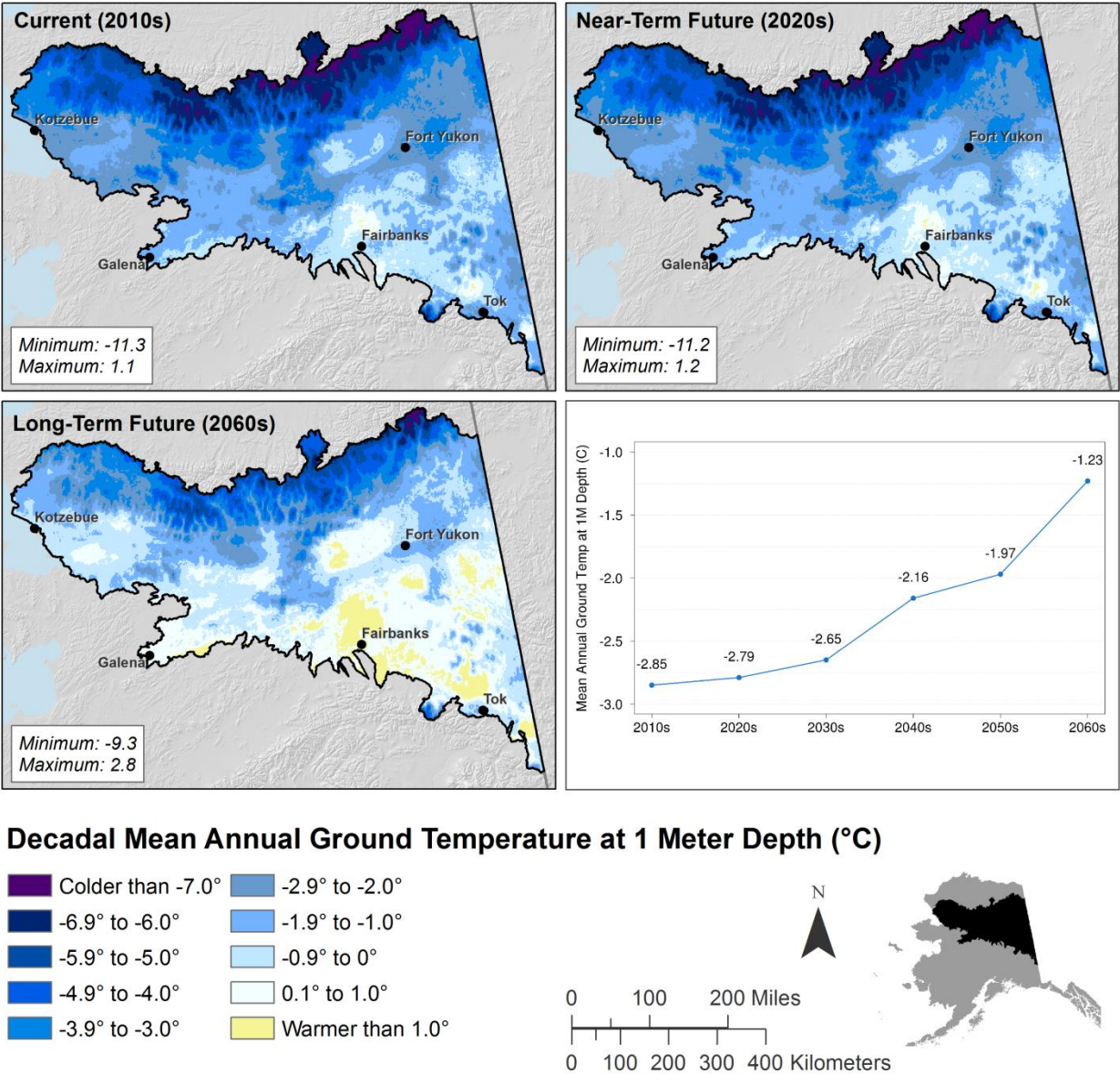


Figure C-32. Current, near-term, and long-term mean annual ground temperature (MAGT) in CYR study area.

Section C. Abiotic Change Agents

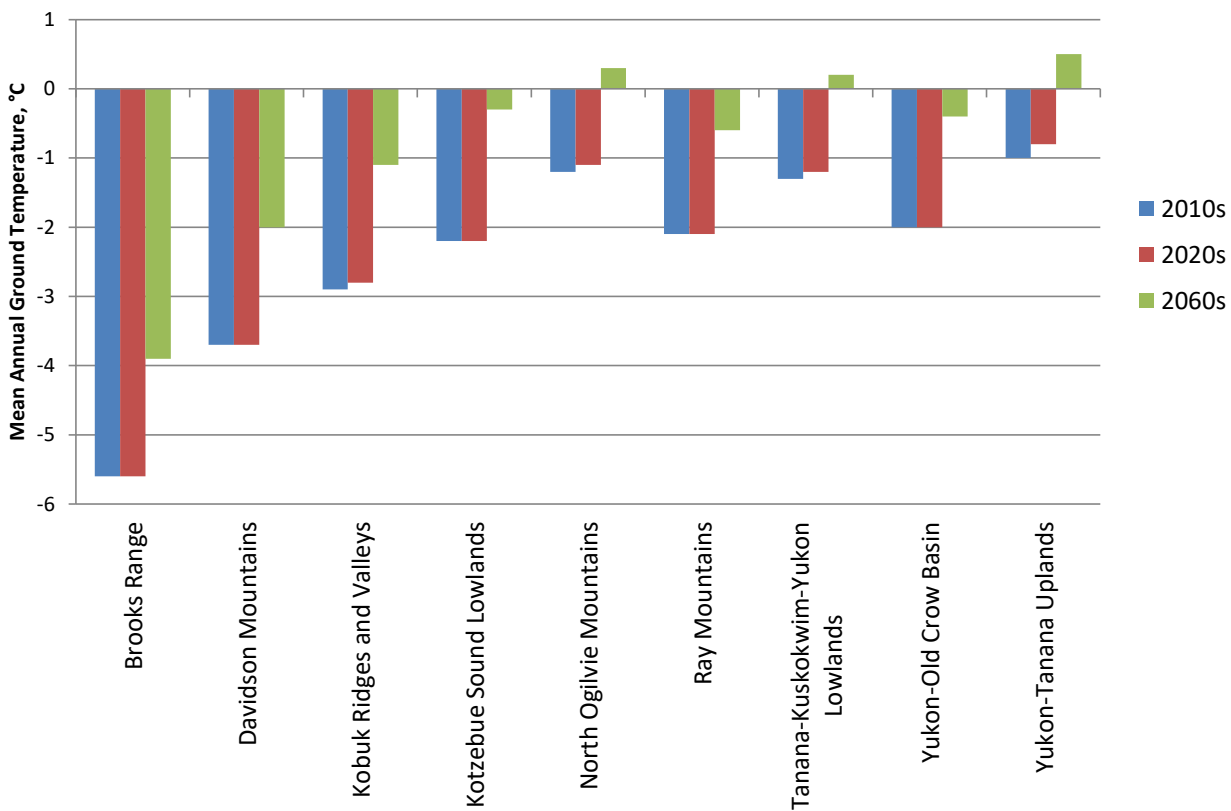


Figure C-33. Mean annual ground temperature at 1-m depth by ecoregion.

Table C-12. Mean annual ground temperature averaged across 5th-level hydrologic units.

Community	2010s	2020s	2060s	Community	2010s	2020s	2060s
Anaktuvuk Pass	-6.9	-6.9	-5.4	Chicken	-1.4	-1.3	-0.1
Arctic Village	-5.4	-5.5	-3.8	Beaver	-1.4	-1.4	0.2
Wiseman	-4.7	-4.8	-3.1	Tanana	-1.3	-1.3	0.1
Coldfoot	-4.3	-4.4	-2.7	Dot Lake	-1.3	-1.2	0.1
Red Dog Mine	-4.3	-4.2	-2.2	Venetie	-1.3	-1.3	0.1
Allakaket	-3.9	-3.9	-2.3	Alcan Border	-1.3	-1.1	0.2
Chalkyitsik	-3.5	-3.5	-1.9	Manley Hot Springs	-1.2	-1.1	0.2
Noatak	-3.5	-3.4	-1.4	Galena	-1.1	-1.1	0.6
Kobuk	-3.3	-3.2	-1.5	Pleasant Valley	-1.0	-0.8	0.4
Shungnak	-3.3	-3.2	-1.5	Northway	-1.0	-0.8	0.5
Bettles	-2.9	-3.0	-1.3	Minto	-0.9	-0.8	0.4
Kotzebue	-2.8	-2.6	-0.7	Big Delta	-0.9	-0.6	0.5
Fort Yukon	-2.6	-2.5	-0.9	Ruby	-0.9	-0.9	0.7
Noorvik	-2.5	-2.4	-0.5	Four Mile Road	-0.8	-0.7	0.6
Circle	-2.5	-2.4	-0.9	Healy Lake	-0.8	-0.6	0.7
Kiana	-2.4	-2.4	-0.6	Fairbanks	-0.8	-0.4	0.7
Rampart	-2.3	-2.2	-0.7	Two Rivers	-0.7	-0.4	0.8
Stevens Village	-2.2	-2.2	-0.6	Nenana	-0.4	-0.3	0.8
Tok	-2.1	-2.0	-0.8	Livengood	-0.4	-0.3	1.1
Ambler	-2.1	-2.1	-0.2	Salcha	-0.3	-0.1	1.1
Birch Creek	-2.0	-1.9	-0.4	Chena Ridge	-0.3	0.0	1.2
Selawik	-1.9	-1.9	-0.1	Harding-Birch Lakes	-0.3	-0.1	1.1
Hughes	-1.9	-1.9	-0.2	Fox	-0.2	0.0	1.2
Eagle	-1.8	-1.7	-0.3	Steele Creek	-0.2	0.0	1.2
Central	-1.6	-1.5	-0.1	Whitestone	-0.1	0.1	1.2

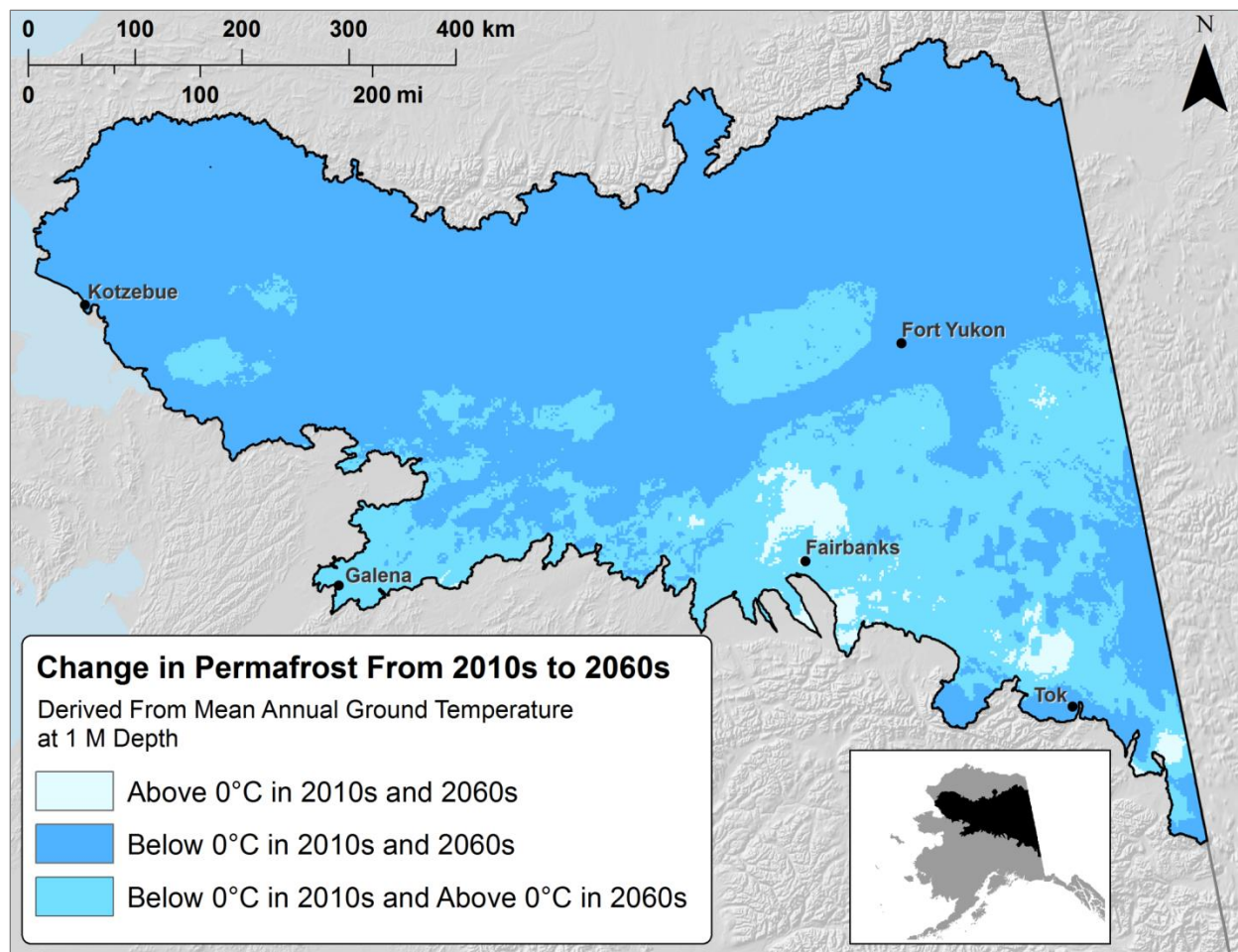


Figure C-34. Current and potential long-term change in permafrost at 1-m depth.

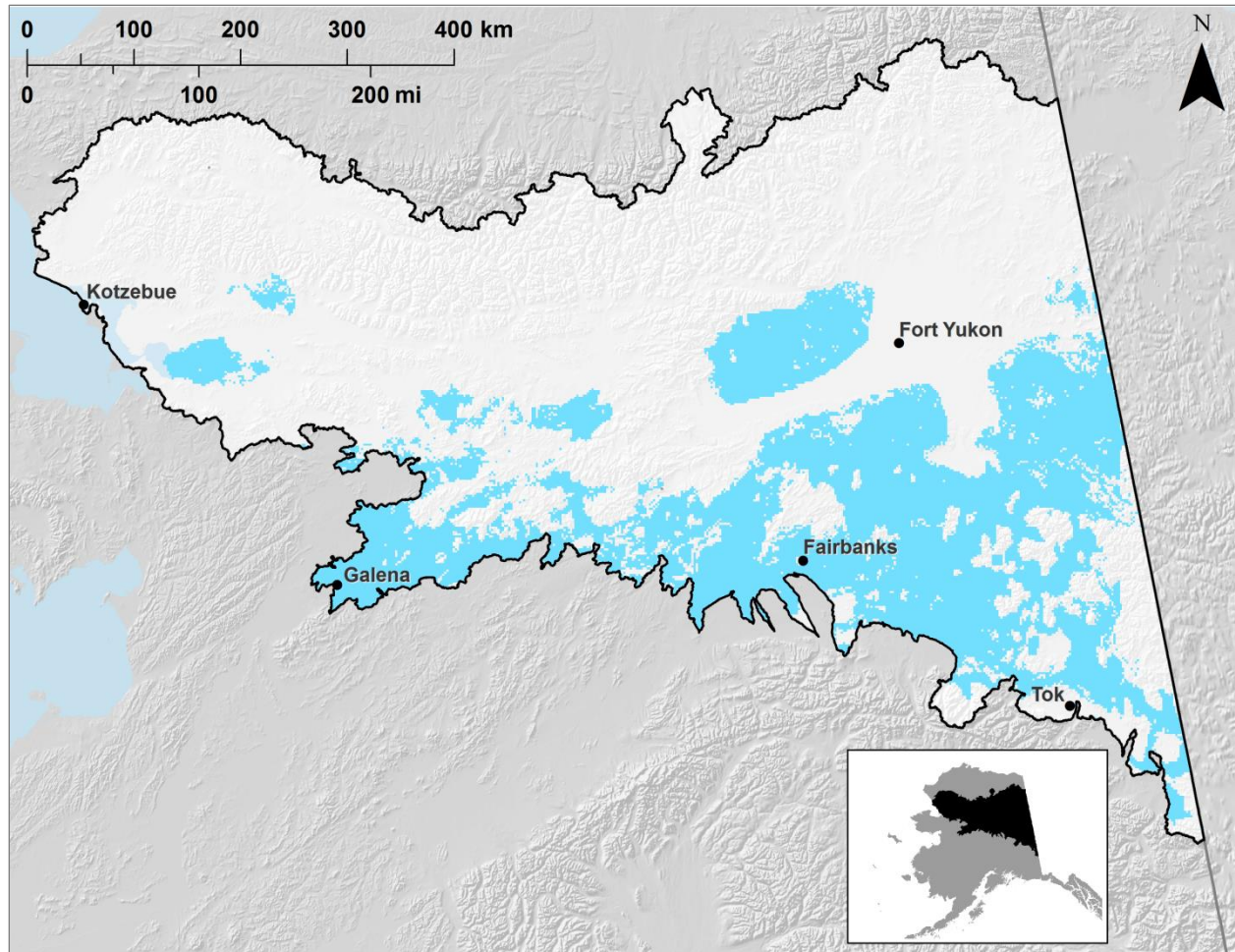


Figure C-35. Areas of Projected Permafrost Thaw 2010s to 2060s.

Active Layer Thickness

Active Layer Thickness refers to the depth of the top layer of soil that thaws during the summer months in a permafrost environment. For the purposes of this report, the ALT dataset also includes the depth of surface freeze during winter months, in areas that do not have permafrost at one-meter depth. Because the CYR study area includes areas with and without shallow permafrost, Figure C-36 shows both of these variables. The chart included in this figure underscores the fact that although only subtle change is expected in the near-term, by 2060s a shift is expected from 98% permafrost to only 70% permafrost across the region. The magnitude of the projected change nonetheless suggests that changes in soil thermal dynamics and accompanying changes in hydrology may be among the most important driving forces for geophysical, ecological, and linked human uses of the landscape.

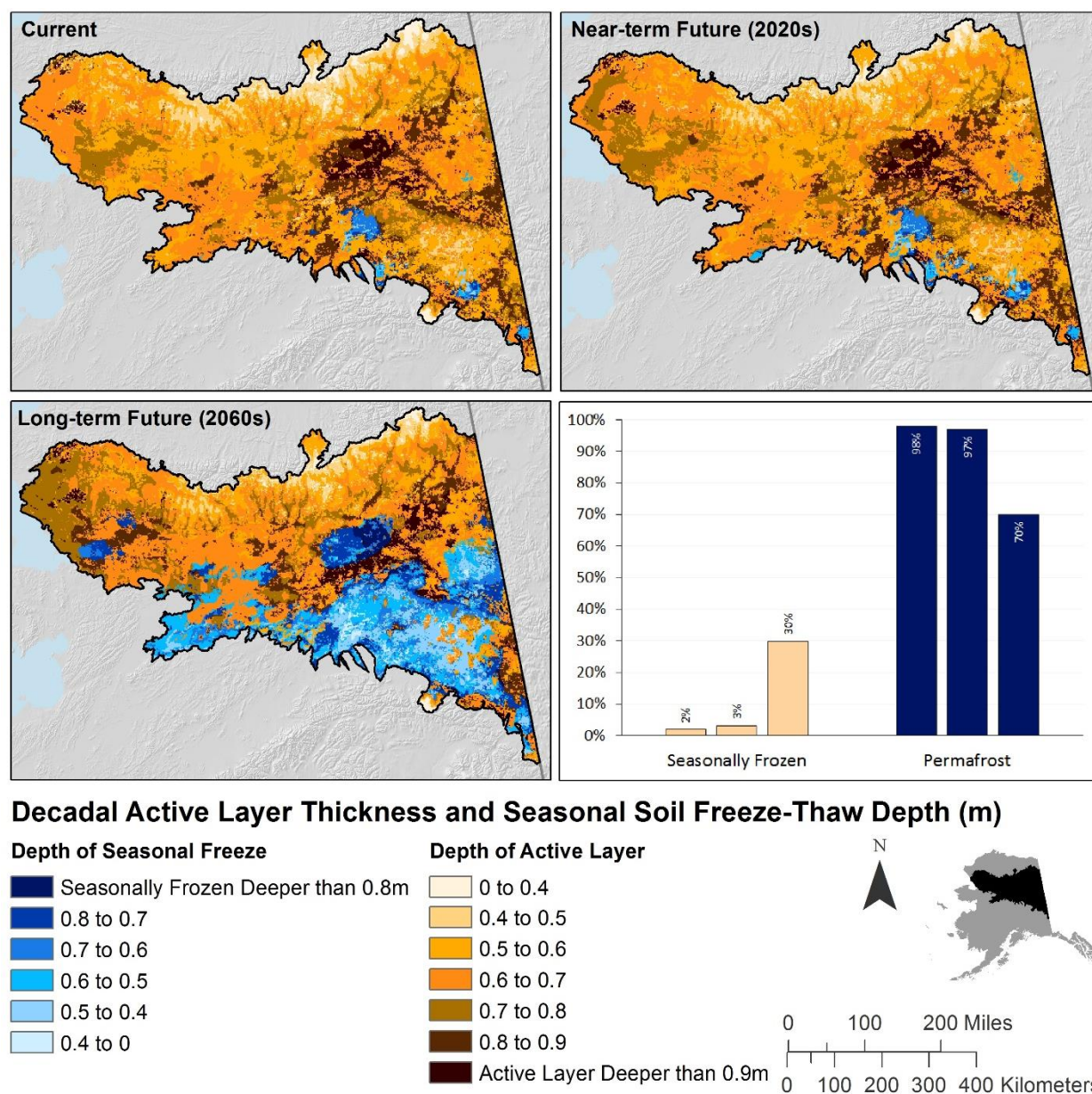


Figure C-36. Current, near-term, and long-term active layer thickness (ALT) and seasonally frozen ground in CYR study area. Little change is expected in the near-term, however, a shift is expected from 98% permafrost to only 70% permafrost across the region in the long-term.

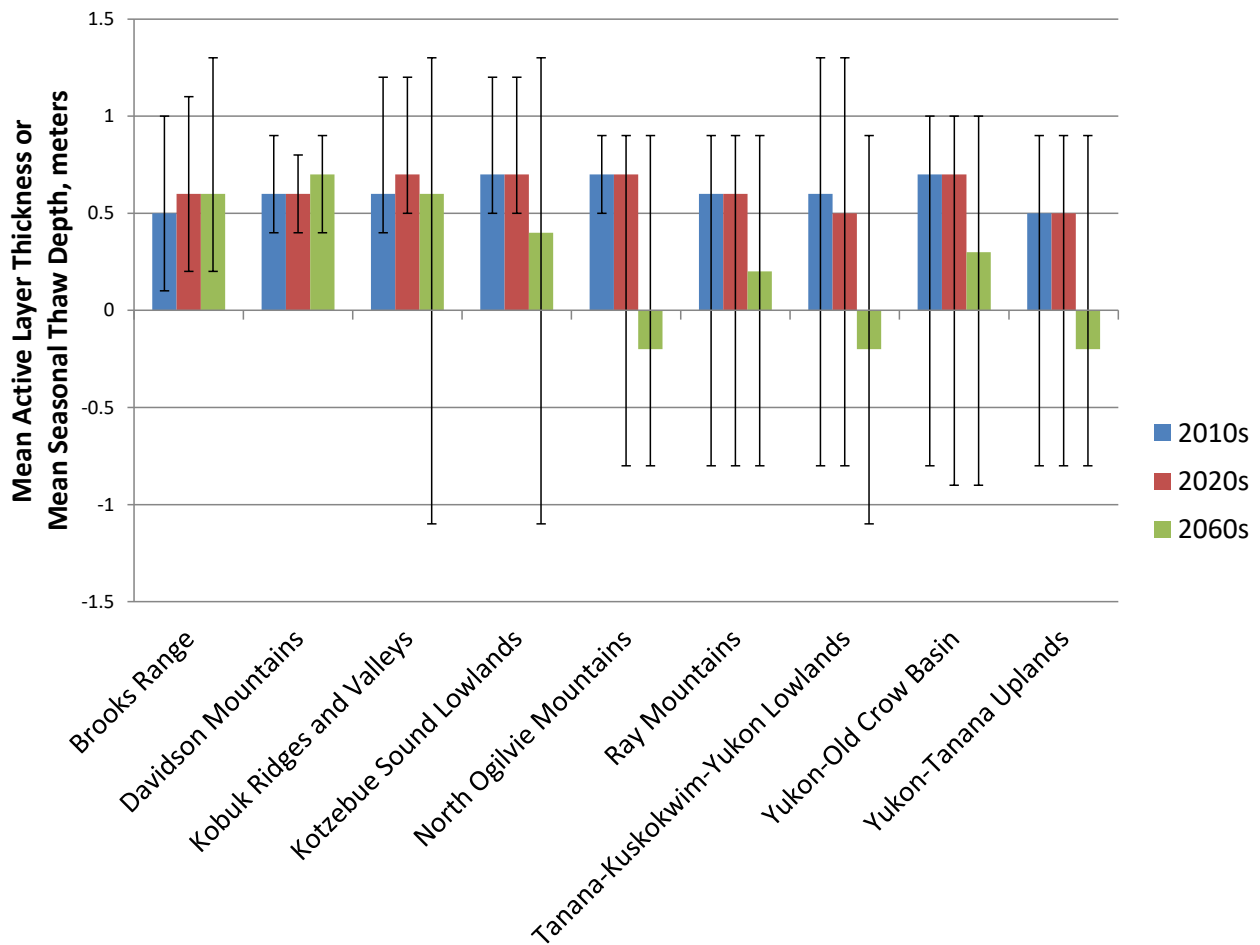


Figure C-37. Active layer thickness (positive values) or annual thaw depth (negative values) by ecoregion. Color bars show mean values, and bars depict the full range in maximum and minimum values for all 1-km pixels.

Active layer thickness varies enormously on a site-by-site basis (Figure C-37). Only in the two mostly northerly and mountainous ecoregions are all pixels frozen at 1 meter for all time periods. In three other ecoregions (North Ogilvie Mountains, Yukon-Old Crow Basin, and Yukon-Tanana Uplands) current conditions show no thawed pixels, but such thaw is predicted in the near-term or by 2060. In four ecoregions, current areas of thaw already yield negative ALT values. True site-specific variability would be even greater than that suggested by this chart, given that such variability occurs at scales finer than 1 km.

Thermokarst

A thermokarst is a depression from soil collapse due to permafrost thaw. Thermokarst potential (Figure C-38) classifies the landscape into areas of low, medium, and high potential for a thermokarst to initiate and expand under warming climate at a 1-km resolution. The general hypothesis underlying the development of this model was that thermokarsts occur in lowland peatlands with ice-rich permafrost.

Based on projections of MAGT, many areas in the southern half of the CYR REA are projected to experience permafrost thaw to 1-m depth by 2060s. Those areas were combined with the

thermokarst predisposition layer (Figure C-38) to extract thermokarst projections in areas projected to undergo permafrost thaw to a depth of at least 1 m (Figure C-39).

Thermokarst potential is generally low in the Brooks Range and other mountainous regions because soils are rocky, well-drained, and ice-poor. Thus, although some permafrost may thaw in such soils, structural collapse is unlikely. Thermokarst potential is greatest in the ice-rich soils south of the Brooks Range—particularly in the Davidson Mountains and Kobuk Ridges and Valleys ecoregions (Figure C-38). However, as can be seen in Figure C-39, these areas are less likely to actually undergo thermokarst, given the colder temperatures experienced there, and the low level of predicted permafrost thaw. Thus, in both the near-term and long-term future, we are most likely to see the effects of thermokarst in the Yukon-Tanana uplands and the Fairbanks and Galena areas.

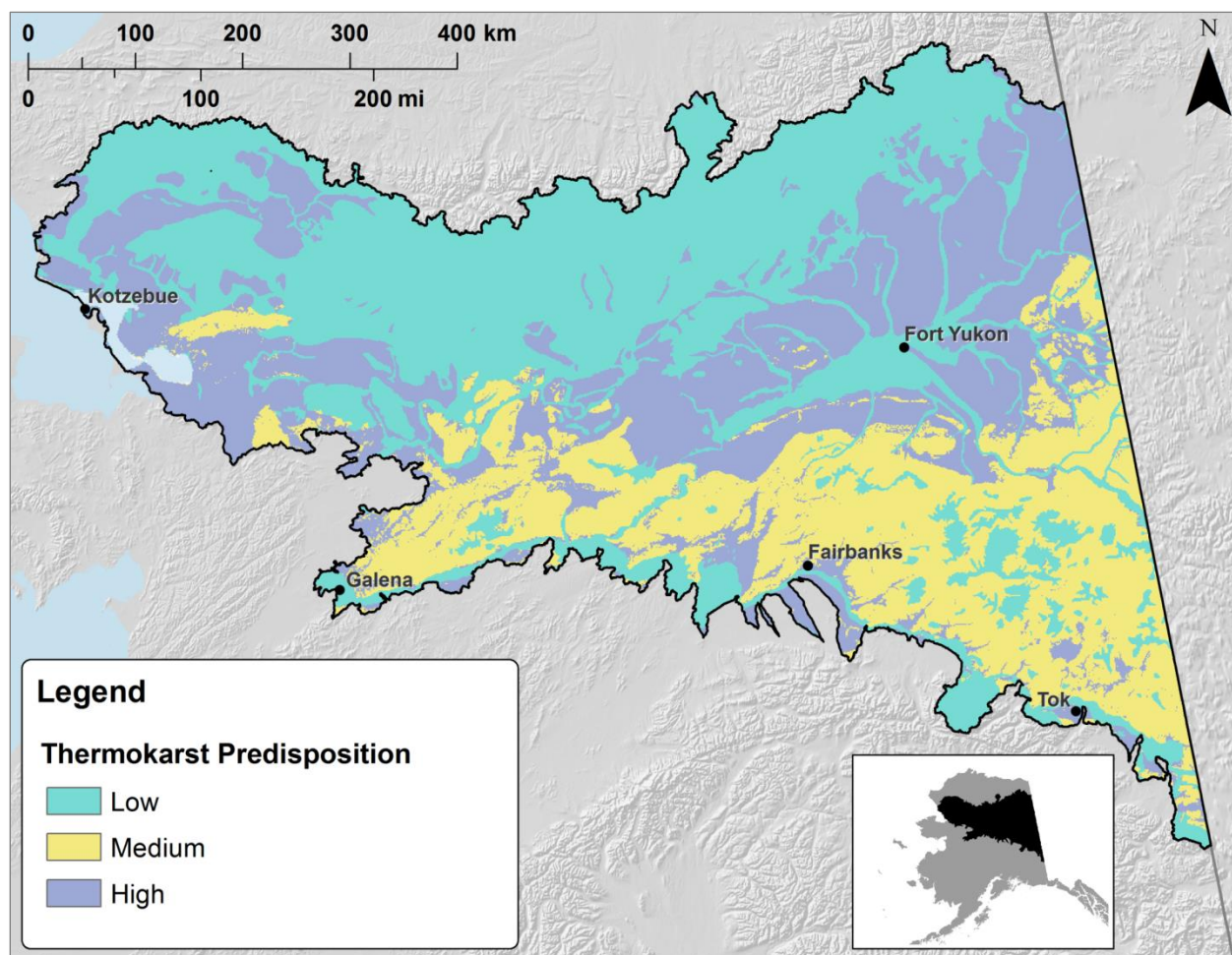


Figure C-38. Thermokarst predisposition in the CYR study area.

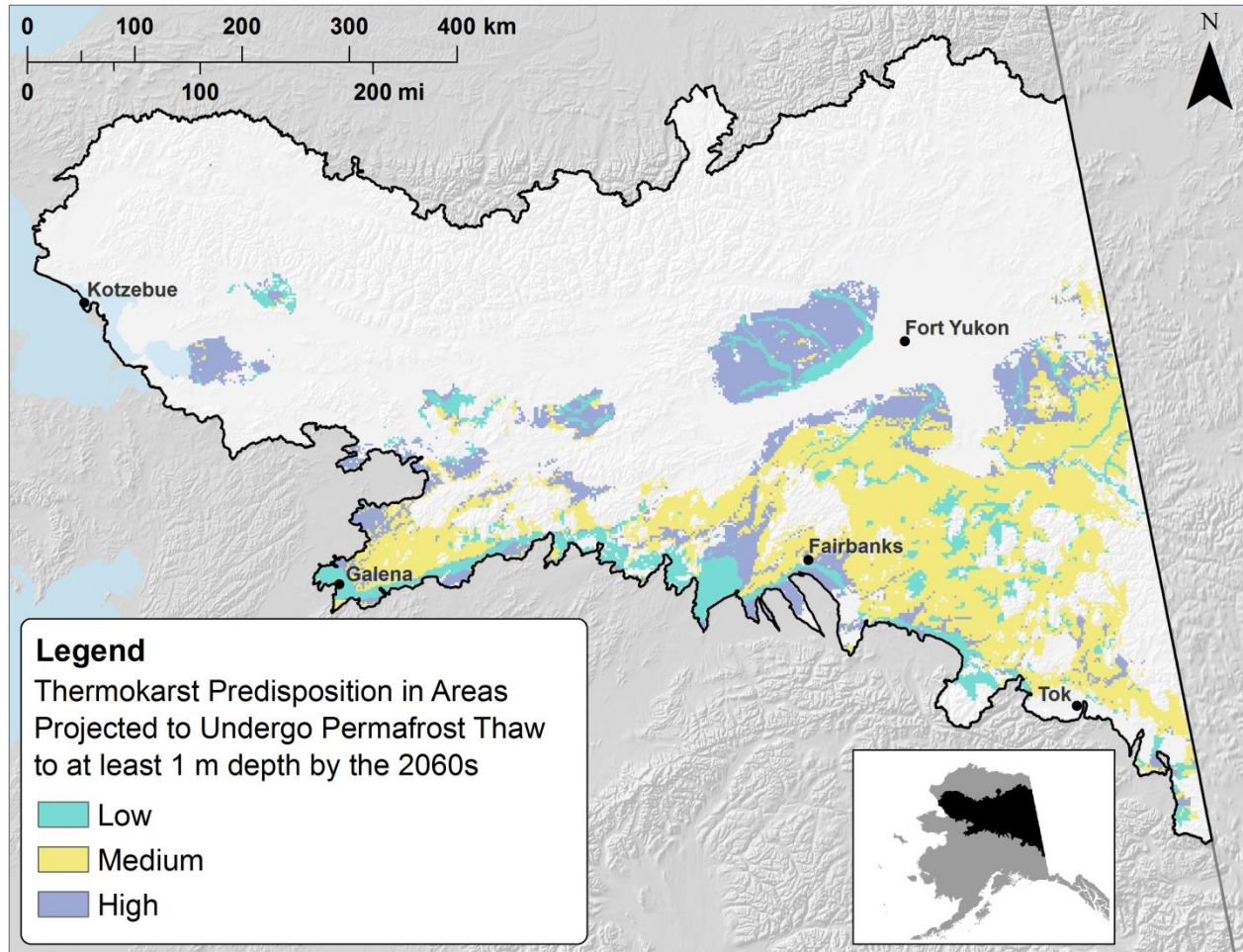


Figure C-39. Thermokarst potential in areas projected to thaw to at least 1-m depth by the 2060s in the CYR study area.

3.4 Discussion

Implications

The effects of increased ground temperature, changing active layer, thawing permafrost, and thermokarst are complex. Recent studies of the impacts of thermokarst in boreal Alaska (Osterkamp et al. 2000) suggest that in areas of ice-rich permafrost, thermokarst can lead to complete destruction of forest ecosystems. Forests can be replaced under such conditions by wet sedge meadows, bogs, thermokarst ponds, lakes, or floating mat fens. Climate warming and associated permafrost degradation and increased fire are linked to peatland expansion (Myers-Smith et al. 2008). In addition to the ongoing effects of climate warming, fire can yield immediate and dramatic thermokarst conditions not only in the boreal forest, but also on tundra sites (Jones et al. 2015). Not only is thaw and thermokarst likely to have local ecological effects, but recent findings also suggest that the release of organic carbon from peat due to permafrost thaw in boreal Alaska is likely to accelerate ongoing atmospheric warming (O'Donnell et al. 2012).

3.5 Limitations

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

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

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

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

3.6 Literature Cited

- Arp, C. D., M. S. Whitman, B. M. Jones, G. Grosse, B. V. Gaglioti, and K. C. Heim. 2015. Distribution and biophysical processes of beaded streams in Arctic permafrost landscapes. *Biogeosciences* 12:29–47.
- Barnhart, K. R., R. S. Anderson, I. Overeem, C. Wobus, G. D. Clow, and F. E. Urban. 2014. Modeling erosion of ice-rich permafrost bluffs along the Alaskan Beaufort Sea coast. *Journal of Geophysical Research-Earth Surface* 119:1155–1179.
- Brown, J., O. J. Ferrians, Jr., J. A. Heginbottom, and E. S. Melnikov. 1998, revised February 2001. Circum-Arctic map of permafrost and ground ice conditions. Boulder, CO: National Snow and Ice Data Center. Digital media.
- Callaghan, T. V., L. O. Björn, Y. Chernov, T. Chapin, T. R. Christensen, B. Huntley, R. A. Ims, M. Johansson, D. Jolly, S. Jonasson, N. Matveyeva, N. Panikov, W. Oechel, G. Shaver, S. Schaphoff, and S. Sitch. 2004. Effects of changes in climate on landscape and regional processes, and feedbacks to the climate system. *Ambio* 33:459–468.
- Frey, K. E., and J. W. McClelland. 2009. Impacts of permafrost degradation on Arctic river biogeochemistry. *Hydrological Processes* 23:169–182.
- Global Land Cover Characterization (GLCC). 2016. USGS Long-Term Archive. Available: <https://lta.cr.usgs.gov/GLCC>
- Hong, E., R. Perkins, and S. Trainor. 2014. Thaw settlement hazard of permafrost related to climate warming in Alaska. *Arctic* 67:93–103.
- Hugelius, G., C. Tarnocai, G. Broll, J. G. Canadell, P. Kuhry, and D. K. Swanson. 2013. The northern circumpolar soil carbon database: spatially distributed datasets of soil coverage and soil carbon storage in the northern permafrost regions. *Earth System Science Data* 5:3–13.
- Jones, B. M., G. Grosse, C. D. Arp, E. Miller, L. Liu, D. L. Hayes, and C. F. Larsen. 2015. Recent Arctic tundra fire initiates widespread thermokarst development. *Scientific Reports* 5.
- Jorgenson, M. T., J. Harden, M. Kanevskiy, J. O'Donnell, K. Wickland, S. Ewing, K. Manies, Q. L. Zhuang, Y. Shur, R. Striegl, and J. Koch. 2013. Reorganization of vegetation, hydrology and soil carbon after permafrost degradation across heterogeneous boreal landscapes. *Environmental Research Letters* 8(3):035017
- Jorgenson, T., K. Yoshikawa, M. Kanevskiy, Y. Shur, V. Romanovsky, S. Marchenko, G. Grosse, J. Brown, and B. Jones. 2008. Permafrost characteristics of Alaska. Institute of Northern Engineering, University of Alaska Fairbanks, NICOP.
- Kittel, T. G. F., B. B. Baker, J. V. Higgins, and J. C. Haney. 2011. Climate vulnerability of ecosystems and landscapes on Alaska's North Slope. *Regional Environmental Change* 11:S249–S264.
- Luo, D. L., J. HuiJun, S. Marchenko, and V. Romanovsky. 2014. Distribution and changes of active layer thickness (ALT) and soil temperature (TTOP) in the source area of the Yellow River using the GIPL model. *Science China-Earth Sciences* 57:1834–1845.
- McMichael, C. E., A. S. Hope, D. A. Stow, and J. B. Fleming. 1997. The relation between active layer depth and a spectral vegetation index in Arctic tundra landscapes of the North Slope of Alaska. *International Journal of Remote Sensing* 18:2371–2382.
- Myers-Smith, I. H., J. W. Harden, M. Wilking, C. C. Fuller, A. D. McGuire, F. S. Chapin. 2008. Wetland succession in a permafrost collapse: interactions between fire and thermokarst. *Biogeosciences* 5:1273–1286.
- O'Donnell, J. A., M. T. Jorgenson, J. W. Harden, A. D. McGuire, M. Z. Kanevskiy, K. P. Wickland. 2012. The effects of permafrost thaw on soil hydrologic, thermal, and carbon dynamics in an Alaskan peatland. *Ecosystems* 15:213–229.
- Osterkamp, T. E., L. Viereck, Y. Shur, M. T. Jorgenson, C. Racine, A. Doyle, and R. D. Boone. 2000. Observations of thermokarst and its impact on boreal forests in Alaska, USA. *Arctic Antarctic and Alpine Research* 32:303–315.

Section C. Abiotic Change Agents

Stephani, E., D. Fortier, Y. Shur, R. Fortier, and G. Doré. 2014. A geosystems approach to permafrost investigations for engineering applications, an example from a road stabilization experiment, Beaver Creek, Yukon, Canada. *Cold Regions Science and Technology* 100:20–35.

4. Management Questions

4.1 Climate Change and Fire Regime (MQ A1)

MQ A1: How is climate change likely to alter the fire regime in the dominant vegetation classes and riparian zones?

Projected changes in fire regime and associated changes in vegetation across the CYR study area are based on ALFRESCO model outputs. However, ALFRESCO vegetation classifications are built into the model and are not the same as those used for other purposes in the REA. Thus, answering this question requires not only interpretation of fire projections by region but also analysis of how ALFRESCO vegetation classifications relate to those classified as coarse-filter change agents in this report.

The relative flammability map presented in the Fire section of this report (Figure C-24) and the area burned graph (Figure C-40) are based on the mean number of times each pixel was projected to burn, averaged across 1000 model runs (200 runs for each of five downscaled climate models). Increased burning and shorter fire-return intervals are projected across much of the region, across vegetation classes, and in riparian zones. Flammability for any given pixel depends on simulated weather conditions in spring and summer months, but it also depends on the age and vegetation type of that pixel, and is calibrated to replicate observed historical fire patterns. Thus, it is highest in older stands of black spruce and white spruce, and much lower in deciduous stands, graminoid tundra, and shrub tundra. This results in spatial differences in projected flammability, as shown in Figure C-24. Although burning is projected to increase, variability is extremely high, making specific predictions by year or site impossible.

Fire regime is likely to change across vegetation classes and in riparian zones in two different ways. First, as described above, fire intervals are likely to become shorter across all existing classes as a result of warming conditions, particularly in spring and early summer. Second, fire regime is likely to shift as the vegetation itself shifts, driven by both fire and climate. These projected shifts are described in the Fire section of this report. Of particular interest are the projected shifts in shrubline (Figure C-28) and treeline (Figure C-29). These maps are not based on an average across many model runs, but rather on a selected “typical” or “best replicate” run from a single model, ECHAM5. In general, shrub tundra is projected to replace graminoid tundra, and white spruce forest is projected to replace shrub tundra.

Cross-walking ALFRESCO vegetation classes with those defined as Coarse-Filter CEs (Floodplain Forest and Shrub, Lowland Woody Wetland, Upland Spruce-Hardwood Forest, Upland Spruce Forest, Upland Low-Tall Shrub, Alpine and Arctic Tussock Tundra, and Alpine Dwarf Shrub Tundra) provides imperfect matches with ALFRESCO classes. Not only are the two classification systems based on different input data, each with its own biases, flaws and assumptions, they also incorporate fundamentally different views of the landscape: static versus dynamic. In ALFRESCO, pixels shift from class to class depending on fire behavior, climate conditions, and stand age. Deciduous vegetation exists only as young age classes of black and white spruce. Static vegetation maps do not account for the fact that in this fire-driven landscape, many pixels that are shrubby or even unvegetated are merely early successional stages of forest. Thus, neither model is necessarily “wrong”; instead, they can be viewed as complementary, offering two different ways of thinking about the landscape.

How reliable are these predictions? Are there other data/models which provide information that is different than the output presented?

No other currently available landcover or vegetation model offers a dynamic perspective on fire and vegetative succession. Thus, ALFRESCO outputs, while not precise predictions due to the highly variable nature of fire behavior and the stochasticity of the model, offer the most reliable predictions and data available to address this MQ.

Please see limitations section under the Fire section for a discussion on the accuracy and limitations of the analysis.

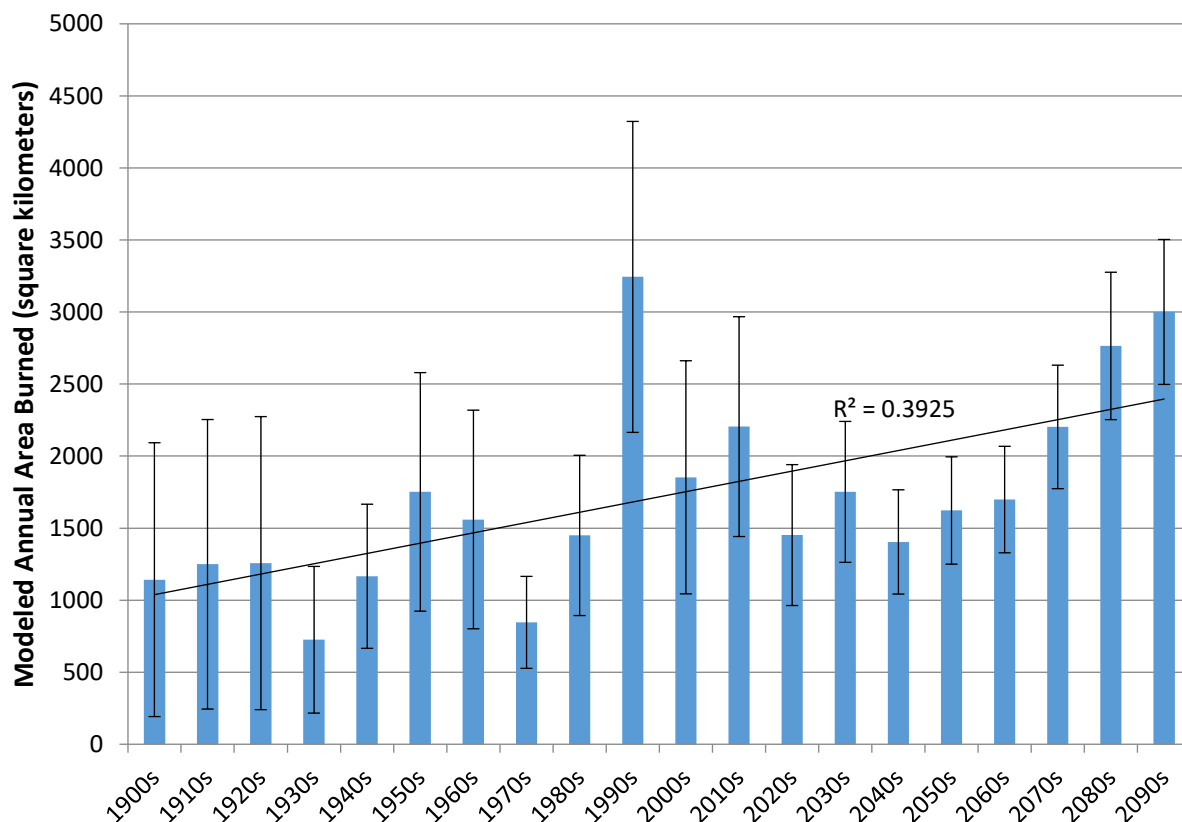


Figure C-40. Modeled annual area burned, averaged by decade, based on 1000 ALFRESCO replicates.

4.2 Permafrost, Precipitation, and Evapotranspiration (MQ B1)

MQ. B1: How is climate change likely to alter permafrost distribution, active layer depth, precipitation regime, and evapotranspiration in this region?

This question is primarily addressed by the core analysis provided in other sections of this report. A full description of projected changes in precipitation (seasonally and annually) is provided in the Climate section. In the Soil Thermal Dynamics section, we summarize how permafrost distribution and active layer dynamics can be estimated based on the projected MAGT at 1-m depth and the ALT.

Precipitation maps are based on SNAP downscaled monthly climate projections averaged across five models, using the A2 emissions scenario (as defined by the IPCC). All precipitation is measured in rainwater equivalent (mm). Annual precipitation includes decadal averages of all twelve months (Figure C-8). Outputs project slight increases in precipitation over time, across all seasons (Figure C-9, Figure C-10).

Mean annual ground temperature and ALT are modeled by the GIPL, using SNAP climate data as one of the input layers. Projections show a relatively steady increase in MAGT across the region over time, with acceleration as the century progresses (Figure C-32–Figure C-35). Because permafrost conditions are highly site-specific at fine resolution, actual conditions are likely to vary within pixels. Thus, these outputs must be viewed at a coarser level.

Active Layer Thickness refers to either a) the depth of the top layer of soil that thaws during the summer months in a permafrost environment, or b) the depth of surface freeze during winter months, in areas that do not have permafrost at 1-m depth. Climate change is likely to increase ALT in areas with permafrost at one meter depth, and decrease winter depth of freeze in areas without shallow permafrost (Figure C-36, Figure C-37).

In fully addressing this question, it should be noted that uncertainty in precipitation projections is relatively high, and that any increase in water availability may be affected by changes in seasonality, as demonstrated by changing snow day fraction (percentage of days on which precipitation would be expected to fall as snow as opposed to rain) in spring and fall (Figure C-11).

Increased precipitation also may be offset by increased evapotranspiration (due to temperature increases). Climate-driven changes in potential evapotranspiration (PET) were explored in a previous study performed using models created by Stephanie McAfee of the Wilderness Society along with SNAP researchers, and analyzed on behalf of BLM (Rupp and Springsteen 2009). This report was used in the development of a Resource Management Plan and associated Environmental Impact Statement for the BLM Eastern Interior Management Area, which overlaps with the CYR study area. The modeling of potential evapotranspiration in this study was done using the relatively simplistic Priestley-Taylor model, which is essentially a temperature-driven model. The results presented suggest that during the growing season, increased evapotranspiration is likely to outpace increases in precipitation, leading to overall drying conditions. This modeled trend is likely to be the case.

However, later work by McAfee (2013), the same researcher who created the PET model used by Rupp and Springsteen (2009) examined simple temperature-driven PET models and suggests that

“discrepancies in PET trends appear to derive from regional changes in incoming shortwave radiation, wind speed and humidity—phenomena simpler equations cannot capture. Because multiple variables can influence trends in PET, it may be more justifiable to use data-intensive methods, where the source(s) of uncertainty can be identified, rather than using simpler methods that could mask important trends.”

Accurate/reliable PET measurements are a current data gap for the CYR study area and further research is warranted.

How reliable are these predictions? Are there other data/models which provide information that is different than the output presented?

The reliability of SNAP climate predictions is discussed in the climate section of this report; no existing data or models offer more reliable or finer-scale projections for precipitation or active layer depth than the SNAP and GIPL models referenced here. Existing models of potential evapotranspiration are likely too simplistic to account for fine-scale variations in incoming shortwave radiation, wind speed and humidity. Thus, examining the impacts on vegetation from changes in PET may more effectively be conducted using outputs from the stochastic ALFRESCO fire model. As discussed in the Fire section of this report, summer warming and drying conditions are likely to trigger greater overall flammability and vegetation shifts.

Please see limitations section under the Climate Change and Soil Thermal Dynamics section for a discussion on the accuracy and limitations of the analysis.

4.3 Surface Water Availability (MQ C1)

MQ C1: How will changes in precipitation, evapotranspiration, and active layer depth alter surface water availability and, therefore, ecosystem function (dominant vegetation classes)?

This question is partially addressed in the core analysis under Climate and Soil Thermal dynamics. These sections include full analyses of annual and seasonal precipitation, snow day fraction, active layer thickness, and thermokarst potential.

Precipitation maps (Figure C-8–Figure C-10) project slight increases in precipitation over time, across all seasons. However, it should be noted that uncertainty in precipitation projections is relatively high, and that any increase in water availability may be affected by changes in seasonality, and/or may be offset by increased evapotranspiration (due to temperature increases).

Active Layer Thickness refers to either a) the depth of the top layer of soil that thaws during the summer months in a permafrost environment, or b) the depth of surface freeze during winter months, in areas that do not have permafrost at one-meter depth. Climate change is likely to increase ALT in areas with permafrost at one meter depth, and decrease winter depth of freeze in areas without shallow permafrost (Figure C-36, Figure C-37). Deeper ALT suggests deeper potential rooting depths, which suggests possible shifts from shallow-rooted dominant vegetation class such as graminoid tundra to deeper rooted shrub or tree species. White spruce require deeper rooting than black spruce. As suggested by Lloyd et al. (2003), tree and tall shrub species may be limited at the Arctic treeline by the availability of well-drained microsites.

Area-wide, ground-surface flows would be expected to increase with increases ALT. Surface flows may also be affected by thermokarst. The thermokarst predisposition maps (Figure C-38, Figure C-39) represents the likelihood that thermokarst could initiate and expand under warming climate (1-km resolution). The general hypothesis underlying the development of this model is that thermokarsts occur in lowland peatland with ice-rich permafrost.

How reliable are these predictions? Are there other data/models which provide information that is different than the output presented?

The reliability of SNAP climate predictions is discussed in the climate section of this report; no existing data or models offer more reliable or finer-scale projections for precipitation or active layer depth than the SNAP and GIPL models referenced here. As described under MQB1, existing models of potential evapotranspiration are likely too simplistic to account for fine-scale variations in incoming shortwave radiation, wind speed and humidity. Thus, examining the impacts on vegetation from changes in PET may more effectively be conducted using outputs from the stochastic ALFRESCO fire model. As discussed in the Fire section of this report, summer warming and drying conditions are likely to trigger greater overall flammability and vegetation shifts.

Please see limitations section under the appropriate section for a discussion on the accuracy and limitations of the analysis.

4.4 Climate Change and Seasonality (MQ E1)

MQ E1: How is climate change affecting the timing of snow melt and snow onset, spring breakup and green-up, and growing season length?

As described in the Climate section of this report, DOT represents the day on which the mean temperature, interpolated between monthly values, crossed the freezing point in the spring. Date of Freeze represents a similar date in the fall, and LOGS represents the number of days between those two dates. Date of Thaw correlates with snow melt, spring breakup, and green-up, although with varying lag-times in each case. Likewise, DOF correlates with snow onset, while not matching it exactly. Length of Growing Season correlates with the actual growing season length, although actual growing seasons will always be shorter than LOGS, and will vary by species.

As can be seen in, Figure C-16 and Table C-7, LOGS is projected to increase across the CYR study area, due to shifts in both DOT and DOF, with subtle short-term shifts and marked long-term shifts. Average long-term change in LOGS by ecoregion is 8–10 days. For DOT, the expected change is 2–4 days, and for DOF, 6–7 days. Greater variation occurs at the pixel level, and high-elevation areas in the Brooks Range can have a LOGS of less than 2 months.

Length of Growing Season at the level of the small watersheds (5th-level HUCs) that surround communities can be seen in Table C-13. While the projected long-term shift is not dissimilar among communities, an increase of 8–10 days may make a greater difference in communities that currently have extremely short summer seasons, such as Arctic Village or Anaktuvuk Pass.

Green-up has been recorded in Fairbanks from 1976 to the present (McGuire et al. 2015), and although the data show large standard deviations, the trend is toward an earlier date, with a shift of about 3 days in about 40 years, from about May 12th to about May 9th (Figure C-41). Similarly, DOT projections suggest a shift of about 3 days in the next 40–50 years. For Fairbanks, this shift is from April 11th to April 8th. There is clearly a lag time between DOT and green-up, but if we assume that the lag time holds steady at about 29 days, then we might expect green-up in the Fairbanks area to occur, on average, on about May 6th by 2060. However, we would also expect the high degree of variability seen in Figure C-41 to continue. This variability is so high that the trend has not yet reached statistical significance (regression; $P = 0.45$).

Similarly, the annual breakup date for river ice has been carefully recorded for one site in Interior Alaska, thanks to the annual betting pool known as the Nenana Ice Classic, which has taken place since 1917 (Figure C-42). Examining the data from the 1970s to the present shows a similar statistically significant trend (regression; $P < 0.001$) to that seen in the green-up data and the LOGS projections. Note that breakup always occurs prior to green-up, and that the lag time varies slightly, but that the two appear to have a very strong correlation (Figure C-43).

How reliable are these predictions? Are there other data/models which provide information that is different than the output presented?

The reliability of SNAP climate predictions is discussed in the climate section of this report; no existing data or models offer more reliable or finer-scale projections for precipitation or active layer depth than the SNAP models referenced here. With regard to application of SNAP data to questions of the timing of seasonality, as pinpointed in this MQ, the recorded data presented in

Figure C-41 through Figure C-43 corroborates modeled data and also provides possible means for data calibration.

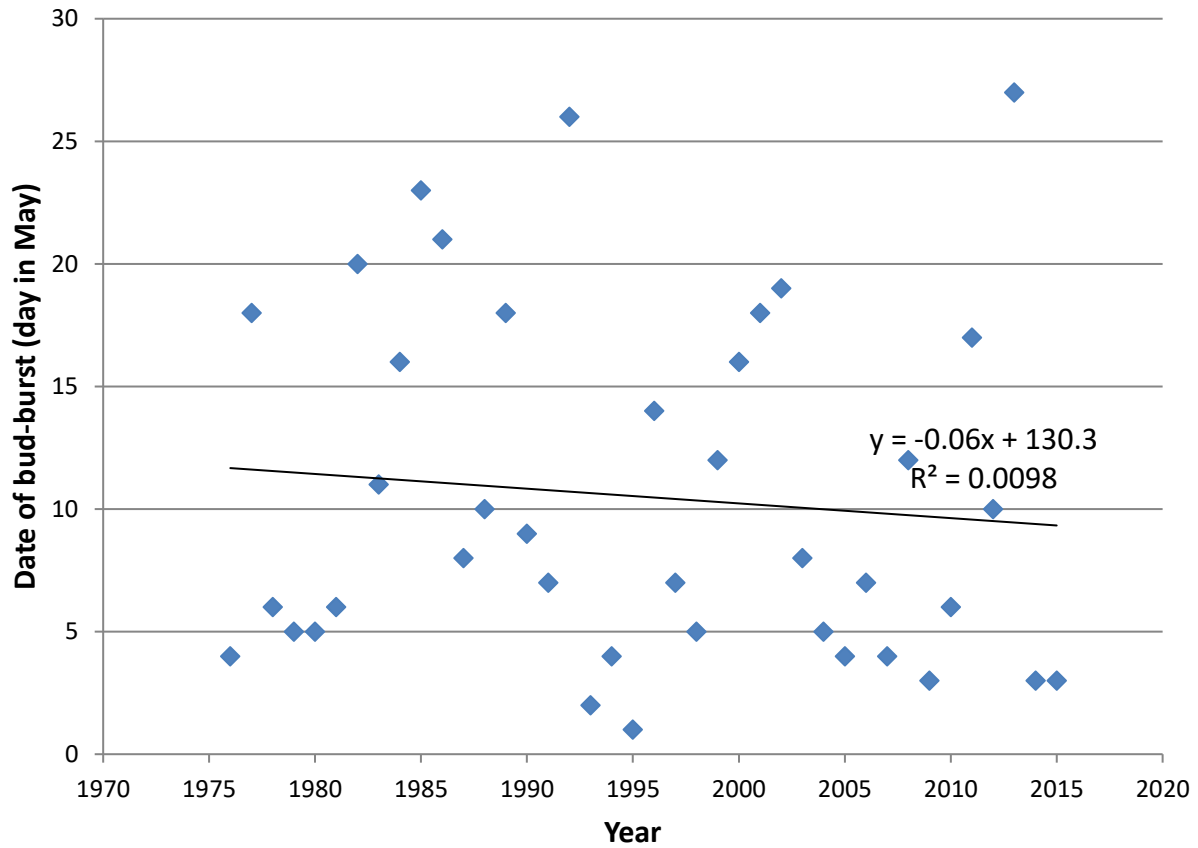


Figure C-41. Date of bud-burst (green-up) in the Fairbanks areas, 1976 to the present. Date from McGuire et al. 2015. Although the trend is toward earlier green-up, the regression is not statistically significant ($P = 0.45$).

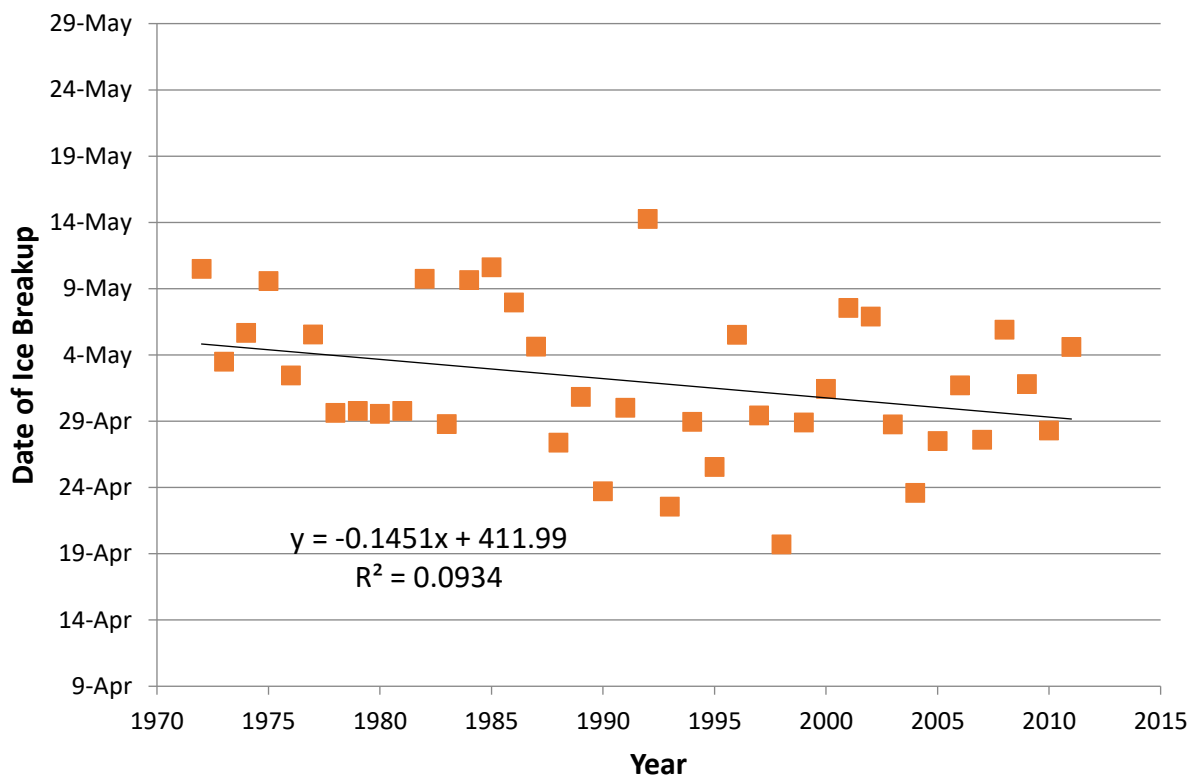


Figure C-42. Date of historical ice breakup of the Nenana Ice Classic. The trend toward earlier dates (negative slope of regression) is statistically significant ($P < 0.001$).

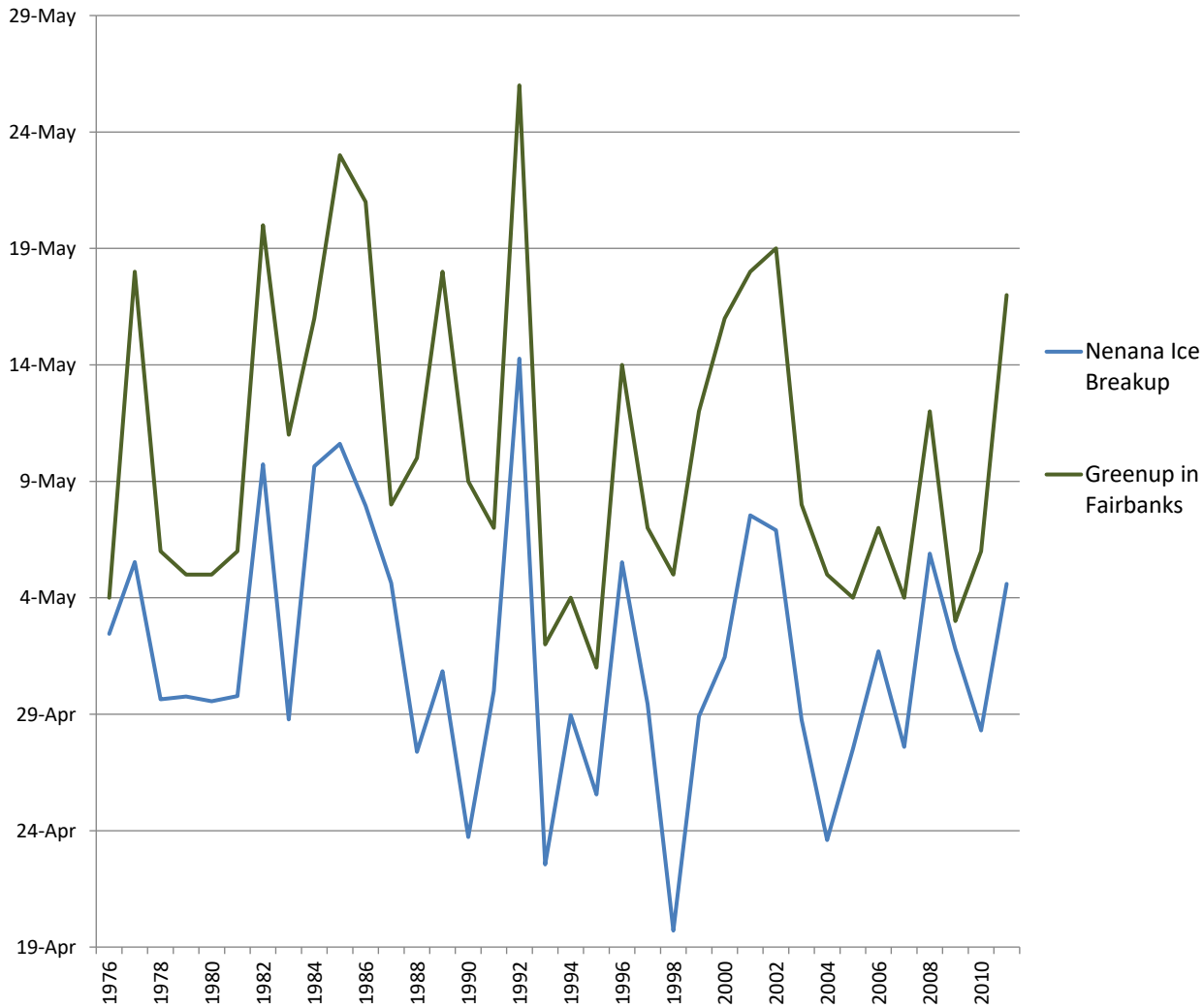


Figure C-43. Correlation between Nenana River ice breakup dates (Nenana 2011) and green-up dates in Fairbanks (McGuire et al 2015).

Table C-13. Length of Growing Season (LOGS) by community, based on 5th-level watersheds (HUCs).

Community	2010s	2020s	2060s	Community	2010s	2020s	2060s
Alatna	156	157	166	Healy Lake	170	170	179
Alcan Border	170	169	178	Hughes	163	164	173
Allakaket	156	157	166	Kiana	151	153	162
Ambler	153	155	165	Kobuk	156	157	168
Anaktuvuk Pass	123	125	133	Kotzebue	145	147	156
Arctic Village	136	138	144	Livengood	173	173	182
Badger	177	177	185	Manley Hot Springs	173	173	181
Beaver	161	162	170	Minto	173	173	181
Bettles	157	158	167	Moose Creek	176	175	183
Big Delta	176	176	184	Nenana	175	175	183
Birch Creek	160	160	168	New Allakaket	156	157	166
Central	159	159	168	Noatak	144	145	154
Chalkyitsik	161	161	170	Noorvik	149	151	160
Chena Ridge	177	177	185	North Pole	177	177	185
Chicken	157	157	166	Northway	173	172	181
Circle	160	160	167	Northway Junction	173	172	181
Coldfoot	151	152	161	Pleasant Valley	175	175	183
College	177	177	185	Rampart	165	165	174
Dot Lake	170	169	179	Red Dog Mine	139	141	149
Dot Lake Village	170	169	179	Ruby	167	167	176
Dry Creek	170	169	179	Salcha	176	175	183
Eagle	166	165	175	Selawik	147	149	157
Eagle Village	166	165	175	Shungnak	156	157	168
Eielson AFB	176	175	183	South Van Horn	177	177	185
Ester	177	177	185	Steele Creek	177	177	185
Evansville	157	158	167	Stevens Village	163	163	171
Fairbanks	177	177	185	Tanacross	167	166	175
Farmers Loop	177	177	185	Tanana	167	167	175
Fort Yukon	161	161	168	Tok	167	166	175
Four Mile Road	175	174	182	Two Rivers	176	176	185
Fox	177	177	185	Venetie	162	162	170
Galena	165	165	175	Whitestone	177	176	185
Goldstream	177	177	185	Wiseman	146	147	156
Harding-Birch Lakes	175	174	183				

A short summer season occurs in the CYR study area and small changes can trigger large changes in vegetation and wildlife. Shoulder-season changes can also be seen in changes in the percentage of days on which any precipitation would be expected to arrive as snow, as opposed to rain.

4.5 Literature Cited

- Lloyd, A. H., K. Yoshikawa, C. L. Fastie, L. Hinzman, and M. Fraver. 2003. Effects of permafrost degradation on woody vegetation at Arctic treeline on the Seward Peninsula, Alaska. *Permafrost and Periglacial Processes* 14:93–101.
- McAfee, S. A. 2013. Methodological differences in projected potential evapotranspiration. *Climatic Change* 120:915–930.
- McGuire, A. D., J. Anderson, C. Elsner, T. Fathauer, and E. S. Euskirchen. 2015. Green-up values for Interior Alaska 1976–Present. BNZ-LTER Dataset. Available: <http://www.lter.uaf.edu/data/data-detail/id/300>
- Nenana Ice Classic. 2011. NSIDC: National Snow and Ice Data Center. Boulder, Colorado USA. Available: <https://nsidc.org/data/nsidc-0064>
- Rupp, T. S., and A. Springsteen. 2009. Projected climate change scenarios for the Bureau of Land Management Eastern Interior Management Area, Alaska, 2001-2099. Available: https://www.snap.uaf.edu/sites/default/files/EIAK_cc_report.pdf

D. Biotic Change Agents

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Summary

Section D. *Biotic Change Agents* provides the detailed descriptions, methods, datasets, results, and limitations for the assessment of current and future impacts of non-native plants in the Central Yukon study area. Additionally, a historic, current, and limited future assessment of the impacts of insect- and disease-related forest damage is provided.

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1. Invasive Species

This section of the Technical Supplement addresses invasive species as a Change Agent (CA) for the Central Yukon (CYR) study area. Invasive species are defined as non-native species whose introduction does or is likely to cause economic or environmental harm or harm to human health (see Executive Order 13112). Nationally, invasive species are recognized to be a major concern for resource management (Pimentel et al. 2005, USDA 2013). In Alaska and the circumpolar North, invasive species are not known to have caused the degree of damage observed at lower latitudes (Carlson and Shephard 2007, Sanderson et al. 2012, Lassuy and Lewis 2013). However, increasing examples of ecological and economic harm are recognized in the state (Croll et al. 2005, Carlson et al. 2008, Spellman and Wurtz 2011, Nawrocki et al. 2011, Schwörer et al. 2012, Spellman et al. 2014). While most non-native species populations are currently small and geographically restricted, they may become more problematic with future changes in land-use, climate, and disturbance regimes (Carlson and Shephard 2007, Spellman et al. 2014).

The CYR Rapid Ecoregional Assessment (REA) does not pose specific invasive species Management Questions (MQs); however, invasive species as agents of change are implicit in all REAs. We, therefore, address the current state and predicted future vulnerability of the landscape to invasive species establishment in the CYR study area. Potential impacts to Conservation Elements (CEs) are summarized here, but additional discussion can be found in sections devoted to each CE. Here we address the general questions:

1. What is the current state of invasive species in the study area and which resources are most at risk?
2. What is the predicted future state of invasive species in the study area?

1.1 Introduction

Numerous populations of non-native plants, including those with large perceived ecological impacts (i.e., “invasive”), are established in the CYR study area. Information on invasive animals and pathogens in the region is substantially more limited; we, therefore, restrict our primary analysis to non-native plant species and describe a vulnerability assessment for invasion under current and future conditions. However, a brief synopsis of non-native animals in the region is included below. We conducted a separate assessment of river and lake vulnerability to establishment of invasive waterweed (*Elodea* spp.) because this species group is anticipated to have potentially strong effects on aquatic resources of high management value (i.e., salmon and fish-bearing waterways). Additionally, the synthetic vulnerability assessment only incorporates terrestrial data that are unlikely to capture vulnerability to aquatic invaders.

Non-native animals known from the region range from birds and mammals to invertebrates, including some species with notable ecological impacts in other regions; distributions of these species appear to be concentrated in the urban area around Fairbanks. Starlings (*Sturnus vulgaris*) have been established in Fairbanks since at least 1979 (Kessel 1979); these birds are believed to pose a particular threat to cavity nesting species (Ingold 1998), although other studies have not been able to detect population declines of native birds in the presence of

starlings (Koenig 2003). While starlings have been documented in the region for over 35 years, populations apparently have remained small and primarily restricted to the urban landscape (Harding Scurr and Van Hemert, pers. comm.). It is not clear what effects starlings may be having on native boreal species. Norway rats (*Rattus norvegicus*) are reported from Fairbanks, but apparently are restricted to the town (ADF&G 2016a). Ecological impacts of non-native rats can be especially severe for ground-nesting birds and are well-documented on seabird islands. Introduced rat populations on continental land masses in natural areas, however, do not appear to typically reach levels that cause significant effects. Invasive invertebrates documented in the region include gypsy moth (*Lymantria dispar*)—an aggressive defoliator that is known in the state from a single male collected in Fairbanks in 2006 (ADF&G 2016b)—and non-native earthworms (S. Seefeldt, pers. comm.). The introduction of earthworms in other boreal and north-temperate forests has resulted in large ecological changes in soil and above-ground ecology (Bohlen et al. 2004, Frelich et al. 2006), but currently populations in the CYR study area are only known from Fairbanks. Non-native sawfly defoliators have caused moderate to severe defoliation for several years in riparian alder communities south of the Alaska Range (Kruse et al. 2010, Kruse and Lisuzzo 2010, Kruse et al. No Date); these defoliators were detected in four locations near Fairbanks, but population levels were extremely low and defoliation was negligible (Kruse and Lisuzzo 2010). Further discussion of non-native insects as pests are included in section D-2.

1.2 Methods

Current Invasive Species Status

To address the current state of invasive species in the CYR study area, we compiled non-native plant data from the statewide weed database ([AKEPIC](#)¹) in September 2015. Data in AKEPIC contain associated non-native plant presence and absence records for the state. Additional non-native plant occurrences were garnered from the [Pacific Northwest Herbaria Consortium](#)² (2015) and [Toolik Lake Field Station Virtual Herbarium](#)³ (2015). Current status of invasive species was evaluated by overlaying the CYR study area with the spatially explicit non-native plant data and extracting all relevant records. Figure D-1 displays an overview of methods and approach.

¹ See <http://accs.uaa.alaska.edu/invasive-species/non-native-plants/> for updated data

² See <http://pnwherbaria.org/>

³ See http://toolik.alaska.edu/edc/biotic_monitoring/virtual_herbarium.php

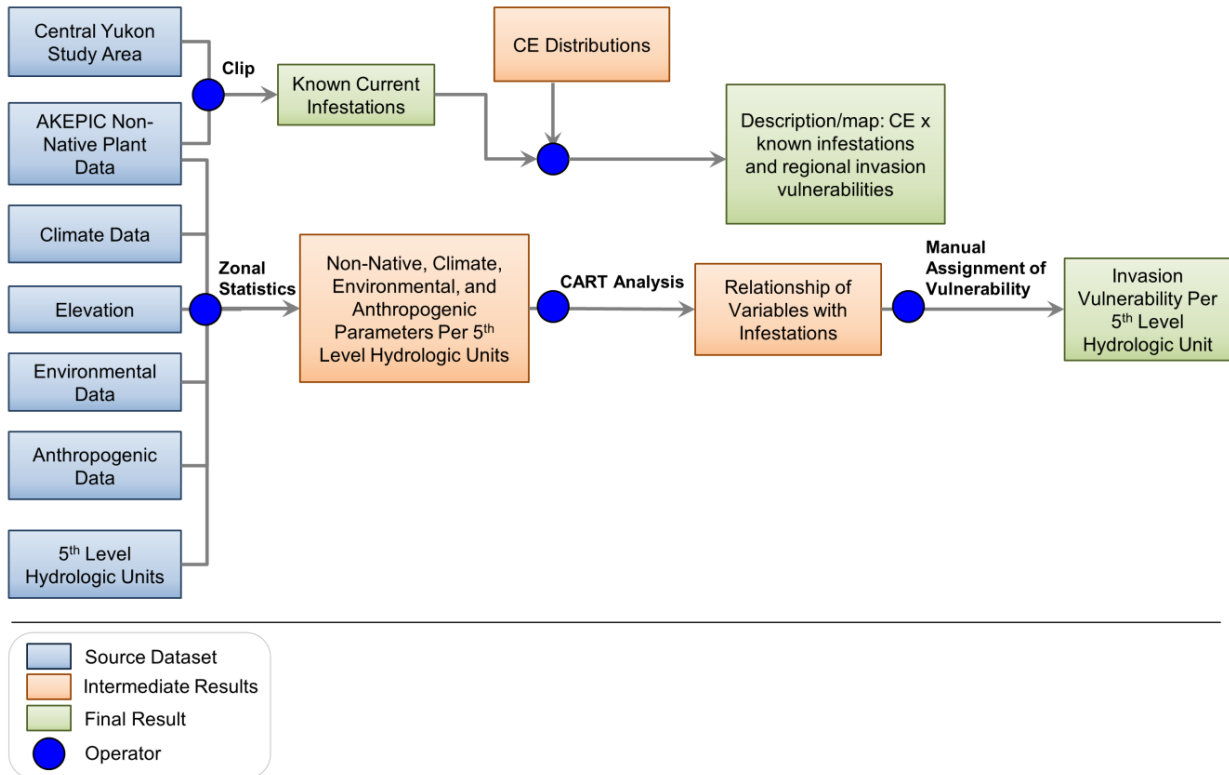


Figure D-1. Process model of invasive species current and predicted future condition methodology.

Current and Future Infestation Vulnerability

Survey intensity for non-native plants in the CYR study area is not strong or consistent across the study area; we, therefore, developed an analytical model to identify areas that are perceived to be currently vulnerable to invasion by non-native plant species. This analysis is intended to supplement the empirical data, identify areas in which future surveys may be directed, and to evaluate the potential change in vulnerability in the future. The analytical approach used here (variance partitioning via classification tree and random forest) facilitates the evaluation of a large number of variables that may have non-linear relationships and complex interactions; this approach has been used elsewhere to understand patterns of plant invasion vulnerabilities (see De'ath and Fabricius 2000, Cutler et al. 2007, Tamayo and Olden 2014), including the Yukon River Lowlands–Kuskokwim Mountains–Lime Hills REA (Carlson et al. 2014).

The basic approach taken here were as follows:

- 1.) Determined the climate, habitat, and anthropogenic variables that are associated with watersheds having weed problems in Interior Alaska based on the non-native plant data.
- 2.) Determined which watersheds in the CYR study area have those climate, habitat, and anthropogenic variables associated with weed problems.
- 3.) Determined which watersheds in the CYR study area are projected to have those future climate, habitat, and anthropogenic variables associated with weed problems.

Watersheds with weed problems are defined by having a species likely to cause management concerns (i.e., invasiveness rank of 60 or greater, see Carlson et al. 2008 and Nawrocki et al. 2011) and at least ten non-native species present. These watersheds (5th-level hydrologic units) are termed “infested.” These criteria separated watersheds into those with only a small number of species that are typically associated with disturbed substrates such as roadsides, and those watersheds that have potentially problematic species and high numbers of non-native species. Infested watersheds are also highly correlated with greater numbers and areas of infestations.

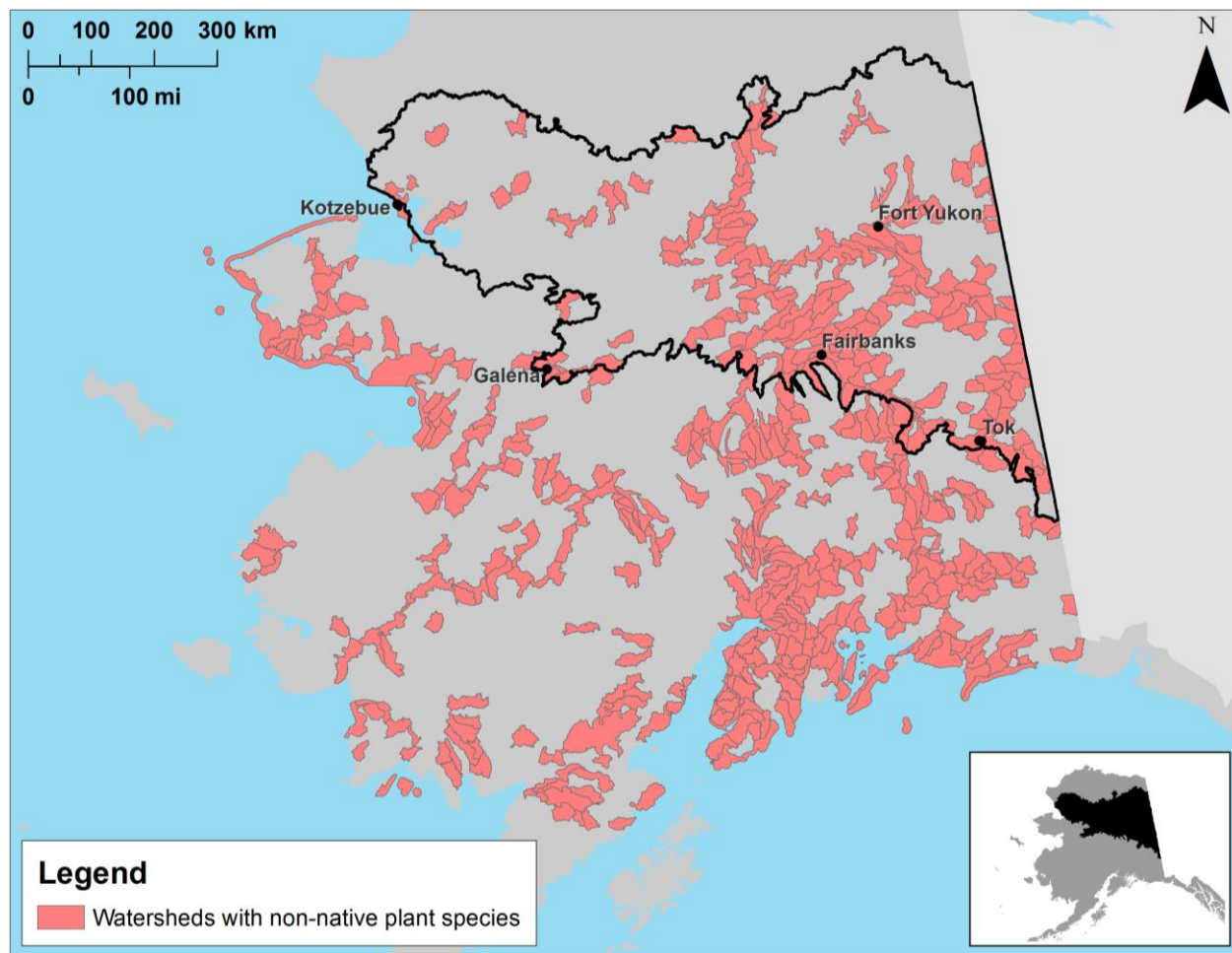


Figure D-2. Map of watersheds (red) south of the ridge crest of the Brooks Range with non-native plant occurrences that were used in the infestation vulnerability model. Watersheds without weed-survey effort were excluded.

The invasion vulnerability model was first developed for the broad region between the Alaska Range and Gulf of Alaska. Model development for this broad region allows for much greater resolution of the relationship among variables. Additionally, it encompasses climate, anthropogenic, and infestation conditions beyond those present in the CYR study area, but conditions that may occur within the region in the future. For example, mean January temperatures warmer than -12°C currently do not occur in the CYR study area, but are anticipated to occur by the 2060s. A total of 441 5th-level HUCs that were surveyed for non-native plants

were included in the broad analysis (Figure D-2). Watersheds that were not surveyed were not included in the analysis.

The relationship of the HUC infested/not infested classification was then compared with 20 climate, habitat, and anthropogenic variables in classification tree and random forest analysis. The climate variables included: mean annual temperature and precipitation, mean January temperature and precipitation, mean July temperature and precipitation, mean growing season length, mean freeze date, mean date of thaw, and mean summer warmth index (Table D-1). The habitat variables included: area of permafrost, river length, and native vegetation richness. Anthropogenic variables included: human population size, total income, area of development, area of agricultural land, length of highways, secondary roads, and trails. Threshold predictor values derived from the classification tree model for the broad region were then used to delineate invasion vulnerabilities within the CYR study area in GIS. Lastly, known infestations were overlaid on the modeled infestation vulnerability map to qualitatively compare outputs.

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

Dataset Name	Data source
Alaska Exotic Plants Information Clearinghouse (AKEPIC): non-native plant species, location, infestation size, associated vegetation community	ACCS
Climate Data: mean annual temperature and precipitation, mean January temperature and precipitation, mean July temperature and precipitation, mean growing season length, mean freeze date, and mean date of thaw, mean summer warmth index for current, 2010s-2020s, and 2060s	SNAP
Anthropogenic GIS: human population size, total income, area of development, area of agriculture, length of highways, secondary roads, and trails	ISER, U.S. Census Bureau, National Land Cover Database
Habitat Data: area of permafrost, river length, and native vegetation richness	SNAP, ADNR, ACCS
<i>Elodea</i> historic and future climate suitability envelope: modeled suitable area based on global distribution and associate climate and topographic variables	Matthew W. Luizza (Colorado State University)

We modeled near-term future (2025) and long-term future (2060) invasion vulnerabilities using the classification tree approach described above. Invasion vulnerability thresholds from the current classification tree model were maintained; however, we used projected future climate and anthropogenic conditions to identify areas vulnerable to invasion for the CYR study area.

Waterweed (*Elodea* spp.) Invasion Vulnerability

Elodea (waterweed) is widely recognized as a serious threat to the ecology of freshwater systems—this plant can achieve dense monospecific stands, reduce the flow of water, and alter the chemical composition of the water body, including hyper-eutrophication and oxygen depletion (Josefsson 2011). It is native to North America south of the limit of the former Laurentide ice sheet, south of the southern US-Canada border. This species was first recorded in Alaska in 1982 and in recent years the number of known sites has increased dramatically, especially in urban waterbodies and those with high use. First, we mapped known populations of waterweed (recently

identified as *Elodea nuttallii* in the Fairbanks region; *E. canadensis* and hybrids between the two species have been introduced south of the Alaska Range) within the CYR study area. Secondly, we identified waterbodies of perceived greater risk of importation and establishment of *Elodea* using a deductive model in GIS. *Elodea* is known to establish by small fragments and can easily attach to equipment, vehicles, and float planes, thus, spreading easily. We, therefore, identified susceptible stream networks based on terrestrial and aquatic anthropogenic vectors and then identified susceptible lakes based on floatplane access as a vector.

The United States Geologic Survey's National Hydrography Dataset (NHD) was queried to identify lotic water bodies within the CYR study area susceptible to the spread of *Elodea*. Network traces were performed downstream of road intersections to identify waterways with potential sources of introduction as natural dispersion upstream would be limited without anthropogenic assistance. Network traces were performed upstream and downstream of public boat launches and known *Elodea* infestations. Potential upstream movement of *Elodea* propagules from public boat launches was invoked as plant fragments may be moved by boats, boaters, and their equipment upstream as well as downstream. We defined boat-navigable waterways in the study area as all named rivers in the NHD and only those portions of Birch Creek downstream of the boat launch located on the creek. River traces were only limited by the most upstream/downstream portion of the river within the study area. River segments were attributed with fields to record these source vectors and given a presence/absence rank (1 = presence, 0 = absence) based on the results of the geometric network traces. Vectors were assumed equal as vector significance is a data gap. River segments were then assigned a susceptibility to invasion rank by summing across all vector fields. The susceptibility to invasion field ranged from 1–4 with higher values indicating higher risk of introduction and were summarized as low, medium, medium-high, and high.

Floatplanes are a potential vector for *Elodea* introductions (Alaska DNR no date) and we, therefore, identified lakes ≥ 1 km in longest axis as "likely accessible" by floatplane and those 0.5 to < 1.0 km in length as "possibly accessible." This distance criterion was developed based on a review of lakes used for floatplane landings in the Kanuti National Wildlife Refuge. Other features such as lake depth or shape, presence of obstructions, high waves, lack of appropriate approach to shore, etc., may result in inaccessibility of lakes longer than 1 km; however, these features are not readily assessed with GIS or other datasets at hand. Additionally, this approach only considers a component of the likelihood of *Elodea* transport and does not encompass habitat suitability (e.g., lake depths less than 9 feet, pH from 6.0-7.5, etc., see Gollasch 2006), or probability/frequency of landings (e.g., lakes closer to urban centers, or those with greater recreational uses).

For vulnerable lakes identified above, we then overlaid regions assessed to be of high, moderate, and low suitability for both historic and future scenarios. Habitat suitability was based on associations of known locations of *Elodea* worldwide with 23 climate and topographic variables from analysis by Luizza et al. (2016). The habitat suitability model of Luizza et al. (2016) indicated that temperature during the warmest quarter was the most important variable with very little probability of *Elodea* occurring below a threshold of approximately 10 °C during the summer. Precipitation and topographic variables were of secondary importance. Matthew Luizza graciously shared his GIS layers of *Elodea* habitat suitability, which we then overlaid with our lake vulnerability layer.

1.3 Results

Current Distribution of Non-Native Plants

A total of 110 non-native vascular plant taxa have been documented with nearly 6,900 infestation records, encompassing a total of 2,156 acres (Table D-2). This accounts for 0.0022% of the CYR land area. Figure D-3 displays the spatial distribution and density of known infestations in the CYR study area. Highway corridors, urban centers, and villages are the primary areas with major populations of non-native plants established.

The species with the greatest perceived ecological risk established in the study area are *Phalaris arundinacea*, *Melilotus albus*, *Elodea nuttallii*, *Cirsium arvense*, *Caragana arborescens*, *Prunus padus*, *Sonchus arvensis* ssp. *arvensis*, *Vicia cracca* ssp. *cracca*, and *Rosa rugosa*. *Rosa rugosa*, however, is known from a single historic collection at the former Rampart Experiment Station and is likely extirpated in the region. *Phalaris arundinacea* cultivars are currently restricted to roadsides in the immediate Fairbanks area (note: native genotypes of this grass are known from hot springs in the region, see Jabowski et al. 2013). *Cirsium arvense* was recorded in Stevens Village on the Yukon in 2011, and above-ground biomass was clipped and bagged. The current status of this *Cirsium arvense* population is unknown. The invasive waterweed, *Elodea nuttallii*, is found in the Chena Slough (to the confluence with the Tanana River) and in nearby Chena Lake. *Caragana arborescens* is planted as an ornamental shrub, with scattered records in communities such as Eagle, Fort Yukon, Fort Greely, and a few populations noted along roadsides, such as the Steese Highway. *Sonchus arvensis* ssp. *arvensis* is primarily known from the Fairbanks and Delta Junction areas, and is particularly problematic along roadsides in agricultural contexts; however, outlying populations are found north along the Steese and Dalton Highways. *Prunus padus* is noted from Fairbanks, Delta Junction, Fort Yukon, as well as isolated trees along Chena Hot Springs Road and the Elliot Highway north of Chatanika Creek. *Vicia cracca* ssp. *cracca* is quite widely dispersed throughout the CYR study area, including remote cabin and trails along the Yukon River and as far north as Coldfoot. This species is particularly problematic along the Interior road system. Similarly, *Melilotus albus* is widely distributed in the region from the northern boundary of the CYR study area on the Dalton Highway, west in Galena, and east to the Yukon border along the Alaska Highway. While this species is primarily found along road right-of-ways, it is also known to establish in openings in the boreal forest (e.g., after fires) and along sandbars of rivers. Low soil pH may limit establishment of this species in some regions of Alaska (Conn et al. 2008).

The most commonly occurring species include highly invasive *Melilotus albus*, *Vicia cracca*, and *Hordeum jubatum*, as well as more weakly invasive, disturbance specialists: *Chenopodium album*, *Crepis tectorum*, *Matricaria discoidea*, *Plantago major*, *Polygonum aviculare*, and *Taraxacum officinale*. With the exception of *Taraxacum officinale*, these species typically require continued ground disturbance to persist in Alaska and are unlikely to establish in large numbers in natural areas outside of active floodplains or recent fires. Most recorded non-native plants are known from right-of-ways and villages.

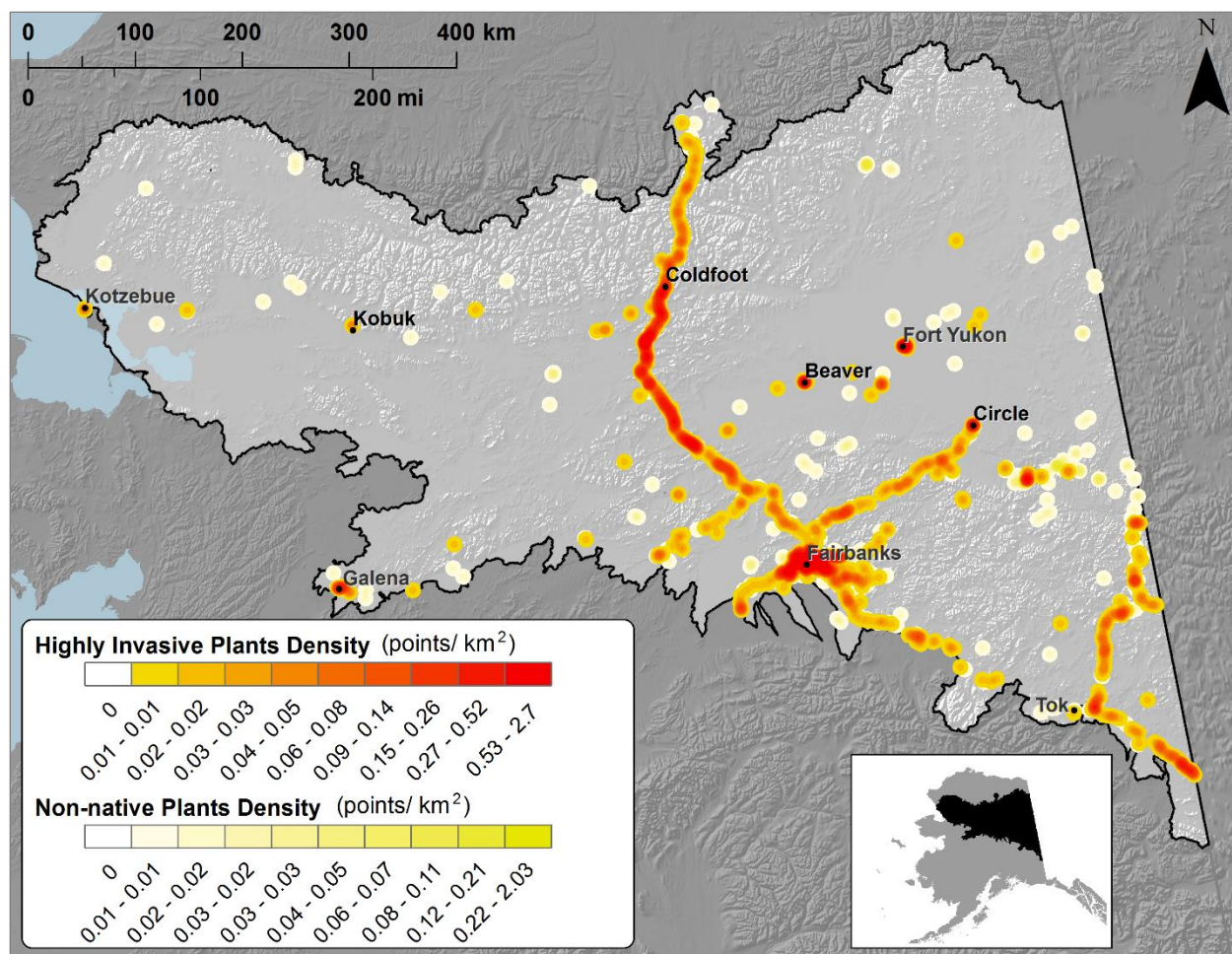


Figure D-3. Distribution of non-native plant infestations in the CYR study area (white to red circles). Warmness of points is scaled to density of all non-native plants (white to yellow) and density of highly invasive plants (white to red).



Figure D-4. *Vicia cracca* infestation at the intersection of the Parks Highway and Sheep Creek Road in Fairbanks (left), and *Caragana arborescens* infestation at Mile 44, Steese Highway (right).

Table D-2. Non-native vascular plant species known to occur in the CYR study area ordered by Invasiveness Rank (abbreviated in table as IR). See Carlson et al. 2008 for discussion of ranking criteria. NA = indicates taxa that have not received an invasiveness rank.

Scientific Name	Common Name	IR	Scientific Name	Common Name	IR
<i>Phalaris arundinacea</i>	reed canarygrass	83	<i>Brassica rapa</i>	rape	50
<i>Melilotus albus</i>	white sweetclover	81	<i>Galeopsis bifida</i>	splitlip hempnettle	50
<i>Elodea nuttallii</i>	western waterweed	79	<i>Fallopia convolvulus</i>	black bindweed	50
<i>Cirsium arvense</i>	creeping thistle	76	<i>Alopecurus geniculatus</i>	water foxtail	49
<i>Caragana arborescens</i>	Siberian peashrub	74	<i>Medicago lupulina</i>	black medick	48
<i>Prunus padus</i>	European bird cherry	74	<i>Rumex crispus</i>	curly dock	48
<i>Sonchus arvensis</i> ssp. <i>arvensis</i>	field sowthistle	73	<i>Tripleurospermum inodorum</i>	scentless false mayweed	48
<i>Vicia cracca</i> ssp. <i>cracca</i>	bird vetch	73	<i>Persicaria lapathifolia</i>	pale smartweed	47
<i>Rosa rugosa</i>	rugosa rose	72	<i>Persicaria maculosa</i>	spotted ladythumb	47
<i>Linaria vulgaris</i>	butter and eggs	69	<i>Poa annua</i>	annual bluegrass	46
<i>Melilotus officinalis</i>	yellow sweetclover	69	<i>Sonchus asper</i>	spiny sowthistle	46
<i>Lonicera tatarica</i>	Tatarian honeysuckle	66	<i>Polygonum aviculare</i>	prostrate knotweed	45
<i>Lotus corniculatus</i>	bird's-foot trefoil	65	<i>Lappula squarrosa</i>	European stickseed	44
<i>Medicago sativa</i> ssp. <i>falcata</i>	yellow alfalfa	64	<i>Plantago major</i>	common plantain	44
<i>Hordeum jubatum</i>	foxtail barley	63	<i>Mentha spicata</i>	spearmint	43
<i>Bromus inermis</i>	smooth brome	62	<i>Silene noctiflora</i>	nightflowering silene	42
<i>Leucanthemum vulgare</i>	oxeye daisy	61	<i>Silene latifolia</i>	bladder campion	42
<i>Cirsium vulgare</i>	bull thistle	61	<i>Stellaria media</i>	common chickweed	42
<i>Elymus repens</i>	quackgrass	59	<i>Thlaspi arvense</i>	field pennycress	42
<i>Medicago sativa</i> ssp. <i>sativa</i>	alfalfa	59	<i>Anthemis cotula</i>	stinking chamomile	41
<i>Trifolium repens</i>	white clover	59	<i>Descurainia sophia</i>	herb sophia	41
<i>Taraxacum officinale</i>	common dandelion	58	<i>Hesperis matronalis</i>	dames rocket	41
<i>Trifolium hybridum</i>	alsike clover	57	<i>Lolium multiflorum</i>	Italian ryegrass	41
<i>Crepis tectorum</i>	narrowleaf hawksbeard	56	<i>Capsella bursa-pastoris</i>	shepherd's purse	40
<i>Myosotis scorpioides</i>	true forget-me-not	54	<i>Hordeum vulgare</i>	common barley	39
<i>Phleum pratense</i>	timothy	54	<i>Papaver croceum</i> ⁴	Iceland poppy	39
<i>Ranunculus repens</i>	creeping buttercup	54	<i>Poa compressa</i>	Canada bluegrass	39
<i>Elymus sibiricus</i>	Siberian wildrye	53	<i>Chenopodium album</i>	lambquarters	37
<i>Trifolium pratense</i>	red clover	53	<i>Cerastium glomeratum</i>	sticky chickweed	36
<i>Alopecurus pratensis</i>	meadow foxtail	52	<i>Senecio vulgaris</i>	old-man-in-the-Spring	36
<i>Poa pratensis</i> ssp. <i>pratensis</i>	Kentucky bluegrass	52	<i>Spergularia rubra</i>	red sandspurry	34
<i>Hieracium umbellatum</i>	narrowleaf hawkweed	51	<i>Viola tricolor</i>	johnny jumpup	34
<i>Rumex acetosella</i>	common sheep sorrel	51	<i>Matricaria discoidea</i>	disc mayweed	32
			<i>Spergula arvensis</i>	corn spurry	32
			<i>Lepidium densiflorum</i>	common pepperweed	25

⁴ This taxon is recognized as *Papaver nudicaule* in the Integrated Taxonomic Information System; however, the name *Papaver croceum* is used in Alaska to distinguish the introduced cultivar from the native species, *P. nudicaule*.

Table D-2 Continued. Non-native vascular plant species known to occur in the CYR study area ordered by Invasiveness Rank (abbreviated in table as IR). See Carlson et al. 2008 for discussion of ranking criteria. NA = indicates taxa that have not received an invasiveness rank.

Scientific Name	Common Name	IR	Scientific Name	Common Name	IR
<i>Amsinckia menziesii</i>	Menzies' fiddleneck	NA	<i>Lathyrus pratensis</i>	meadow pea	NA
<i>Artemisia biennis</i>	biennial wormwood	NA	<i>Nemophila menziesii</i>	baby blue eyes	NA
<i>Atriplex hortensis</i>	garden orache	NA	<i>Pastinaca sativa</i>	wild parsnip	NA
<i>Avena fatua</i>	wild oat	NA	<i>Plagiobothrys figuratus ssp. figuratus</i>	fragrant popcornflower	NA
<i>Bidens cernua</i>	nodding beggartick	NA	<i>Polygonum achoreum</i>	leathery knotweed	NA
<i>Borago officinalis</i>	common borage	NA	<i>Puccinellia distans</i>	weeping alkaligrass	NA
<i>Chenopodium leptophyllum</i>	narrowleaf goosefoot	NA	<i>Raphanus sativus</i>	cultivated radish	NA
<i>Chenopodium rubrum</i>	red goosefoot	NA	<i>Rudbeckia hirta</i>	blackeyed Susan	NA
<i>Chenopodium simplex</i>	mapleleaf goosefoot	NA	<i>Rumex acetosa</i>	garden sorrel	NA
<i>Collomia linearis</i>	tiny trumpet	NA	<i>Rumex maritimus</i>	golden dock	NA
<i>Conyza canadensis</i>	Canadian horseweed	NA	<i>Schedonorus pratensis</i>	tall fescue	NA
<i>Dianthus barbatus</i>	sweetwilliam	NA	<i>Sisymbrium altissimum</i>	tall tumbled mustard	NA
<i>Echium vulgare</i>	common viper's bugloss	NA	<i>Solanum nigrum</i>	black nightshade	NA
<i>Erodium cicutarium</i>	redstem stork's bill	NA	<i>Sonchus arvensis ssp. uliginosus</i>	moist sowthistle	NA
<i>Erucastrum gallicum</i>	common dogmustard	NA	<i>Sorbaria sorbifolia</i>	false spiraea	NA
<i>Eschscholzia californica</i>	California poppy	NA	<i>Taraxacum erythrospermum</i>	rock dandelion	NA
<i>Gaillardia pulchella</i>	Indian blanket	NA	<i>Trifolium lupinaster</i>	lupine clover	NA
<i>Geranium bicknellii</i>	Bicknell's cranesbill	NA	<i>Veronica longifolia</i>	longleaf speedwell	NA
<i>Gnaphalium uliginosum</i>	marsh cudweed	NA	<i>Vicia sativa ssp. nigra</i>	garden vetch	NA
<i>Helianthus annuus</i>	common sunflower	NA	<i>Vicia villosa</i>	winter vetch	NA
<i>Lactuca tatarica</i>	blue lettuce	NA			

Table D-3. Most abundant non-native vascular plant species present in the CYR study area (more than 100 recorded infestations), number of infestations by each species and total area infested, and Invasiveness Rank (see Carlson et al. 2008 for discussion of ranking criteria).

Species	Number of Infestations	Total Infested Acres	Invasiveness Rank
<i>Melilotus albus</i> (white sweetclover)	1108	259	81
<i>Vicia cracca</i> ssp. <i>cracca</i> (bird vetch)	990	75	73
<i>Hordeum jubatum</i> (foxtail barley)	649	252	63
<i>Plantago major</i> (common plantain)	503	187	44
<i>Taraxacum officinale</i> (common dandelion)	488	214	58
<i>Crepis tectorum</i> (narrowleaf hawksbeard)	361	83	56
<i>Matricaria discoidea</i> (disc mayweed)	282	123	32
<i>Bromus inermis</i> (smooth brome)	256	85	62
<i>Chenopodium album</i> (lambquarters)	252	70	37

Species	Number of Infestations	Total Infested Acres	Invasiveness Rank
<i>Trifolium hybridum</i> (alsike clover)	167	103	57
<i>Lepidium densiflorum</i> (common pepperweed)	165	63	25
<i>Polygonum aviculare</i> (prostrate knotweed)	161	58	45

Current and Future Infestation Vulnerability

Classification tree analysis of Interior Alaska invasion vulnerability produced a model with moderate to good explanatory power (misclassification rate = 19%, Cohen's kappa = 0.53; Figure D-5). The resulting five categories were defined as "High Infestation Vulnerability," "Potentially High Infestation Vulnerability," "Moderate Infestation Vulnerability," "Potentially Low Infestation Vulnerability," and "Low Infestation Vulnerability," based on the proportion of infested HUCs to the total number of HUCs defined in each terminal branch, as well as the uncertainty associated with sample size. Very high certainty is associated with the Low Infestation Vulnerability based on percent developed area and secondary road density (only 5 out of 182 watersheds were misclassified). Less certainty is associated with the higher vulnerability classes. The variables that best describe the variance, and, thus, defined our categories were: percent developed land, mean thaw date, highway road density, and secondary road density.

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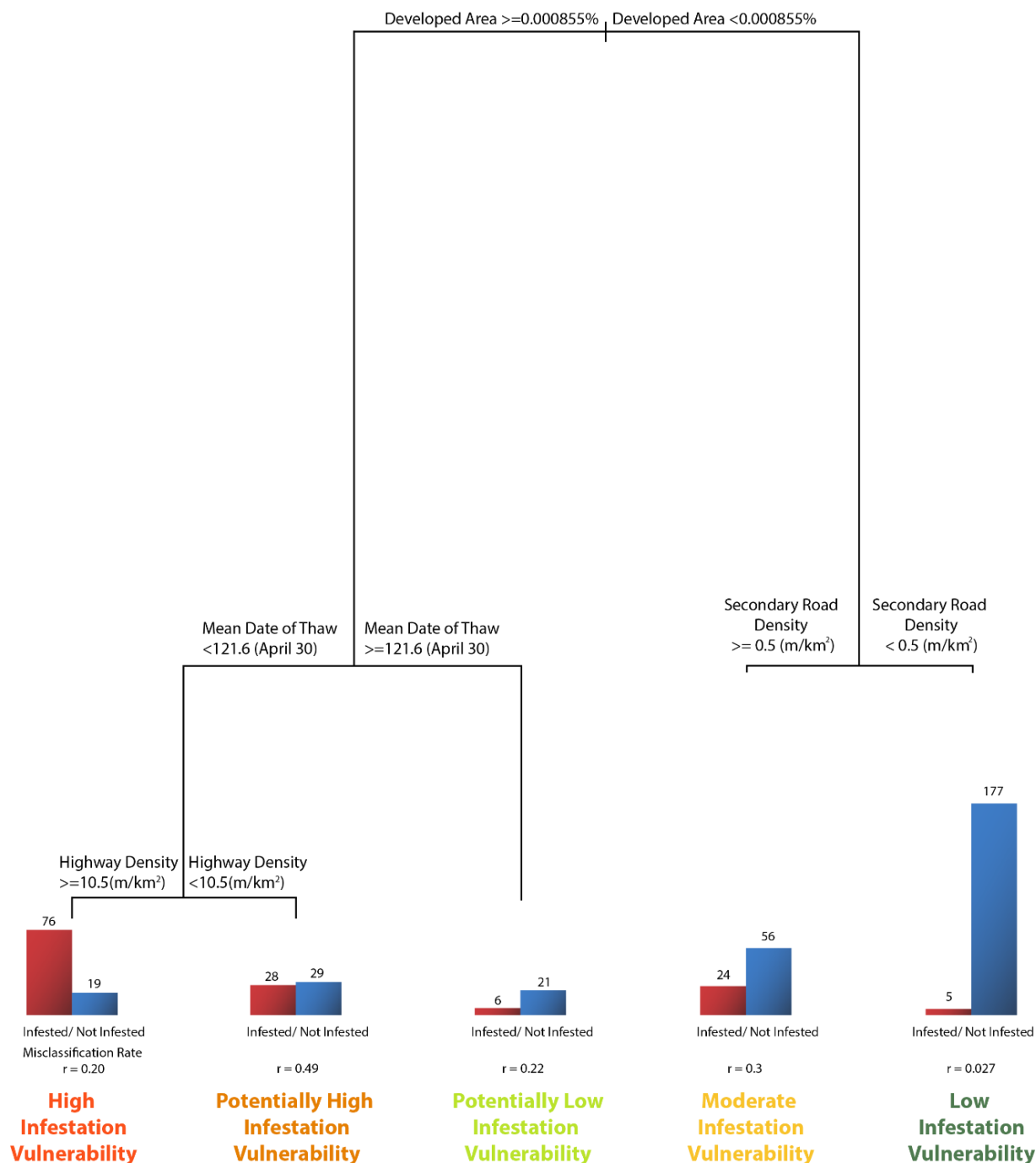


Figure D-5. Classification tree for non-native plant infestations in 5th-level HUCs for Interior Alaska. At each node predictor thresholds are indicated. Colored labels below the terminal nodes indicate levels of infestation vulnerability. Thus, the far left terminal node defined as “High Infestation Vulnerability” illustrates that HUCs in Interior Alaska with highway road densities ≥ 10.5 m/km², mean thaw dates prior to the Julian date of 121.6 (April 30), and with greater than 0.00085% of the land area developed have a very high probability of being correctly classified as “infested” (ie., 76/95 HUCs are correctly classified; $r = 0.20$). Red and blue bars at the terminal branches represent the number of HUCs that are “infested” or “not infested” based on empirical data with the predictor characteristics described in their branches. R values represent misclassification rate.

Probability of a HUC being infested followed a threshold response for anthropogenic variables, with probability of infestations increasing dramatically with even modest amounts of human activity (not shown). However, area of agricultural land was the least important variable in this analysis. Climate variables had more diverse relationships with probability of infestation. In general, HUCs with warmer summers and earlier thaw dates had higher probabilities of being infested.

Potential current and projected future infestation vulnerabilities based on the classification tree model are shown in Figure D-6. HUCs predicted to have low infestation vulnerabilities typically have zero to few records of non-native plant infestations. Non-native plants known in these watersheds predicted to be of low vulnerability are generally widespread disturbance-associated plants such as *Plantago major*, *Matricaria discoidea*, and *Chenopodium album*. Because these plants rarely achieve high biomass and are poor competitors, we anticipate minimal ecological impacts. Five watersheds in central Alaska were predicted to be of low invasion vulnerability by the model, but in fact had known infestations of highly invasive plants—two of these watersheds were within the CYR study area (see Figure D-6). These infested watersheds were found along the upper Yukon River. The small village of Birch Creek had the typical contingent of widespread ruderal non-native plants, as well as more ecologically threatening species such as *Melilotus albus* and *Bromus inermis*. Beaver Creek has populations of *Bromus inermis*. Factors that are not encompassed in the CART model or stochastic events are likely responsible for these misclassifications; in general, the few infested watersheds predicted not to be infested all have concentrated human activity despite minimal ground disturbance.

Overall, there is a strong association of known infestations with modeled moderate to high vulnerabilities, indicating the classification tree results correspond well with empirical data in the region and are, therefore, useful for near- and long-term scenarios. It should be stressed that the characterization of vulnerability at the 5th-level HUC is very coarse for plant invasion and it is likely that only a fraction of the HUC is in fact vulnerable to non-native plant establishment. Infestations are typically localized to areas on or adjacent to the human footprint in the state (Bella 2011, Flagstad 2010), but there are increasing cases of plants moving into natural areas (Carlson and Shephard 2007, Spellman et al. 2014).

Areas predicted to be of highest current vulnerabilities follow the primary highways. The predicted vulnerability of the northern portion of the Dalton Highway transitions to “Potentially Low” due to cooler temperatures (specifically later date of thaw). HUCs with moderately sized villages are typically classified with vulnerabilities of “Moderate” or “Potentially High.”

Invasion vulnerabilities based on this model are anticipated to change in the long-term future time step, while no changes in watershed classification occur in the near term. The most dramatic change anticipated is associated with increased density of secondary roads associated with the “Roads to Resources” (to the Ambler Mining District and preferred road to Nome, see Section-E. Anthropogenic Change Agents) in which more than 30 watersheds transition from low predicted invasion vulnerability to “Moderate Vulnerability.” With earlier thaw dates, and potential increases in highway road density by 2060, HUCs along upper Steese Highway near Circle and the watershed around Kiana are predicted to transition from low vulnerabilities to high vulnerabilities. The percentage of watersheds predicted to be of low invasion vulnerability drops from 80%

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currently, to 74% by 2060 in the CYR study area. Thus, while there are predicted increases in vulnerability to non-native plant invasion, the majority of watersheds are anticipated to have a low probability of developing weed problems.

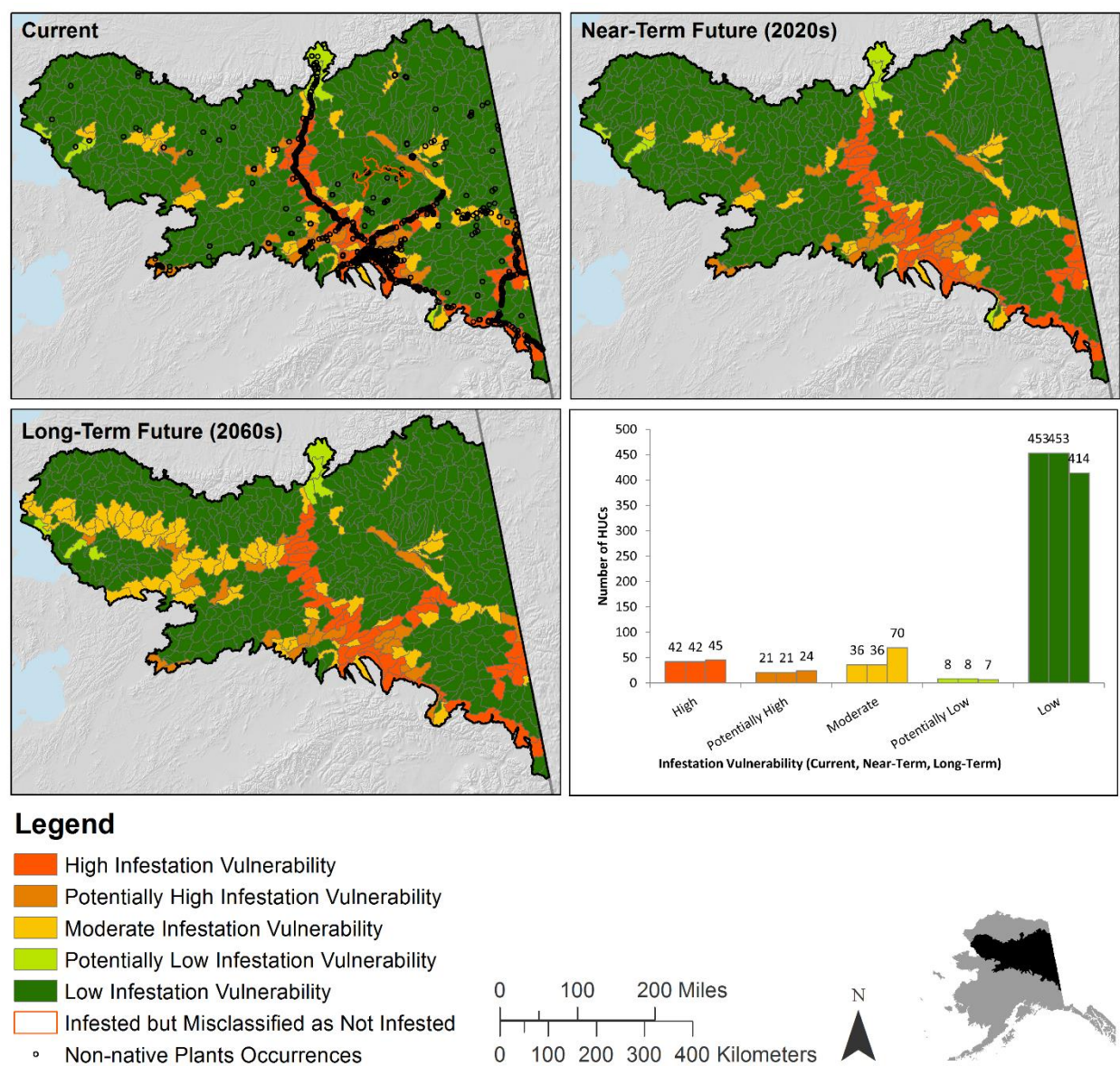


Figure D-6. Modeled infestation vulnerability on 5th-level HUC watersheds in the CYR for current (upper left), near-term (upper right), and long-term (lower left). HUCs with low predicted vulnerabilities are shown in green, potentially low in yellow-green, moderate in yellow, and potentially high in yellow-orange, and high in orange. Two HUCs that were misclassified (predicted to have low vulnerability, but are known to have invasive plants currently established) are indicated with an orange outline in the current map. Locations of non-native plant occurrences are shown as circles in the current map.

Waterweed (*Elodea* spp.) Invasion Vulnerability

A total of 37 public boat launches were identified as potential invasion points; boats and trailers moving from infested waters to other locations are a likely source for future infestations of waterweed (Table D-4). A number of launches on the Chena River with known infestations are included.

We identified 2,060 km of named streams that were categorized as 'High Susceptibility' to invasion of *Elodea* spp. and 6,079 km of named streams that were categorized as 'Medium-High Susceptibility' (Table D-4). These susceptible water networks had the highest combination of total potential vectors. Streams with the greatest projected risk of future establishment of waterweed are downstream on the Tanana from its confluence with the Chena, where waterweed is well established (Figure D-7). It is likely that plant fragments have been moving down the Tanana for some time, particularly during spring breakup. While some reports indicate *Elodea* is able to grow in turbid waters (see references in Invasive Species Compendium 2015), we are not aware of records of this plant in waterbodies with high sediment concentrations in Alaska. The most likely habitats for establishment would be clear-water eddies, where smaller streams join the Tanana. For example, *Elodea* was found in 2015 in Totchaket Slough, 19 km north of Nenana, off of the Tanana River and just south of the study area—potentially establishing from fragments from the Chena River. The Yukon and upper Tanana rivers are perceived to have moderate-high invasion vulnerability due to the proximity to known infestations and number of public launches. Again, establishment along the main stem of these rivers is not likely due to the high flow and sediments, but clear-water eddies are vulnerable. Moderately vulnerable streams and rivers include the Koyukuk and numerous upstream systems that drain into the Tanana (Figure D-7).

Table D-4. Summary of river length (in km) of named rivers (with loops, braids, and connections) categorized as susceptible to *Elodea* infestation.

Susceptibility to Invasion	Total River Length (km)
Low	15,129.81
Medium	3,870.92
Medium–High	6,079.39
High	2,060.21

Over 1,500 lakes and ponds are road accessible in the CYR study area, with the majority located in the Fairbanks-North Pole area where *Elodea* is already known to occur (Figure D-8). *Elodea* infestations in the state are primarily known from shallow lakes and ponds, indicating these waterbodies are particularly at risk. We identified 3,500 lakes in the region that are likely floatplane accessible, in which waterweed may be accidentally transported on float rudders (Figure D-9). Smaller lakes with marginal accessibility to aircraft number nearly 11,000 in the CYR study area. Overlaying Low and Moderate climate suitability, based on modeling effort by Luizza et al. (2016), results in only a minor reduction in numbers of vulnerable lakes in the Kobuk and Selawik river valleys (Figure D-10). In general, lower elevation regions along the Tanana, Yukon, and Koyukuk watersheds were identified as highly vulnerable. The Yukon-Old Crow Basin is predicted to have the largest area of high climate suitability in the CYR study area by mid-century (2040–2059;

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Luizza et al. 2016). These broader regions correspond closely with both likely accessible lakes and rivers with public boat launches (Figure D-10).

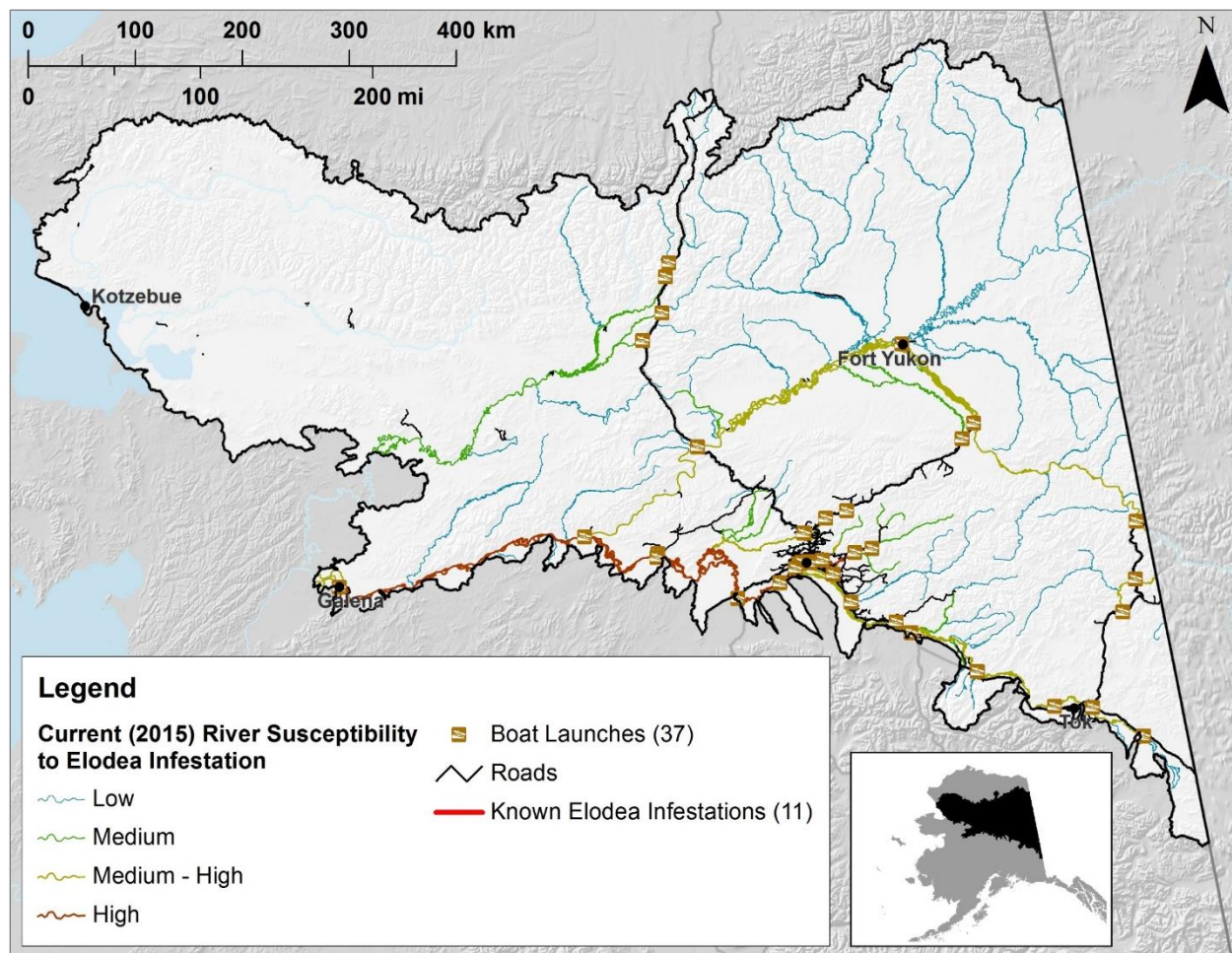


Figure D-7. Named rivers (without loops and braids) susceptible to *Elodea* introduction in the CYR study area.

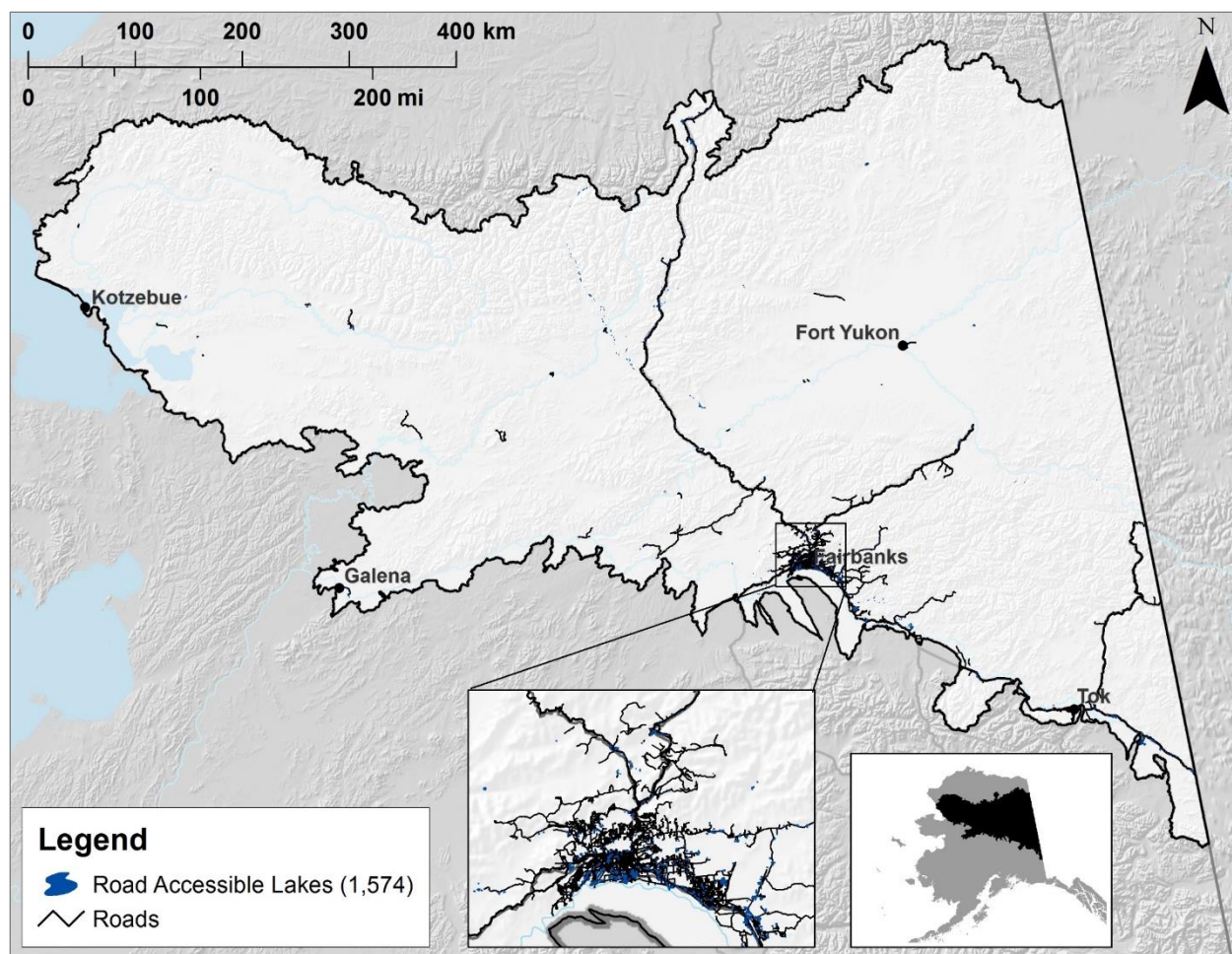


Figure D-8. Road accessible ponds and lakes in the CYR study area susceptible to *Elodea* introduction.

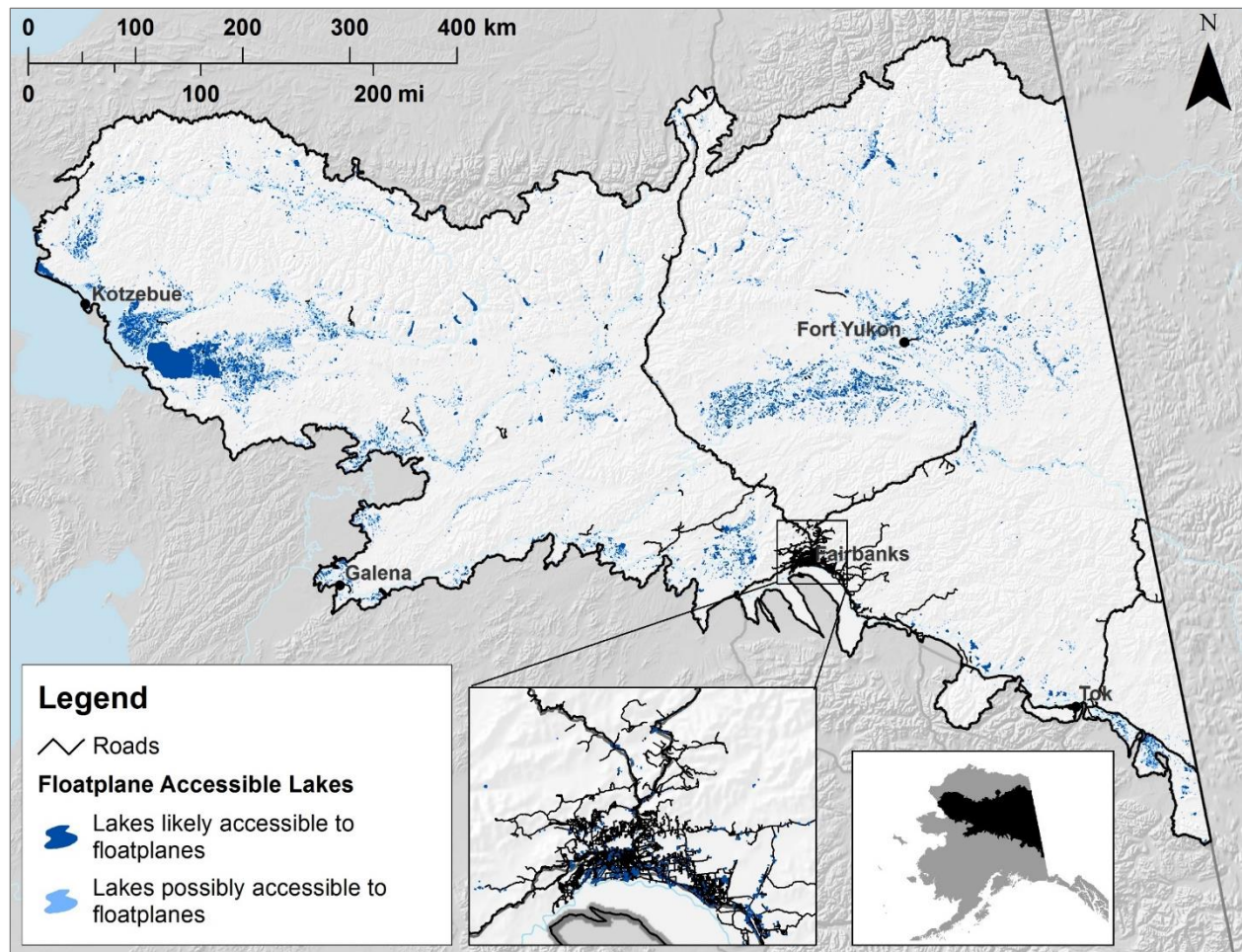


Figure D-9. Floatplane accessible lakes in the CYR study area susceptible to *Elodea* introduction.

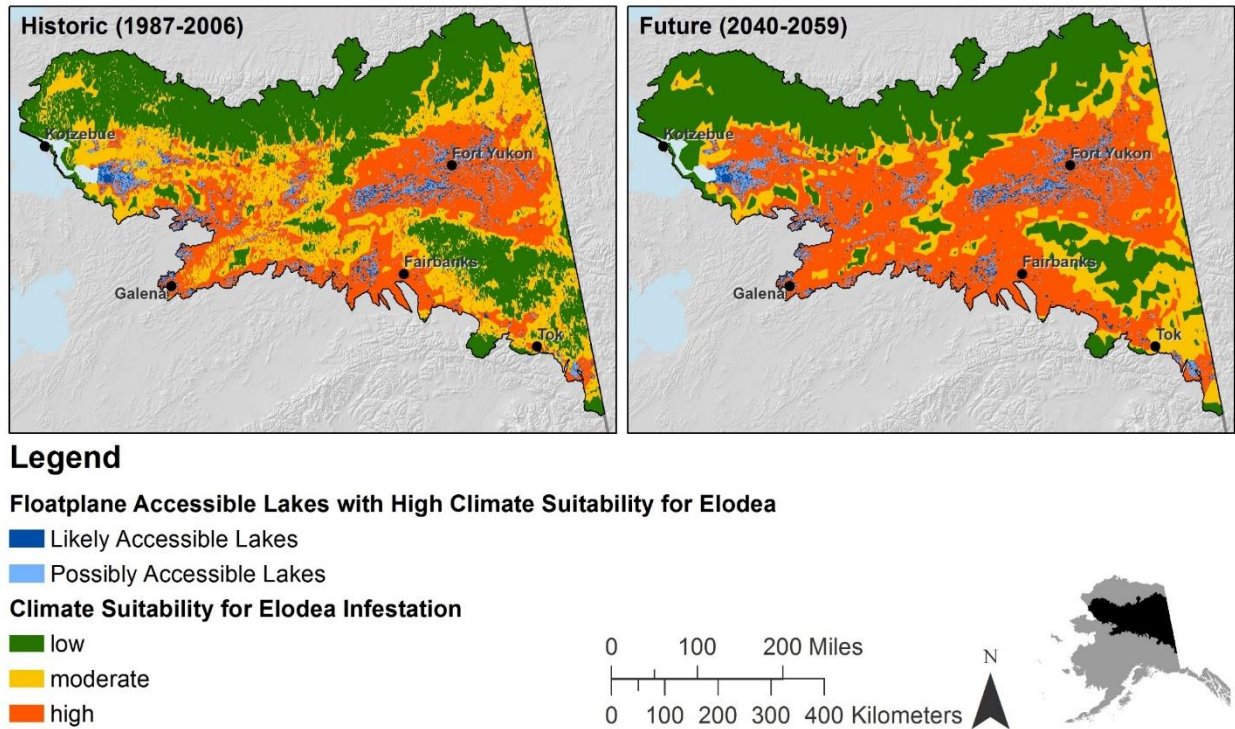


Figure D-10. Floatplane accessible lakes in the CYR study area susceptible to *Elodea* introduction in areas of high climate suitability, overlaid with climate suitability layer, based on climate and topographic variables (Luizza et al. 2016).

Vulnerability Summary

In summary, non-native plants are largely restricted to areas of human habitation, roadsides, and ground disturbance, both in urban areas, villages, and in a few cases around remote cabins and trails. Numerous species that are perceived to be ecologically damaging are present, some such as *Melilotus albus* and *Viccia cracca* are some of the most abundant in the CYR study area. Control of *Elodea* is seen as an important management action statewide, due to the potential impacts to aquatic resources. This plant is established in the Fairbanks region and persists despite mechanical control efforts in the last few years—current, non-chemical tools are estimated to require five years for an eight-person team to remove the whole 55-acre infestation in Chena Slough (Lane et al. 2013). We identified a large number of waterbodies that are perceived to be susceptible to invasion by this species. Impacts of currently established or potentially occurring invasive species on Coarse- and Fine-Filter CEs are discussed in those sections (Sections G.–J.).

We anticipate few increases in invasive plant vulnerability under the near-term scenario. However, we anticipate substantially more watersheds becoming vulnerable to invasion in the long-term scenario, due to increases in road density associated with the road to the Ambler Mining District and associated with increases in summer warmth. The establishment of a road running west from the heavily infested Dalton Highway to the Ambler District is likely to serve as corridor for non-native plant establishment and movement. Additionally, this road would bisect numerous streams and rivers and further spread of invasive plants down river floodplains is possible. *Melilotus albus*

and *Vicia cracca* are two of the more problematic weeds along roadsides and floodplains in this region that would likely be initial colonizers of future roadsides.

Direct impacts of invasive species on the Terrestrial Fine-Filter CEs in these time periods seem unlikely, or at least not acute. Increased establishment of the invasive *Melilotus albus* on early successional floodplains could impact snowshoe hares indirectly through reductions in willow browse, as *M. albus* has been shown to depress willow and native forb establishment (see Spellman and Wurtz 2011). Golden eagles in turn are highly reliant on snowshoe hare as prey; however, it again seems unlikely that, based on the current and perceived future conditions of invasive plants, measurable impacts would occur. It is unclear how the establishment of the aquatic plant *Elodea* may impact trumpeter swans or beavers. *Elodea* was found to be one of the primary diet components to trumpeter swans in the greater Yellowstone area in the winter, but was much less frequently consumed in the summer (Squires and Anderson 1995). Thus, it is difficult to predict how the presence of *Elodea* may impact trumpeter swans in a region where the birds do not overwinter. Understanding the nutritional quality of *Elodea* relative to the native species that it is replacing would be a key piece of information. The nitrogen concentration of *Elodea* appears to be similar to that of other aquatic plants, but higher concentrations of defensive flavonoid compounds (at least in *Elodea nuttallii*) appear to inhibit invertebrate herbivores (Harper and Daniel 1934, Erhard et al. 2007). The movement of trumpeter swans and other waterfowl may result in increased spread of *Elodea* in the CYR study area.

Ecological impacts of invasive plants to Terrestrial Coarse-Filter CEs is likely to be minor as well. We do not anticipate extensive establishment of invasive plants in the upland Coarse-Filter CEs. However, *Vicia cracca* is well-known to establish in, and adjacent to, mesic spruce-hardwood forests and this Coarse-Filter CE is also susceptible to the establishment of *Caragana arborescens*, as evidenced by expanding infestations in mixed aspen-white spruce forests in and around Fairbanks. As *Caragana arborescens* can form very dense coppices in its introduced and native range, current and future expansion of this shrub could be problematic (Carlson et al. 2008). In the peatland-dominated lowland woody wetlands, expansion of wetland-associated invasive species, such as *Phalaris arundinacea*, is not particularly likely; however, the establishment of this species in more nutrient-rich areas within the lowland woody wetlands does seem possible.

The two lowland Coarse-Filter CEs are more likely to experience measurable impacts from non-native species. Floodplains in Alaska have a large diversity on non-native plant species established, including species perceived to have greater ecological impacts, such as *Melilotus albus*, *Hordeum jubatum*, and *Prunus padus*. Once invasive plant populations establish in river systems they will likely expand downstream rapidly. *Prunus padus* could become increasingly problematic in mixed lowland forests in this region, as it is becoming a dominant tree in semi-natural forests around Anchorage. Additionally, alder-dominated riparian habitats are susceptible to defoliating green alder sawflies (*Monsoma pulveratum*). While only minor damage has been recorded in the Interior due to this species, higher sawfly population sizes fueled by warmer and longer summers could result in defoliation and mortality similar to that observed in Southcentral Alaska. Currently, extensive defoliation by non-native sawflies is restricted to climates with cool winters, moderate length warmish summers, and moderate precipitation (Cline 10, see Section C. Abiotic Change Agents). This climate is projected to be present in the

CYR study area within a few decades, and by the 2060s this climate is expected to occur in much of the region from Galena to Kotzebue.

Aquatic CEs may be negatively impacted by *Elodea*. Currently, Aquatic Coarse-Filter CEs affected by this invasive plant are small streams and small connected lakes in the Fairbanks area. The more recent discovery of *Elodea* in Totchaket Slough off the Tanana is suggestive that large rivers and streams may be acting as vectors for the establishment of the plant in smaller, and slower-moving waterbodies downstream. Our deductive modeling results indicate that the Tanana downstream from Fairbanks and the Yukon downstream from Circle are the most susceptible to *Elodea* establishment due to known populations upstream or numerous public boat launches. A large number of small and large connected lakes occur in the CYR study area that could receive *Elodea* fragments from floatplanes. *Elodea* is currently established in Chena Lake and the DNR is pursuing plans to eradicate the plant using herbicides.

Aquatic Fine-Filter CEs could be negatively impacted by the establishment and expansion of *Elodea*, as this species forms very dense monospecific stands that reduces water flow, increases sedimentation, affects dissolved oxygen concentrations, and lowers biodiversity (Nawrocki et al. 2011 and references therein). Establishment of dense *Elodea* stands could be beneficial for pike because of increased cover from which to ambush prey. Chinook salmon breeding habitat is degraded by establishment of *Elodea* in its native range (Merz et al. 2008) and the other Aquatic Fine-Filter CEs that are reliant on less vegetated and organic substrates are likely to be negatively impacted by *Elodea* as well.

Our analysis indicated that the human footprint, date of thaw, highway, and secondary road density are the most important drivers of plant invasion at this scale. Most of these variables are not anticipated to change in such a manner to greatly increase the probability of invasive plant establishment, with the exception of secondary roads. However, watersheds that already have populations of highly invasive plant species are likely to see increases in those populations with future warming and increases in fire frequency, assuming control actions are not initiated.

1.4 Limitations and Data Gaps

Survey data on non-native species are lacking for many regions of the state, including a large portion of the CYR study area. Additionally, surveys are concentrated in areas associated with population centers and along road systems. Thus, interpretation of current infestations is based on a fraction of the area being surveyed for non-native plants, and those surveys being conducted preferentially in habitats likely to have non-native plants.

The spatial bias in survey intensity towards areas in, and adjacent to, human habitation is likely to inflate the importance of roads and population centers in the classification tree analysis. However, the surveys that have been conducted in more remote areas of the state suggest that non-native species are indeed very uncommon outside of roadways and population centers. In fact, weed surveys conducted in remote areas in Alaska generally have not detected any non-native species without cabins, roads, or other human infrastructure (see Greenstein and Heitz 2013).

Section D. Biotic Change Agents

The invasion vulnerability model did not include a number of variables that may influence invasion potential, notably wildfire. The frequency, extent, and severity of wildfire may influence probabilities of future invasions in this region. We suggest that watersheds with either known infestations or high predicted invasion vulnerability that are also predicted to have high frequency and extent of wildfire (see Section C. Abiotic Change Agents) are more susceptible to establishment of problematic species off of the human footprint. However, regional differences in soil and vegetation composition were shown to be more important in invasive plant establishment than the severity of the burns or soil moisture (Spellman et al. 2014), and areas subjected to wildfire in remote areas of the Interior rarely have non-native plants at present (Greenstein and Heitz 2013).

Our invasion vulnerability approach to the aquatic invader, *Elodea*, likewise did not incorporate many habitat and probability of dispersal variables that are known to be important. We developed a coarse rubric to define accessibility of lakes by floatplanes, which was not able to include additional factors such as lake depth or shape, presence of obstructions, lack of appropriate approach to shore, etc., that would result in inaccessibility of lakes longer than 1 km. Additionally, the probability or frequency of landings was not incorporated; lakes closer to urban centers or those with greater recreational uses are likely to receive more floatplane traffic. While we did include a broad-scale climate suitability approach with this species, we were not able to incorporate finer-scale habitat features that influence the establishment of *Elodea* (e.g., pH from 6.0-7.5, organic substrates, etc., see Gollasch 2006). The inclusion of these elements are likely to substantially reduce the number of waterbodies that are in fact highly vulnerable to *Elodea* invasion.

Future infestation vulnerabilities are based on scenarios of climate change and development that are inherently uncertain (see Section C. Abiotic Change Agents) and caution should be exercised in interpretation of those outputs. Other disturbances such as herbivorous insect outbreaks and wildfires are expected to increase the probability of non-native plant invasion; however, we are unable to incorporate these factors in a meaningful spatial context. We suggest disturbances within regions known to harbor infestations or predicted to harbor infestations are more likely to experience expansions of existing populations.

The analysis of infestation vulnerability is restricted to a scale coarser than the area we are likely to see invaded on the landscape. For example, a 5th-level HUC with “high infestation vulnerability” is likely to have weed infestations present only in a small portion of the HUC.

1.5 Literature Cited

- ADF&G. 2016a. Invasive Species — Norway Rat (*Rattus norvegicus*). Available: http://www.adfg.alaska.gov/index.cfm?adfg=invasiveprofiles.norwayrat_distribution
- ADF&G. 2016b. Invasive Species — Gypsy Moth (*Lymantria dispar*). Available: http://www.adfg.alaska.gov/index.cfm?adfg=invasiveprofiles.gypsymoth_distribution
- AKEPIC. 2015. Alaska Exotic Plant Information Clearinghouse Database. Alaska Natural Heritage Program, University of Alaska Anchorage.
- Bella, E. 2011. Invasion prediction on Alaska trails: distribution, habitat, and trail use. *Invasive Plant Science and Management* 4:296-305.
- Bohlen, P. T., S. Scheu, C. M. Hale, M. A. McLean, S. Migge, P. M. Groffman, and D. Parkinson. 2004. Non-native invasive earthworms as agents of change in northern temperate forests. *Frontiers in Ecology and the Environment* 2:427–435.
- Carlson, M. L., and M. Shephard. 2007. Is the spread of non-native plants in Alaska accelerating? Pages 111-127 *in* Meeting the challenge: invasive plants in Pacific Northwest ecosystems, Portland, Oregon. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, En. Tech. Rep. PNW-GTR-694.
- Carlson, M., I. Lapina, M. Shephard, J. Conn, R. Densmore, P. Spencer, J. Heys, J. Riley, and J. Nielsen. 2008. Invasiveness ranking system for non-native plants of Alaska. USDA Forest Service, R10-TP-143. 218 pp.
- Carlson, M. L., M. Aisu, E. J. Trammell, and T. Nawrocki. 2014. Invasive Species. *In* E. Trammell, J., M. L. McTeague, and M. L. Carlson, eds. Yukon River Lowlands – Kuskokwim Mountains – Lime Hills Rapid Ecoregional Assessment Technical Supplement. Prepared for the U.S. Department of the Interior, Bureau of Land Management, Denver, Colorado.
- Conn, J. S., K. Beattie, M. A. Shephard, M. L. Carlson, I. Lapina, M. Herbert, R. Gronquist, R. Densmore, and M. Rasy. 2008. Alaska *Melilotus* invasions: distribution, origin, and susceptibility of plant communities. *Arctic, Antarctic, and Alpine Research* 40:298-308.
- Croll, D. A., J. L. Maron, J. A. Estes, E. M. Danner, and G. V. Byrd. 2005. Introduced predators transform sub-Arctic islands from grassland to tundra. *Science* 307:1959-1961.
- Cutler, R. D., T. C. Edwards Jr., K. H. Beard, A. Cutler, K. T. Hess, J. Gibson, and J. J. Lawler. 2007. Random forests for classification in ecology. *Ecology* 88:2783–2792.
- De'ath, G., and K. E. Fabricius. 2000. Classification and regression trees: a powerful yet simple technique for ecological data analysis. *Ecology* 81:3178-3192.
- Erhard, D., G. Pohnert, and E. M. Gross. 2007. Chemical defense in *elodea nuttallii* reduces feeding and growth of aquatic herbivorous lepidoptera. *Journal of Chemical Ecology* 33:1646-1661.
- Executive Order 13112. 1999. Invasive Species. *Federal Register* /Vol. 64, No. 25. 6183.
- Flagstad, L. A. 2010. 2009 Campbell Tract non-native plant survey: revisiting permanent monitoring transects established in 2006. Prepared for the Bureau of Land Management- Anchorage Field Office. Alaska Natural Heritage Program, University of Alaska Anchorage, Anchorage, Alaska. 45 pp.
- Frelich, L. E., C. M. Hale, S. Scheu, A. R. Holdsworth, L. Heneghan, P. J. Bohlen, and P. B. Reich. 2006. Earthworm invasion into previously earthworm-free temperate and boreal forests. *Biological Invasions* 8:1235–1245.
- Gollasch, S. 2006. *Elodea canadensis*. DAISIE (Delivering Alien Invasive Species Inventories for Europe) Summary. Available: http://www.europe-aliens.org/pdf/Elodea_canadensis.pdf
- Greenstein, C., and B. Heitz. 2013. Non-native plant surveys on public lands affected by forest fires 2009-2010. Prepared for the Bureau of Land Management – Alaska State Office. Alaska Natural Heritage Program, University of Alaska Anchorage, Alaska. 54 pp.
- Harper, H., and H. A. Daniel. 1934. Chemical composition of certain aquatic plants. *Botanical Gazette* 96:186-189.

Section D. Biotic Change Agents

- Ingold, D. J. 1998. The influence of starlings on flicker reproduction when both naturally excavated cavities and artificial nest boxes are available. *Wilson Bulletin* 110:218–225.
- Invasive Species Compendium. 2015. *Elodea nuttallii* (Nuttall's waterweed) invasive species data sheet. Available: <http://www.cabi.org/isc/datasheet/20761>
- Jabowski, R. A., M. 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. DOI 10.1007/s10530-012-0300-3.
- Josefsson, M. 2011. NOBANIS - invasive species fact sheet – *Elodea canadensis*, *Elodea nuttallii* and *Elodea callitrichoides*. Online Database of the European Network on Invasive Alien Species – NOBANIS. Available: www.nobanis.org
- Kessel, B. 1979. Starlings become established at Fairbanks, Alaska. *Condor* 81:438-443.
- Koenig, W. D. 2003. European starlings and their effect on native cavity-nesting birds. *Conservation Biology* 17:1134–1140.
- Kruse, J., and N. Lisuzzo. 2010. An exotic pest new to Alaska: the green alder sawfly. Forest Health Conditions in Alaska – 2010. Forest Service, Alaska Region. R10-PR-23. 11 pp.
- Kruse, J. J., D. R. Smith, and N. M. Schiff. 2010. *Monsoma pulveratum* (Hymenoptera: Tenthredinidae), a palaearctic sawfly defoliator of alder in Alaska and new to the United States. *Proceedings of the Entomological Society of Washington* 112:332-335.
- Kruse, J. J., K. Zogas, N. Lisuzzo, and S. Swenson. No Date. Alder-feeding sawflies of Alaska. Available: http://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5430500.pdf
- Lane, R., M. Osborne, and D. Etcheverry. 2013. It came from the aquarium: management of the *Elodea* invasion in Chena Slough. Available: https://www.uaf.edu/files/ces/2013_Inva_Species_Conf/Lane_CameFromAqua.pdf
- Lassuy, D. R., and P. N. Lewis. 2013. Invasive species: human-induced. In Meltofte, H., A. B. Josefson, and D. Payer, eds. Arctic Biodiversity Assessment. Status and Trends in Arctic Biodiversity. Conservation of Arctic Flora and Fauna, Akureyri. Draft.
- Luizza, M. W., P. H. Evangelista, C. S. Jarnevich, A. West, and H. Stewart. 2016. Integrating subsistence practice and species distribution modeling: assessing invasive elodea's potential impact on Native Alaskan subsistence of Chinook salmon and whitefish. *Environmental Management* 58:144-63.
- 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. DOI: 10.1577/M07-043.1.
- 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, Alaska. 253 pp.
- Pacific Northwest Herbaria Consortium. 2015. Specimen database. Available: <http://www.pnwherbaria.org/>
- Pimentel, D., R. Zuniga, and D. Morrison. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics* 52:273-288.
- Sanderson, L. A., J. A. McLaughlin, and P. M. Antunes. 2012. The last great forest: a review of the status of invasive species in the North American boreal forest. *Forestry* 85:329-339.
- Schwörer, T., R. Federer, and H. Ferren. 2012. Investments in statewide invasive species management programs in Alaska: 2007-2011. CNIPM presentation.
- 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.
- Spellman, K. V., T. Hollingsworth, and C. P. H. Mulder. 2014. Susceptibility of burned black spruce (*Picea mariana*) forests to non-native plant invasions in Interior Alaska. *Biological Invasions* 16:1879-1895.

- Squires, J. R., and S. H. Anderson. 1995. Trumpeter swan (*Cygnus buccinators*) food habits in the Great Yellowstone Ecosystem 133:274-282.
- Tamayo, M., and J. D. Olden. 2014. Forecasting the vulnerability of lakes to aquatic plant invasions. *Invasive Plant Science and Management* 7:32-45.
- Toolik Lake Field Station Virtual Herbarium. 2015. Specimen database. Available: http://toolik.alaska.edu/edc/biotic_monitoring/virtual_herbarium.php
- USDA, USFS. 2013. Forest Service National Strategic Framework for invasive species management. FS-1017. 36 pp. Available: http://www.fs.fed.us/foresthealth/publications/Framework_for_Invasive_Species_FS-1017.pdf

2. Insect- and Disease-Related Forest Damage

2.1 Introduction

Insect and disease agents can change native plant communities within Alaskan boreal forests. Dominant tree and shrub species across boreal forest in Alaska are subject to large-scale, stochastic defoliation and/or mortality events caused by surges in population, referred to in this assessment as outbreaks, of a variety of native insects (bark beetles, woodborers, sawflies, leafminers, etc.) and disease agents (wood decay, canker fungi, root disease, etc.). Large-scale defoliation and mortality of dominant boreal forest trees and shrubs result in cascading changes on plant communities and wildlife, increased fuels availability for fires, and changes in nutrient cycling (Matsuoka et al. 2001, Juday et al. 2005, Boucher and Mead 2006, Fricker et al. 2006, Werner et al. 2006a, Parent and Verbyla 2010, Tremblay et al. 2011).

While non-native insects and disease agents occur in the CYR study area, the insect and disease agents reviewed in this assessment are native to the CYR study area. For example, the green alder sawfly (*Monosoma pulveratum*) is an invasive alder defoliator, native to Eurasia and North Africa, that has caused large areas of alder defoliation in Southcentral and Southeast Alaska and has been observed in the study area near Fairbanks (Kruse et al. 2010). Other non-native defoliating insects have been captured within the CYR study area as well (Kruse et al. 2010). While forest damage caused by non-native insect agents may have been recorded during past aerial surveys, non-native insects have not been identified as the causal agents for forest damage polygons in the study area. Any potential forest damage caused by non-native species has been lumped with forest damage caused by native insect and disease agents.

Using aerial survey data from USDA Forest Service, we addressed forest damage caused by insect and disease agents in the CYR study area in several ways:

- 1.) mapped the distribution of observed insect- and disease-related forest damage and summarized spatial trends in the relative impact of that damage per ecoregion for the past 15 years;
- 2.) summarized spatial trends in the relative impact of insect- and disease-related forest damage and of spruce mortality per tree- and shrub-dominated CE for the past 15 years;
- 3.) assessed the status of the four most prevalent host/damage type combinations at five year intervals for the past 15 years; and
- 4.) assessed the near-term and long-term future climate vulnerability of the CYR study area to severe, regional outbreaks of spruce beetle. A climate-vulnerability approach was taken because predicting areas or intensity of future spruce beetle outbreaks was not possible.

2.2 Methods

Data on forest damage caused by insect and disease agents in the CYR study area were limited to the United States Department of Agriculture (USDA) Forest Service annual forest damage aerial surveys. Data on insect distribution and ranges within the CYR study area were identified

as a data gap. The United States Department of Agriculture (USDA) conducted annual forest damage aerial surveys using fixed-wing aircraft along predetermined routes across Alaska's forests, with up to 25% of the total forested area of Alaska surveyed each year. Insect damage within one to two miles on either side of flight paths was recorded by drawing polygons onto 1:250,000 scale USGS topographic maps or a digital elevation model (FS-R10-FHP 2012, 2013). Some damage observations included an assessment of severity, which for this assessment was standardized to three categories: high (greater than 50% of trees/shrubs affected), moderate (approximately 50% of trees/shrubs affected), and low (less than 50% of trees/shrubs affected). Recorded damage polygons were necessarily noticeable from a flying aircraft, generally indicating that they were areas of at least 10% mortality or defoliation (Juday et al. 2005).

Aerial Survey Flight Paths and Distribution of Observed Damage

Because data collected in any single year represented less than 25% of the study area, grouping the data into cumulative, multi-year assemblages provided greater spatial coverage of the study area and more meaningful insights into trends. Forest damage polygons and aerial flight path polygons were available from USDA Forest Service (Table D-5). Although forest damage polygons were available dating from prior to 2000, the corresponding flight paths were only available beginning in 1999. To enable a comparison of observed damaged areas to area surveyed, no data from before 1999 was included in this assessment. Data related to forest damage were compiled into a historic time interval consisting of the 15-year period from 2000 to 2014.

Table D-5. Source datasets for historic and current distribution of forest pest outbreaks.

Dataset Name	Data source
Region 10 Forest Damage Polygons 1997–2014 (datasets integrated)	Forest Health Protection Insect & Disease Detection Survey Data Explorer (IDS Explorer)
Region 10 Aerial Forest Damage Survey Flight Paths 1999–2014	Forest Health Protection Insect & Disease Detection Survey Data Explorer (IDS Explorer)

Forest damage polygons from 2000 to 2014 were selected and joined to a standardized attribute table to ensure consistency of the data between years. All polygons damaged by the following agents were removed from the final dataset: flooding-high water, none (pockets of no damage within damaged areas), fire, mud-land slide, wind-tornado/hurricane, and winter injury (Figure D-11). The cumulative historic data provide a baseline from which to assess future conditions and trends in insect and disease related damage.

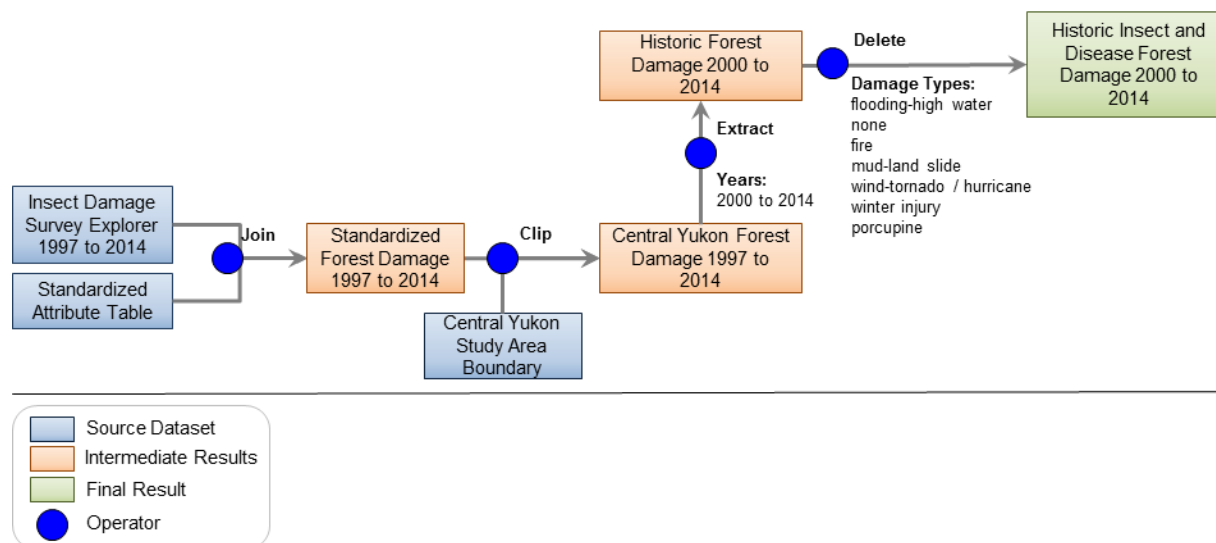


Figure D-11. Process model for historic and current distribution of insect- and disease-related forest damage.

To assess spatial trends across the CYR study area, insect- and disease-related forest damage was summarized by ecoregion. Because not all ecoregions were surveyed equally, the impact that insect and disease agents exerted within ecoregions (referred to as "impacted proportion" in the rest of this document) was measured as the proportion of ecoregion area damaged to ecoregion area surveyed rather than the proportion of ecoregion area damaged to total ecoregion area.

$$\text{Impacted Proportion} = \frac{\text{Area of Ecoregion Damaged}}{\text{Area of Ecoregion Surveyed}}$$

Impacted proportion was the relative proportion of surveyed ecoregion area that was damaged by insect and disease agents, not the proportion of observed damage located within a particular ecoregion. Impacted proportion represented the amount of ecosystem pressure insect and disease agents have exerted on a particular ecoregion.

Spatial Trends by Tree- and Shrub-Dominated CE

Insect- and disease-related forest damage was also summarized by tree- and shrub-dominated CE. Because not all CEs were surveyed equally, impacted proportion was measured as the proportion of CE area damaged to CE area surveyed rather than the proportion of CE area damaged to total CE area.

$$\text{Impacted Proportion} = \frac{\text{Area of CE Damaged}}{\text{Area of CE Surveyed}}$$

Impacted proportion was the relative proportion of surveyed CE area that was damaged by insect and disease agents, not the proportion of observed damage located within a particular CE. Impacted proportion represented the amount of ecosystem pressure insect and disease agents have exerted on a particular CE. The distributions of five Terrestrial Coarse-Filter CEs were compared to the extent of observed insect- and disease-related forest damage in the CYR study

area. Alpine Arctic tussock tundra and alpine dwarf shrub tundra were omitted from the comparison because these CEs lack or have low cover of trees and low/tall shrubs and have mostly not been surveyed for damage by USDA Forest Service aerial surveys.

Status of Four Most Prevalent Types of Biotic Forest Damage

Area of forest damage was calculated per unique host/damage type combination and per insect or disease agent. Tabular outputs were generated for both. The four host/damage type combinations that have contributed the largest areas of forest damage within the study area were correlated to their causal agent(s). Area of forest damage was calculated and described for each of the four most prevalent host/damage type combinations at five year intervals from 2000 to 2014. Severity of damage for the entire 15-year period from 2000 to 2014 was summarized for insect agents that had associated severity data.

Observed damage polygons from 2000 to 2014 for the entire state were converted to points for kernel density estimation for each causal insect agent. Kernel density estimation using least squares cross validation bandwidth was run through the Geospatial Modeling Environment and R. The output of the kernel density estimation was interpreted as a series of isopleths representing 10% intervals of the total number of input points. The resulting kernel densities provided a comparative sense of how much damage each insect agent has caused within the CYR study area relative to the rest of the state.

Future Climate Vulnerability of CYR Study Area to Spruce Beetle Outbreaks

Because of the stochasticity of insect outbreaks, it was not possible to predict or model future spruce beetle outbreaks by area, location, or intensity. Modeling future potential for spruce beetle outbreaks was also not possible because of stochasticity of outbreaks and poor understanding of some environmental factors influencing outbreaks. However, linkages have been previously demonstrated for several climate variables with spruce beetle life cycle and with potential for severe, regional outbreaks. It was possible to map the relevant climate variables into future. Two important limitations to a climate-based approach were: a.) there existed some uncertainty in regional variation in the nature and strength of correlations between climate and outbreak potential, and b.) many non-climate factors have affected spruce beetle populations and distribution of outbreaks. With awareness of the limitations of a climate-based approach, we predicted 5th-level hydrologic units where climate conditions are likely to become similar to climate conditions that existed in parts of Alaska that supported the highest density of spruce beetle-induced spruce mortality during the 2000s decade. The potential for climate within a hydrologic unit to become more suitable for spruce beetle outbreaks is referred to as "climate vulnerability" in the rest of this assessment. To assess future climate vulnerability, we:

- 1.) identified three relevant climate variables through a literature review;
- 2.) determined thresholds for the three climate variables based on a statewide inductive analysis;
- 3.) applied those thresholds to near-term and long-term future climate variables within the study area;
- 4.) determined areas of overlap where all three climate variables were greater than or equal to the identified thresholds for the near-term and long-term future; and
- 5.) summarized areas of overlap by 5th-level hydrologic units (Figure D-12).

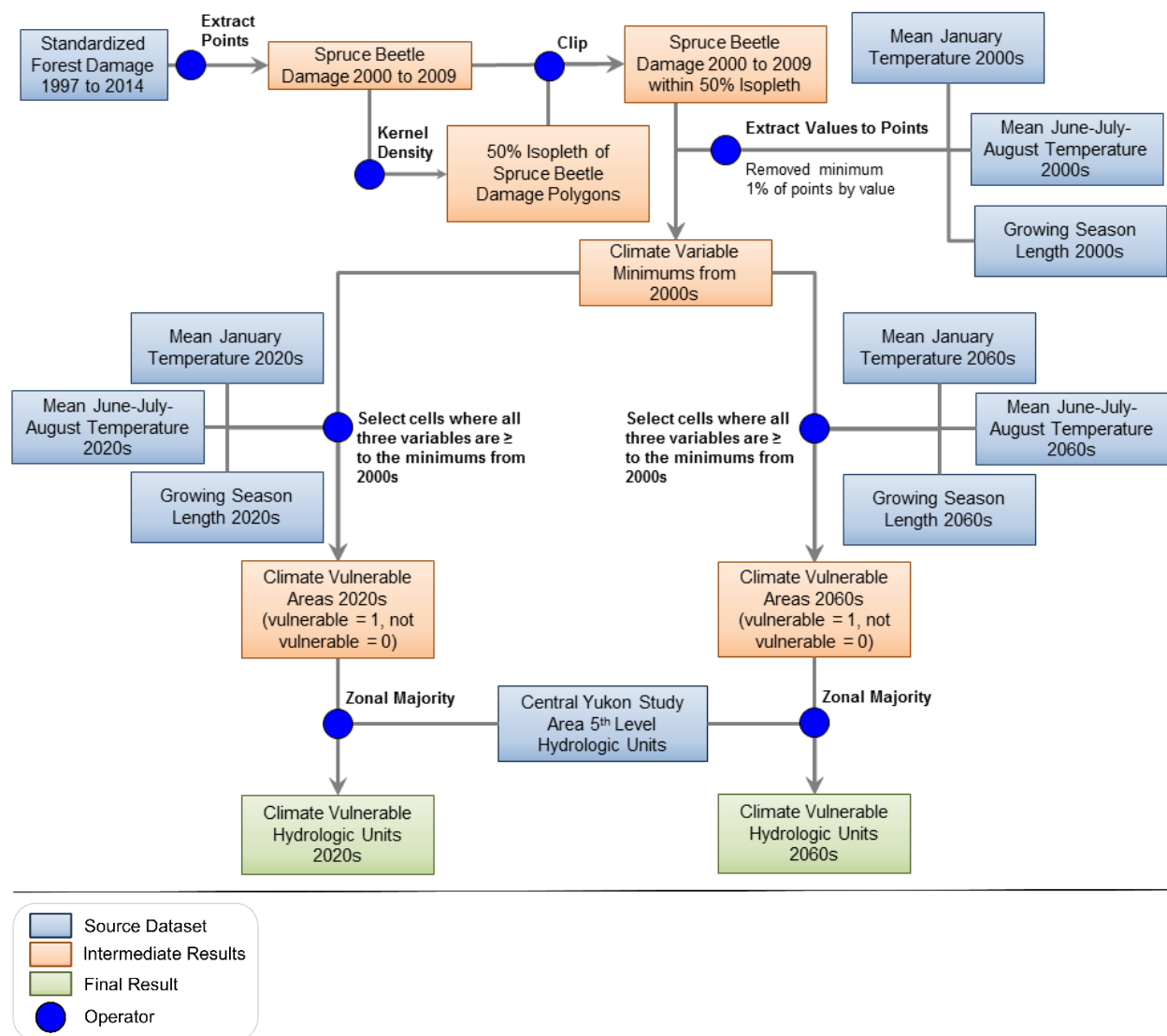


Figure D-12. Process model for near-term and long-term future climate vulnerability.

Mean June-July-August temperature was selected to represent mean summer temperature, which was identified as a relevant variable based on Werner and Holsten (1985), Juday et al. (2005), Berg et al. (2006), and Bentz et al. (2010). Growing season length was selected as a proxy for both cumulative hours above 14.5 °C and cumulative hours above 17 °C, which were identified as relevant variables based on Miller and Werner (1987), Berg et al. (2006), and Sherriff et al. (2011). Mean January temperature was selected as a proxy for January average minimum temperature, which was identified as a relevant variable based on Werner (1980), Miller and Werner (1987), Juday et al. (2005), Berg et al. (2006), and Bentz et al. (2010). Because the thresholds identified in the literature did not always correspond exactly to the available climate metrics and because no thresholds from the literature were based on decadal averages, thresholds for the selected decadal average climate metrics had to be identified inductively.

Spruce beetle polygons for 2000 to 2009 from the entire state were selected and converted to points for kernel density estimation. Kernel density estimation using least squares cross validation

bandwidth was run through the Geospatial Modeling Environment and R. The output of the kernel density estimation was interpreted as a series of isopleths representing 10% intervals of the total number of input points. The 50% isopleth represented the highest density of spruce mortality for the 2000s decade (i.e., areas that have been impacted by severe, regional outbreaks of spruce beetle).

Climate raster values were extracted to spruce beetle points within the 50% isopleth. Minimum values were identified for each climate variable for the 2000s decade after removing the lowest 1% of points by climate value from consideration to eliminate numerical outliers. Values below the identified minimums were set to 0 and values greater than or equal to the identified minimums were set to 1 for the three selected climate variables for the 2020s and 2060s. Cells with values of 1 for all three variables were extracted as climate-vulnerable areas. Zonal statistics with 5th-level hydrologic units providing the zones and statistics type set to "MAJORITY" were performed for the 2020s and 2060s climate-vulnerable areas. The resulting raster values were applied to the 5th-level hydrologic units, resulting in climate-vulnerable hydrologic units for the 2020s and 2060s.

2.3 Results

Assuming that 3.2 km (2 miles) on either side of flight paths were surveyed, approximately 138,000 km², or 52% of the area occupied by tree- and shrub-dominated CEs within the CYR study area, was surveyed from 2000 to 2014. Survey flight paths mostly followed riparian corridors, and major riparian corridors were surveyed with the highest frequency (Figure D-13). Large, contiguous blocks of spruce, deciduous, and mixed forest were not surveyed from 2000 to 2014. Therefore, absence of forest damage polygons within the study area does not indicate absence of damage; aerial survey data for the study area indicate presence only. Low accuracy of damage polygons and unequal survey efforts prevented true quantification of insect and disease damage. All spatial data, numbers, figures, and percentages should be regarded as approximations. For this reason, only general trends are discussed in this section and discussion of specific area values has been avoided.

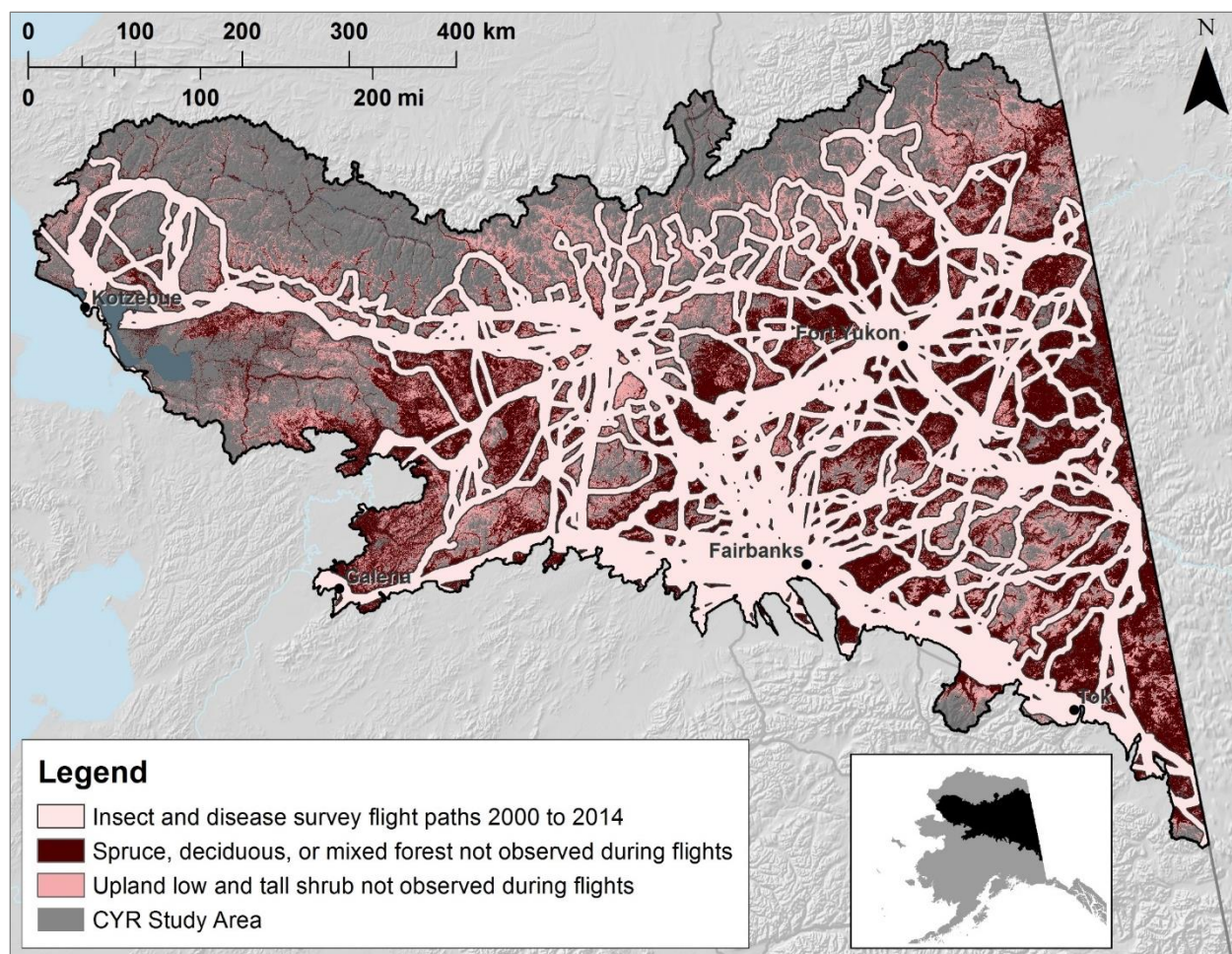


Figure D-13. Total area surveyed along flight paths for aerial forest damage surveys conducted from 2000 to 2014 and unsurveyed patches of forest and shrub. Approximately 52% of the area occupied by tree- and shrub-dominated CEs has been surveyed between 2000 and 2014.

Distribution of Insect- and Disease-Related Forest Damage

Much of the observed forest damage was concentrated along the Yukon, Porcupine, and Tanana rivers (Figure D-14), but the distance of damaged area extent from the main branches of these rivers was not consistent. Smaller and less dense areas of damage were observed along most of the other flown rivers. Survey coverage was lower in the west and north of the study area, where it mainly concentrated around Kotzebue, along the Kobuk River, and along small rivers in the southern Brooks Range. Where surveys were conducted in the north and west of the study area, the observed damage areas were categorized by low density and small area.

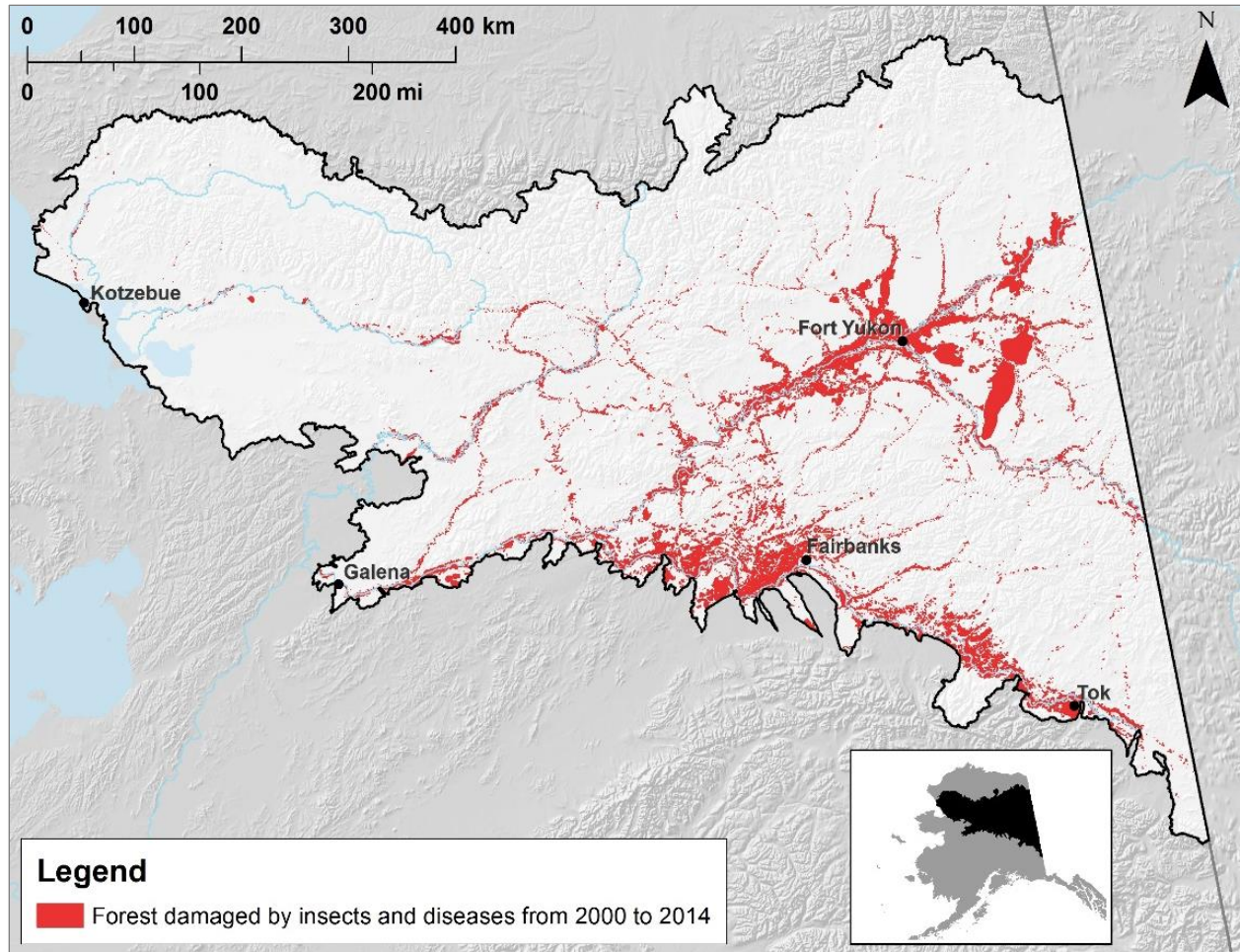


Figure D-14. Cumulative areas of insect- and disease-related forest damage from 2000 to 2014.

The impacted proportions of the Yukon–Old Crow Basin and Tanana-Kuskokwim-Yukon Lowlands were at least two times higher than the impacted proportion of any other ecoregion (Figure D-15). Trees and low/tall shrubs within the Brooks Range, Kotzebue Sound Lowlands, and Davidson Mountains have been damaged at rates much lower than trees and low/tall shrubs within any of the other included ecoregions.

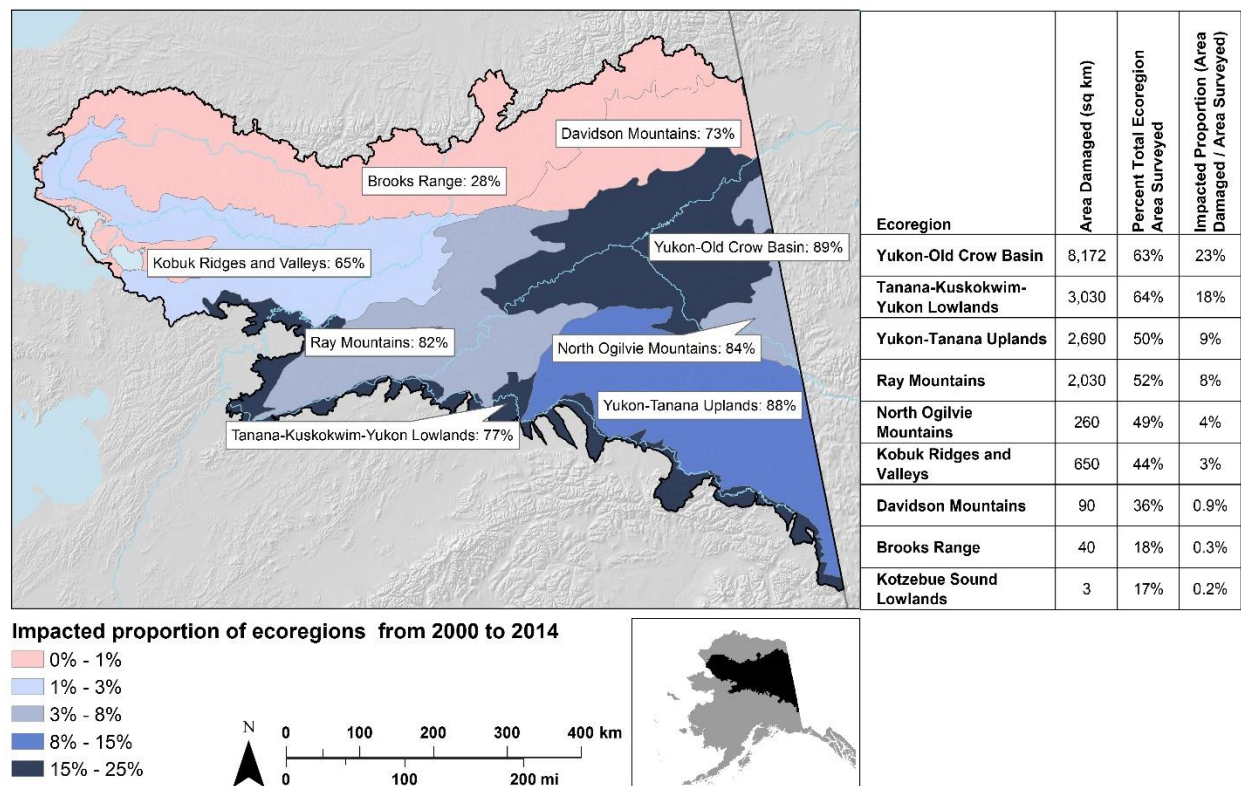


Figure D-15. Impacted proportion of ecoregions in the CYR study area from 2000 to 2014. Ecoregions are labeled on the map with the percent of total ecoregion area occupied by tree- and shrub-dominated CEs.

Spatial Trends by Tree- and Shrub-Dominated CE: Historic (2000 to 2014)

The impacted proportions of upland mesic spruce–hardwood forest and floodplain forest and shrub were the highest of any CE: each was at least two times greater than the impacted proportion of upland mesic spruce forest, lowland woody wetland, or upland low and tall shrub (Figure D-16). This trend corresponded with the majority damage types: quaking aspen defoliation and willow defoliation caused by aspen leaf miner and willow leafblotch miner respectively. Quaking aspen and willow defoliation were observed in some areas where quaking aspen and/or willow were present but not dominant or co-dominant (e.g., areas classified as upland mesic spruce forest). Upland mesic spruce forest was damaged at a rate less than would be expected purely based on the proportion of the study area that it covered compared to either upland mesic spruce–hardwood forest or floodplain forest and shrub. As a result, the impacted proportion of upland mesic spruce forest was half that of either upland mesic spruce–hardwood forest or floodplain forest and shrub, despite the largest area of observed forest damage being located within upland mesic spruce forest.

Upland low and tall shrub were damaged at a rate much less than would be expected purely based on the proportion of the study area that it covers. The impacted proportion of upland low and tall shrub tundra was the lowest of the impacted proportions of the five tree- and shrub-dominated CEs. The least area of observed damage occurred in lowland woody wetland, but the impacted proportion of lowland woody wetland was still two times greater the impacted proportion of upland low and tall shrub tundra.

Most of the observed forest damage within upland low and tall shrub was aspen defoliation, which was not expected based on the definition of upland low and tall shrub. Several factors likely compounded to cause this result:

- 1.) the NLCD forested classes required presence of trees over 5 meters so some low spruce, mixed, and deciduous forests were likely mapped as shrub/scrub;
- 2.) the NLCD likely contained some areas of deciduous forest that were misclassified as shrub/scrub because differences between deciduous forest and tall shrub can be very subtle in source imagery; and
- 3.) low spatial accuracy of forest damage polygons caused overlap with vegetation classes other than those where the damage was actually observed.

Misclassification of the host tree during the aerial insect and disease damage surveys is not a likely a cause of low agreement between observed aspen damage and mapped upland low and tall shrub tundra. Aspen defoliation caused by aspen leaf miner is easily recognizable from the air because leaf cuticles remain intact, giving infested hosts a silver-gray color (Reich et al. 2013). Aspen defoliation aside, little forest damage was observed in upland low and tall shrub (this was also the least surveyed of the five tree- and shrub-dominated CEs).

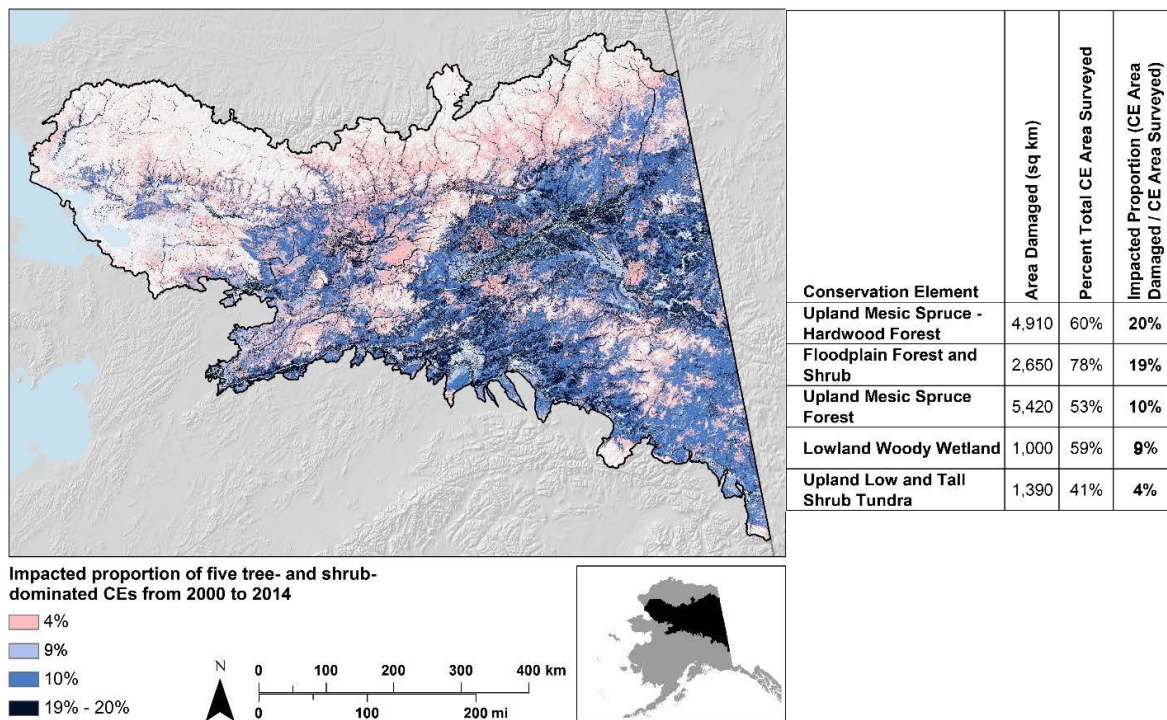


Figure D-16. Impacted proportion of five tree- and shrub-dominated CEs from 2000 to 2014 in the CYR study area.

Spruce mortality contributed only 4% of observed forest damage from 2000 to 2014. The impacts of spruce mortality on CEs were specifically considered for this assessment because spruce mortality has high potential to cause ecosystem change and provides fuels for wildfire.

Additionally, area of spruce mortality may increase in the future (Sherriff et al. 2011). Spruce mortality may have the greatest management implications of all forest damage types in the future because increases in spruce mortality could increase costs associated with fuels reductions and fire control.

The impacted proportion of floodplain forest and shrub was approximately five times greater than the impacted proportion of either lowland woody wetland or upland mesic spruce–hardwood forest (Figure D-17). Additionally, the largest area of spruce mortality was observed in floodplain forest and shrub. Spruce mortality occurred in upland mesic spruce–hardwood forest and upland mesic spruce forest at rates lower than would be expected based on the area occupied by those CEs. The association of spruce mortality with floodplain forest and shrub corresponded with the trend that much of observed forest damage was concentrated along major riparian corridors. The impacted proportion of upland low and tall shrub tundra was lowest of all tree- and shrub-dominated CEs.

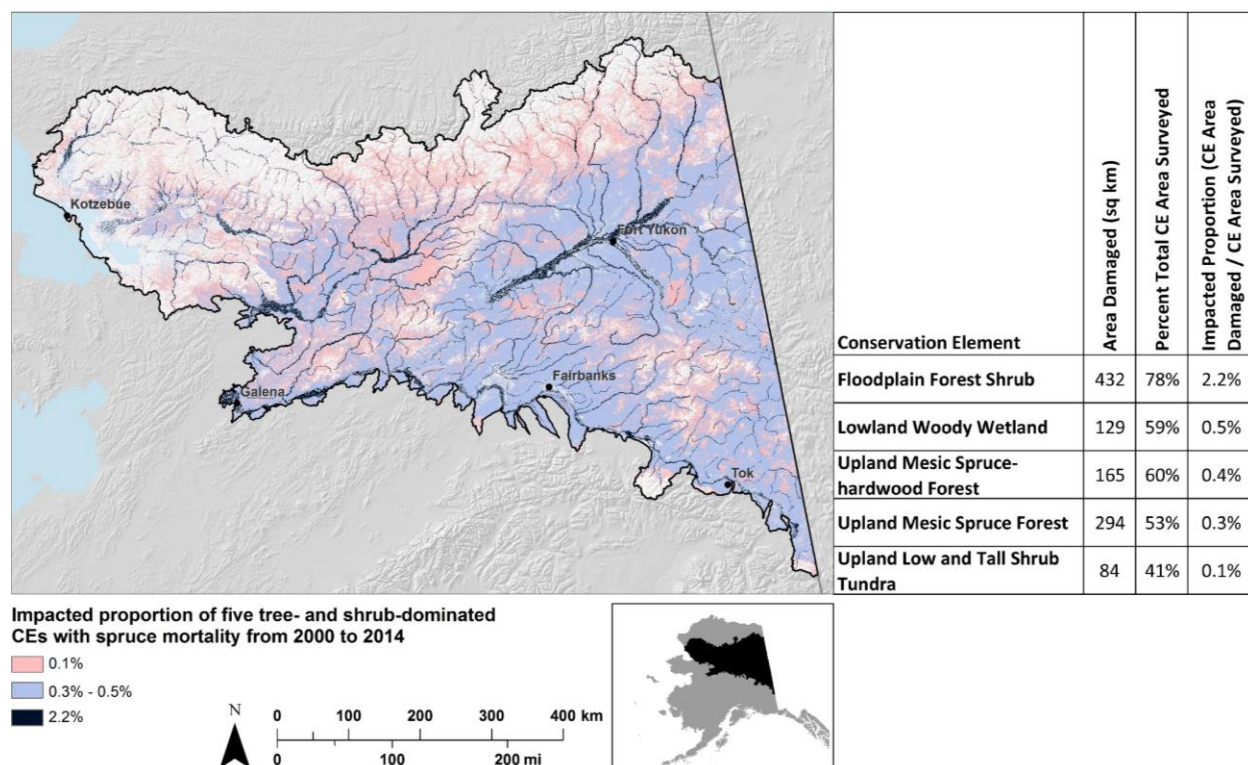


Figure D-17. Impacted proportion of five tree- and shrub-dominated CEs with spruce mortality from 2000 to 2014 in the CYR study area.

Cumulative Forest Damage by Host Species and Insect or Disease Agent

Quaking aspen defoliation, willow defoliation, spruce defoliation, and spruce mortality contributed most of the observed forest damage from 2000 to 2014 (Table D-6). These host/damage type combinations were caused by aspen leaf miner, willow leafblotch miner, spruce budworm, and northern spruce engraver beetle and spruce beetle, respectively (Table D-7). More detail is provided for each host/damage type combination in the paragraphs below. During the 1990s decade, larch sawfly (*Pristiphora erichsonii*) defoliated—and eastern larch beetle

(*Dendroctonus simplex*) subsequently killed--large amounts of tamarack (*Larix laricina*) within the CYR study area (Werner et al. 2006b). However, from 2000 to 2014, further tamarack defoliation and mortality were minimal and are not discussed further in this assessment. Other insect and disease agents have been observed within the study area but have caused only a small amount of the total observed damage. They are also not discussed further in this assessment.

Table D-6. Forest damage summarized by host/damage type combination within the CYR study area for the 15-year period from 2000 to 2014 and the 5-year period from 2010 to 2014. Total damaged area represents the area of damage for one or more hosts. Because multiple hosts may have been damaged within the same area, this value is less than the sum of the columns.

Host/Damage Type Combination	Area (km ²)	
	2000 to 2014	2010 to 2014
quaking aspen defoliation	11,580	2,790
willow defoliation	3,760	2,380
spruce defoliation	1,100	40
spruce mortality	790	220
cottonwood/poplar defoliation	280	150
birch defoliation	240	180
alder dieback	180	180
tamarack mortality	70	0
alder defoliation	60	50
tamarack defoliation	30	0.4
spruce discoloration	9	8
willow dieback	7	7
unknown defoliation	30	20
unknown mortality/dieback	0.4	0.4
Total	16,960	5,870

Table D-7. Forest damage summarized by causal agent within the CYR study area for the 15-year period from 2000 to 2014 and the 5-year period from 2010 to 2014. Total damaged area represents the area damaged by one or more agents. Because multiple agents may affect the same area, this value is less than the sum of the columns.

Causal Agent	Scientific Name	Area (km ²)	
		2000 to 2014	2010 to 2014
aspen leaf miner	<i>Phyllocnistis populiella</i>	11,380	2,710
willow leafblotch miner	<i>Micrurapteryx salicifoliella</i>	3,740	2,350
spruce budworm	<i>Choristoneura fumiferana</i>	1,010	40
general insect/disease damage	causal agent not identified	970	580
northern spruce engraver beetle	<i>Ips perturbatus</i>	680	180
large aspen tortrix	<i>Choristoneura conflictana</i>	190	90
spruce beetle	<i>Dendroctonus rufipennis</i>	120	40
eastern larch beetle	<i>Dendroctonus simplex</i>	70	0
larch sawfly	<i>Pristiphora erichsonii</i>	30	0.4
birch aphid	<i>Euceraaphis betulae</i>	30	30
cankers (general)	many causal agents	30	30
birch leafroller	<i>Epinotia solandriana</i>	20	20
spear-marked black moth	<i>Rheumaptera hastata</i>	15	0
cottonwood leafminer	<i>Phyllonorycter nipigon</i>	14	1
spruce broom rust	<i>Chrysomyxa arctostaphyli</i>	9	6
large-spored spruce-Labrador tea rust	<i>Chrysomyxa ledicola</i>	2	2
birch leafminers	<i>Profenusa thomsoni</i> <i>Heterarthrus nemoratus</i> <i>Fenusa pumila</i>	2	2
cottonwood leaf beetle	<i>Chrysomela scripta</i>	2	0.8
Total Damaged Area		16,960	5,870

Quaking Aspen Defoliation: Aspen Leaf Miner

The defoliation of quaking aspen (*Populus tremuloides*) caused by aspen leaf miner (*Phyllocnistis populiella*) accounted for over 60% of observed forest damage by area from 2000 to 2014 within the CYR study area. Approximately 40% of aspen defoliation by area was high severity (over half of aspen within the damage polygon were defoliated). From 2010 to 2014, quaking aspen defoliation remained one of the major forms of insect- and disease-related forest damage and accounted for approximately 45% of observed forest damage by area. The area of

quaking aspen defoliation has fluctuated every 5-year period between 2000 and 2014 (i.e., 2000 to 2004, 2005 to 2009, and 2010 to 2014) but has always remained the most common form of insect- and disease-related forest damage by area within the study area.

The consistently high area of quaking aspen defoliation suggests that environmental conditions steadily favor high populations and/or frequent outbreaks of aspen leaf miner. For example, temperature and precipitation have, among other environmental factors, driven the distribution of aspen leaf miner in Alaska (Reich et al. 2013). Most aspen defoliation caused by aspen leaf miner in Alaska from 2000 to 2014 occurred within the CYR study area (Figure D-18). Reich et al. (2013) modeled the probability of observing aspen leaf miner in Alaska based on temperature and precipitation zones and presence of the host. They found that the region with warm summers and relatively little precipitation, which overlaps the CYR study area, had the highest suitability, although factors other than temperature and precipitation also influenced the location and severity of infestations.

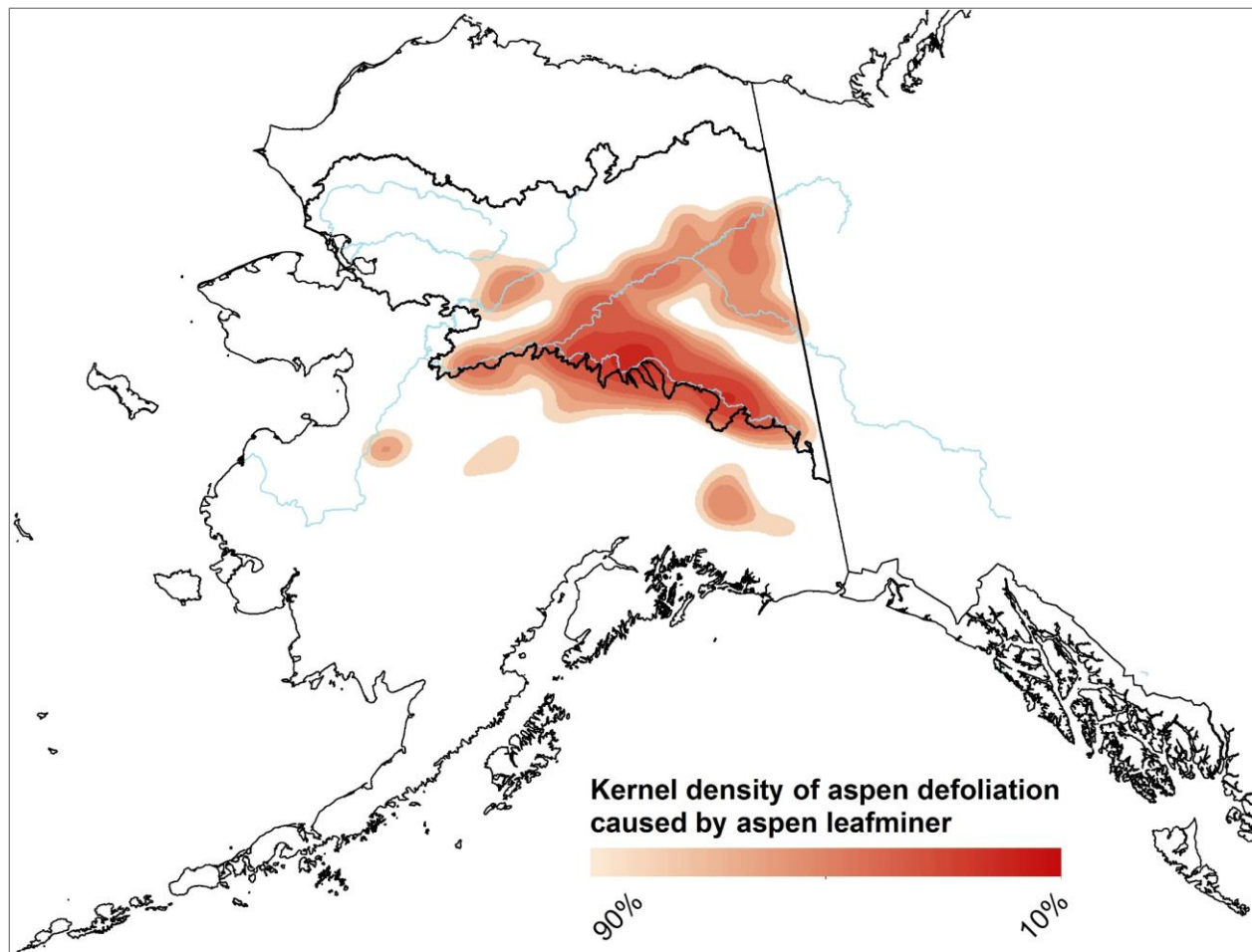


Figure D-18. Kernel density of aspen defoliation caused by aspen leaf miner within Alaska from 2000 to 2014 with CYR study area shown for reference. The densest aggregations of aspen defoliation in Alaska fell within the CYR study area.

Willow Defoliation: Willow Leafblotch Miner

Willow leafblotch miner (*Micrurapteryx salicifoliella*) was not known from Alaska prior to 1991 (Furniss et al. 2001). From 1991 to 1993, willow leafblotch miner defoliated large areas of willow (*Salix* spp.) along the Yukon and Kuskokwim rivers. From 1998 to 1999, a regional willow leafblotch miner outbreak occurred around the Yukon Flats National Wildlife Refuge (Furniss et al. 2001). Willow defoliation caused by willow leafblotch miner was observed every year from 2000 to 2014 constant within the CYR study area. Defoliation has occurred on numerous tall and low shrub willow species with the notable exception of felt-leaf willow (*Salix alaxensis*), which is protected by dense hairs on lower leaf surfaces (Furniss et al. 2001).

The defoliation of willow caused by willow leafblotch miner accounted for over 20% of observed forest damage by area from 2000 to 2014. High severity defoliation (over half of willow within the damage polygon were defoliated) was observed in 45% of damaged area. The area of observed willow defoliation doubled every 5-year period from 2000 to 2014. From 2010 to 2014, approximately 40% of observed forest damage was caused by willow leafblotch miner. This may indicate that environmental conditions are becoming more favorable for willow leafblotch miner within the study area. Most of the defoliation caused by willow leafblotch miner in Alaska occurred within the CYR study area (Figure D-19), although more sporadic, widely separated defoliation sites occurred throughout the state. Within the study area, defoliation was widespread except for in the western third of the study area and the southern Brooks Range.

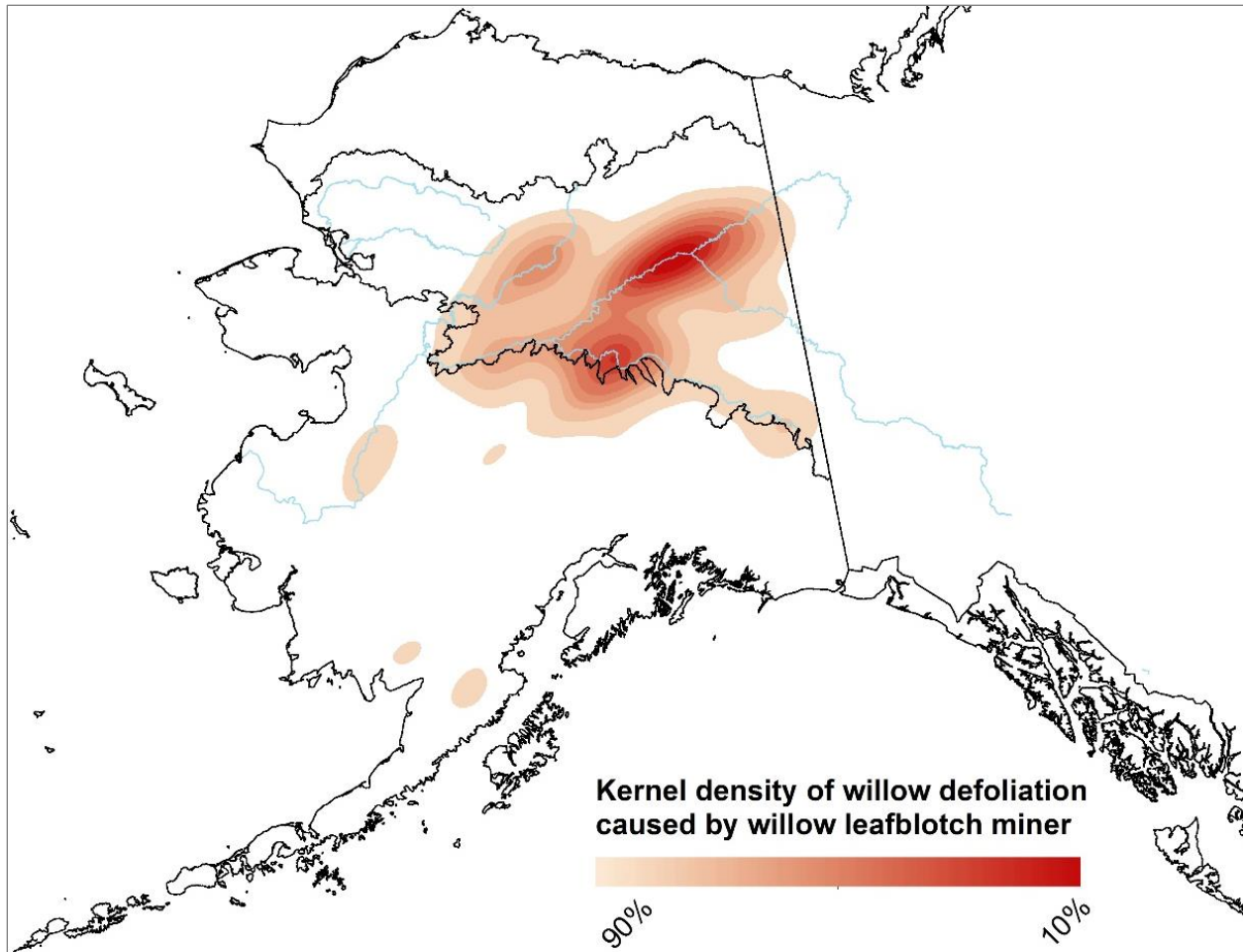


Figure D-19. Kernel density of willow defoliation caused by willow leafblotch miner within Alaska from 2000 to 2014 with CYR study area shown for reference. The densest aggregations of willow defoliation in Alaska fell within the CYR study area.

Spruce Defoliation: Spruce Budworm

Spruce defoliation caused by spruce budworm (*Choristoneura fumiferana*) accounted for 6% of observed forest damage by area from 2000 to 2014. However, most of the observed spruce defoliation (around 85%) was low severity (less than half of spruce within damage polygon were defoliated). Spruce budworm did not cause large areas of forest damage from 2010 to 2014: spruce defoliation was relatively high from 2000 to 2004 and 2005 to 2009 and then dropped to almost undetected levels from 2010 to 2014.

Spruce budworm outbreaks from 2000 to 2014 were concentrated in areas along the Tanana River near Fairbanks and around the confluence of the Porcupine and Yukon rivers (Figure D-20). An additional small aggregation of spruce budworm damage was located on the Kobuk River. Only sporadic, widely separated outbreaks occurred outside these areas. Most of the spruce budworm outbreaks occurred within the CYR study area.

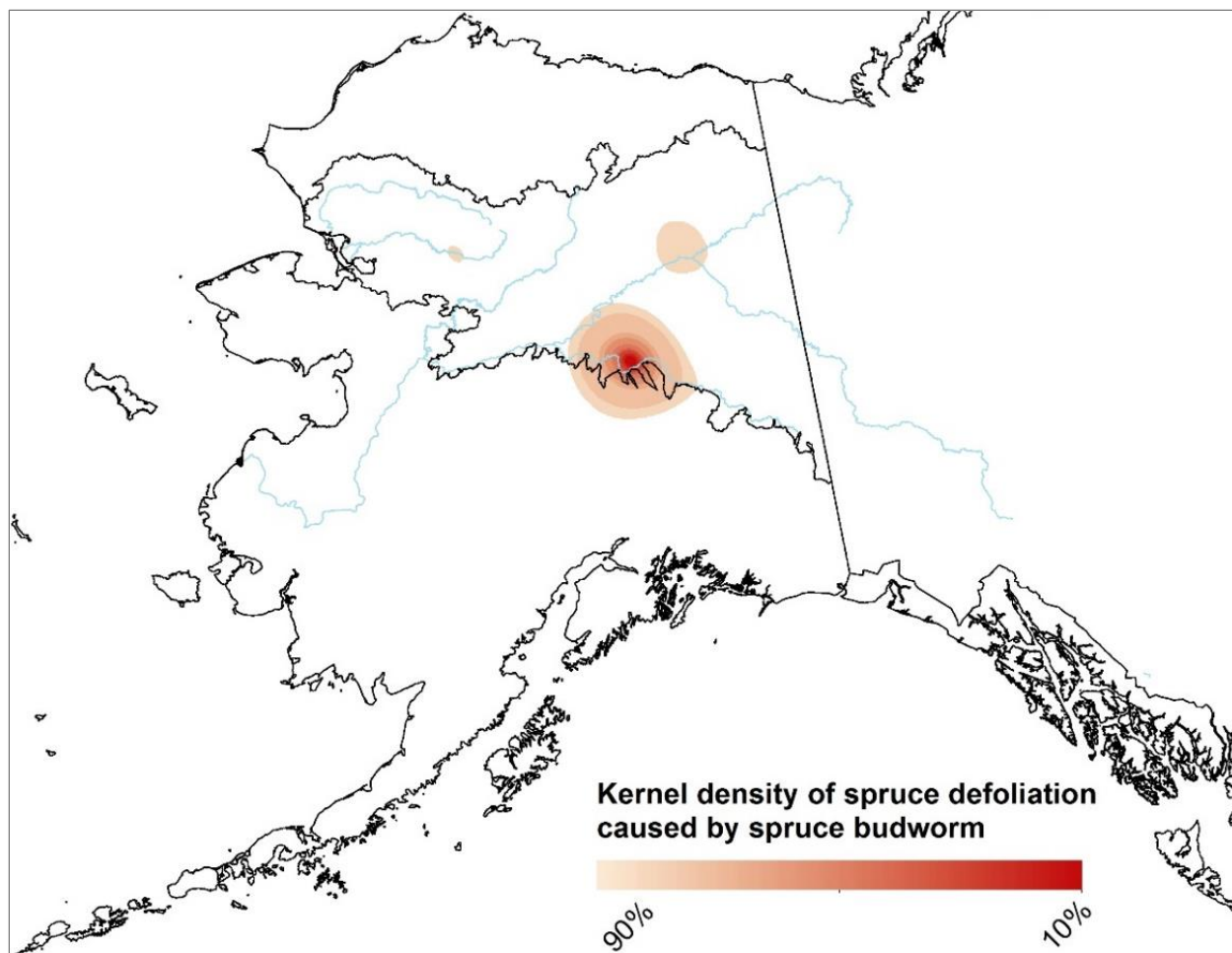


Figure D-20. Kernel density of spruce defoliation caused by spruce budworm within Alaska from 2000 to 2014 with CYR study area shown for reference. Most of the spruce budworm damage observed in Alaska occurred within the CYR study area.

Spruce Mortality: Northern Spruce Engraver Beetle and Spruce Beetle

White spruce has been the most susceptible tree or shrub to mortality from insect and disease agents within the CYR study area. However, the total area of spruce mortality observed from 2000 to 2014 accounted for only 4% of total observed forest damage by area. Severity of damage has not been consistently identified for spruce mortality.

Northern spruce engraver beetle caused approximately 5 times more observed damage by area than spruce beetle. Much of the spruce mortality caused by northern spruce engraver beetle in Alaska fell within the CYR study area (Figure D-21). A high density of northern spruce engraver beetle damage occurred near and north of the confluence of the Porcupine and Yukon rivers. Northern spruce engraver beetle damage occurred along the lower Noatak River, and sporadic northern spruce engraver beetle damage extended the length of the Kobuk River. However, for the most part, little spruce mortality was observed in the western third of the study area.

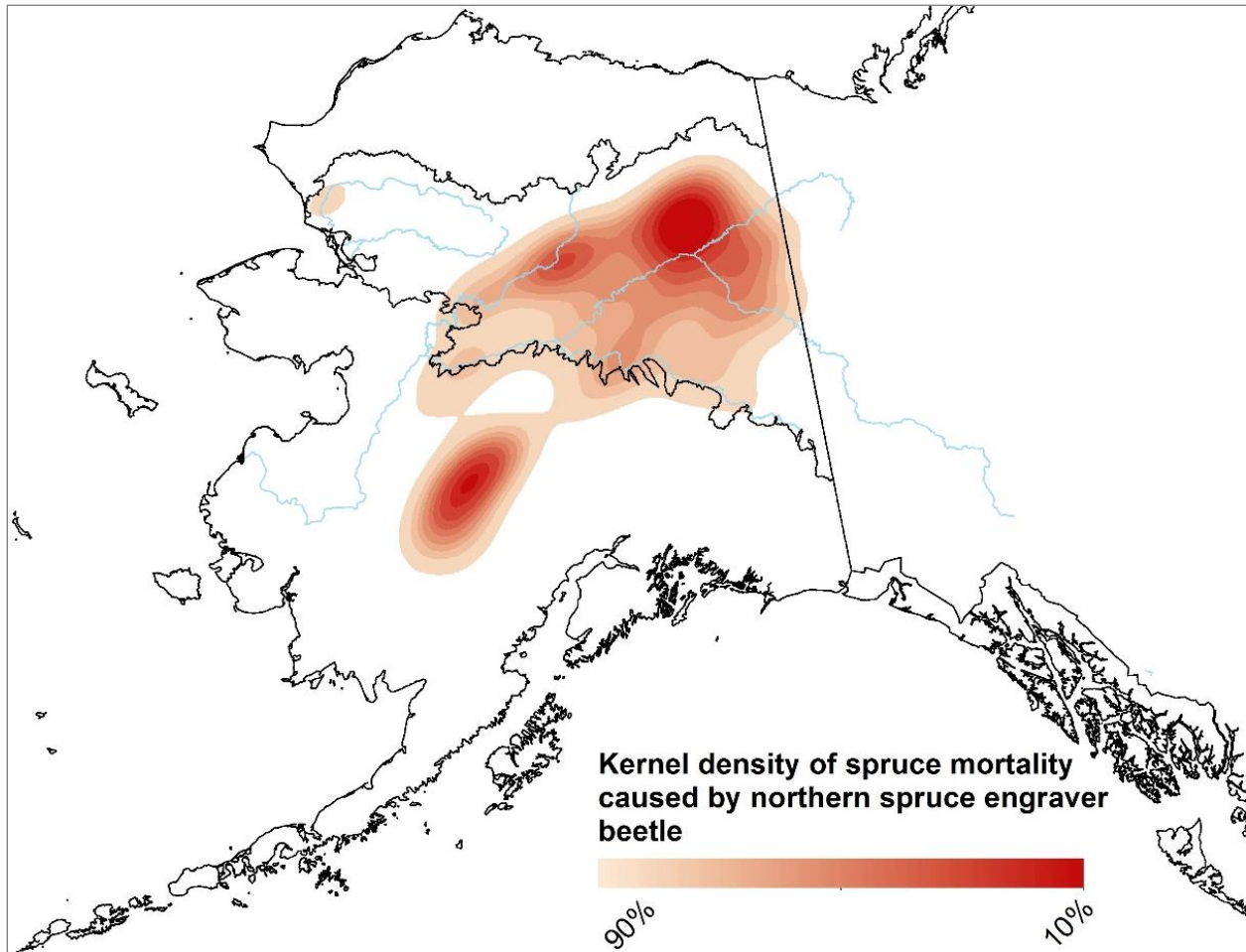


Figure D-21. Kernel density of spruce mortality caused by northern spruce engraver beetle within Alaska from 2000 to 2014 with CYR study area shown for reference. Much of the spruce mortality caused by northern spruce engraver beetle in Alaska fell within the CYR study area.

While spruce beetle outbreaks have caused severe, regional spruce mortality in Southcentral Alaska, spruce beetles have caused only localized and sporadic damage in Interior Alaska (Werner et al. 2006b). From 2000 to 2014, relatively little spruce beetle damage occurred within the CYR study area (Figure D-22). A small region of the 90% isopleth existed along the Yukon River upstream from the confluence with the Porcupine River. However, none of the 80% to 10% isopleths included any area within the CYR study area, and spruce beetle activity was limited north of the eastern and central Alaska Range. From 1990 to 2014, spruce beetle caused only 370 km² of spruce mortality. This long-term trend suggests that environmental conditions in the CYR study area have historically prevented severe, regional spruce beetle outbreaks. Despite outbreaks being uncommon in the study area, spruce beetles are present in stressed or dying spruce throughout Interior Alaska (Werner et al. 2006b).

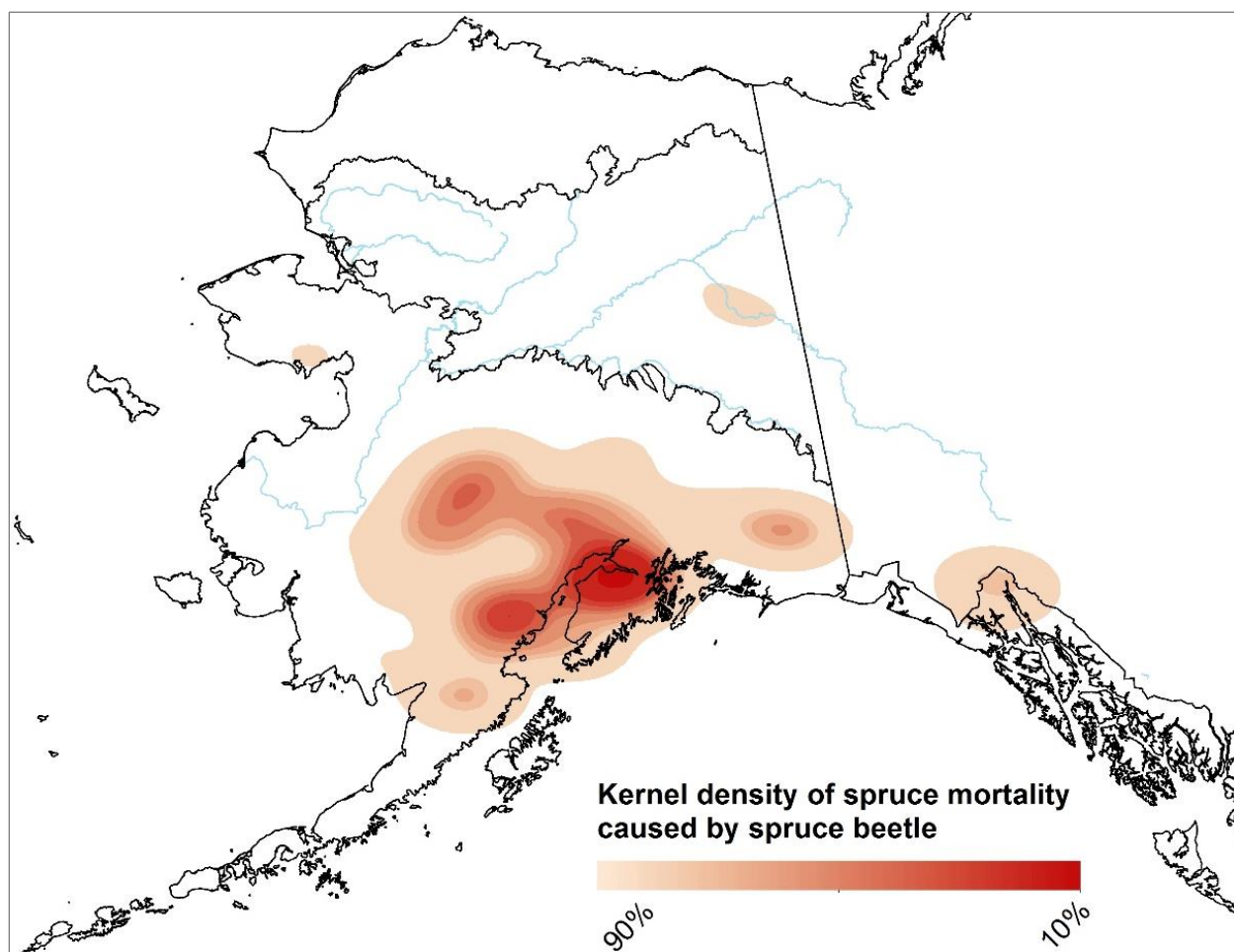


Figure D-22. Kernel density of spruce mortality caused by spruce beetle within Alaska from 2000 to 2014 with CYR study area shown for reference. The majority of spruce mortality occurred in Southcentral Alaska; however, a small pocket of the 90% isopleth was located along the upper Yukon River.

Spruce mortality caused by both spruce beetle and northern spruce engraver beetle remained the dominant form of mortality from 2010 to 2014. Northern spruce engraver beetle continued to contribute more mortality area than spruce beetle from 2010 to 2014. However, no steady trends were apparent for northern spruce engraver beetle. The area of spruce mortality caused by northern spruce engraver beetle increased by more than five times between 2000 to 2004 and 2005 to 2009. During 2010 to 2014, activity of northern spruce engraver beetle declined from the amount observed from 2005 to 2009, though not to the levels of 2000 to 2004.

Future Climate Vulnerability for Spruce Beetle Outbreaks

Spruce Beetle and Climate

Temperature exerts a stronger influence on phytophagous insects at northern latitudes than in temperate zones (Werner et al. 2006b). Although exact relationships vary per agent, insect outbreaks are often associated with sustained warm periods (Juday et al. 2005). Future potential climate vulnerability for spruce beetle is considered in this section because the costs of fuels reduction and wildfire management may increase if severe, regional spruce beetle outbreaks

occur in the study area in the future. Additionally, interactions between climate change, fire, and spruce beetle outbreaks have been shown to influence the distribution of vegetation and wildlife (Matsuoka et al. 2001, Juday et al. 2005, Boucher and Mead 2006, Werner et al. 2006a). Future changes in temperature will likely shift the location, density, and severity of spruce beetle outbreaks in Alaska (Sherriff et al. 2011).

Regional spruce beetle outbreaks in Alaska have been linked with warmer, longer summers compared to historic averages (Werner and Holsten 1985, Juday et al. 2005, Berg et al. 2006). Increased summer temperature increased reproductive success and reduced the generation time of spruce beetles on the Kenai Peninsula (Werner and Holsten 1985). Spruce beetle outbreaks on the Kenai Peninsula have been concurrent with 5 to 6 years of sustained warm summers for at least the past 200 years when stands of mature spruce were available (Berg et al. 2006, Sherriff et al. 2011). Longer growing seasons have allowed earlier emergence, attack, and breeding of adult spruce beetles (Hansen et al. 2001, Berg et al. 2006, Sherriff et al. 2011).

Successive cold winters cause high spruce beetle mortality so that the potential for a subsequent population surge is low (Holsten 1990 in Juday et al. 2005). Warmer winters increase the overwintering survival of spruce beetle, especially for beetles overwintering above snow line (Miller and Werner 1987, Berg et al. 2006). Warmer decadal average January temperatures would be likely to increase spruce beetle overwinter survival in the CYR study area because temperatures cold enough to kill spruce beetles would be reached less frequently and sustained for less time. Winter minimum temperatures in Interior Alaska have historically been cold enough to kill spruce beetles overwintering above snow line (Miller and Werner 1987).

The 50% isopleth of spruce mortality caused by spruce beetle from 2000 to 2009 occurred primarily in the Kenai Peninsula and Cook Inlet region of Southcentral Alaska with two smaller outliers south of McGrath and between Lake Iliamna and Lake Clark (Figure D-23). The areas included within the 50% isopleth were those where the densest aggregation of spruce mortality caused by spruce beetle occurred. From 2000 to 2009, spruce beetle outbreaks within the 50% isopleth were characterized by mean June-July-August temperatures $\geq 10.5^{\circ}\text{C}$, mean January temperatures $\geq -21.3^{\circ}\text{C}$, and growing season length ≥ 173 days.

The threshold selected for mean June-July-August temperature approximately matched the finding of Berg et al. (2006) that spruce beetle outbreak probability reached 50% when the 5-year average summer temperature reached 10.3°C . The threshold selected for mean January temperature was close to, but not directly comparable to, the -24°C average minimum monthly temperature threshold for spruce beetle overwinter survival reported by Berg et al. (2006) from data collected by Miller and Werner in 1987 (average minimum monthly temperature was not an available climate metric). Differences in units prevented any meaningful comparisons between the inductively identified threshold for growing season length and thresholds for cumulative hours above 14.5°C and 17°C previously identified by Hansen et al. (2001) and Berg et al. (2006).

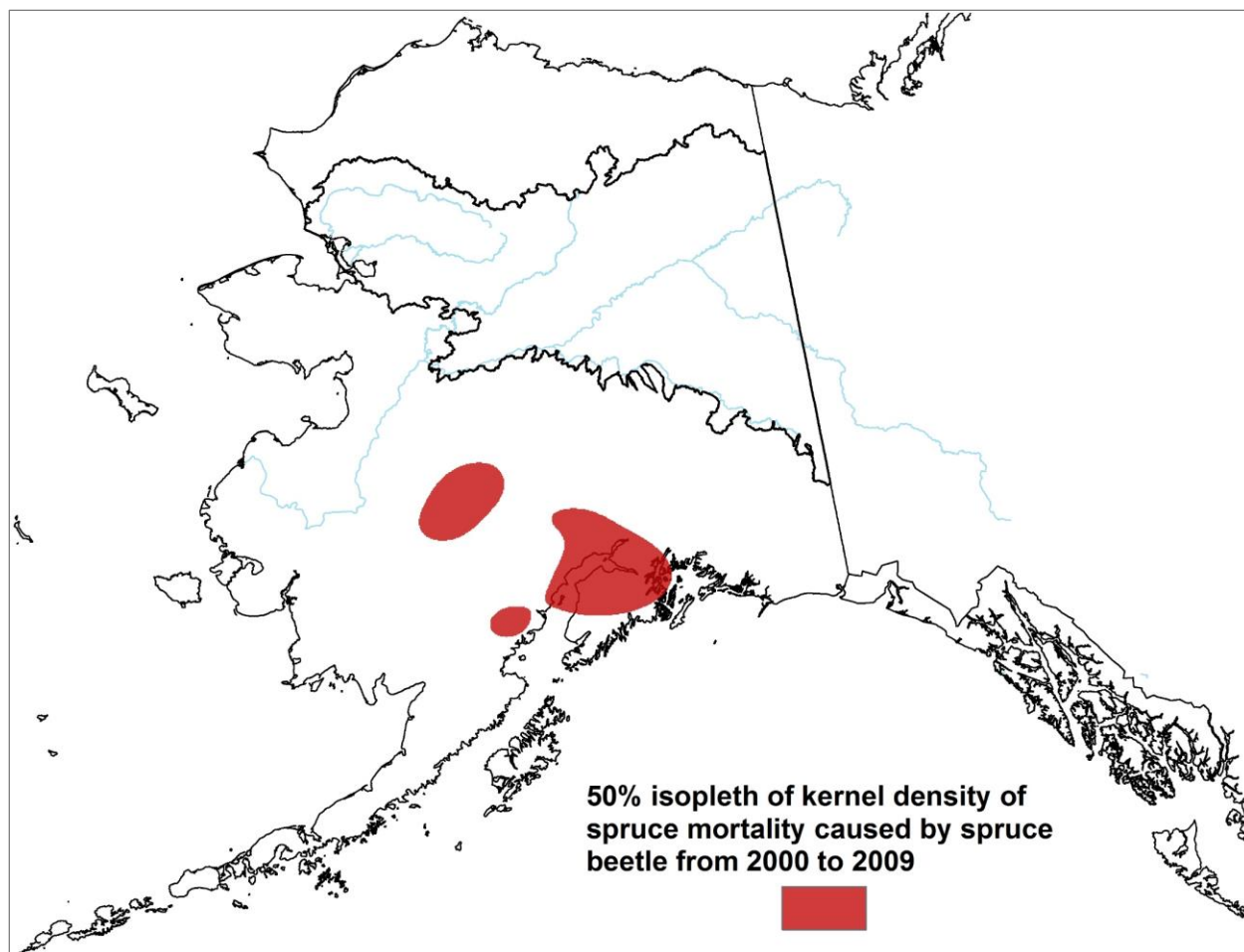


Figure D-23. 50% isopleth for spruce mortality caused by spruce beetle in Alaska from 2000 to 2009 with CYR study area shown for reference.

Climate-vulnerable areas were defined for each decade by the area where mean June-July-August temperatures were ≥ 10.5 °C, mean January temperatures were ≥ -21.3 °C, and growing season length was ≥ 173 days. Slightly more than 88% of spruce beetle damage observed from 2000 to 2009 in Alaska corresponded spatially with the climate-vulnerable area calculated for the 2000s decade. However, the southern border of the CYR study area was at the northernmost extent of the climate-vulnerable area during the 2000s decade: 96% of the climate-vulnerable area occurred south of the CYR study area (Figure D-24). These results suggest that spatial distribution of spruce beetle outbreaks in Alaska has been regulated partially by climate variables and that climate has not been favorable for outbreaks of spruce beetle in the CYR study area in the recent past.

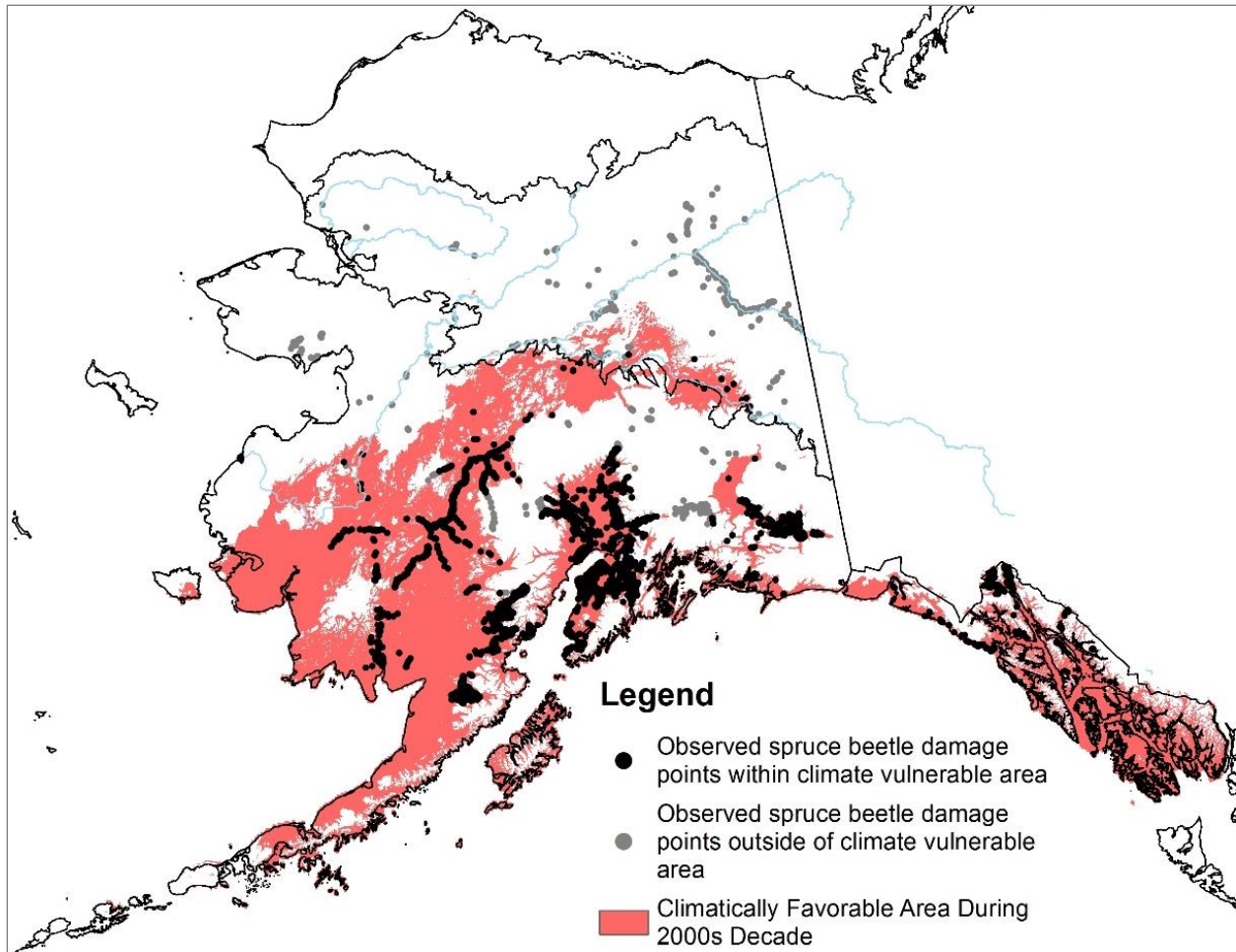


Figure D-24. Overlap of spruce beetle damage observed from 2000 to 2009 in Alaska with climate-vulnerable area calculated for the 2000s decade was 88%, but 96% of the climate-vulnerable area occurred south of the CYR study area.

Of the three climate variables assessed, mean June-July-August temperature was not historically limiting spruce beetle outbreaks in the study area. Mean June-July-August temperature was mostly ≥ 10.5 °C in the study area from 2000 to 2009. This corresponds with previous research indicating that spruce beetles in much of Interior Alaska have been able to reproduce in a single growing season because of warm summer temperatures (Werner et al. 2006a). Mean January temperature and growing season length, which was a proxy for cumulative hours above 14.5 °C and 17 °C, were both historically limiting for spruce beetle outbreaks. Although no statistical analysis of variable importance was part of the climate-vulnerability assessment, mean January temperature and growing season length are the factors driving the spatial distribution of climate-vulnerable areas in the CYR study area.

Future Climate Vulnerability

Future climate vulnerability indicates 5th-level hydrologic units where the majority of the hydrologic unit is predicted to have mean June-July-August temperatures ≥ 10.5 °C, mean January temperatures ≥ -21.3 °C, and growing season length ≥ 173 days. During the 2020s decade, conditions along the central Tanana River and north of Fairbanks will be climate-vulnerable to

severe, regional spruce beetle outbreaks. By the 2060s decade, climate-vulnerable regions will include: along most of the Tanana River, Fairbanks north to the Yukon River, along the upper Yukon River between Eagle and Circle, along the Yukon River from the confluence with the Tanana River to Galena at the edge of the study area, and along the southern Koyukuk River (Figure D-25). Much of the CYR study area will not likely become climate-vulnerable to severe, regional spruce beetle outbreaks by the 2060s decade.

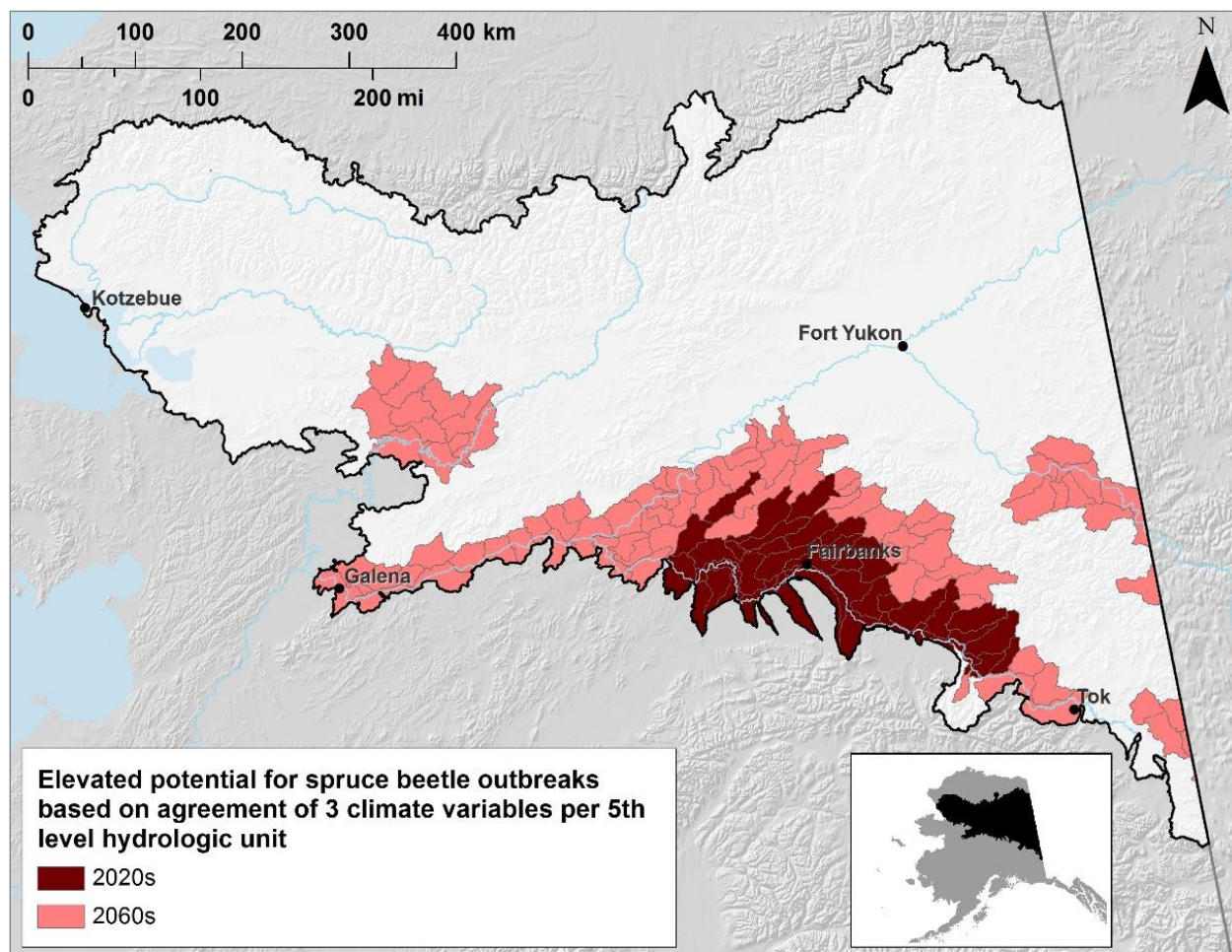


Figure D-25. Elevated potential for spruce beetle outbreaks during the 2020s and 2060s based on agreement of three climate variables per 5th-level hydrologic unit.

Spruce Beetle Outbreaks and Non-Climate Factors

The approach in this section has been to show 5th-level hydrologic units that may be vulnerable to severe, regional spruce beetle outbreaks based solely on climate factors. The climate-vulnerability approach is not a prediction of where future spruce beetle outbreaks will occur: spruce beetle damage has occurred and will likely continue to occur sporadically throughout the study area wherever there is spruce. In the regions of the study area not predicted to become climate-vulnerable by the 2060s, spruce beetle damage polygons will likely be observed but will continue to be small in size and low in density. Many additional environmental factors other than climate or indirectly related to climate exert strong influences on the potential for severe, regional

spruce beetle outbreaks. The following review explains some, but not all, additional factors influencing spruce beetle outbreaks that were ignored in the climate-vulnerability assessment.

The maturity of host stands is an important factor affecting distribution of spruce beetle outbreaks. Closed canopy stands of mature spruce were more susceptible to spruce beetle outbreaks because trees were weakened by resource competition (Berg et al. 2006). In the Kenai Peninsula, heavy mortality occurred in a mature spruce stand while an adjacent stand of 60- to 70-year old spruce showed only light mortality (Juday et al. 2005, Berg et al. 2006). Evidence from the Copper River Basin also suggested that increases in diameter at breast height and decreases in basal area increment increased the susceptibility of individuals to spruce beetle-induced mortality (Doak 2004). Based on field work conducted in 1997 and 1998, Matsuoka et al. (2001) determined that the highest proportion of white spruce killed in the Copper River Basin were those with diameter at breast height greater than 23 cm. In the event of very severe spruce beetle outbreaks, the availability of mature spruce can eventually limit spruce beetle population growth, such as occurred in some stands on the Kenai Peninsula during the late 1980s and 1990s (Berg et al. 2006).

Low fire return interval has been a factor historically preventing major spruce beetle outbreaks in the Kluane region of Yukon (Berg et al. 2006). Low fire return interval could prevent major spruce beetle outbreaks in the CYR study area if fires destroy available stands of large diameter, mature white spruce. This interaction is complicated by the increased availability of fuels following insect-related forest damage, including spruce beetle-induced spruce mortality. Modeled fire return interval from ALFRESCO was not suitable for inclusion in the vulnerability assessment because of low spatial specificity.

Differences between northern and southern spruce beetle populations in Alaska are not likely causes for regional differences in severity and density of spruce beetle damage. Molecular and behavioral analyses do not indicate genetic differences between northern and southern populations (Werner et al. 2006b). No differences in fungal associates among spruce beetles of different regions in Alaska have been found (Werner et al. 2006b). It is possible that differences in inoculation levels of fungal associates in spruce beetles may affect outbreak potential, based on data from a study of fungal associates of European spruce beetle (*Ips typographus*) in Norway (Krokene and Solheim 1998). However, the inoculation levels of spruce beetles in Alaska have not been tested (Werner et al. 2006b).

2.4 Limitations and Data Gaps

Range polygons or distribution models for insect agents are not available in Alaska. Aerial forest damage surveys do not delineate the ranges of insect agents. Therefore, data are only available to show where insect agents have been present in high enough concentration to cause defoliation or mortality severe enough to be seen from an airplane. Defoliation or mortality typically must be over 10-20% to be observable from the air (Juday et al. 2005). Similarly, it is not possible to determine insect agent populations based on aerial survey data.

Aerial forest damage surveys have concentrated along major riparian corridors in the past, leaving large areas of spruce forest, mixed spruce–hardwood forest, and tall shrub unsurveyed. Surveys have targeted large, continuous extents of forest. Smaller forest patches and mixed shrub and

forest habitats are likely under-sampled. Of surveyed areas, some were visited in multiple years where others were only flown during a single year. Additionally, no more than 25% of the forested area of Alaska is surveyed during a single year, so data from any single year provide an incomplete synopsis of trends in the status of insect and disease agents (FS-R10-FHP 2012, 2013).

Forest damage is determined by aerial detection surveys during which an observer sketches observed damage areas onto a map. Time, funding constraints, and the interpretation of the observer influence the data collected and the areas mapped. Many of the observations are not ground-truthed because of the limited resources. Some insect and disease agents are not readily detectable by aerial survey. However, aerial detection surveys currently provide the most efficient and effective method to monitor forest health in Alaska (FS-R10-FHP 2012, 2013). Damage polygons vary in accuracy. Generally, they should be regarded as having low accuracy boundaries. The centroids of forest damage polygons, however, are accurate such that they fall within the actual damaged area.

A large area of forest damage observed in the CYR study area is not associated with a causal agent. It is also possible that causal agent was misclassified in some cases. Only native insect and disease agents have been specifically identified as causal agents. It is possible that some of the area of forest damage not associated with a causal agent was the result of non-native defoliating insects, such as green alder sawfly (*Monosoma pulveratum*). Other non-native defoliating insects have been captured within the CYR study area as well (Kruse et al. 2010). Any potential forest damage caused by non-native species has been lumped with forest damage caused by native insect and disease agents in the aerial forest damage surveys and, therefore, in this assessment as well.

Distinguishing the relative contribution of stochasticity versus annual survey coverage is not possible when comparing data between individual years. Large fluctuations in the amount of damage observed annually for a single insect agent could be the result of: a.) actual annual fluctuations in insect activity and population, or b.) survey coverage of areas differentially affected by particular insect agents. Identification of trends between years is obscured by the uncertainty that arises from surveying different areas each year with low overall annual coverage of the study area. An ideal set of data collected with current methods would allow the identification of trends in decadal sums over a period of at least 50 years, matching the amount of time between the current and long-term future scenarios. However, only 15 years of insect damage polygons and flight lines were available for this assessment. The identification of long-term trends in decadal sums would provide a better understanding of how changing environmental variables have affected insect outbreaks.

Because of the stochasticity of insect outbreaks, it was not possible to predict or model future insect outbreaks by area, location, or intensity. Modeling future potential for insect outbreaks was also not possible because of stochasticity of outbreaks and poor understanding of many environmental factors influencing outbreaks. The environmental factors influencing most phytophagous insects have not been documented and information on specific interactions is not available to support a climate-vulnerability approach. The influences of several climate factors on spruce beetle life cycle and severe, regional spruce beetle outbreaks have been previously

demonstrated. Spruce beetle was the only biotic agent of forest damage within the study area for which a climate-vulnerability approach could be supported by available literature. The climate-vulnerability assessment for spruce beetle cannot be interpreted as a prediction of location or severity of future spruce mortality nor does it show the locations of future severe, regional spruce beetle outbreaks.

2.5 Literature Cited

- Bentz, B., J. Régnière, C. Fettig, E. Hansen, J. Hayes, J. Hicke, R. Kelsey, J. Negrón, and S. Seybold. 2010. Climate change and bark beetles of the western United States and Canada: direct and indirect effects. *BioScience* 60:602-613.
- Berg, E., J. Henry, C. Fastie, A. de Volder, and S. 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.
- Boucher, T., and B. Mead. 2006. Vegetation change and forest regeneration on the Kenai Peninsula, Alaska following a spruce beetle outbreak, 1987-2000. *Forest Ecology and Management* 227:233-246.
- Doak, P. 2004. The impact of tree and stand characteristics on spruce beetle (Coleoptera: Scolytidae) induced mortality of white spruce in the Copper River Basin, Alaska. *Canadian Journal of Forest Research* 34:810-816.
- Fricker, J., H. Chen, and J. Wang. 2006. Stand age structural dynamics of North American boreal forests and implications for forest management. *International Forestry Review* 16:395-405.
- FS-R10-FHP. 2012. Forest health conditions in Alaska 2011. Publication R10-PR-25. Alaska Region, USDA Forest Service. Anchorage, Alaska. 68 pp.
- FS-R10-FHP. 2013. Forest health conditions in Alaska 2012. Publication R10-PR-32. Alaska Region, USDA Forest Service. Anchorage, Alaska. 89 pp.
- Furniss, M., E. Holsten, M. Foote, and M. Bertram. 2001. Biology of willow leafblotch miner, *Micrurapteryx salicifoliella* (Lepidoptera: Gracillariidae) in Alaska. *Environmental Entomology* 30:736-741.
- Hansen, E., B. Bentz, and D. Turner. 2001. Temperature-based model for predicting univoltine brood proportions in spruce beetle (Coleoptera: Scolytidae). *The Canadian Entomologist* 133:827-841.
- Juday, G., V. Barber, P. Duffy, H. Linderholm, S. Rupp, S. Sparrow, E. Vaganov, and J. Yarie. 2005. Chapter 14: forests, land management, and agriculture. Page 1042 in Symon, C., L. Arris, and B. Heal, eds. 2005. Arctic climate impact assessment. Cambridge University Press. New York, New York.
- Krokene, P., and H. Solheim. 1998. Pathogenicity of four blue-stain fungi associated with aggressive and nonaggressive bark beetles. *Phytopathology* 88:39-44.
- Kruse, J., D. Smith, and N. Schiff. 2010. *Monosoma pulveratum* (Retzius) (Hymenoptera: Tenthredinidae: Allantinae), a Palearctic sawfly defoliator of alder in Alaska and new to the United States. *Proceedings of the Entomological Society of Washington* 112:332-335.
- Matsuoka, S., C. Handel, and D. Ruthrauff. 2001. Densities of breeding birds and changes in vegetation in an Alaskan boreal forest following a massive disturbance by spruce beetles. *Canadian Journal of Zoology* 79:1678-1690.
- Miller, L., and R. Werner. 1987. Cold-hardiness of adult and larval spruce beetles *Dendroctonus rufipennis* (Kirby) in interior Alaska. *Canadian Journal of Zoology* 65:2927-2930.
- Parent, M., and D. Verbyla. 2010. The browning of Alaska's boreal forest. *Remote Sensing* 2:2729-2747. DOI: 10.3390/rs2122729.
- Reich, R., J. Lundquist, and V. Bravo. 2013. Characterizing spatial distributions of insect pests across Alaskan forested landscape: a case study using aspen leaf miner (*Phyllocnistis populiella* Chambers). *Journal of Sustainable Forestry* 32:527-548.
- Sherriff, R., E. Berg, and A. Miller. 2011. Climate variability and spruce beetle (*Dendroctonus rufipennis*) outbreaks in Southcentral and Southwest Alaska. *Ecology* 92:1459-1470.
- Tremblay, M., S. Rossi, and H. Morin. 2011. Growth dynamics of black spruce in stands located between the 51st and 52nd parallels in the boreal forest of Quebec, Canada. *Canadian Journal of Forest Research* 41:1769-1778.
- Werner, R., and E. Holsten. 1985. Factors influencing generation times of spruce beetles in Alaska. *Canadian Journal of Forest Research* 15:438-443.

- Werner, R., E. Holsten, S. Matsuoka, and R. Burnside. 2006a. Spruce beetles and forest ecosystems in Southcentral Alaska: a review of 30 years of research. *Forest Ecology and Management* 227:195-206.
- Werner, R., K. Raffa, and B. Illman. 2006b. Dynamics of phytophagous insects and their pathogens in Alaskan boreal forests. *In* Chapin, F., ed. *Alaska's changing boreal forest: Bonanza Creek, Alaska*. Oxford University Press. Cary, North Carolina.

E. Anthropogenic Change Agents

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Summary

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

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1. Introduction

The Central Yukon (CYR) Rapid Ecoregional Assessment (REA) focused on a diverse socioeconomic region with remote subsistence-based communities, resource extraction activities, military bases, and western urban regions. Due to the large size of the CYR study area, we focused anthropogenic analyses into one of three different arrangements: watershed, road access, and urban (Fairbanks North Star Borough (FNSB)/rural status (Figure E-1). While there are many watersheds, we identified four major watersheds (Kotzebue, Koyukuk, Tanana, and Yukon rivers) that influence the availability of natural resources, landscape features, and overall use of the land. These were chosen because 1) residents in these watersheds have different subsistence harvest patterns, cultures (e.g., Inupiaq, Athabascan, Gwich'in, and mixed along the road), and 2) four is a manageable number about which to make inferences. In remote areas, rivers are commonly used as transportation pathways, but the region also contains five of the 13 highways in Alaska. Connection to the state highway system dramatically alters community dynamics, including but not limited to prices of fuel, employment, and access to hunting and fishing resources. In addition to a sprawling road network, there are two large active mines, Red Dog and Fort Knox, which are both significant taxpayers to the Northwest Arctic and Fairbanks North Star Boroughs, respectively. Certain components of the CYR study area are very dependent on prices of minerals, as well as fuel costs. One of the biggest issues facing residents is the price of heating fuel and gasoline, which on average cost \$2.89 and \$2.74 more, respectfully, in communities off the road system than on it (AKDCCED 2015). Overall, this region is complex and rapidly evolving, therefore, this report focuses on topics covered under the management questions. Since this area is quite large and diverse, examining trends at the global level can mask sub-regional dynamics. We have divided the study area into three different types of sub-regions based on: river drainages, road access, and the Fairbanks North Star Borough (Figure E-1).

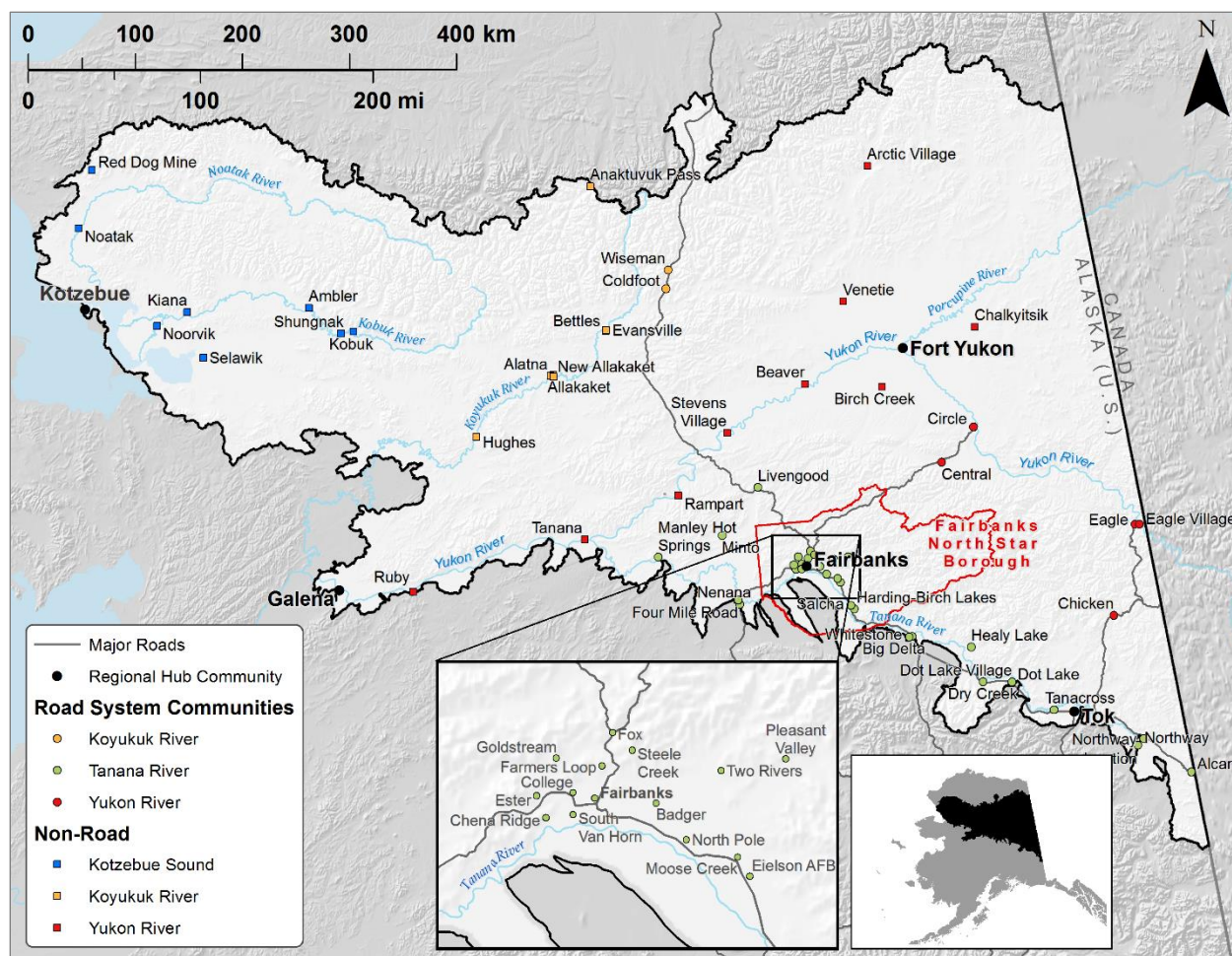


Figure E-1. Categorical groupings of communities in the CYR study area. The boundary of the Fairbanks North Star Borough is shown to identify communities within the FNSB and outside. Circles and squares represent communities on the road system and off, respectively.

1.1 Management Questions

MQ Q1: Which subsistence species (aquatic and terrestrial) are being harvested by whom and where is harvest taking place?

MQ U1: Compare the footprint of all types of landscape and landscape disturbances (anthropogenic and natural changed) over the last 20 to 50 years?

MQ U3: How and where is the anthropogenic footprint most likely to expand 20 to 50 years into the future?

Three Management Questions (MQs) were included in the CYR REA based on the concerns of land managers within the study area. Based on these MQs, we focused our assessment on:

- Subsistence and sport harvest activities for aquatic and terrestrial animals, including moose, caribou, and Dall sheep. Data on fish harvest were largely from sport fishing and were available at a resolution of 5th-level hydrologic units.

Subsistence and sport harvest activities are influenced by access, abundance of resources, regulations, and human population size.

- Socioeconomic demographics, which include information about population size and composition, income, and employment.
- Industrial activities, including mining, material extraction, oil and gas exploration, and timber harvest.
- Non-industrial activities, such as renewable energy, transportation infrastructure, and recreational activities.

The current year is defined as 2013, or if census data are required, then 2010. So references to the past and future 20 (2030 or 2033) and 50 (2060 or 2063) years will evolve around respective timespans.

2. Methods

2.1 Datasets

The spatial datasets used to define the anthropogenic footprint are listed in Table E-1.

Table E-1. Source datasets for analysis of current, near-term future, and long-term future anthropogenic footprint.

Dataset Name	Data Source
Community Footprints	Digitized from aerial and satellite imagery
Generalized Land Status of Alaska, 2015	ADNR Information Resources Management
Alaska Highways 63,360	ADNR Information Resources Management
Alaska Major Roads	ADNR Information Resources Management
ADNR RS2477 Trails	ADNR Information Resources Management
Forestry Roads	ADNR Information Resources Management
Mining Compliance Trails	Bureau of Land Management
Dalton Pipeline Gravel Access Roads	Bureau of Land Management
Dalton Highway Ground Transportation Linear Feature mining roads and trails	Bureau of Land Management
Pipelines including the Trans Alaska Pipeline system 63,360	ADNR Information Resources Management
Railroads 63,360	ADNR Information Resources Management
Northern railroad expansion including railroads, bridges, and levees	HDR
Timber sales	ADNR Information Resources Management
Five-year over-the-counter re-offer sales	ADNR Information Resources Management
Tanana Valley Forest	ADNR Information Resources Management
Alaska Resource Data File (ARDF)	U.S. Geological Survey (USGS)
Mineral Potential Data	U.S. Geological Survey (USGS)
Federal Mining Claims in Alaska	Bureau of Land Management
ADNR State Mining Claims	ADNR Information Resources Management
ADNR State Prospecting Sites	ADNR Information Resources Management
Active placer mining permits	ADNR Information Resources Management
Hard rock exploration permits	ADNR Information Resources Management
Suction dredge permits	ADNR Information Resources Management
Closed mining permits	ADNR Information Resources Management
Material sites	ADNR Information Resources Management
Abandoned mine land inventory system (AMLIS)	U.S. Department of the Interior, Office of surface mining reclamation and enforcement
Historic coal mines	Ground truth trekking

Dataset Name	Data Source
Nanushuk coal mine	Ground truth trekking
Ambler mineral belt	Ground truth trekking
Oil and Gas Wells	ADNR Information Resources Management
Land estate—permits and leases	ADNR Information Resources Management
Land estate—easements	ADNR Information Resources Management
Mineral estate—permits and leases	ADNR Information Resources Management
Resource Sales	ADNR Information Resources Management
Distant Early Warning (DEW) sites and Formerly Used Defense Sites (FUDS)	U.S. Army Corps of Engineers
Contaminated sites program database	Alaska Department of Environmental Conservation (ADEC)
Renewable energy infrastructure*	Alaska Energy Authority (AEA)
Fairbanks North Star Borough Growth Model	Fairbanks North Star Borough
Digitized historic footprint (Fairbanks)	Fairbanks North Star Borough
Alaska parks visitation data*	National Park Service
Subsistence Use Areas*	Alaska Department of Fish and Game, Division of Subsistence, Council of Athabascan Tribal Governments
Game Management Subunits*	Alaska Department of Fish and Game, Division of Wildlife Conservation
Sport hunting intensity*	Alaska Department of Fish and Game, Division of Wildlife Conservation and Federal Subsistence Management
Sport fishing intensity*	Alaska Department of Fish and Game

*Not included in the landscape condition model

2.2 Human footprint and demography

The human footprint captures the extent of human activity on the landscape. The extent includes physical alterations, such as roads, military installations, power lines, and communities. It also includes activities that involve the physical presence of humans on the land, such as subsistence hunting, fishing, and berry picking. Land use was divided into four categories: industrial, non-industrial, sport/subsistence, and recreational use. Industrial use activities are associated with resource extraction or construction related to resource extraction. Non-industrial uses reflect the presence of humans for purposes other than resource extraction, such as community footprints, roads, powerlines, and cables. The line between sport and subsistence harvest of resources can be blurry, and there could be users in rural Alaska who were reported in both the subsistence household surveys and the harvest tickets returned to the Alaska Department of Fish and Game (ADF&G). However, subsistence household surveys often capture harvests not reported on tickets and also provide harvest data at the community level (Andersen and Alexander 1992, Schmidt and Chapin 2014). Component datasets listed in Table E-1 were merged into a unified and comprehensive anthropogenic footprint dataset (Figure E-2).

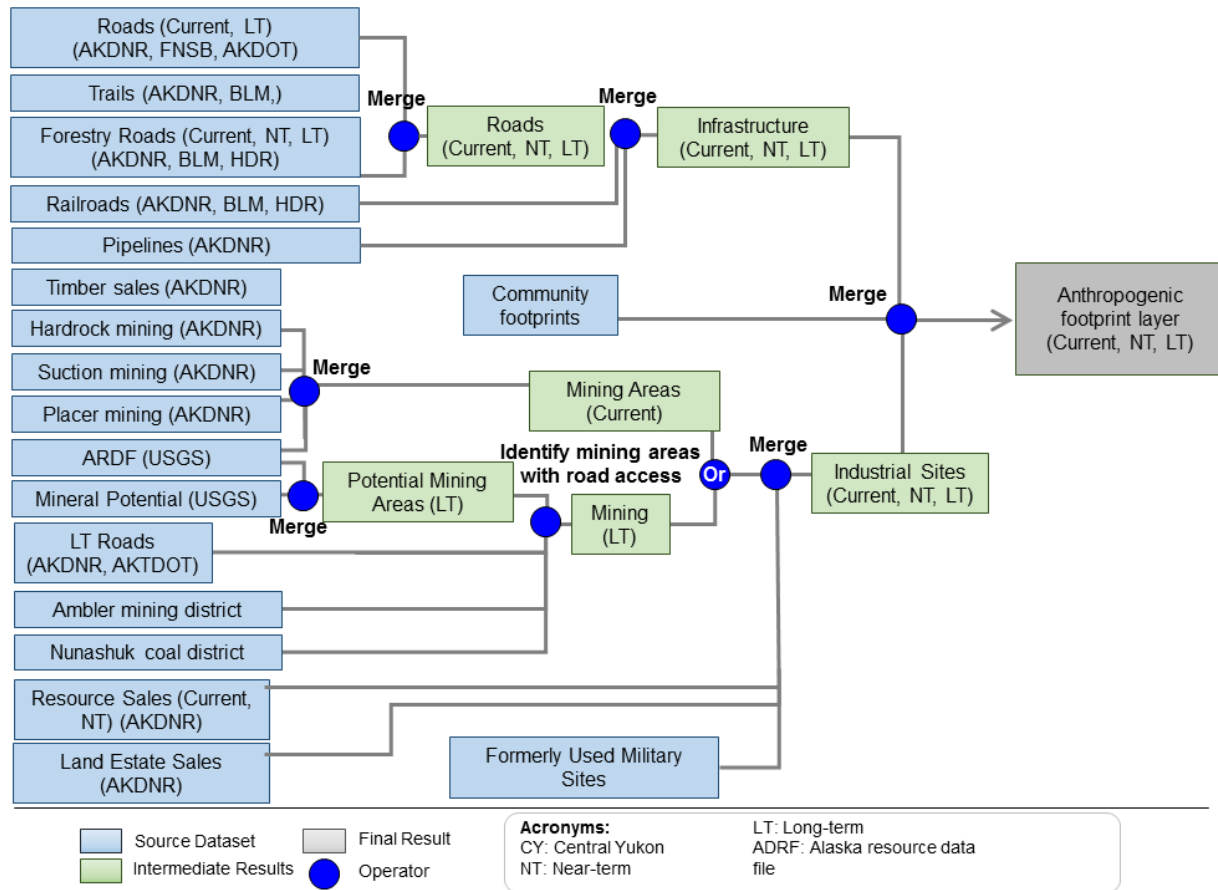


Figure E-2. Process model for computing human footprint in the CYR study area.

2.3 Community footprints

Since the data from the U.S. Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) files did not always accurately represent the actual extent of developed areas within communities, we digitized a community footprints dataset from satellite imagery (Alaska Mapped 2016). Community footprints included all permanent or semi-permanent impacts on the landscape, such as buildings, roads, pipelines, and waste dumps. The final product was a series of shapefiles that represent polygon, linear, and point features for each community within the CYR study area.

There were two major concerns with the TIGER community footprints:

1. Community boundary polygons represented the legal boundaries of each community and not the actual developed areas. The developed area for each community was much smaller than its legal boundary. Moreover, in many instances, boundaries as identified in TIGER community footprints did not match legal boundaries recognized under state law. Therefore, TIGER polygon boundaries were not accurate representations of existing communities and over-represented the actual community footprint.
2. Many of the maps produced for this project show community-level social and demographic information. For better representation in such maps, communities were

represented by points instead of polygons. Generating points from the TIGER community footprints often resulted in community locations that fell outside of the community developed areas.

The digitized community footprints produced for this study better represented the small communities of rural Alaska. However, not every community footprint in the study area was re-digitized. The CYR study area included the city of Fairbanks and its surrounding communities in the Fairbanks North Star Borough (FNSB), which has a major urban footprint. Because of denser population and development in Fairbanks and the surrounding areas, the U.S. Census Bureau TIGER community footprints were selected as the best representations of the greater Fairbanks metropolitan area. There are no clear breaks or boundaries between Fairbanks, and the TIGER community boundaries were contiguous. TIGER community footprints were selected for a total of 17 communities: Badger, Chena Ridge, College, Eielson Air Force Base, Ester, Fairbanks, Farmers Loop, Fox, Goldstream, Harding-Birch Lakes, Moose Creek, North Pole, Pleasant Valley, Salcha, South Van Horn, Steele Creek, and Two rivers.

2.4 Demographics and population projections

We used the population estimates from the Alaska Department of Labor and Workforce Development (ADLWD) and the U.S. Census Bureau for past and current human population. There were three nearly complete census areas within the CYR study area: FNSB, Northwest Arctic Borough (minus Kivalina, Deering, and Buckland), and Southeast Fairbanks (minus Tetlin Village and Delta Junction). Vital statistics (i.e., birth, death, and pregnancy rates) were available from the Alaska Department of Health and Social Services. When vital statistics spanned several years, we used the mean year when plotting data to help with interpretation and comparability. Future community population projections were calculated with an autoregressive integrated moving average model, which is often used to forecast time series data (Durbin and Koopman 2001).

In 2000, several communities were added to the census, though these communities were previously categorized as "other" within the census regions. The change in census communities did not present a data issue for the FNSB because all the newly created communities were within the study area, so the "other" category prior to 2000 represented the sum of the added community populations. However, for the Southeast Fairbanks and Yukon-Koyukuk Census Areas, the "other" category prior to 2000 included populations from communities outside the CYR study area. Therefore, for the communities created in 2000 we used the average community size from 2000–2014 as the 1990–1999 population size. Since over 65 communities were located within the study area, we grouped communities based on watersheds, presence in the FNSB, and access to roads to help examine trends (Table E-2). Watersheds were selected as a metric by which to group communities because major rivers often serve as transportation corridors between communities and, thus, provide a linkage between communities. Examination of patterns in subsistence harvests composition confirmed this delineation (see Section E-3.3). The FNSB is the only major urban area in the CYR study area and is classified as non-rural according to the Federal Subsistence Management Program (USFWS 2014, Wolfe and Fischer 2003). Lastly, some data were only available at the resolution of census area.

Table E-2. Categorical regions used to examine trends in demographics within the CYR study area.

Region Type		Number of Communities
Watershed	Kotzebue Sound	8
	Koyukuk River	9
	Tanana River	32
	Yukon River	16
FNSB Status	FNSB	16
	Non-FNSB	49
Road Status	Roaded	39
	Non-roaded	26

An urban growth model has been developed for use by the FNSB (FNSB 2014). We will provide an overview of the methods here but for more details see references. The FNSB undertook the task of creating an urban growth model for the 2040 future time-scale specifically to assess how future growth will influence air quality of the region. The mapping unit of the model was traffic analysis zones (TAZ; $n = 465$), which incorporated the five major roads leading in and out of Fairbanks and included about 90% of the population in the FNSB. The TAZs were based on the 2010 geographical census data because this is the unit at which the population size is collected. A growth rate of 1.1% was used and the population was distributed across the TAZs. Experts were asked to provide feedback on the estimated number of people per TAZ. The projection assumed the maximum growth and 100% occupancy of all zones. The projected number of people and buildings per TAZ in 2040 was calculated, and experts were asked to provide feedback as a score from 1 to 10 on the projected number of people per TAZ. The average feedback score was used to adjust the previous assumption of 100% capacity. Group quarters were captured in the human population numbers but household numbers were not. The future size of the military was determined by the common operating procedure used by the military, with the assumption that 82% of the population will live on base. The model also assumed no zoning changes over the years. We used these data to provide more detailed information about demographic changes in the FNSB.

2.5 Transportation infrastructure

Transportation networks are comprised of land (e.g., highways, roads, secondary roads, forestry roads, and trails), air (e.g., airports and airstrips), and water (e.g., rivers). Communities in the FNSB and a few outlying communities are connected by roads, but many communities in the study area are only accessible by airplane, boat, or snow machine in winter. Rather than use an infrastructure dataset compiled by the Alaska Department of Natural Resources (ADNR) in 2006, we compiled a roads and trails network using more recent datasets provided by ADNR, Bureau of Land Management (BLM), and FNSB (Table E-1). Most data were obtained from the Alaska State Geo-Spatial Data Clearinghouse, but other data sources were also incorporated into the comprehensive dataset.

Included in trails were those designated under the Revised Statute (RS) 2477 of the Mining Act of 1866 that granted public right-of-way across unreserved federal land to guarantee access as land transferred to state or private ownership. Rights-of-way were created and granted under RS 2477 until its repeal in 1976. However, trails that existed in 1976 continue to be valid rights-

of-way for public use and given the large study area, it was not feasible to examine this with satellite imagery. Along the Dalton Highway, there are a number of trails and access routes that were provided by the BLM, including: mining compliance trails, Dalton pipeline gravel access roads, and Dalton Highway ground transportation linear feature mining roads and trails. FNSB also has its own GIS repository with a roads dataset, which was used to provide any additional roads that might not be represented in the previously mentioned datasets.

The CYR study area included areas managed for timber harvest. Forestry roads in the study area, notably in the FNSB, are continuously changed based on timber sales. These roads can vary in their accessibility and type of access they permit. There are three different types of forestry roads as described below in the Tanana Valley State Forest (2001):

- **Primary:** A primary road is a main arterial into a unit or large subunit of the forest. They will usually be 5–25 miles long, allow speeds over 20 mph, and are intended for long-term use. They will generally be 1½ lanes allowing for slow, careful passing of large trucks.
- **Secondary:** A secondary road will typically be a 1–5 mile branch off a primary road or highway. It will provide long-term access to within a mile of multiple forest operations. Use may be intermittent. It will usually be narrower and have sharper curves and steeper grades than a primary road, requiring slower speeds. Passing widths for large trucks may be limited to wider turnouts. Construction methods are the same as primary roads, but gravel fills or surfacing will be used less frequently.
- **Spur Roads:** A short road built to access a specific forest management action, such as a timber sale. They are not part of the permanent forest transportation network and are only used for the duration of the action. Spur roads are single lane without provision for passing and allow speeds of 5–15 mph.

Forestry roads can be accessible all year round, or for summer or winter only. Year-round roads are intended for summer and winter use but may not be passable in wet weather. They are constructed from on-site materials but may be surfaced with gravel over wet or erosion-prone sections. They are located on drier, thaw-stable soils as much as possible. On boggy or permafrost soils, roads are usually constructed using a fill of dry embankment material placed over the natural ground. Forestry roads are also classified based on activity status: active, inactive, closed, or proposed. We used these categories to provide a time perspective. To add the forestry roads and Dalton datasets, we visually selected roads from the forestry roads dataset that were not represented in other datasets listed. Proposed roads in the selected forestry roads dataset were exported as a future forestry roads dataset. Inactive roads were reclassified as past roads to address MQ U1. We performed similar visual inspection processes to select roads from the Dalton Highway mining compliance, Dalton mining roads and trails, and Dalton pipeline gravel access roads datasets. All four trails from the Dalton Highway mining compliance dataset were included in the compiled infrastructure dataset. Dalton pipeline gravel access roads dataset contained no new data. The Dalton mining roads and trails dataset contained some duplication of roads; only the unduplicated roads were selected for inclusion in the compiled infrastructure dataset. Satellite imagery was used to determine if a footprint remained from inactive roads; if not, then those roads were used for examining the past human footprint. The proposed roads were also examined and if not present then they were included in the near-term future human footprint.

Future road development is largely related to two natural resource extraction projects: the Ambler mining district and oil extraction in the National Petroleum Reserve–Alaska (NPR-A). An additional future road to Nome was considered a possibility for this assessment (AKDOT 2012a, AKDOT 2012b). The access proposed to the NPR-A and Umiat is also known as the Foothills West Transportation Access project (AKDOT 2010b, AKDOT 2010c). Table E-3 lists the potential future roads to resources, of which we only selected the most likely roads for inclusion in our analyses.

Table E-3. Source datasets for analysis of current and future human footprints.

Purpose	Name	Length (mi)	Cost (in \$)
Road to Ambler mining district	Northern route (road)	220	430 M
	Southern route (road)	250	510 M
	Elliott Highway north road (road)	370	990 M
	Nenana North (railroad)	420-450	1.8-2.0 B
Ambler to Red Dog Mine port	Delong Mountain Transportation System (DMTS) corridor (road or railroad)	260	860 M/1.25 B
Cape Darby to Ambler	Cape Darby/Seward Peninsula (road or railroad)	340	960 M/1.57 B
Road to NPR-A/Umiat	Franklin Bluffs	88	372 M
	Pump Station 2	95	380 M
	Galbraith	90	357 M
Nome council road to Ambler	Selawik Flats corridor (road or railroad)	330	960 M/1.56 B
Port by Kotzebue to Ambler	Cape Blossom (road or railroad)	250	860 M/1.33 B
Road to Nome	Route 1 (Jim River)	437	NA
	Route 2a (Yukon Bridge)	495	NA
	Route 2b (Manley Hot Springs)	438	NA
	Route 3 (Yukon River corridor)	477	2.3-2.7 B

The other major transportation expansion project is south of Fairbanks where the railroad is being extended to Delta Junction. There are four phases of this project, with Phase 1 underway and included in the current infrastructure dataset. In Phase 1, several tasks were completed, including:

- Bridges across the Tanana River and Boundary and Beebee sloughs. Only the Tanana River Bridge is permanent.
- Upgrading and extending the Tom Bear Trail.
- Construction of a levee along the right bank of the Tanana River.

Phase 2 includes expansion of the railroad from Moose Creek near North Pole to across the newly built Tanana River Bridge by Salcha. This phase was included in the near-term future scenario. The completion of phases 3 and 4 is dependent on funding and, therefore, uncertain; however, they were included in the long-term future scenario. During these phases the railroad will be extended to Delta Junction and temporary bridges across sloughs were removed.

2.6 Industrial Activity

Forestry

Industrial activities within the CYR study area included timber sales and harvests, mining, and gravel removal. Every other year, the ADNR Division of Forestry develops a five-year sale plan that then allows land listed for sale to be sold. Land that is not sold can subsequently be purchased via over-the-counter re-offer sales. Currently spatial data are not available from the Tok office, representing a **data gap**. We used data provided by ADNR on timber sales and over-the-counter re-offer sales to calculate past and current timber harvest activities. Timber sales of less than 160 acres, salvage sales, and emergency sales may be offered without appearing on at least one of the two five-year schedules proceeding the sale. Old historic timber harvest activities were those that occurred prior to 1993. Recent historic activity included timber sales that occurred between 1993 and 2009. Current activity included sales that occurred between 2010 and 2014. These numbers aligned with the methods used to look at sport hunting and fishing.

Material Sites

Material sites, which are managed by ADNR and BLM, are the locations of resource extraction activities not channeled through the mining claims process. Material sites provide gravel for roads, peat, ballast, riprap, etc. (AKDNR 2015). All sites are located around roads. In 2012, there was a major change in the process of designating material sites for ADNR sites. Sites that were used before 2012 were grandfathered in and there is now a two-step permitting process. The GIS data are only digitized as sites are used, so any site grandfathered in but not used is not represented in the spatial data. Material sites can be in different stages of the permitting processes. For example, active sites are those currently being used by a wide variety of both public and private owners. Permit applications include statuses of complete, under review, and review pending. Lastly, material sites can be transferred or issued, but not currently active.

Mining

Mining information was largely provided by ADNR and the United States Geological Survey (USGS). The Alaska Resource Data File (ARDF) is compiled by the USGS and contains mineral occurrences, prospects, and mines. ARDF is a continuously updated dataset with several categories lacking information. The attribute table was standardized (Table E-4) for easier interpretation of the data. In addition, the data are not systematically updated, and the submission of information used to populate the dataset is largely voluntary. The historic and current mining activity received from ADNR was aggregated to the 10th-level hydrologic unit, whereas the ARDF contained point location data. We aggregated the ARDF data to the same 10th-level hydrologic unit scale by calculating the number and density of active mines per hydrologic unit.

Table E-4. Categories used in the original ARDF and the standardized categories used to determine mining activity in the CYR study area.

Mine type (original)	Mine type (new)	Status (original)	Status (new)
Mine	Mine	active	Active
Mine and prospect	Mine	Active	Active
Mine?	Mine	Active (1983)	Active
Mines	Mine	Active?	Active
Mines (?)	Mine	inactive	Inactive
Occurrence	Mine	Inactive	Inactive
Occurrence (?)	Occurrence	Inactive?	Inactive
Occurrence?	Occurrence	Inactive since about 1985.	Inactive
Occurrences	Occurrence	Inactive.	Inactive
Prospect	Occurrence	Not determined	Undetermined
Prospect (?)	Prospect	Probably inactive	Inactive
Prospect; Mine	Prospect	Undetermined	Undetermined
Prospect?	Prospect	Undetermined.	Undetermined
Prospects	Prospect	[Blank. No data]	Undetermined
Prospects (?)	Prospect		

Historic and current mining data were compiled out of three datasets, ARDF, ADNR, reports with maps of past mining activity (ADF&G 1986), and historic coal mines from Ground Truth Trekking (Ground Truth Trekking 2012). Examination of the databases did not indicate issues with duplication of mines. The ARDF historic mines were those classified as inactive (Table E-4). Historic ADNR data are placer, hard rock, or suction dredge mines that closed sometime between 2004 and 2013. No reason for closures of the mines was documented. Current mines used the same ARDF, active status, and ADNR datasets. The landscape condition model (LCM) required raw spatial data, so we used the original ARDF point data and created random points datasets for each of the ADNR density maps (e.g. placer, hard rock, or suction dredge activities that closed mines) at the 5th-level hydrologic unit.

Rather than using the ARDF to determine future mining activity, which is a work in progress we used additional datasets. Future mines are difficult to predict but we used three datasets to represent future mining activity: Ambler mining belt, Nanushuk coal mine, and USGS mineral potential GIS database (Jones et al. 2015). Jones et al. (2015) documented the potential and certainty of six minerals deposit groups:

- 1.) Rare earth elements (REE),
- 2.) Placer and paleoplacer gold (Placer),
- 3.) Platinum group element (PGE),
- 4.) Carbonate-hosted copper deposits (CuCarb),
- 5.) Sandstone uranium deposits (SandU),
- 6.) Tin-tungsten-molybdenum-fluorspar deposits associated with specialized granites (SnGranite).

The mineral resource potential datasets produced by the USGS (Jones et al. 2015) were used in conjunction with access to identify areas with the most likely long-term future mining activity. Mineral resource potential datasets only cover a portion of our study area (63.9% or 252,845 km²) but can still provide a useful indicator of future mining potential. Our goal was to use this dataset to identify areas with the greatest mineral potential in the long-term future. First, we used the mineral potential and certainty that were ranked into three categories (low, medium, and high). We used the potential and certainty categories to select areas of greatest mineral potential. We chose the areas that had either 1) high potential and certainty (i.e., high resource potential), or 2) a combination of high and medium (i.e., lower resource potential; Table E-5). The Jones et al. (2015) analysis was performed at the 6th-level hydrologic unit, a finer resolution than the other REA datasets, so we upscaled the dataset to the 5th-level hydrologic unit. Finally, after selecting the areas of mineral potential and upscaling the data, we used access to further refine areas with potential mineral activity because access is one limiting factor for potential mining activity. From the areas with potential mining activity we retained the unit if they intersected roads, trails, railroads, or proposed roads to Ambler or Nome.

After the future mining dataset was completed, we overlaid the ADRF prospect mines and state and federal mining claims not currently being mined to verify the datasets were in agreement.

Mining potential is based only on the physical potential for a resource and it does not take into account management or land ownership issues that might prevent mining activity. According to the General Mining Law of 1872, mining is prohibited in federal parks and wilderness areas. Legislative actions determine mining status on protected state of Alaska land greater than 2.5 km² (Alaska Statutes 38.05.300), and examination of legal actions indicate state parks and recreation areas do have mining activity, but state forests are open to mining. Critical habitat and refuges are also subject to legislation but typically closed. For example, the Minto Flats Game Refuge was closed to mining when created (Alaska Statutes 16.20.037). Regardless, we used the ADRF to examine how many past and present mines occur within federal- and state-protected lands. For the future-term projections, we identified high potential mining areas classified with the above methods via the USGS report, and documented how much high potential area occurs within protected zones. However, when assessing the impact of mining on the landscape condition, we do not place mining within a federal- and state-protected area, with the exception of state forests.

Table E-5. Categories used to determine the areas with the greatest mineral potential (bold) and the number of HUCs classified in each of the mineral resource potential GIS databases by the USGS. Mineral deposit groups include: Rare earth elements (REE), Placer and paleoplacer gold (Placer), Platinum group element (PGE), Carbonate-hosted copper deposits (CuCarb), Sandstone uranium deposits (SandU), Tin-tungsten-molybdenum-fluorspar deposits associated with specialized granites (SnGranite).

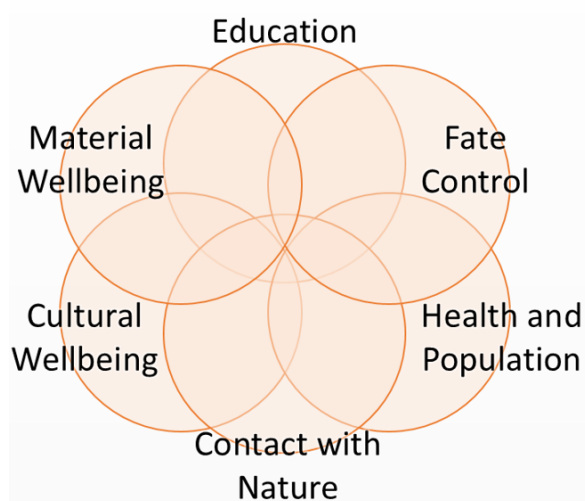
Potential, Certainty	Certainty	No. of HUCs in Each Category					
		REE	Placer	PGE	CuCarb	SandU	SnGranite
High	High	75	230	48	83	54	132
High	Medium	270	6	98	110	1	31
Medium	High	71	201	62	187	444	294
High	Low	17	0	8	0	0	4
Medium	Medium	476	0	639	447	273	317
Medium	Low	138	361	636	0	0	174
Low	High	394	374	490	711	453	1035
Low	Medium	713	1131	137	763	1072	214
Low	Low	144	0	181	0	0	97
Unknown	Unknown	15	10	14	12	16	15

2.7 Energy infrastructure

The Alaska Energy Authority (AEA) helps to provide access to renewable energy in the state of Alaska. The types of energy production installations include wind, hydro, thermal, and biomass. Through multiple rounds over the last decade, the AEA Renewable Energy Fund has funded, or is considering funding, a variety of renewable energy projects. Projects can be in several funding phases, and we reduced this to three phases. Current projects are considered those under construction or feasibility/construction. Planned projects include those in the feasibility stage, reconnaissance, and final design. Lastly, there are projects that are not active, which are those not funded by the AEA. We examined projects that were funded in rounds 1–7 to estimate current and near-term future renewable facilities.

2.8 Social and economic conditions

We used the six domains chosen by the Arctic Social Indicators: ASI II (ASI; Figure E-3; Larsen et al. 2014). Three of these were also included in the Arctic Human Development Report to assess social conditions in communities in the CYR study area. These indicators were selectively chosen based on data availability, affordability, ease of measurement, robustness, scalability, and inclusiveness. Figure E-3 shows the key variables used by the ASI report. However, there are several potential metrics within each indicator (Arctic Social Indicators 2010), some of which are more readily available for the CYR study area (see Table E-6).



Arctic Social Indicators	
Health and Wellbeing	
	Infant mortality
	Net migration
	Net migration rate
Material Wellbeing	
	Per capital household income
Cultural Wellbeing	
	Language retention rate
Contact with Nature	
	Harvest of traditional foods (kg)
Education	
	Post-secondary completion rate
Fate control	
	Political control
	Control over land
	Economic control
	Control over knowledge construction

Figure E-3. Arctic Social Indicators (ASI) organized into six domains along with key indicators.

Table E-6. Indicators identified in ASI report (Larsen et al. 2014). Key variables that, according to the ASI report, best represent the domain are indicated with an asterisk.

Domain	Variables suggested by Nordic Council	Community level data availability	Used
Health	Access to health care	Unavailable.	N
	Self-assessed health		
	Smoking rate		
	Obesity rate	Community-level data are confidential.	
	Child mortality rate		
	Infant mortality rate*		
	Suicide rate		
Population/ Demography	Total population	AK DOLWD and U.S. Census.	Y
	Population growth or decline rates and projections	Calculated.	Y
	Number of births	Information is available for the Fairbanks North Star Borough only.	Y/N
	Age/sex/ethnicity composition of the population including age and sex ratios		
	Birth rates	Information is available for the Fairbanks North Star Borough only.	
	Mortality rates		
	Infant or child mortality rates		
	Net migration*		
	Number of death		
Material Well-being	Per capita household income *	ACS 2006-2010 moving average	Y
		Proxy variable: Per capita income (past 12 months) for total population and for AIAN (ACS 2006-2010).	
		Alaska Department of Labor estimates of annual per capita earnings by community.	
	Per capita gross domestic product	GDP data for Alaska are available at U.S. Government Federal Reserve.	
	Unemployment rate	AKDOLWD–ALARI provides unemployment insurance claimants by community.	
	Poverty rate	Community-level data are not available.	
	Subsistence harvest per person	ADF&G subsistence harvest data are not collected every year in every community, nor for every species in every year. However, they are available for nearly all of the North Slope communities.	
	Net migration rate	Community-level data are not available. State- and census area-level are available.	

Domain	Variables suggested by Nordic Council	Community level data availability	Used
	A composite index that takes into account three sectors: Per capita household income, Net migration rate, Subsistence harvest	Lacking complete data.	
Education	Proportion of students pursuing post-secondary education	<i>Proxy variable:</i> Proportion of students pursuing secondary education (AK DEED; NCES).	Y
	Ratio of students successfully completing post-secondary education *	<i>Proxy variable:</i> Ratio of students successfully completing secondary education (AK DEED; NCES).	
	Proportion of graduates who are still in their own community (or have returned to it) 10 years later	Unavailable.	N
Cultural Well-being	Cultural autonomy	Unavailable.	N
	Do laws and policies recognize institutions that exist to advocate for cultural autonomy or national minority populations?		
	Do institutions representing national minority cultures exist?		
	What is the proportion of such institutions to minority peoples, e.g. are all peoples represented through such organizations?		
	Are resources available to such institutions?		
	Are funding policies in place and how well-resourced are they?	<i>Proxy variable:</i> Multiple variables from community-level language data from U.S. Census.	Y
	Language retention*		
	(E.g. what percentage of a population speaks its ancestral language?)	ADF&G subsistence harvest data report the number of people attempting to harvest, successfully harvesting, and using each species. However, data are not available for all communities.	N
	Belonging (e.g. what percentage of people are engaged in recreational or subsistence activities?)		
Contact with Nature	A composite index that takes into account above three sectors	To be computed but data unavailable.	
	Harvest of country foods*	Partial subsistence data available from ADF&G.	Y
	Consumption of country foods*	Partial subsistence data available from ADF&G.	
	Number of people or households engaged in the traditional economy	ADF&G subsistence harvest data report the number of people attempting to harvest, successfully harvesting, and using each species. However, data are not available for all communities.	

Domain	Variables suggested by Nordic Council	Community level data availability	Used
Fate Control	Percentage of indigenous members in governing bodies (municipal, community, regional) relative to the percentage of the indigenous people in the total population	<i>Proxy variable:</i> native corporations' earnings.	Y
	Percentage of surface lands legally controlled by the inhabitants through public governments, Native corporations, and	Acres of land owned by native corporations.	
	Community governments*		
	Percentage of public expenses within the region (regional government, municipal taxes, community sales taxes) raised locally	<i>Proxy variable:</i> Municipal taxation, state of Alaska from AKDCCED, Alaska Taxable.	
	Percentage of individuals who speak a mother tongue in relation to the percentage of individuals reporting corresponding ethnicity	U.S. Census collects the data that show how many people speak only English in the community.	

*Key variables to use as indicators—According to authors of the ASI report.

2.9 Distressed communities

We determined levels of community distress by examining risk and vulnerability rankings from Himes-Cornell and Kasperski (2015), the Alaska Governor's subcabinet on climate change (Immediate Action Work Group 2009), and the Denali Commission. Himes-Cornell and Kasperski (2015) examined vulnerability among Alaskan fishing communities based on climate change indicators, resource dependency, and adaptive capacity. They examined 315 communities and used principal components to select the most relevant variables to represent the three selected indices (see Himes-Cornell and Kasperski 2015 for details). Risk due to exposure to climate change was largely represented by sea ice and permafrost melting. Communities with greater resource dependency had higher commercial and sport harvests of fish, with some halibut subsistence fishing. Lastly, communities with higher adaptive capacity, which could be used to offset exposure to climate change and changes in availability of resources, had higher employment and work opportunities, more stable population, and less people on financial assistance. Principal components that represented each of the three indices are listed in Table E-7 below.

Table E-7. Parameters used to assess whether communities in Alaska are distressed and, thus, qualify for financial assistance.

Index	Principal Component
Climate change	Mean and max ice coverage
	Erosion risk
	Permafrost type/latitude
	Distance to next permafrost zone
	100% ice coverage
Resource dependency	Participation and subsistence halibut
	Sport fishing
	Participation per capita
	Commercial landings per capita

	Sport fishing per capita
	Marine mammals pounds
	Subsistence halibut per capita
	Commercial landings
	Subsistence salmon
	Marine mammal animals
Adaptive capacity	Poverty
	Transient population
	Population composition
	Employment diversification
	Labor force composition
	Lack of opportunities
	Social Security recipients
	Foreign population
	Elderly population

The Immediate Action Work Group to the Alaska Governor's subcabinet on climate change assessed vulnerabilities of communities, including those within the CYR study area. The Immediate Action Work Group included information on state flood disasters declared by communities in Alaska from 1978 through 2008. The Government Accountability Office also examined flooding and erosion in Alaska; however, they determined no communities within the CYR study area were considered at risk for flooding.

Lastly, the Denali Commission was created in 1998 and, since 2001, has annually assessed the distress status for communities in Alaska, releasing a list of distressed communities based on three criteria. If a community meets two of the three criteria listed below, they are classified as distressed.

- Average Market Income is less than \$14,872 (which is the yearly equivalent of a full-time, minimum wage job).
- More than 70% of residents 16 and over earned less than \$14,872 in the study year.
- Less than 30% of residents 16 and over worked all four quarters in the study year.

Communities that are classified as distressed are only required to provide a 20% match on Denali Commission grants. Communities that are not classified as distressed are required to provide a 50% match on Denali Commission grants.

2.10 Recreation

To examine recreational use of the CYR study area we used the National Park Service (NPS) Visitor Use Statistics reporting system that is publicly available. This reporting system includes numerical information in addition to comments from staff members about changes in visitation and methods used to collect data. We used linear regression to examine trends.

2.11 Subsistence harvests and use areas

Subsistence harvest data were obtained from the Community Subsistence Information System (CSIS), which provided data from subsistence household surveys conducted mostly by the ADF&G Division of Subsistence. Subsistence surveys were mostly conducted in rural communities, with some communities surveyed multiple years and others never surveyed. Data were available at the household level, which we aggregated to the community level. Since few comprehensive subsistence surveys were completed per community over the years, we examined specific species trends over time from CSIS data. Since many surveys targeted subcategories, we selected a subset of species for which we examined trends and harvest patterns in rural Alaska: moose, caribou, Dall sheep, salmon, non-salmon, waterfowl (species within the family Anatidae), and marine mammals. Survey years ranged from 1982 through 2012 and excluded the FNSB. We calculated the total and annual average per capita (in pounds) harvest of the subset species per community and per region. When calculating the annual average, we excluded villages that had total harvest of less than 5 lbs. per capita since this was likely the result of survey error. Spatial data of subsistence hunting collected during the ADF&G subsistence households were available for a limited number of communities.

For communities with subsistence use spatial data available, we also calculated the percent of the subsistence use area that occurs within the most pristine landscape condition (i.e., very high condition) for the current, near- and long-term landscape condition models. This provides an estimate of the quality of the habitat within those subsistence use areas for all three time periods.

2.12 State and Federal Subsistence Hunting and Sport Fishing

ADF&G has collected hunting and fishing information from Alaska residents and non-residents since just after statehood in 1960. Hunting data are typically reported on harvest permits that are returned to the ADF&G Division of Wildlife Conservation, regardless of success (ADF&G Wildlife Conservation 2016). State harvest ticket data do not reflect the number of hunters but rather the number of hunts. Hunts are defined as hunting activity associated with a harvest ticket while hunters are the individuals who possess harvest tickets. A hunter may possess several harvest tickets and participate in several hunts. The distinction between hunters and hunts is important because the number of moose hunts has been increasing statewide while the number of hunters has been relatively constant since the 1990 due to individuals obtaining multiple hunt permits (Schmidt et al. 2015). Harvest represents the actual taking of an animal (e.g., kills). However, examination of hunts and harvests for moose, caribou, and Dall sheep since 1990 can provide valuable insight regarding use of land and animals.

Data are collected at the GMU (Game Management Unit) level, and there are 24 GMUs within the CYR study area. Some GMUs are only partially included in the CYR study area, so we adjusted the number of hunts and hunters based on the percent of area of the GMU that occurred within the study boundary (Table E-8). Adjusting data by percent GMU area may not accurately reflect hunting activity, especially if access or animal density within the GMU influences harvest, but it avoids the certain overestimation of using sport hunt data unadjusted. Caution should be used when interpreting the data; limitations are summarized in the Data Gaps and Limitations Section.

Table E-8. Percentage of the total area of a game management subunit (GMU) within the CYR study area.

GMU	Percent in GMU %	GMU	Percent in GMU %
12Z	28.8	23Z	70.4
13B	0.003	24B	99.0
13C	0.002	24D	63.3
20A	16.4	25A	98.7
20C	10.23	26A	0.008
20D	76.3	26B	7.1
21B	16.3	26C	0.008
21D	12.9	20B,E,F; 21C; 24A, C; 25B,C,D	100

Given that most of the sport harvest of animals is done with state permits, we used the state database to spatially display harvest for moose, caribou, and Dall sheep by GMU. By only using the state database we were able to present more up-to-date data. Current hunting and fishing data were represented as the average harvest per GMU from 2010 through 2013. The earliest reliable harvest data were from 1990, so historic harvest was represented by the average harvest per GMU from 1991-1994. We calculated the percent change from historic to current in hunts and harvests for each GMU. Percent change was calculated as:

$$\text{Percent Change} = \frac{\text{Current} - \text{Historic}}{\text{Historic}} * 100$$

Sport fish data were obtained from results of sport fish surveys that have been mailed to anglers since 1977, although the current methodology dates back to 1996 (ADF&G Sport Fish 2016). These data were used to compare angler harvest and species composition of harvest over time and among rivers. In this dataset, Dolly Varden and Arctic char were reported together, so results for Dolly Varden include Arctic char.

Even though the Federal Subsistence Management database includes subsistence hunts these numbers are a small portion of overall hunts (see results). The Federal Subsistence Board regulates federal subsistence hunting in Alaska. Federal hunts are subsistence hunts because unlike the state, the federal government differentiates between rural and urban Alaska residents when issuing hunting opportunities. Only residents of areas identified as rural are eligible to participate in the Federal Subsistence Management Program on federal public lands in Alaska. Rural and urban status is determined first by population size, with communities of 2,500 or less classified as rural. Communities between 2,501 and 7,000 in population size are urban unless they have characteristics of rural areas. Characteristics used to determine rural status include: economy, community infrastructure, level of fish and wildlife use, transportation, and educational institutions present in the community. Subsistence harvest data from the Federal Subsistence Management Board were available at the community level and game management unit (GMU) level for multiple species. Because data were available at the community level, unlike ADF&G data, we were able to assess changes within different regions over time. We assessed changes in user groups harvesting fish and game through 2010. The main reason we use this database is because it provides residency information for ADF&G state harvest tickets, unlike the publicly available ADF&G data portal. The federal subsistence database does not accurately capture

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subsistence hunting and harvests in Alaska. The previously mentioned ADF&G subsistence household surveys are the most accurate data available for subsistence hunting in Alaska, but even this database, as with all human self-reporting databases, has biases and shortcomings.

3. Results

3.1 Communities

The CYR study area (395,854 km²) is slightly smaller than the state of California (403,466 km²) and has widely ranging socioeconomic conditions, including both urban and rural areas. The study area contains the second largest city in Alaska (Fairbanks, $N = 31,535$ in 2010) and some of the smallest (Bettles, Coldfoot, Evansville, and Wiseman, $N < 20$ in 2010). The overall population in the study area is expected to grow in size, more so among the older age classes than the younger, but regional variation exists. Changes in population growth do not account for immigration, which can offset aging of current residents. Overall, the total community footprint in the CYR study area is minimal (2,442 sq. km² or < 0.01% of total study area). FNSB (19,297 km²) is the major urban center ($N = 97,581$) in Interior Alaska. The size of the community footprint according to the TIGER tracts is 2,226 km² or about 11.5% of FNSB (Figure E-4). Rural communities in the CYR study area have a very small average footprint (4.3 km²).

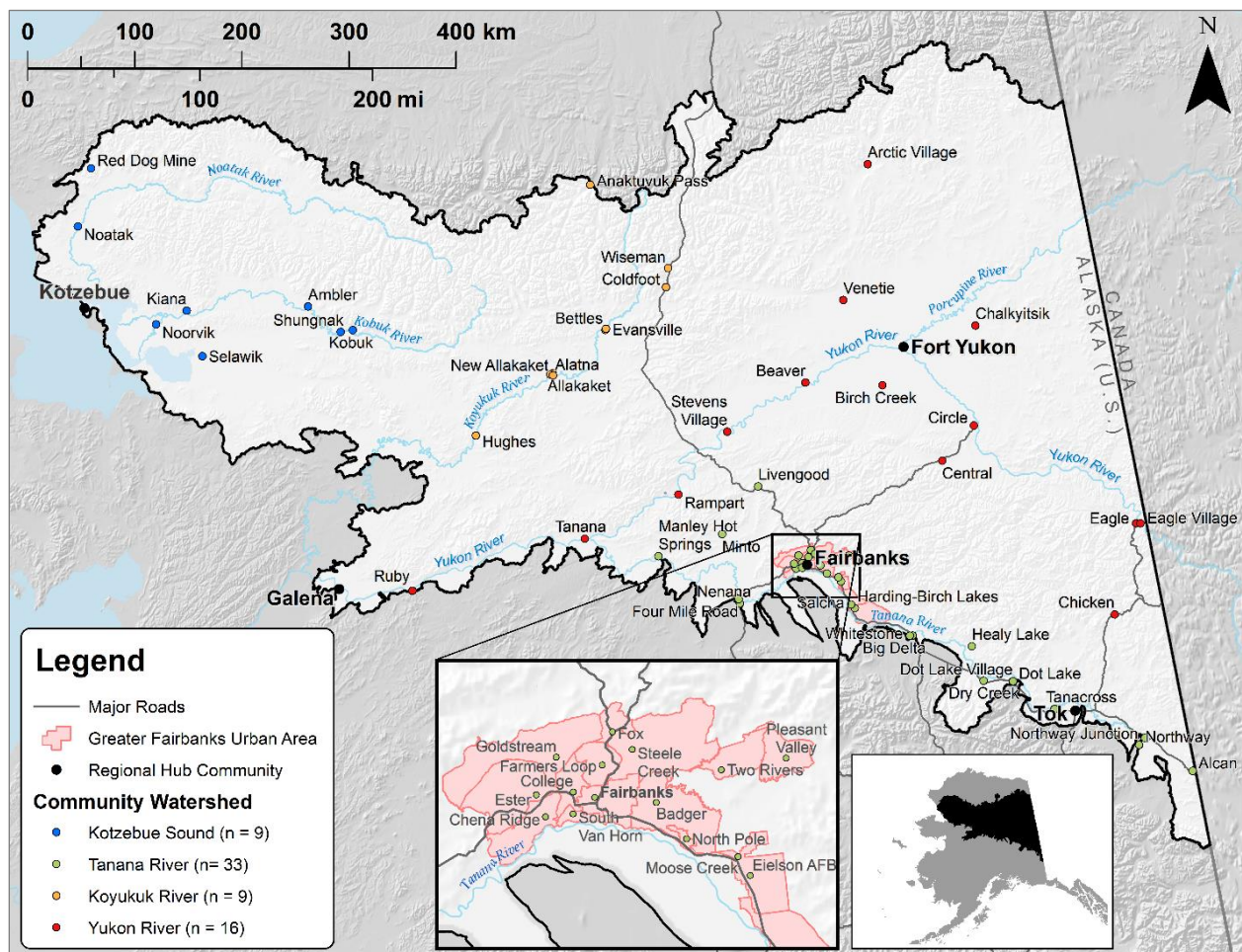


Figure E-4. Footprints of communities and populated places in the CYR study area.

Demographic structure

The CYR study area contains a diverse human population with very remote communities and urban centers. Remote communities are typically mixed subsistence-cash economies populated by Alaska Natives. Jobs are limited and the cost of living can be quite high. Urban areas like Fairbanks and North Pole have more employment opportunities, increased infrastructure, mixed race, and a lower cost of living than rural communities. Overall, the population within the CYR study area is expected to increase over the next 45 years (Table E-9; Figure E-5). Most of the increase is expected to be within urban areas and communities with road access (AKDLWD 2016a; Table E-10). The average rate of change for all regions was between 0% and 0.01%, and some regions expect a decline in population size (Table E-10). The largest growth from 2013 through 2060 is projected in the FNSB (41.0%), which was slightly more than the overall growth estimate (40.2%) for the CYR study area. Meanwhile, Yukon River and Koyukuk River communities are predicted to lose population by -2.2% and -1.3%, respectively.

Table E-9. Projected population for the CYR Study Area (excluding Red Dog Mine).

Year	Base Projection	Low Projection	High Projection
2020	118,082	110,917	125,247
2025	122,886	113,185	132,587
2030	127,690	115,990	139,390
2035	132,494	119,090	145,898
2040	137,298	122,384	152,213
2045	142,102	125,817	158,388
2050	146,906	129,356	164,456
2055	151,710	132,981	170,439
2060	156,514	136,676	176,353

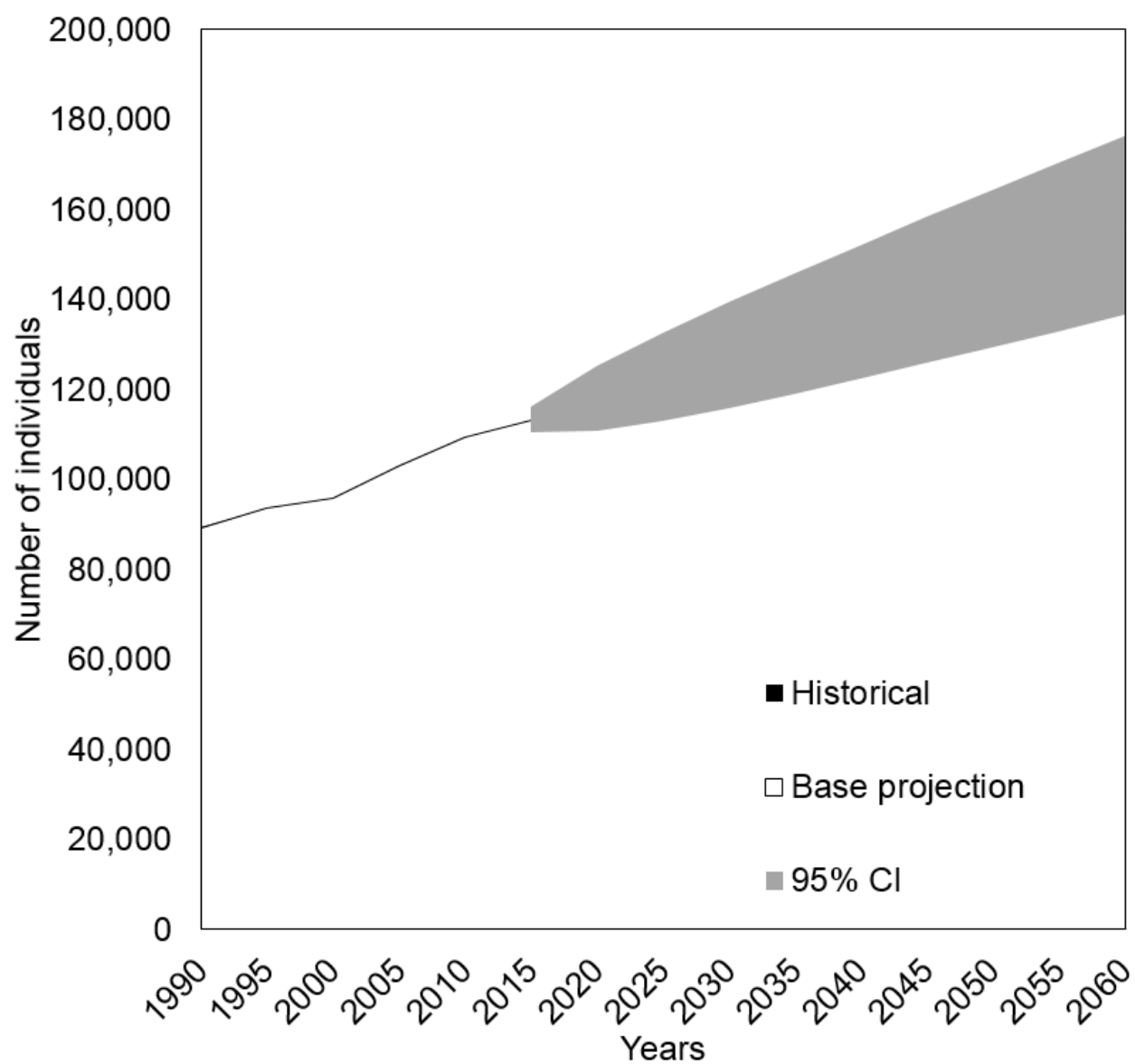
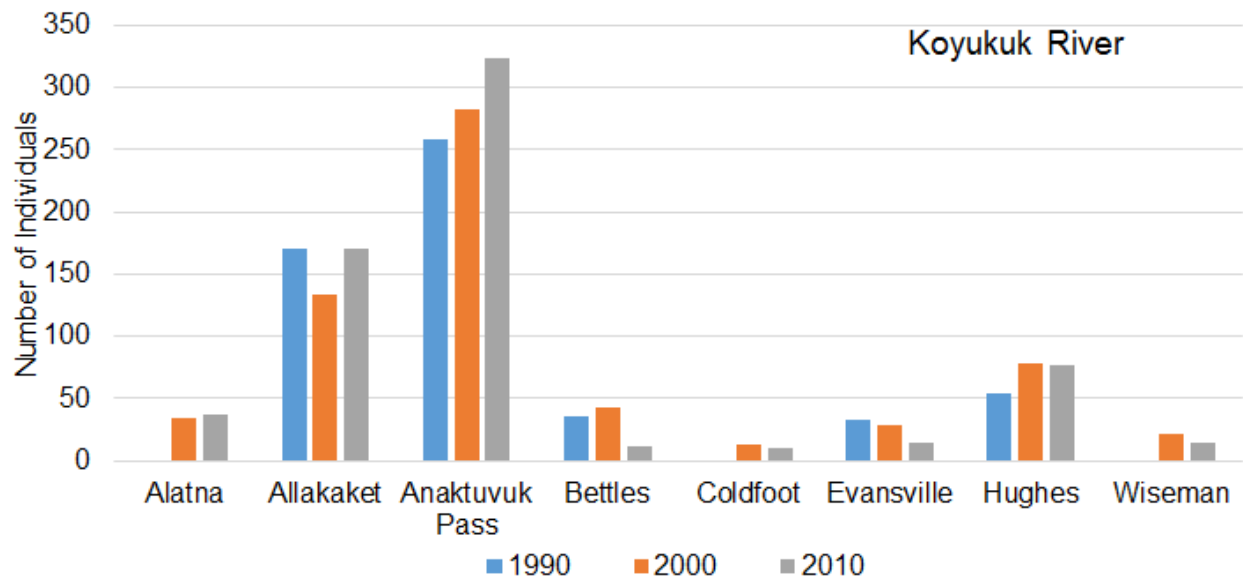
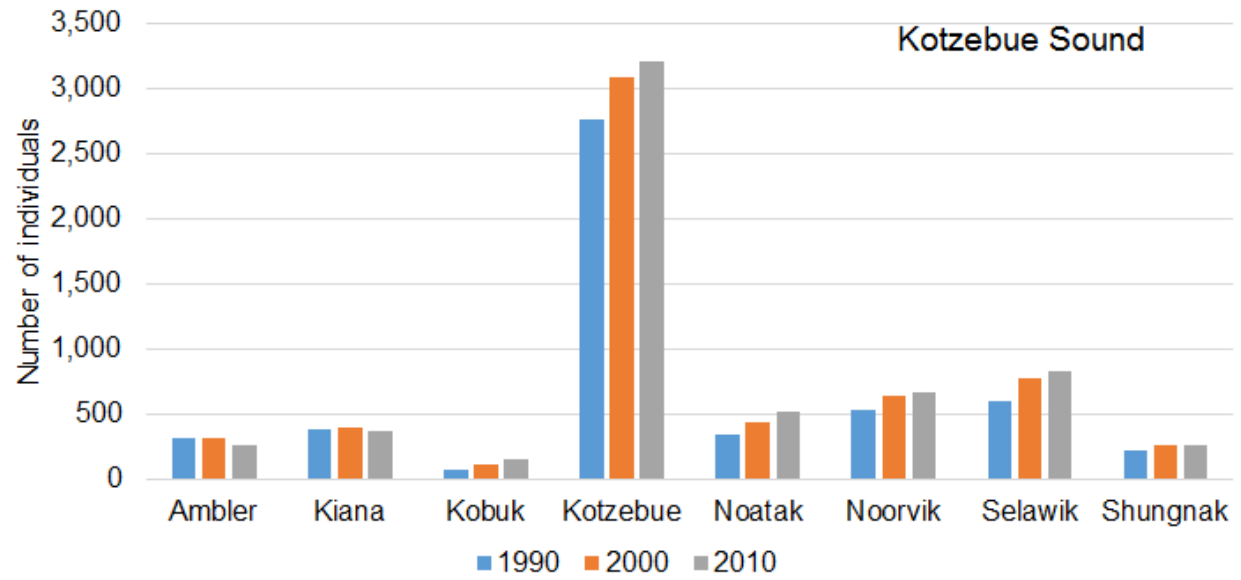


Figure E-5. Population projection of the CYR study area (excluding Red Dog Mine and group quarters) with 95% confidence intervals.

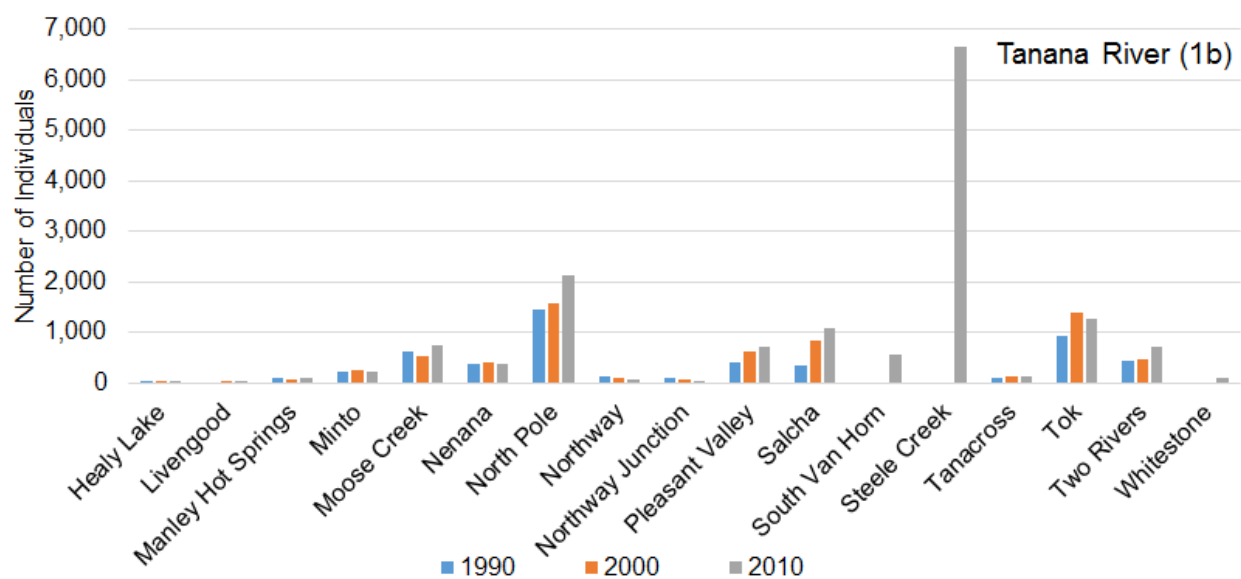
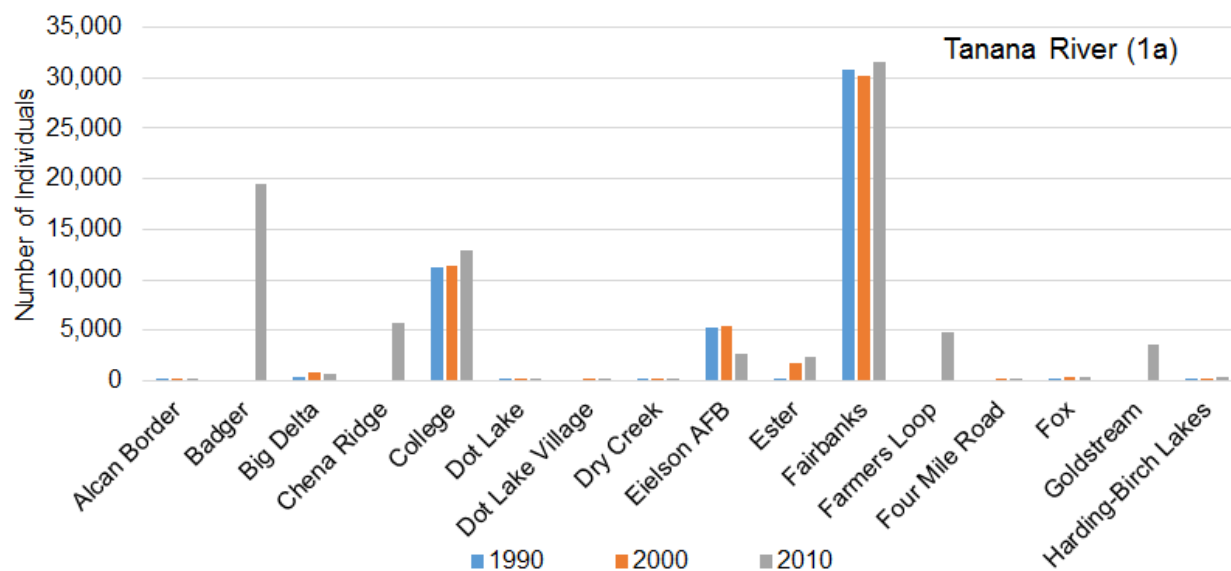
Table E-10. Population structure of the regions (by watershed) in the CYR study area (excluding group quarters and Red Dog Mine).

Community Category	Total pop. (2013)	Pop. change from 2013–2030	Pop. change from 2030–2060	Avg. rate of change from 2013–2060	Males (2010)	Change in males from 2000–2010
Kotzebue Sound	6,336	7.2%	20.8%	0.01%	53.50%	1.40%
Koyukuk River	678	-1.3%	0%	0%	55.30%	1.90%
Tanana River	102,729	14.7%	23.5%	0.01%	52.80%	1.00%
Yukon River	2,422	-2.2%	0%	0%	54.30%	-0.30%
FNSB	100,132	13.8%	23.9%	0.01%	52.80%	1.00%
Non-FNSB	12,855	0.2%	0%	0%	53.60%	1.10%
Roaded	103,018	13.4%	23.5%	0.01%	52.80%	1.00%
Non-roaded	9,969	9.3%	13%	0%	53.90%	0.90%
All	112,987	14.4%	22.6%	0.01%	52.90%	0.90%

Based on decadal census data, most communities in the CYR study area, except for the Yukon River drainage, increased in population size from 1990 to 2010 (Figure E-6).



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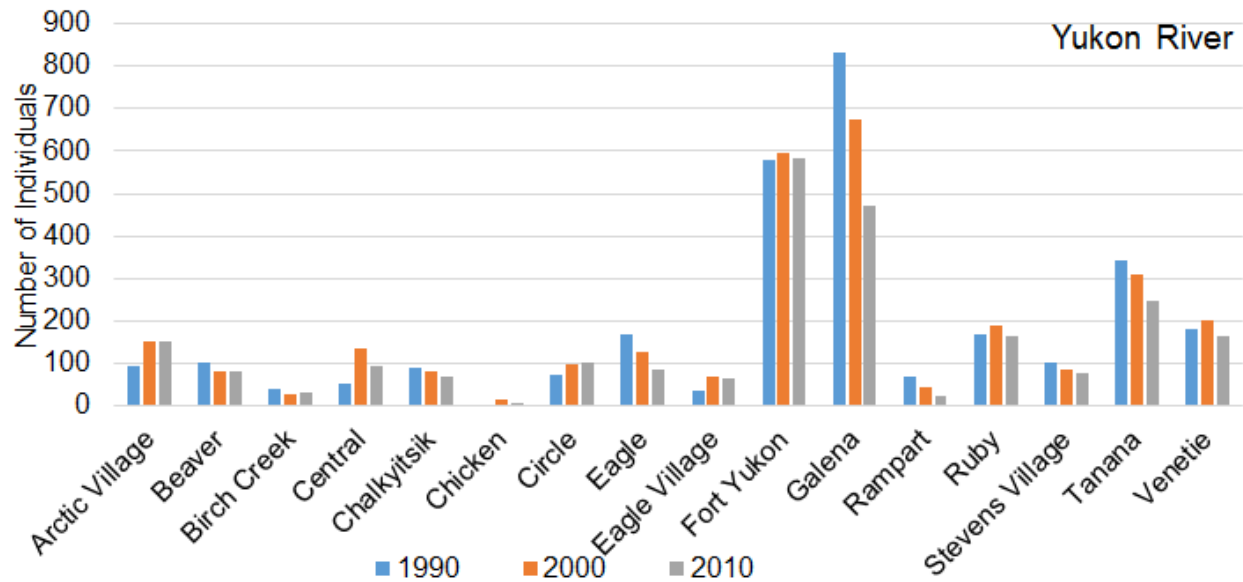


Figure E-6. Population size of regions in the CYR study area (Census data for 1990, 2000, and 2010). Data shown are the number of individuals.

In general, people in Alaska are very mobile and migration fluctuates greatly from year to year (Figure E-7, Figure E-8, and Figure E-9). When looking at immigration and emigration among rural Alaskan communities, most migration involved larger numbers of people moving to urban areas such as Anchorage, FNSB, and the Matanuska-Susitna Borough. Kotzebue is the largest community within the Kotzebue Sound. Between 2000 and 2013, an annual average of 67 people moved from a village within the Northwest Arctic Borough (NWAB) to Kotzebue, which is slightly greater than the annual average number of people (63 people) who moved from Kotzebue to another village within the NWAB (AKDLWD 2016b). Excluding Kivalina, Deering, and Buckland (because they are not in the study area), the population of NWAB declined from 2000 to 2014 (average annual change of -97 people). Emigration spiked around the time gas prices peaked (2008) and since have declined except for a spike in 2013 (Figure E-7). Migration data presented here do not include changes in population size due to births and deaths. Rural Alaska has a very high birth rate compared with other areas in Alaska (see below Figure E-18). Census data indicate that all but one community within NWAB increased in population since 1990, but the census is done only once a decade, which limits the ability to detect trends (Figure E-6). The average annual percent net migration relative to total population size was lowest for Noorvik (-2.2%) and highest for Noatak (0.3%).

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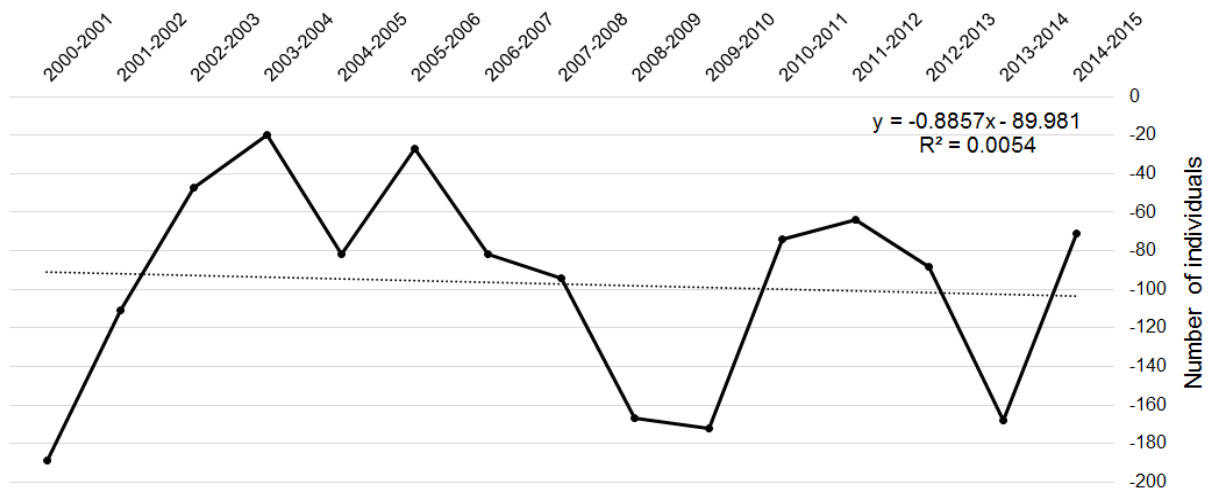


Figure E-7. Net migration to and from the NWAB, excluding Kivalina, Deering, and Buckland. Data from Alaska Department of Labor and Workforce Development (AKDLWD 2016b). Migration data presented here do not include changes in population size due to births and deaths, and rural Alaska has a very high birth rate compared with other areas in Alaska.

Migration in the FNSB was positive during 2004–2005 and 2005–2006, but has largely been negative from 2006–2007 to 2014–2015 (Figure E-8). Rents in Fairbanks have risen by 50% from 2005 to 2015, which could be a factor in the large emigration (Wiebold 2015).

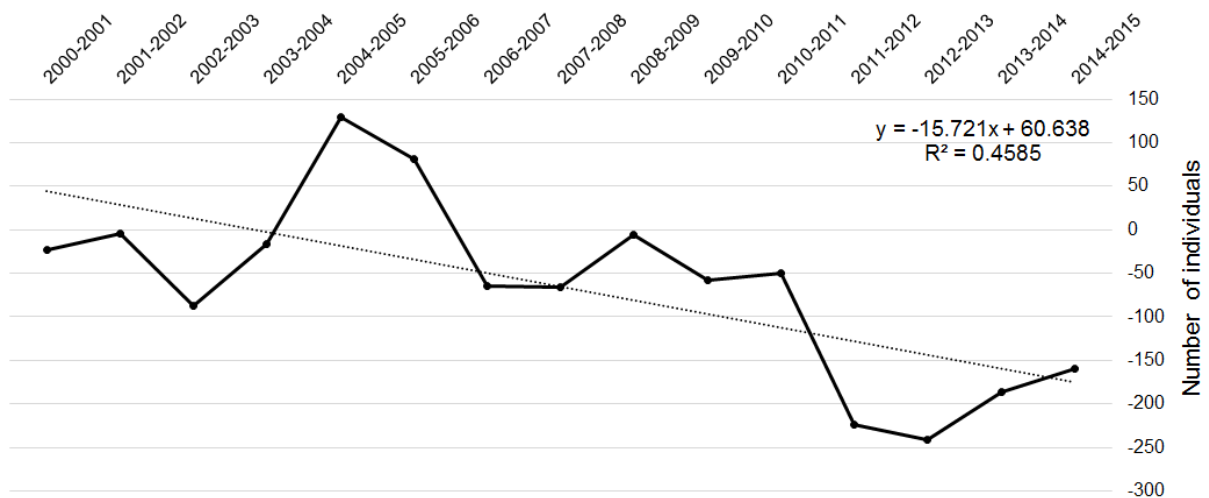


Figure E-8. Net migration to and from FNSB. Data from Alaska Department of Labor and Workforce Development (AKDLWD 2016b).

The emigration in the Southeast Fairbanks Census Area is holistic—only two communities did not decline (Figure E-9). The Delta Junction region has been greatly affected by reductions in military spending and activities associated with Fort Greely. Big Delta lost 200 people while Eagle/Eagle Village and Healy lost a total of 75 people due to either emigration or death.

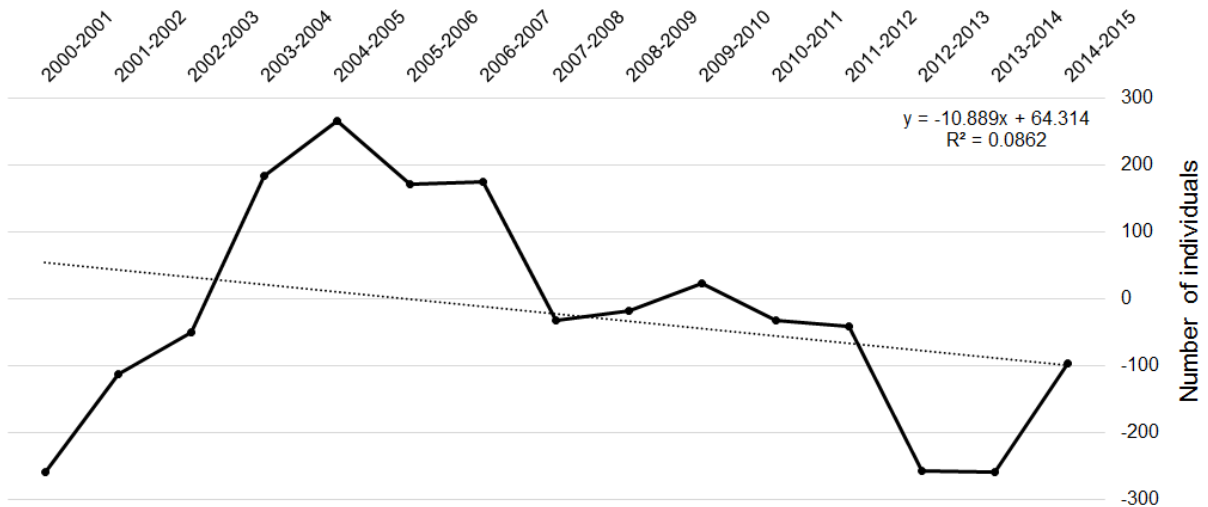
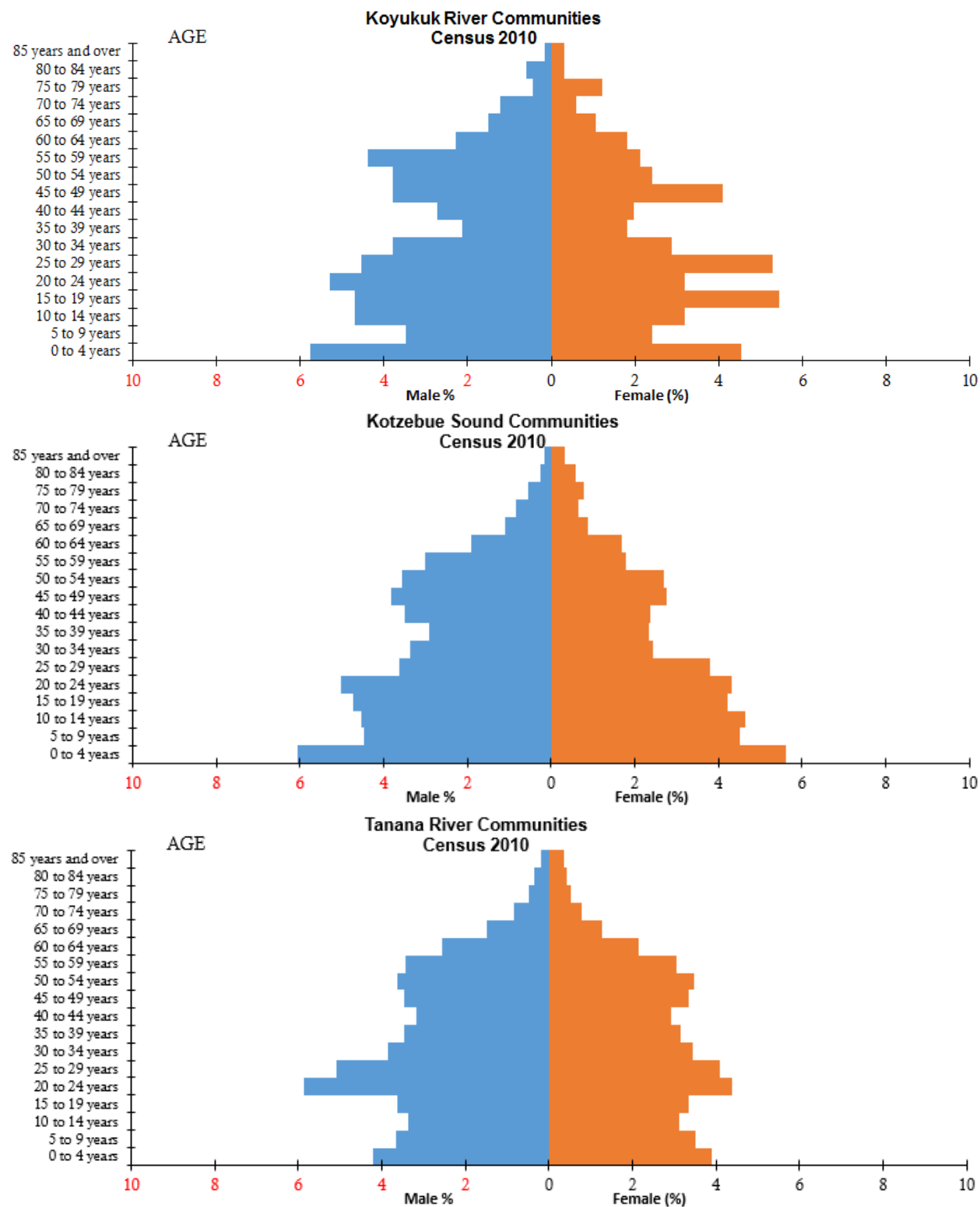


Figure E-9. Net migration to and from the Southeast Fairbanks Census Area. Data from Alaska Department of Labor and Workforce Development (AKDLWD 2016b).

The CYR study area had slightly more male residents (52.0%) than female residents in 2000. The percent of male residents increased to 52.9% by 2010 (52.9%). The Yukon River watershed was the only watershed where the percent of males in the population decreased (Table E-10). Even though the ratios of males to females were similar in all the regions, the age composition differed. In general, the more rural and remote locations had younger residents and a smaller portion of their populations occurred within working age (15–65-years-old; Figure E-10 and Figure E-11). When people above the age of 64 are not considered among the working population, the percent of people employed all four quarters increases greatly in the non-FNSB and slightly in the Yukon River watershed. In these two regions, the total number of residents age 16 and older was much larger than residents between 15 and 64, which, based on the age pyramids, is likely due to the presence of older aged residents (Figure E-10).

Kotzebue Sound communities had the most pyramid shaped age profile with a large base of young children (20.7% of population < 10 years old). Both the Kotzebue Sound and Yukon River communities had a smaller cohort in their 20s during 2000, and 30s in 2010. Research has shown that among young adults in rural communities, migration to more urban areas such as FNSB is common (Howe 2009). The data used here cannot directly assess migration, but we can look at the change in composition of young adults (20–24 years old). The percentage of Alaska Native residents of FNSB increased by 2.1% between 2000 and 2010 (Figure E-12). Communities in the Yukon River watershed had the fewest young adults in 2010 (5.9%). The population of females decreased at a rate nearly 38 times that of the rate of population decline of males, 0.38% versus 0.01%, respectively, between 2000 and 2010 census. Kotzebue Sound had nearly the same percentage of youth as the Tanana River communities, which included FNSB (9.4% versus 10.2%, respectively), which was likely partially due to the presence of the larger hub community of Kotzebue. Kotzebue offers employment and education opportunities not found in the two other more rural watersheds (i.e., Koyukuk and Yukon).

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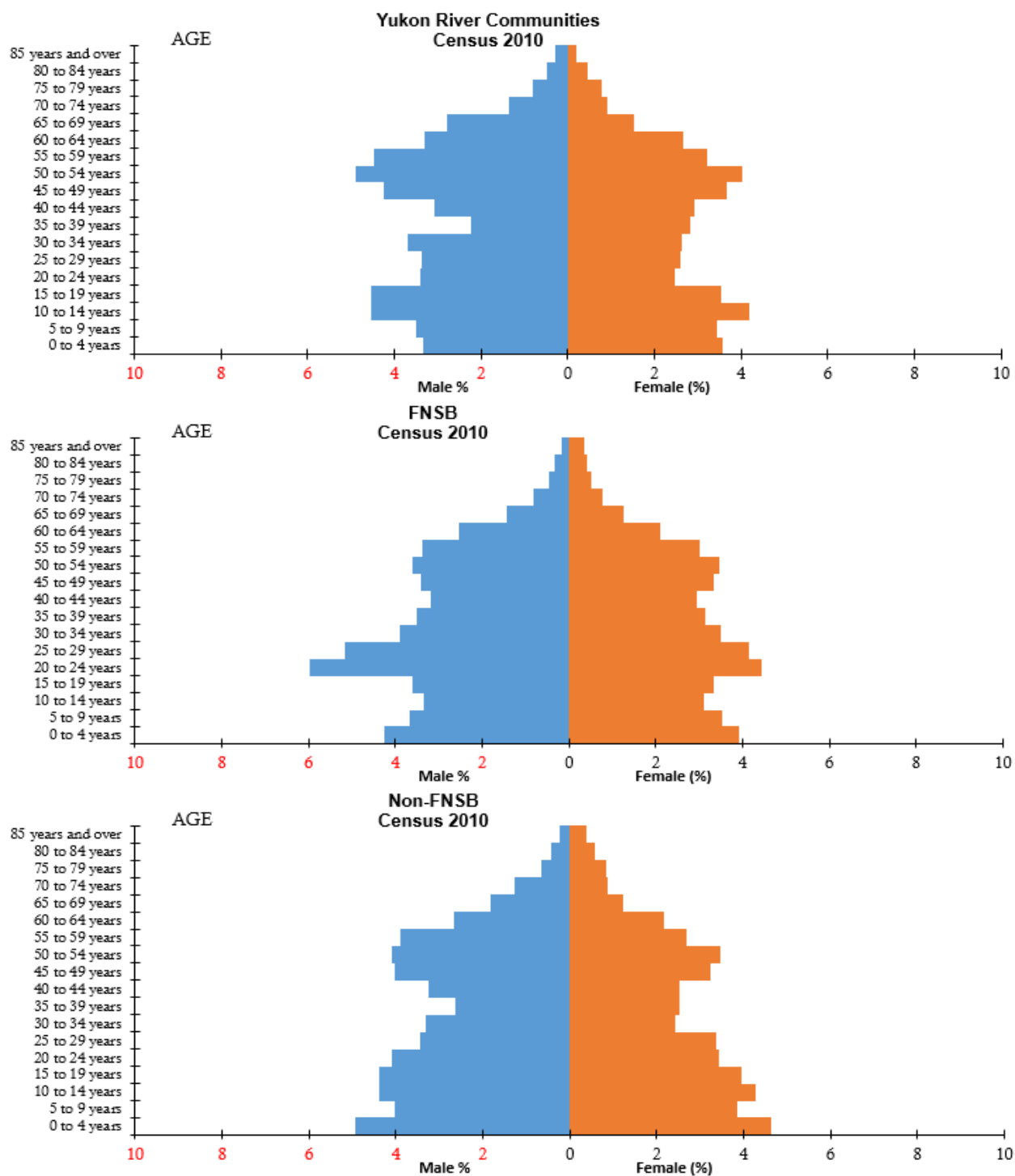


Figure E-10. Population structure of the regions in the CYR study area in 2010 (excluding group quarters and Red Dog Mine). Data are the number of individuals.

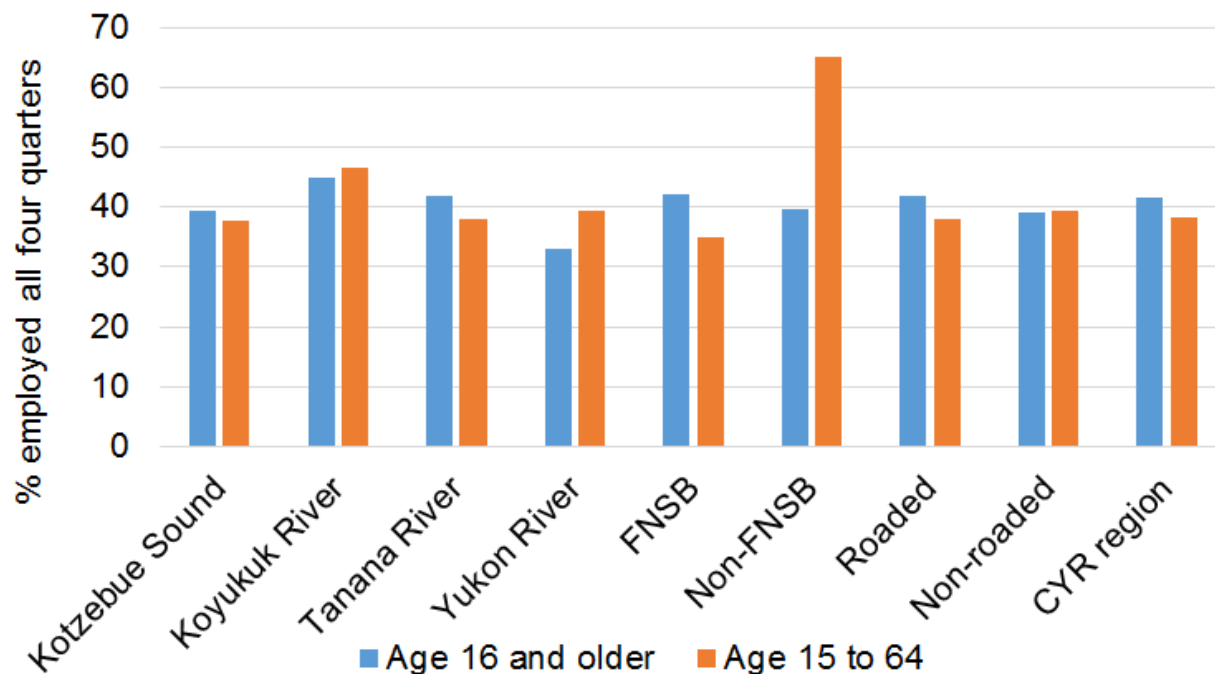


Figure E-11. Average percentage of community residents employed all four quarters within each category according to 2010 census data based on all residents age 16 and older or between 15 and 65.

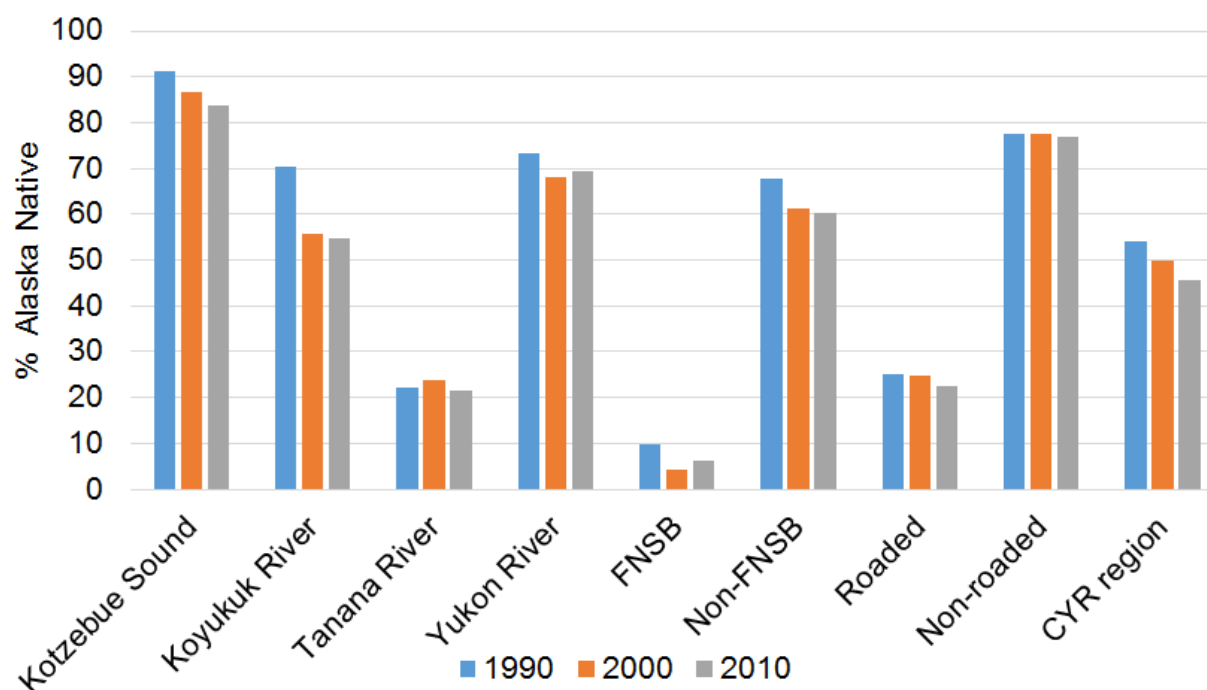


Figure E-12. Average percentage of community residents reported as Alaska Native within each category in the CYR study area.

Education and employment are common reasons for young adults to leave rural Alaska (Howe 2009, Huskey et al. 2004). The percentage of young men increased in the Koyukuk River

watershed (1.4%), while the percentage of young females decreased (0.30%). All regions experienced an aging of the population between 2000 and 2010 (Table E-11), with increases in the percent of residents 55 or older, which is similar to the statewide trend (Schultz 2015). Age structure influences the percentage of the population within working age.

Table E-11. Percent change in population structure from 2000 to 2010. Positive values indicate an increase in that age category.

Community Category	Under age 10 (%)	Ages 10–19 (%)	Ages 20–54 (%)	Ages 55–75 (%)	Over age 75 (%)
Kotzebue Sound	-2.7	-4.1	1.9	3.6	1.2
Koyukuk River	-1.5	-3.5	-0.1	3.6	1.5
Tanana River	-2.0	-2.9	-1.8	6.5	0.2
Yukon River	-2.1	-4.1	-2.6	7.8	1.0
FNSB	-2.1	-2.6	-2.0	6.5	0.1
Non-FNSB	-1.7	-4.6	-0.8	5.9	1.2
Roaded	-2.0	-2.8	-1.8	6.5	0.2
Non-road	-2.1	-4.3	1.0	4.2	1.2
All	-2.2	-3.3	-1.1	6.3	0.3

The population of FNSB increased substantially between 1960 and 2012 (150%). There is a large military presence in FNSB with Fort Wainwright and Eielson Air Force Base (Figure E-13). In 1990, there were 1,362 people in military quarters. The population in military quarters increased to 1,951 by 2010. The proportion of active duty personnel residing on versus off base differs greatly between bases but for Eielson Airforce base, which is 25.1 miles outside of Fairbanks, 66% of military personnel live off base (Fried 2013). This is greater than the 48% of military personnel that live on base at Joint Base Elmendorf-Richardson located in Anchorage. Recently, the population in the FNSB has begun to decline: FNSB population changed by -1,450 residents between 2013 and 2014. Population decline coincided with a 9% reduction in military presence. In 2012, almost a third of residents of FNSB were military, Department of Defense civilians, or dependents (Fried 2013). Reductions in military presence can have dramatic impacts on communities. For example, from 2005 to 2013, the population size of Galena decreased by 25.0% (pre-flood numbers); Galena Air Force Station near Galena, was proposed for deactivation in 2005 and closed in 2010.

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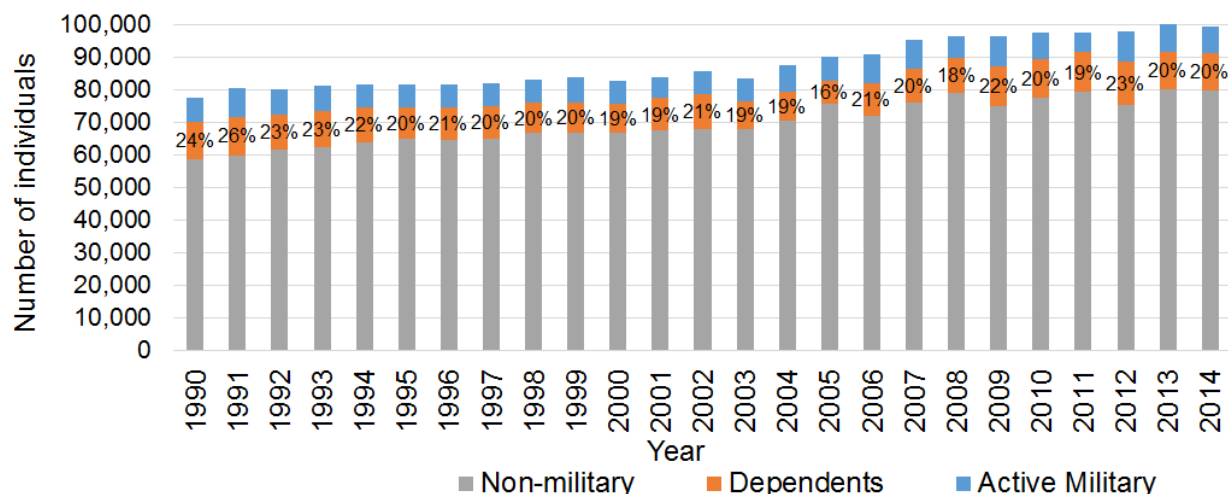


Figure E-13. The number of military and dependents in Alaska and FNSB from 1990–2014 with the percent of the population comprised of military and dependents.

The military presence in Alaska has slightly decreased in recent years (Figure E-13). Reductions in the military would have a large impact on FNSB. Fairbanks Economic Development Corporation (2010) found that 10% of the revenue in FNSB could be attributed to Eielson Air Force Base. Given this influence, the military population was included in a transportation zone analysis and urban population model conducted by FNSB and an independent contractor. All TAZs, except for a small one in Southwest Fairbanks, gained residents by 2040, although population growth was a basic assumption of the model. Growth is likely to be greater in the western portion of the Fairbanks area than the southern or eastern portions (Figure E-14). However, a few pockets in the east portion are expected to increase, likely because these areas are currently mostly forested like much of the western portion. Minimal growth was predicted for large areas in the eastern portion, partially due to less road access than similarly sized remote tracts in the western portion.

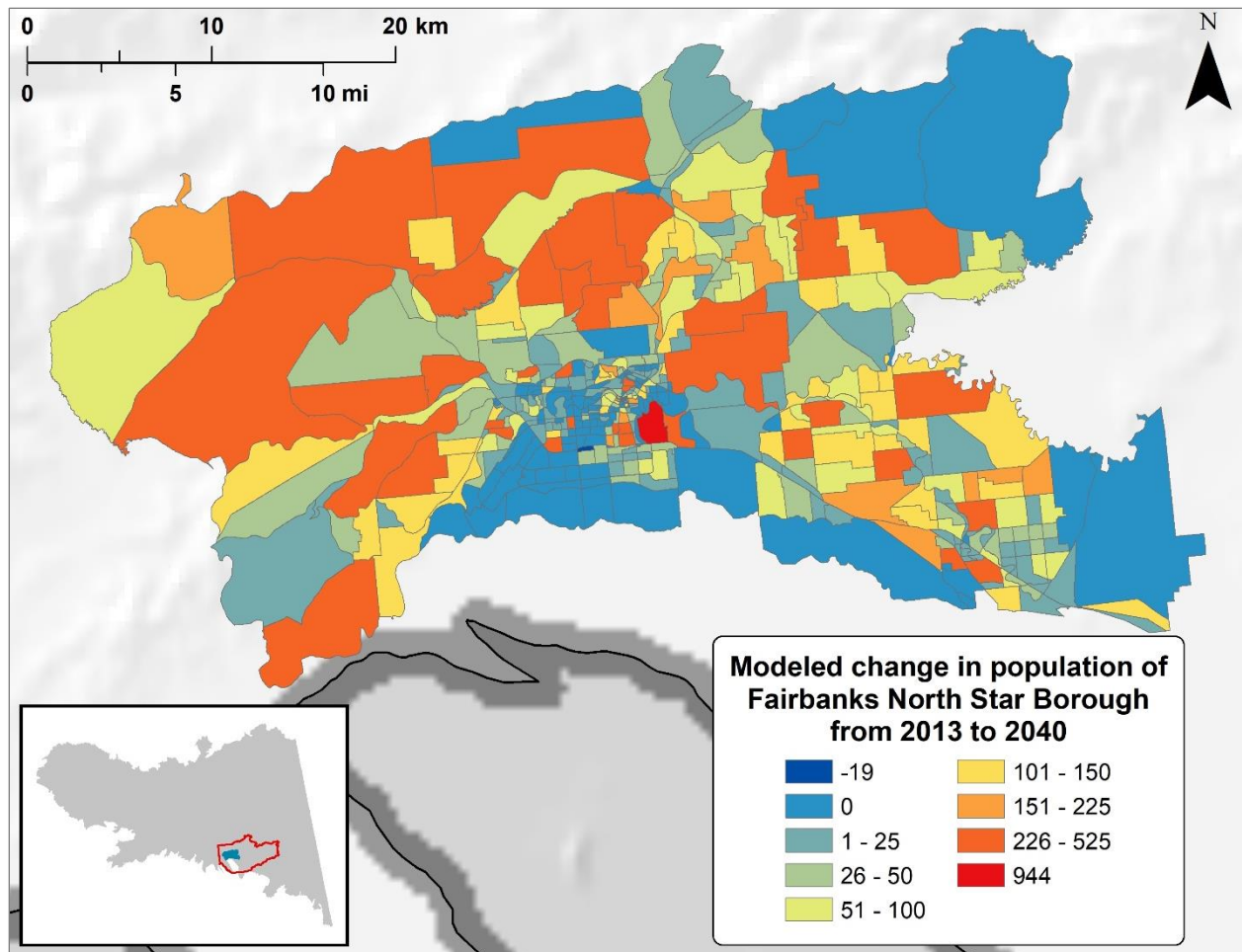


Figure E-14. Modeled change in the population of FNSB between 2013 and 2040. Values represent the number of individuals.

Even though FNSB has experienced emigration, the population of FNSB has grown steadily in the last 50 years with the most rapid growth occurring during the oil boom of the early 1980s (Figure E-15). Recently, the population has leveled off with a decrease observed from 2012 to 2013.

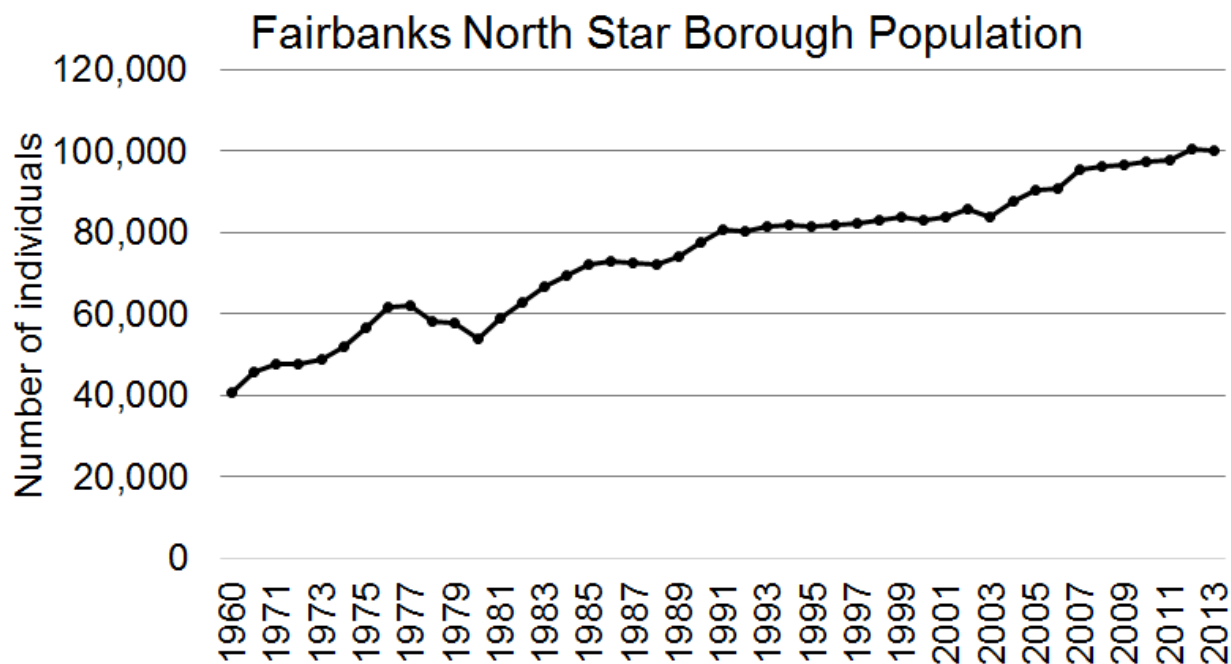


Figure E-15. FNSB human population from 1960–2013.

Birth rates have been stable since the early 1990s with a small decline recently, coinciding with a slower economy in 2009. As the economy fluctuates, births may vary, but typically rural areas have higher rates (Figure E-16, Table E-12).

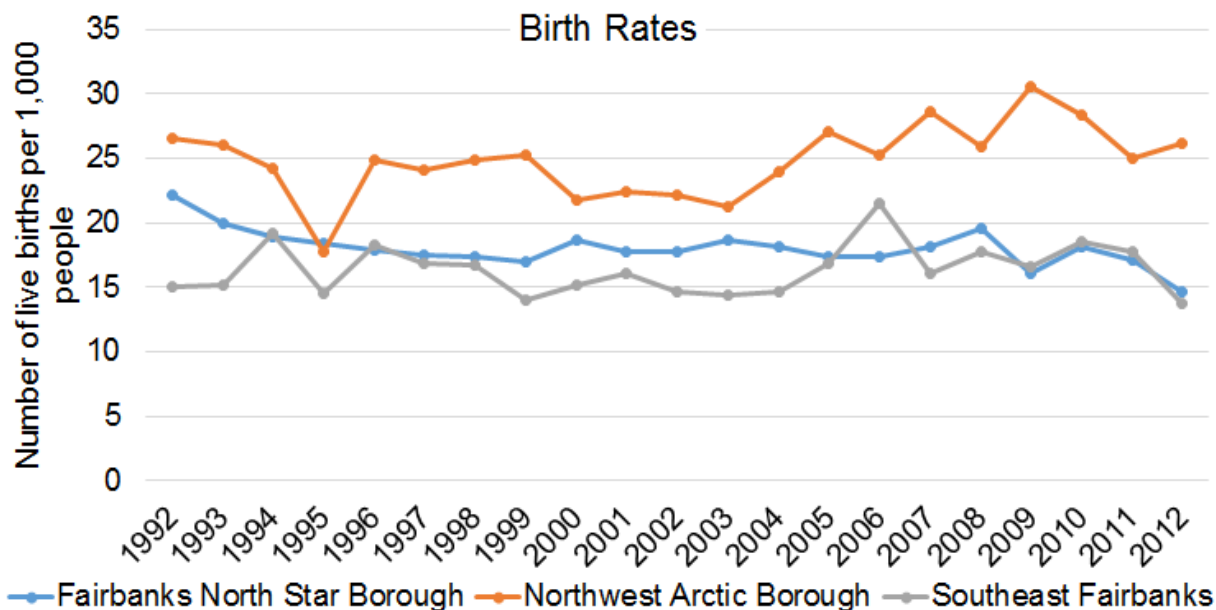


Figure E-16. Number of live births per 1,000 people for the census areas within the CYR study area.

Table E-12. Annual average number of live births, also known as crude birth rate, in the three census areas within the CYR study area.

Period	Fairbanks North Star Borough	Northwest Arctic Borough	Southeast Fairbanks
1992–1997*	1,560	158	104
1997–2002*	1,476	164	95
2002–2007*	1,588	182	101
2007–2012*	1,765	214	130
2012–2017**	1,681	218	120
2017–2022**	1,672	214	131
2022–2027**	1,654	210	135
2027–2032**	1,694	214	143
2032–2037**	1,789	232	159
2037–2042**	1,890	253	180

*averages from estimated data (AKDHSS 2015)

**model data from (AKDOL 2014)

Death rates in FNSB are lower than in the other census areas (Figure E-17, Table E-13). Malignant neoplasms (i.e., cancer) was a common cause of death in all census areas, especially FNSB with it being the leading cause every year since 2001. In Southeast Fairbanks, heart disease used to be the most common (i.e., early 1990s), but now it is cancer. Meanwhile, in 6 of the 19 years of data, unintentional injury was the most common reason for death in NWAB. The increase in the number of deaths in Southeast Fairbanks census region did not correspond with a change in cause of death, large change in population size, or flux of emigration.

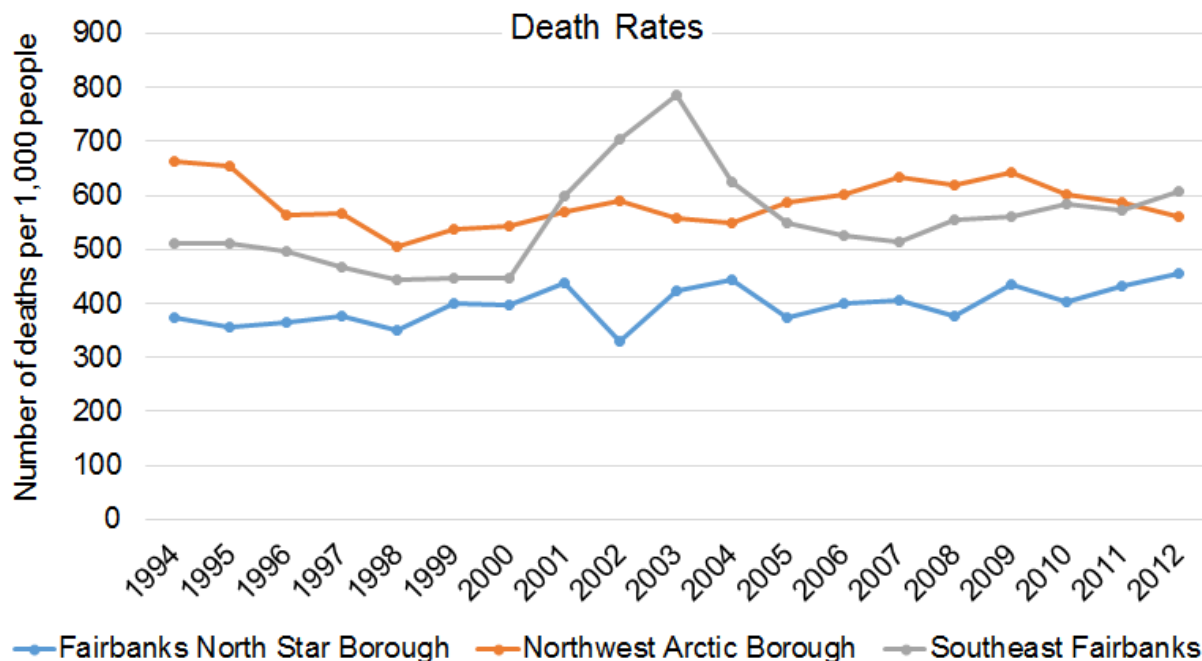


Figure E-17. Deaths per 100,000 people in census areas with available data. Data for the NWAB and Southeast Fairbanks are 3-year moving averages plotted by the middle year to allow for comparable data.

Death rates have remained steady but have increased with population. Empirical data from the Alaska Department of Health and Social Services have far more deaths than the predicted deaths by the Alaska Department of Labor and Workforce. No reasons for the difference in number of deaths are known.

Table E-13. Annual average number of deaths in the three census areas within the CYR study area.

Period	Fairbanks North Star Borough	Northwest Arctic Borough	Southeast Fairbanks
1997-2002*	319	116	95
2002-2007*	352	129	113
2007-2012*	407	137	117
2012-2017**	491	51	45
2017-2022**	571	54	53
2022-2027**	666	59	62
2027-2032**	779	63	71
2032-2037**	899	68	80
2037-2042**	996	73	88

*averages from estimated data (AKDHSS 2015)

**model data from (AKDOL 2014)

Infant mortality rates have decreased since the early 1990s, but increased from 2002 to 2004 compared to 1997 to 2001 (Figure E-18). Rural areas typically had much higher infant mortality rates than urban areas except for when all rates decreased between 1997 and 2001.

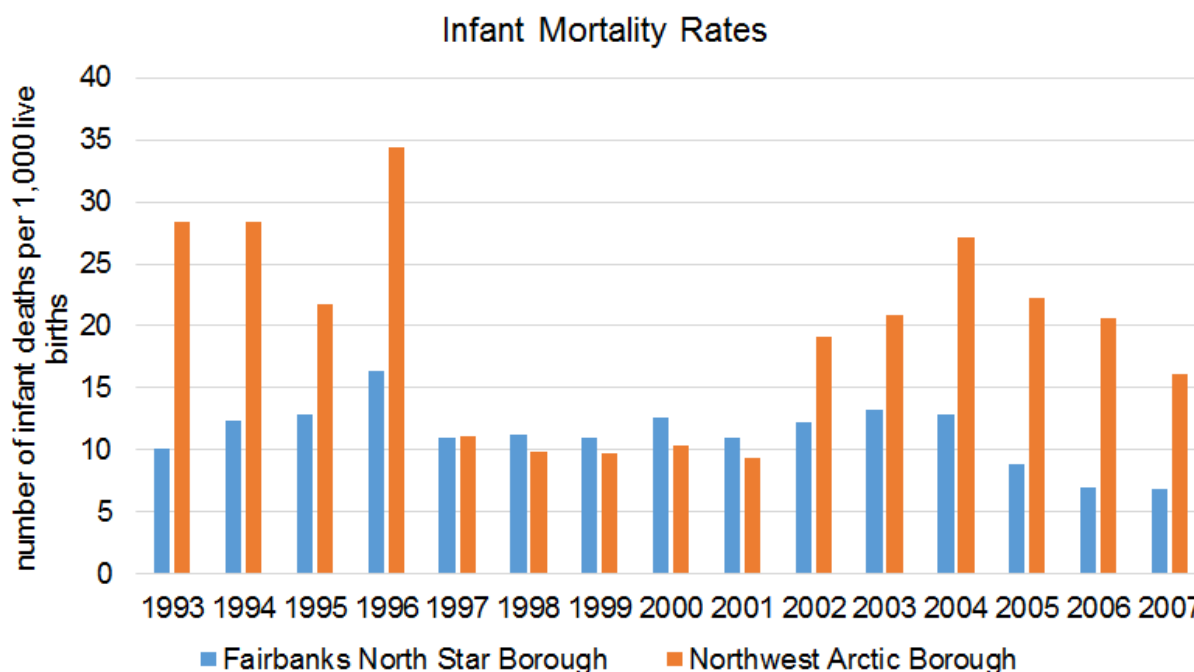


Figure E-18. Infant deaths per 1,000 live births in census areas with available data. Data in the figure are 3-5-year moving averages plotted by the middle year to allow for comparable data.

Transportation

The availability of transportation routes is a major factor that influences the social and economic atmosphere of communities in the CYR study area (Figure E-19). The influences of transportation routes can be both negative and positive, but nonetheless changes occur when a community becomes connected to a larger transportation network. Of the 67 communities in the study area, slightly more than half are accessible by road ($n = 40$). Forestry roads provide the most dynamic changes in access. Based on the Fairbanks area forestry information, 503 km of forestry roads exist from previous harvest activity and currently 336 km of forestry roads are classified as active. Only 82 km of forestry roads are proposed for the future. Of all proposed roads, the road to Umiat is the shortest (29 km), followed by the preferred option for the road to Nome (459 km). The longest proposed road would provide access to the Ambler mining district from the Dalton Highway (1,325 km).

Section E. Anthropogenic Change Agents

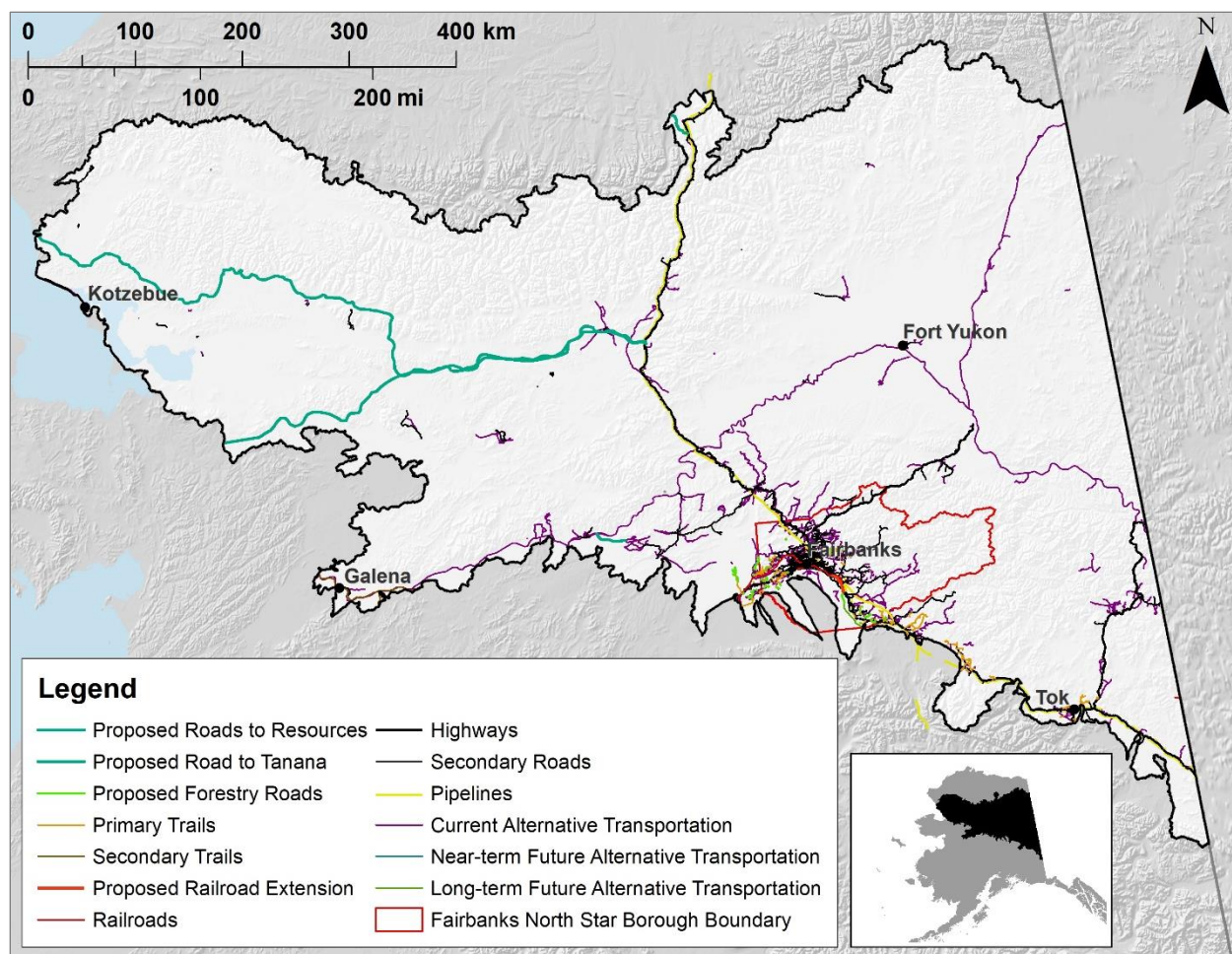


Figure E-19. Current and long-term future linear infrastructure in the CYR study area.

The Alaska Department of Transportation and Public Facilities (ADOT) has funded studies (DOWL HKM 2010, AKDOT 2010a, AKDOT 2010b) of preferred routes for proposed roads (Table E-14). According to the ADOT-funded studies, Galena is the only CYR community that would potentially be influenced by the road to Nome. Even though Route 1 (Jim River) to Nome would also provide access to the Ambler mining district, the more southern Route 3 (Yukon River Corridor) was preferred. However, the level of influence, if any, that the proposed road to Ambler had on the selection of a preferred route to Nome is unknown.

Table E-14. Preferred roads to resources.

Purpose	Name
Road to Ambler mining district	Southern route (road)
Ambler to Red Dog Mine port	Delong Mountain Transportation System (DMTS) corridor (road or railroad)
Cape Darby to Ambler	Cape Darby/Seward Peninsula (road or railroad)
Road to NPR-A/Umiat	Galbraith
Nome council road to Ambler	Selawik Flats corridor (road or railroad)
Port by Kotzebue to Ambler	Cape Blossom (road or railroad)
Road to Nome	Route 3 (Yukon River corridor)

Future road development has the potential to greatly alter the landscape and provide access to consumptive and non-consumptive users. A number of roads with alternative routes were proposed from 2005–2015, but the state of Alaska's financial situation during that time limited discussions of implementation. Nevertheless, the effects of the proposed roads must be evaluated in case the economy makes these projects possible in the near-term or long-term future. Of the four routes suggested to the Ambler mining district, the southern route has been deemed the most likely because it uses existing highways, minimizes crossing federal lands, which require additional scrutiny, facilitates access to rural communities, and provides the most access to mineral resources along the Yukon River (DOWL HKM 2010). Wilson et al. (2014) also determined that winter caribou habitat would be minimally impacted by the southern proposed road to Ambler. An ATV road was proposed to connect Noatak to Red Dog Mine to reduce the cost of fuel in Noatak (Dau 2011). Noatak is also considering building a new airport that would allow large jets to land (Dau 2011). Another large-scale road expansion proposal is a road from Interior Alaska to Nome, which the state of Alaska studied in 2010 along with DOWL HKM and Northern Economics. They determined that the best route was the Yukon River Corridor because it would support mining activities along the route, mail/freight delivery, passenger transportation, and fuel delivery to communities throughout the year. It is estimated that the presence of a road would save each person in Tanana, Ruby, Galena, Koyukuk, Koyuk, and Nome \$3,900 per year in fuel, freight, and mail costs (AKDOT 2010a).

Phases of the Northern Rail Extension Project were included in both the near-term and long-term future transportation datasets because rail and levee construction is expected to occur from Moose Creek to Salcha (first phase) and then from Salcha to Delta Junction (second phase). Two temporary bridges will be built across sloughs. Currently, a levee along and a bridge across the Tanana River have been built as part of phase one. The Northern Rail Extension Project may increase access for hunting and could facilitate transportation and movement of freight between Fairbanks and Delta Junction.

Transportation projects typically need materials (i.e., gravel, sand, stone, etc.) and contractors can apply for sites to obtain these materials from the state and federal (BLM) government. The road to Umiat was scheduled to have one material site every 10 miles with 1,000,000 cubic hectares of material per site (AKDOT 2010b). For the state, a reclamation plan is needed if the area where materials will be gleaned is equal to or greater than 5 acres (ADNR 2015). Most sites are located near existing roads and average sizes are typically less than 2 km² (Table E-15).

Table E-15. ADNR recorded material sites and sales in the CYR study area in 2015.

Status	Count	Total area (sq. km)	Average area (sq. km) \pm SD
State Material Sale			
Application received	2	0.36	0.18 \pm 0.40
Application complete	3	0.31	0.10 \pm 0.13
Issued	97	20.44	0.21 \pm 0.26
Transferred	1	0.15	0.15 \pm 0.00
State Material Sale Site			
Pending review	1	0.05	0.05 \pm 0.00
Active	89	24.70	0.28 \pm 0.29
BLM Material Sale			
Pending	22	51.80	2.35 \pm 3.40
Interim	25	24.05	0.96 \pm 2.53
Authorized	55	62.60	1.14 \pm 1.62
Unknown	697	423.80	0.61 \pm 0.00

Economy

The economy of the FNSB is very different than other areas within the CYR study area. The dominant industries are trade, transportation, and utilities (Figure E-20). Local government plays a much larger role in the economy of rural areas than in the economy of FNSB. Even though the Southeast Fairbanks census region is largely rural, the industry base is much more diverse than NWAB. This is likely because some of the communities in the Southeast Fairbanks census region are connected to the roads, which require maintenance and allow for a larger tourism industry. Kotzebue Sound and Koyukuk are the two watersheds in the study area that are primarily rural, but the Kotzebue Sound watershed includes the Red Dog Mine, which provides employment opportunities in natural resources and mining, along with supporting positions. In 1999, the Red Dog mine provided over a quarter of the wage and salary payroll in the NWAB (Fried et al. 1999). However, Shanks (2009) indicated that government and health care services provided more employment opportunities than mining (Figure E-20).

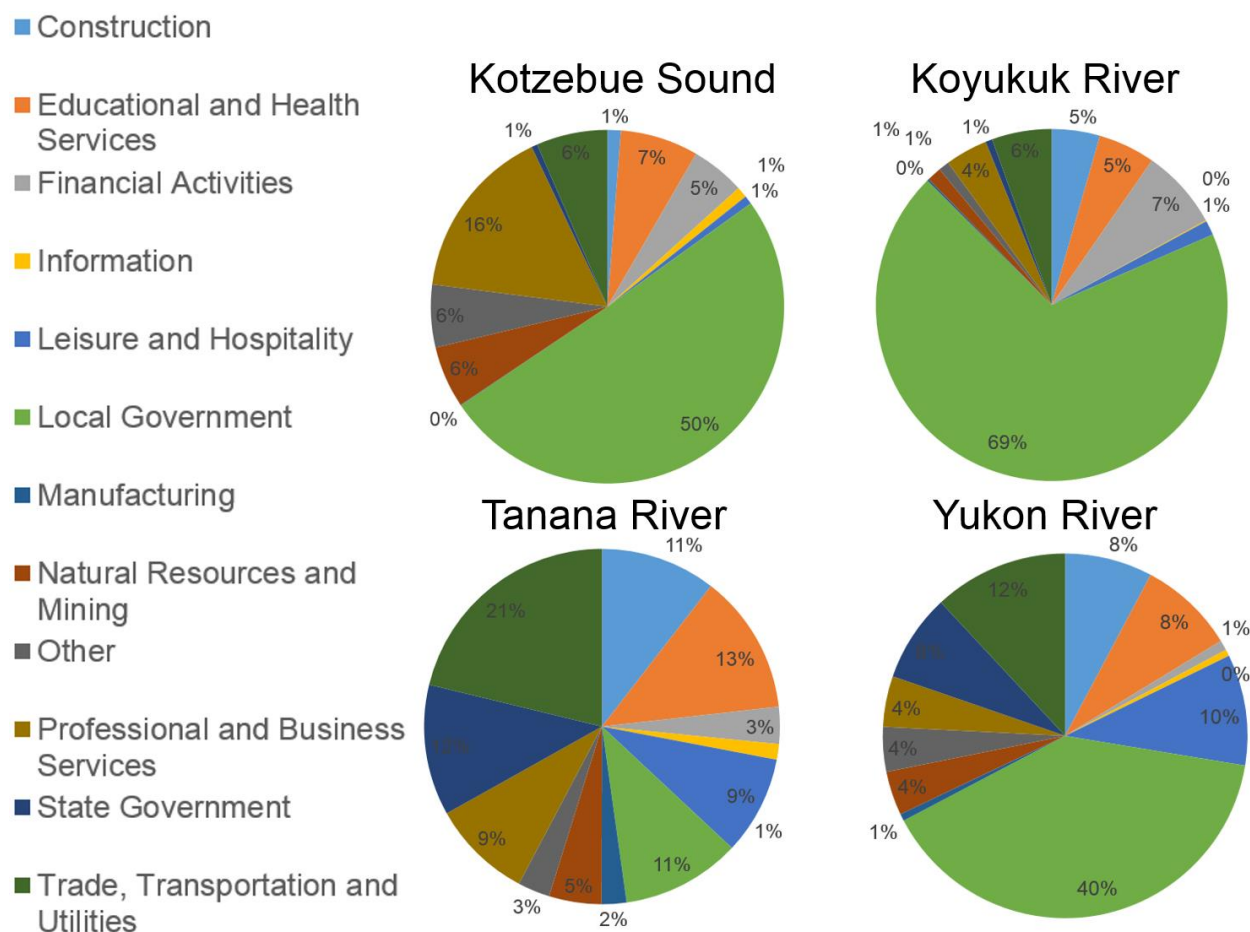


Figure E-20. Percent of people employed in various industries from 2010 through 2013. Data from Alaska Department of Labor and Workforce Development, Research and Analysis.

Employment

Just under half of working age people in the CYR study area were employed in all four quarters per year (Figure E-21). Communities on the Koyukuk River had the highest employment during all four quarters. There are only eight communities in the Koyukuk River region and the population is the smallest of the regions (678 pop. in 2013), therefore, a few communities can greatly influence the overall average. Alatna, Anaktuvuk Pass, and Hughes all had employment rates between 49% and 53%, which raised the regional average. A regional drop in employment between 2006 and 2007 was driven by a 50% decrease in employment in Alatna. Communities on the Yukon River lacked working age people (21–50 years old). Communities with no road access had slightly higher employment than communities on the road system.

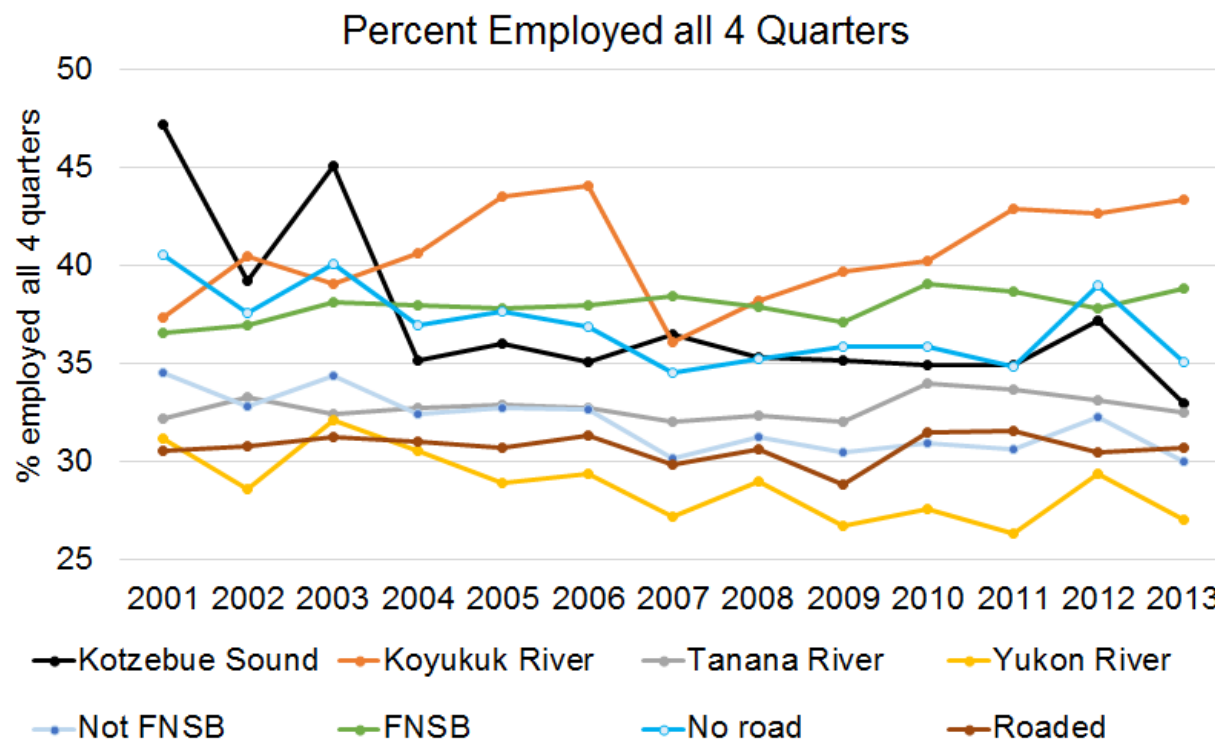


Figure E-21. Percent of working age people who worked all four quarters.

Revenue and income

More than half (54.4%) of households in the CYR study area have a median household income of less than \$50,000 (Figure E-22). In the rural areas of the CYR study area, transfer payments make up a large portion of the income including the Alaska permanent fund dividend payments. For example, in the NWAB, transfer payments made up 28–32% of the total income versus 14–16% for the rest of Alaska. Drivers of the economy and income in FNSB are government, University of Alaska (UA), military, construction, oil industry, and tourism (Applied Development Economics 2016). In 2006, the University of Alaska (UA) contributed over \$119 million in payroll to residents of FNSB (McDowell 2008).

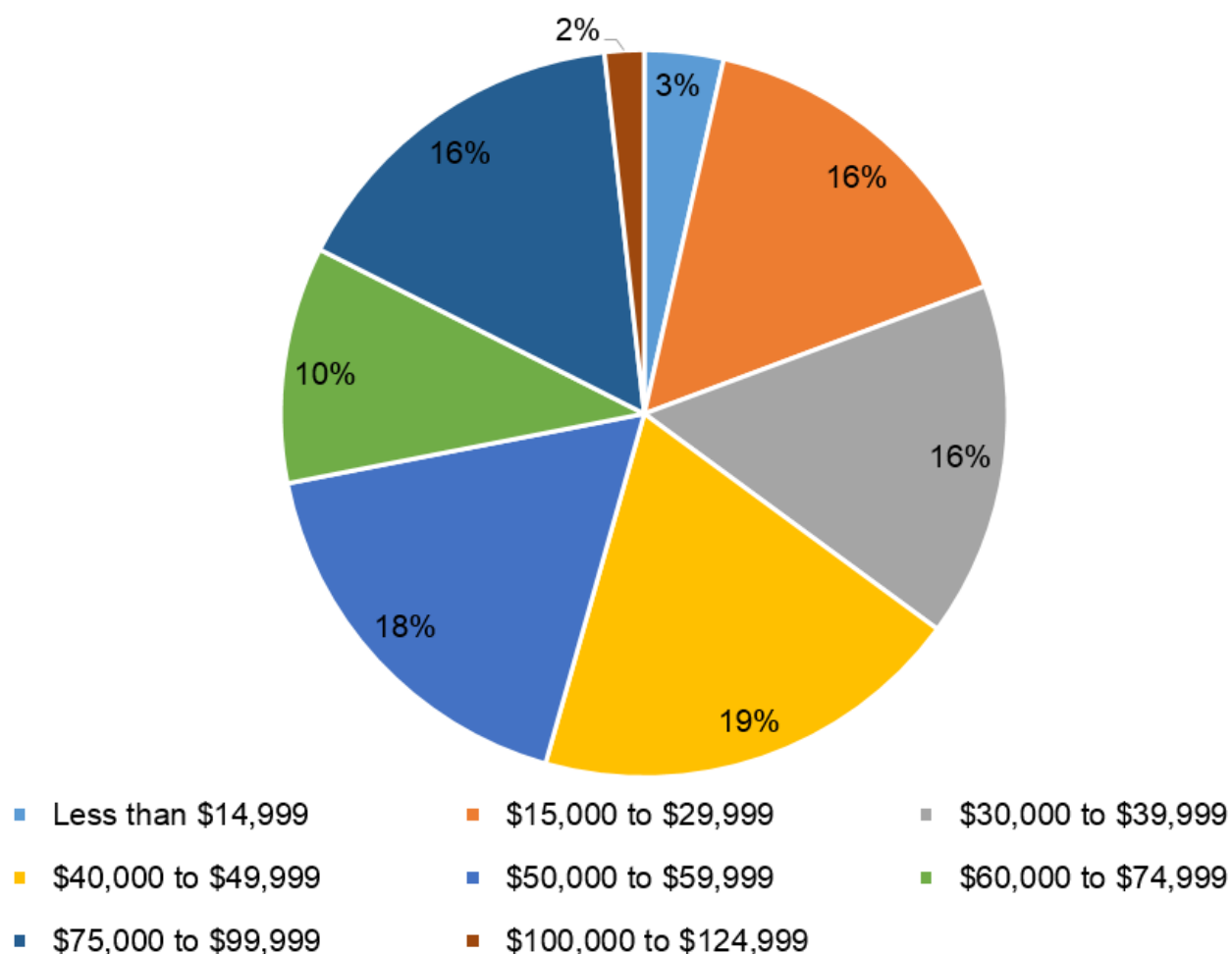


Figure E-22. Percentage of household income in each wage category (2013) in the CYR study area.

Distressed communities

According to Himes-Cornell and Kasperski (2015), the Kotzebue Sound region was at the greatest risk to climate change and had the lowest adaptive capacity (Figure E-23; Table E-16). Climate change vulnerability was driven by higher erosion risk and closer proximity to less stable permafrost types. Low adaptive capacity was likely due to employment factors (low employment diversification and a large number of people not in the labor force or unemployed). Of the CYR communities, Selawik ranked the lowest for adaptive capacity (7th in the state), and Kobuk was classified as the most resource-dependent (32nd in the state), followed closely by Shungnak (34th in the state).



Figure E-23. Erosion in Selawik, Alaska (photo from M. Brubaker, Alaska Native Tribal Health Consortium ANTHC).

Throughout the CYR study area, the resource dependency score was low (Table E-16) largely because commercial fishing is not common in most of the communities. However, rural areas tended to have higher resource dependency scores because subsistence halibut and salmon permits are included as resource use along with marine mammal harvests. Alcan Border in the Tanana River and Wiseman in the Koyukuk River watershed had the second and third highest adaptive capacities in the state, respectively. Both of these communities are small (< 20 residents) and located along major highways with employment primarily in the private sector. The reason that the Tanana River watershed had the lowest adaptive capacity was because this area has a larger number of newer residents.

Table E-16. Average normalized community component scores and rankings for CYR communities with range in parentheses (data from Himes-Cornell and Kasperski 2015). Positive index scores and higher ranks indicate a greater risk to climate-induced changes, higher resource dependency, and lower adaptive capacity.

Watershed	Exposure		Resource Dependence		Adaptive Capacity	
	Index Score	Rank	Index Score	Rank	Index Score	Rank
Kotzebue Sound	1.13 (0.17–2.51)	38 (7–76)	-0.34 (-0.82–0.62)	178 (63–255)	0.37 (-0.27–1.14)	115 (32–195)
Koyukuk River	0.44 (0.15–1.28)	64 (27–80)	-0.38 (-0.88–0.44)	182 (73–273)	0.29 (-2.2–1.89)	124 (13–313)
Tanana River	-0.09 (-0.25–0.06)	127 (90–169)	-0.58 (-0.88–2.64)	232 (10–273)	-0.35 (-2.41–2.10)	195 (8–314)
Yukon River	0.05 (-0.28–0.52)	105 (57–180)	-0.20 (-0.88–1.02)	155 (47–273)	0.20 (-1.26–2.02)	147 (10–286)
All	0.21 (-0.28–2.51)	97 (7–180)	-0.33 (-0.88–2.64)	185 (10–273)	-0.01 (-2.41–2.10)	160 (8–314)

Alaska Governor’s subcabinet on climate change mentioned flooding problems that have occurred along the Yukon River at Eagle and Eagle Village in 2009 (Immediate Action Work Group 2009). Statistics compiled about state disaster flooding events indicate that from 1978 through 2008, communities in the Tanana River watershed had the most flooding events, especially communities within the FNSB. However, many remote communities do not qualify for federal assistance because the economic costs for repairs are greater than the potential economic benefits (Government Accountability Office 2004).

According to the Denali commission, just under half of the communities in the CYR study area qualified as distressed in 2015 ($n = 32$). The Yukon River region consistently had the largest percentage of distressed communities from 2001 to 2015 (Figure E-24). Among the river regions, Kotzebue Sound had the lowest average percent of distressed communities from 2001 to 2015. The Kotzebue Sound watershed benefits financially from the Red Dog Mine through employment opportunities, community outreach activities, and taxes (Haley and Fisher 2012). The FNSB had the lowest average percent of distressed communities from 2001 to 2015. The drop in community distress after 2006 was caused by the addition of new communities that were found to be non-distressed and the reclassification of Salcha from distressed to non-distressed. Other regions did not have a large influx of newly sampled communities.

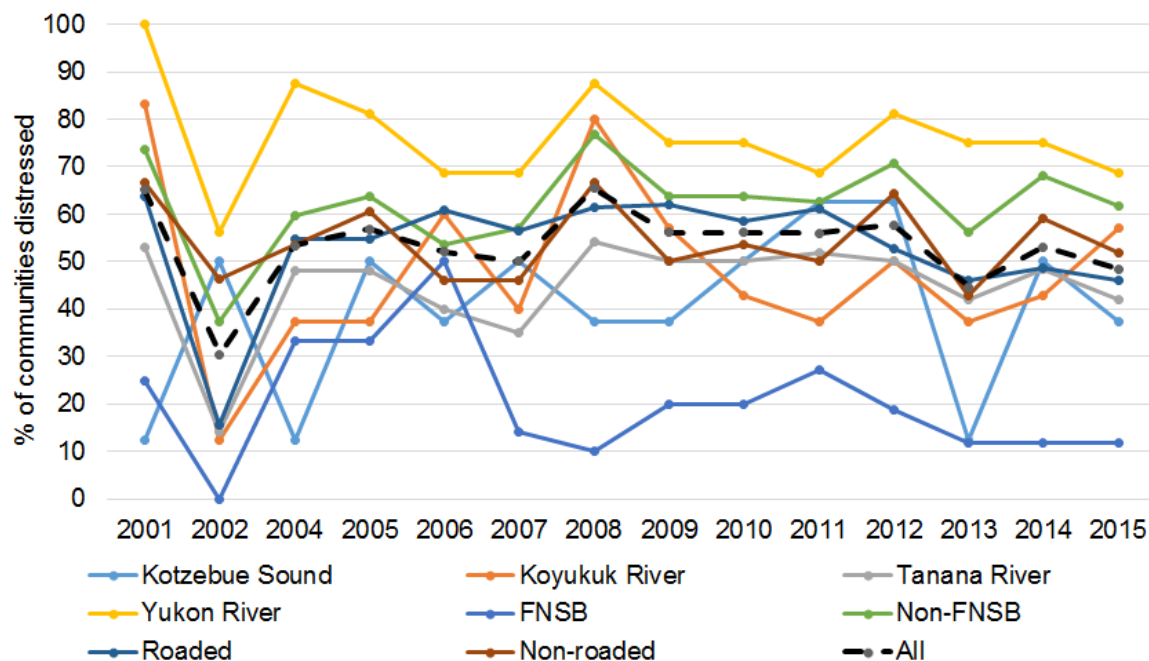


Figure E-24. Percentage of communities examined that were classified as distressed according to the Denali Commission.

Energy prices

Heating fuel prices in the CYR study area are shown in Table E-17. Road access greatly influences fuel prices, resulting in large variation in fuel prices throughout the CYR study area (Table E-18). In Interior Alaska, the price of heating fuel and gasoline cost on average \$2.89 and \$2.74 greater than prices reported in communities on the road system (AKDCCED 2015). For example, if heating fuel and gasoline were \$4.00 on the road system it would cost \$6.89 and \$6.74, respectively. Reducing fuel and electricity costs in rural Alaska are highly desirable goals. In 2008, the Denali Commission ordered a study on electric energy transmission in Alaska (NANA Pacific 2008). Use of electricity through transmission lines could be used to reduce community dependence on fuel, which is expensive in rural Alaska. The report proposed transmission lines throughout the state. In Northwest Alaska, the regional corporation NANA is examining construction of an intertie between Shungnak and Ambler and between Kivalina, Red Dog Mine, and Noatak. Other proposed transmission lines include one between Kotzebue, Noorvik, and Kiana. In the middle of the CYR study area, there are proposed transmission lines to Anaktuvuk Pass and Bettles from the Dalton Highway. All of these actions would be an effort to make energy in rural Alaska cheaper. Other potential developments, which may reduce costs, are the building of roads and large-scale mining activities. For example, if a mine is built at Ambler, residents in nearby communities are expected to see reductions in their heating and electrical bills partly due to lower costs of heating oil and diesel (Cardno 2015).

Meanwhile, in the FNSB, heating costs are still a concern, but so is air quality. A 2006 survey in the Fairbanks nonattainment area indicated the increased use of wood to heat homes since the 1990s. In 2010, the most common heating devices among households surveyed in FNSB were oil furnaces, followed by wood burning devices (Carlson et al. 2010). On average, respondents used 880 gallons of heating oil and 3.6 cords of wood (Carlson et al. 2010). Use of fuel oil decreased by 20% between 2006 and 2010. The percentage of homes heating with wood was

10% in 2006 and 17% in 2010 (Carlson et al. 2010). The decrease in the use of home fuel oil was not attributed to wintertime weather but was likely associated with energy rebate programs and shifts to other modes of heating. Natural gas is not widely used in the CYR study area. However, the use of natural gas is increasing: natural gas costs per household more than doubled from 2006 to 2010 and use increased from 2.5% of households in 2006 to 4.5% of households in 2010 (Carlson et al. 2010). This indicates an increasing use and demand for natural gas and, thus, development of a natural gas pipeline to the FNSB could dramatically shift energy use patterns for a large portion of the residents within the CYR study area.

Table E-17. Fuel prices in July 2015 by community in the CYR study area (AKDCCED 2015).

Community	Community Retailer	Heating fuel #1	Gasoline
Alatna	Alatna Village	\$7.00	\$7.50
Arctic Village	Arctic Village	\$11.00	\$10.00
Circle	Central Corner (HF); Village of Circle (Gas)	\$3.69	\$4.75
Eagle	Telegraph Hill Services	\$5.00	\$5.00
Hughes	City of Hughes	\$9.00	\$9.25
Minto	North Fork Store	\$5.10	\$5.50
Nenana	Nenana Heating	\$4.06	\$3.59
SRuby	Dineega Fuel Company	\$6.00	\$7.00
Tanana	Tanana Tribal Council	\$5.75	\$6.61
Anaktuvuk Pass	Nunamiut Corporation	\$1.55	\$9.49
Kotzebue	Crowley	\$6.52	\$6.61
Koyuk	Koyuk Native Store	\$6.85	\$7.31
Noorvik	Morris Trading Post	\$6.56	\$7.87

Source: AKDCCED 2015, AKDCRA 2015, AKDCCED 2015

Table E-18. Average and range of fuel prices in July 2015 by community in the CYR study area (AKDCCED 2015).

Fuel type	Community Retailer	Average	High	Low
Heating	On road system	\$3.95	\$5.10	\$3.05
	Off road system	\$6.94	\$11.00	\$5.55
Gasoline	On road system	\$4.06	\$5.50	\$2.84
	Off road system	\$7.24	\$10.00	\$6.00

3.2 General land status

The federal government is the largest landowner in the CYR study area (Table E-19, Figure E-25). Land status in Alaska is dynamic and information presented here is from 2015 so any changes made after that point are not included. Fourteen federal parks, refuges, and preserves create a patchwork across the study area. Most native selected land occurs around villages (Figure E-25). Around the greater Fairbanks area, large portions of land are owned by the state of Alaska and Department of Defense (Figure E-26).

Table E-19. Land management status in 2015 in the CYR study area.

Owner/managing agency	Area in sq. km	Percent of total study area
Fish and Wildlife Service	103,243	26.25%
State Patent or TA	93,836	23.86%
National Park Service	66,968	17.03%
Native Patent or IC	49,535	12.59%
Bureau of Land Management	48,745	12.39%
State Selected	19,990	5.08%
Native Selected	6,553	1.67%
Department of Defense	3,034	0.77%
Water	1,168	0.30%
Private	238	0.06%
TOTAL	393,311	100.00%

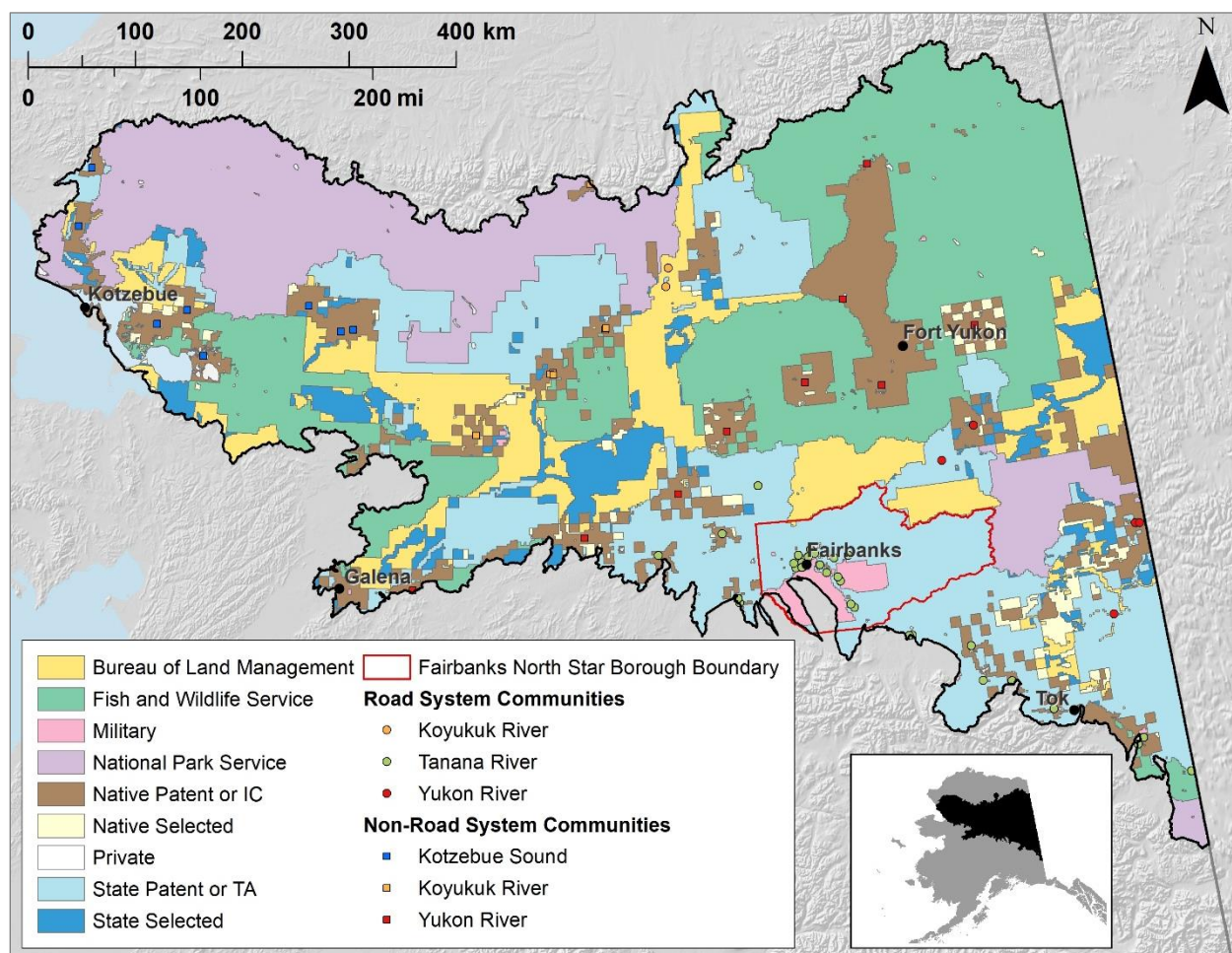


Figure E-25. Land management status in 2015 in the CYR study area. NOTE: changes made after 2015 are not represented in this figure.

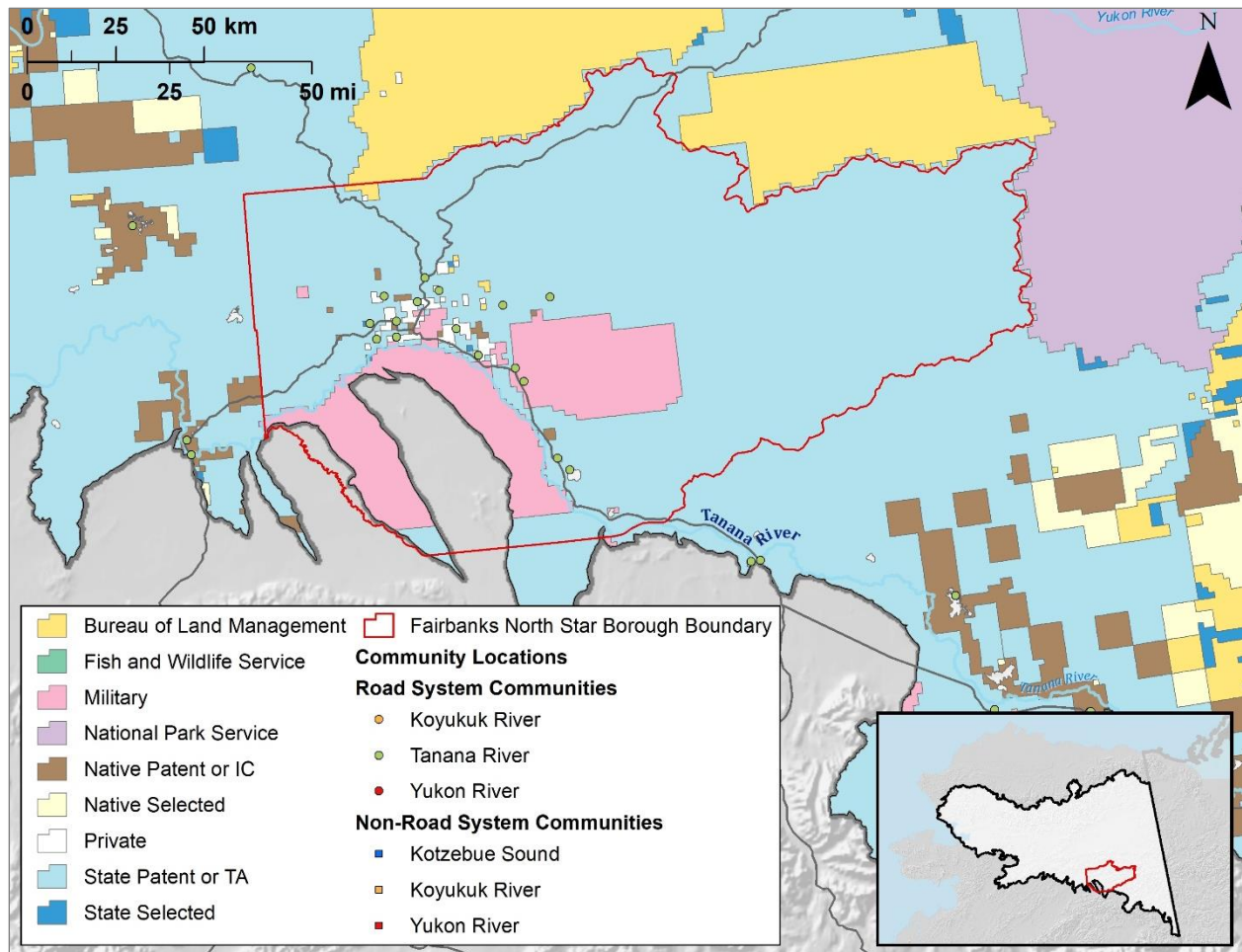


Figure E-26. Land management status around the greater Fairbanks area in the CYR study area.

3.3 Subsistence harvest and land use (MQ Q1)

MQ Q1: Which subsistence species (aquatic and terrestrial) are being harvested by whom and where is harvest taking place?

Summary

The agent and location of subsistence harvest are driven by a combination of factors including access, human density, animal density, and predator control policies. For example, north of Fairbanks the reduction of moose predators and habitats, partly due to trapping and human growth, have resulted in increases in moose populations and subsequently, harvest. Overall, the human population in urban areas, especially FBSN, was closely linked to harvest of subsistence and sport fish resources examined and, thus, changes in harvest will be driven more by urban than rural residents. At the CYR study area level, moose harvest is likely to maintain the levels they have had since 1990. Most moose populations are limited by predation and access is a limiting factor for human harvest. The future proposed roads to resources cross low density moose populations and harvest might increase, but again predators would need to be reduced to provide a greater human harvestable surplus.

Caribou harvest could continue to rise due to increases in the human population and proposed expansion to the Ambler mining district, which would traverse through the winter range of the Western Arctic caribou herd. The road is not expected to influence caribou habitat (Wilson et al. 2014), nevertheless, caribou habitat may decrease in the future due to increases in fire and expansion of shrubs (Gustine et al. 2014, Marcot et al. 2015).

Sheep harvests are highly managed by ADF&G with restrictions on horns and, thus, changes in regulations can have large impacts on harvest levels. For example, from 1989 to 2000 the use of full curl harvest regulations was used nearly statewide to reduce the impact of harvest on sheep population which corresponded to a sharp reduction in sheep harvests (ADF&G 2014). Relaxation in horn restrictions will likely be influential on harvest levels as will weather/climate. Severe winters are thought to be a reason for declining sheep population size (ADF&G 2014). Meanwhile, changes in access will likely have minimal impact since sheep often are located on rugged terrain above 1,000 m, which is not conducive to road development.

Subsistence users often deal with fluctuations in access to resources and over time have developed various coping mechanisms such as switching resources, traveling further, or purchasing food from the store (Nowak 1975, Holen et al. 2012, Wilson 2014). Previous research has shown that when caribou herds declined, hunters in these areas switched to harvesting Dall sheep (Georgette et al. 1991). The Western Arctic caribou herd has decreased by almost 50% between 2003 and 2013 and this herd is a subsistence staple for many communities in the northwest region of the CYR study area. This could increase harvest pressure on Dall sheep in the region. Caribou are highly mobile animals and outside of calving, their spatial and temporal distribution can vary from year to year. Another option is that residents target moose, which have been expanding their northern range as shrubs expand into the tundra (Christie et al. 2014, Tape et al. 2010). However, areas that have long been dependent on caribou sometimes prefer the taste of caribou over moose (unpublished data), which could result in an increased effort to harvest caribou. Regardless, even limited harvest on an expanding long-lived species such as moose could slow expansion into novel habitats.

The inter-annual variation of sport fish harvests from year to year was very large, but trends did exist. Overall, harvest of all fish species have decreased in the CYR study area and most rivers between 1996 and 2013. Rivers in close proximity to large human populations had the largest harvest which, as the human population increases, could mean increased demands on fish. We did not look at harvest among lakes, some of which are stocked in an effort to benefit recreational activity. The rivers with the largest decrease are the Tanana, Yukon, and Chatanika rivers. Salmon runs on the Yukon and Kuskokwim rivers have been very poor, especially since the mid- to late-2000s resulting in a decreasing trend in subsistence harvests (Brown and Godduhn 2015, Ikuta et al. 2013). Declining salmon runs may result in a shift to land-based food resources such as moose, caribou, and sheep. Previous research has shown when moose decline, salmon become more important (Brown et al. 2012), and likely vice a versa. Commercial fishing influences salmon harvests within the CYR study area given that the majority of harvest on the Yukon is commercial fishing, and regulations and closures in conjunction with run sizes will have a large influence on subsistence and commercial harvests.

Changes in climate have the potential to alter future harvest levels and locations of subsistence resources. The two main ways climate can influence harvest is through access and availability. One big issue is ice formation on rivers and the sea (Ford and Furgal 2009, Loring and Gerlach 2010, McNeeley and Shulski 2011, Moerlein and Carothers 2012), the lack thereof, and

unpredictability (i.e., decreased safety; Kofinas et al. 2010, Wilson et al. 2014). Open water, unfrozen spots, and inability to read ice conditions make it more difficult to travel rivers to conduct hunting activities (Wilson et al. 2014). Reductions in precipitation can limit access to harvest areas by creating sandbars and making rivers/streams too shallow to access (Wilson et al. 2014). Meanwhile, availability of certain species might be changed due to climate with species becoming more or less abundant (Springer and Van Vliet 2014). For example, moose numbers and distribution may expand due to increased fire activity and conversion of tundra to shrub (Tape et al. 2010, Tape et al. 2016), while caribou decline may lead to a shift from harvest of caribou to moose. Communities within the CYR study area that are either within the tundra or near the southern extent (< 1 mile or 16 km) of tundra include Ambler, Anaktuvuk Pass, Kiana, Kobuk, Kotzebue, Noatak, Noorvik, Selawik, Shungnak, and Wiseman. For the communities in the Kotzebue watershed, access and availability of marine mammals are anticipated due to decreases in sea ice (Hezel et al. 2012, Stroeve et al. 2012), decline in health of ice-obligate species (i.e., walrus, bearded and ringed seals, etc.), and shifting abundance of ice-associated species (Moore and Huntington 2008). Migration also influences access and temporal abundance, and for many of the communities in the CYR study area, salmon provides food and cultural identity. However, predicting how climate will influence timing and abundance of salmon runs is extremely difficult. Salmon are influenced not only by changes within the CYR study area but also changes in ocean conditions and commercial fishing. Within the CYR region, stream discharge has been negatively correlated with Chinook salmon abundance (Neuswanger et al. 2015). Meanwhile, melting permafrost has been associated with draining of lakes in Interior Alaska (Riordan et al. 2006) and disappearance of fishing spots (McNeeley 2012). Like salmon, waterfowl are highly migratory and influenced by factors beyond Alaska; however, drying lakes will influence their distribution and habitat quality (Inkley et al. 2004) and, ultimately, abundance (Johnson et al. 2005). Changes in climate have also been associated with increases in new bird species and sometimes even in species abundance. Humans are resilient and can adapt to changes using various coping mechanisms (Kofinas et al. 2010). However, development management actions that allow people to respond to change and protect natural resources will be a foreseeable challenge for managers (McNeely 2012).

Subsistence

Reporting rates on federal and state harvest permits in rural areas is known to be low, so we used the subsistence household surveys to better assess harvest patterns in rural Alaska. From 1980 until 2015, per capita harvests decreased by more than half (Figure E-27). This partially agrees with a recent analysis of the same database determined that per capita harvests overall remained flat, but were strongly influenced by access, percent of the community that is Alaska Native, regional location, and income (Magdanz et al. 2016). The large decline in subsistence harvest was associated with decreasing harvests. Harvests were typically lower and also decreased among communities with road access, a lower percent of Alaska Natives, and communities along the Yukon River. Several of the communities in the CYR study area have these characteristics. Average annual per capita harvests were the greatest in the Yukon River watershed (452 lbs.). Only harvest of caribou increased significantly since the early 1980s (Figure E-28). However, annual variation in the data is very high and, therefore, underlying trends may be masked. Subsistence activities reflect not only animal abundance and availability but also socioeconomic conditions and culture. Thus, subsistence harvest is a complex activity.

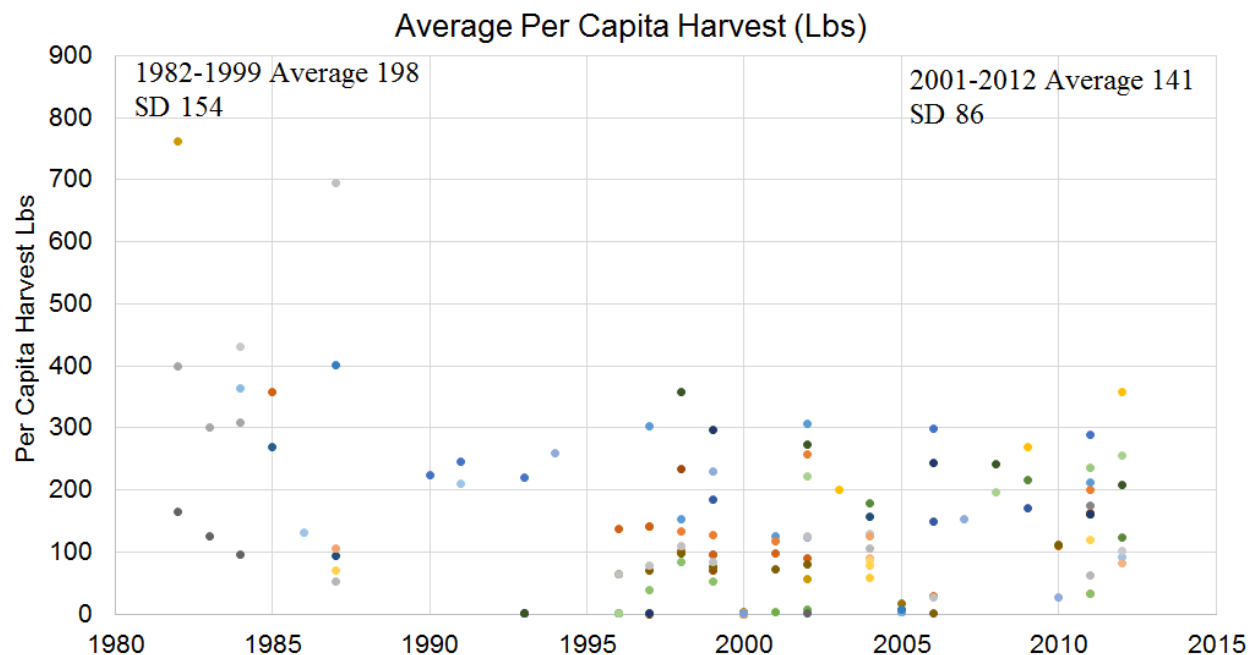


Figure E-27. Per capita subsistence harvests by communities in the CYR study area. Data from moose, caribou, Dall sheep, salmon, non-salmon, waterfowl, and marine mammal harvest estimates from the Community Subsistence Information System (CSIS). Colors correspond to different communities ($n = 37$).

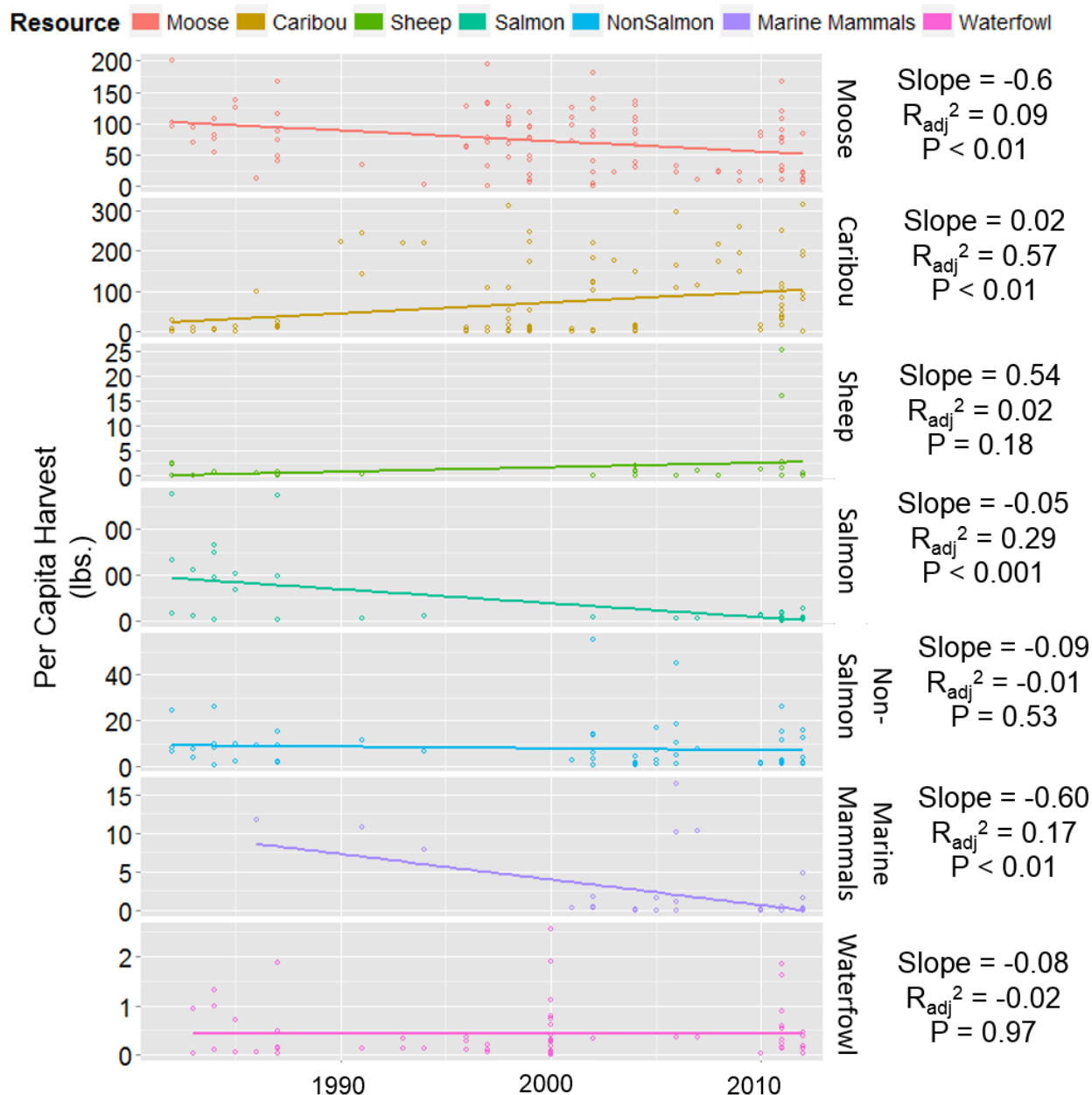


Figure E-28. Per capita subsistence harvests by communities in the CYR study area. Data from moose, caribou, Dall sheep, Salmon, non-salmon, waterfowl, and marine mammal harvest (lbs.) estimates from the Community Subsistence Information System (CSIS). The statistics should be viewed with caution because the data do not always meet the assumptions of linear regression.

Total salmon harvests have been declining on the Yukon River, which is the major river in the CYR study area (Figure E-29). Commercial salmon harvest, which may occur outside the study area, is a large portion of the total salmon harvest. Sport fish harvests on the Yukon River are minimal compared to commercial and subsistence harvests. Declines in subsistence harvests were common across all four watersheds (Figure E-30).

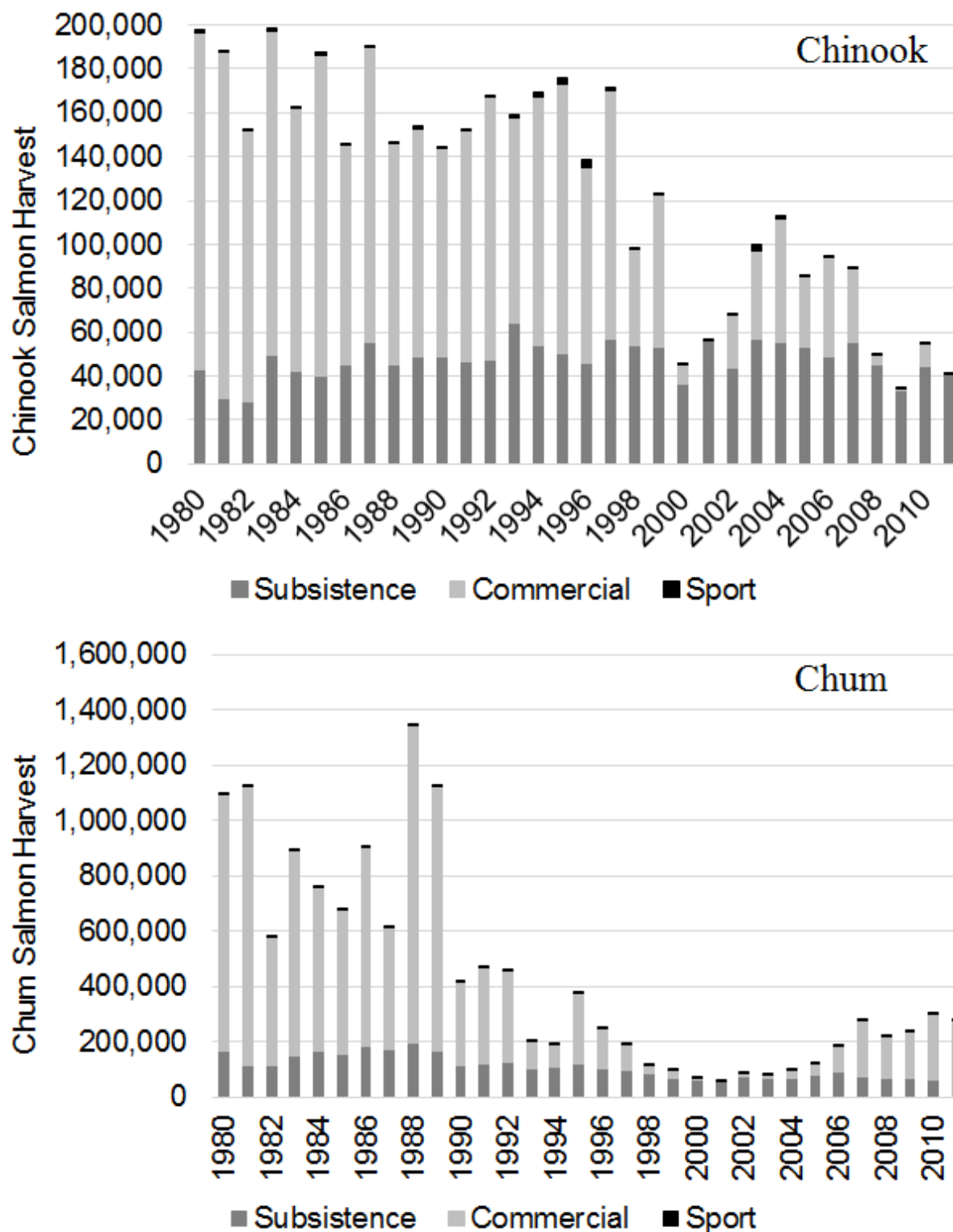


Figure E-29. Subsistence, commercial, and sport harvests of Chinook and chum salmon on the Yukon River. Data taken from Schmidt and Newland (2012).

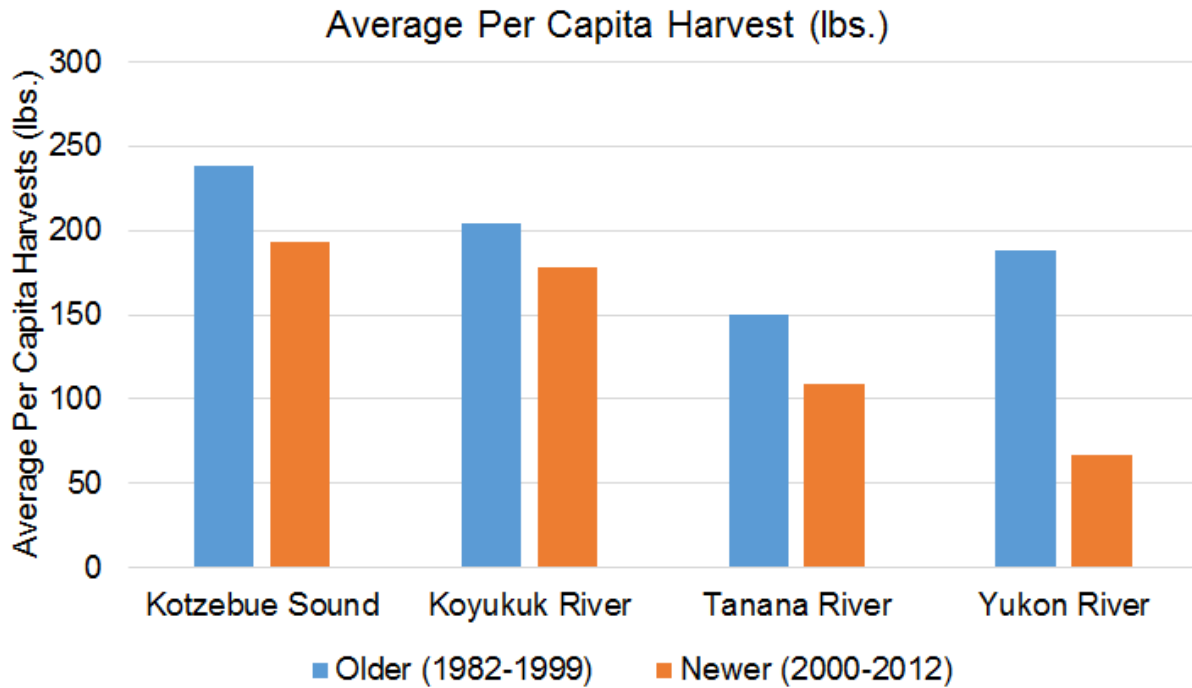


Figure E-30. Per capita subsistence harvests (lbs.) by watersheds within the CYR study area. Data from ADF&G Division of Subsistence.

The composition of harvest is driven by available resources, cultural practices, and access to a large river or ocean (Figure E-31). Going from west to east, there is a shift from caribou to moose as the most commonly harvested large mammal with a mix of both species in the middle. This corresponds with a shift in vegetation and climate due to the fact that the upper west portion of the study area occurring outside of Interior Alaska (e.g., outside of the bounds of the Alaska and Brooks mountain ranges). Interior Alaska is dominated by the boreal forest that is better moose habitat while northwest Alaska contains more tundra that is preferred by caribou. Culture is also influenced by this in that examination of Alaska native clothing, tools, and hunting practices revolve around the respective animals. Even though large mammals are important in these regions, fish provide an important and sizeable amount of protein for many of these communities (Georgette et al. 2003, Magdanz et al. 2010). Communities along the Yukon depend on salmon for their livelihood and are strongly influenced by salmon runs which have been declining and becoming increasingly difficult to predict (Brown and Godduhn 2015, Ikuta et al. 2013).

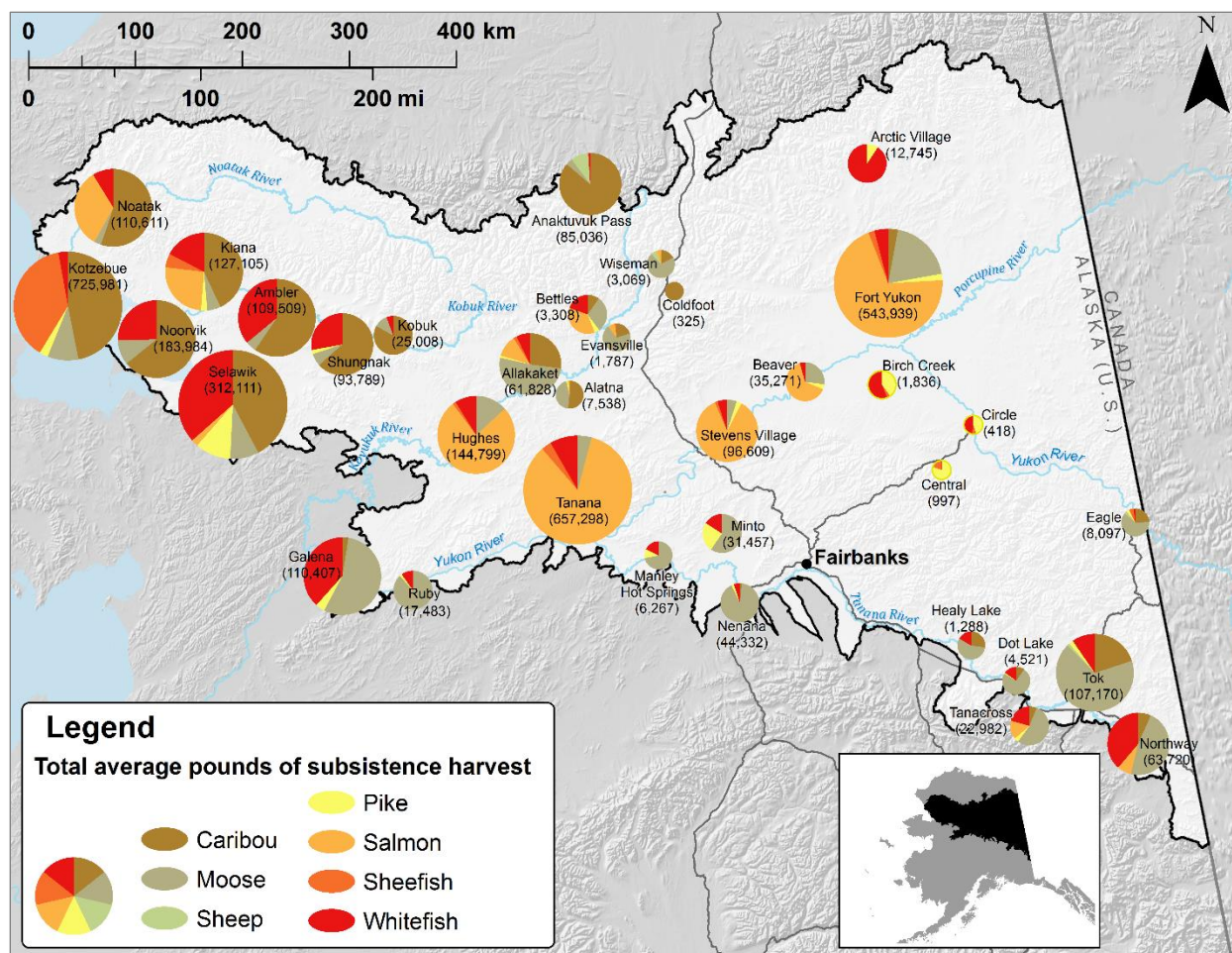


Figure E-31. Relative percentage of subsistence harvests (lbs.) based on available household surveys conducted by the Alaska Department of Fish and Game, Division of Subsistence.

Subsistence use areas of caribou were much larger than moose or Dall sheep (Figure E-31, Figure E-32, Figure E-33, Figure E-34). Overall, the landscape condition in the subsistence use areas is very high (Table E-20). Caribou had the most percent of the harvest area occur in the highest landscape condition, followed by Dall sheep, and moose. Caribou subsistence use areas likely have the most pristine landscape conditions because they encompass much larger use areas than for moose or sheep, and residents of the communities examined typically traveled further from communities to hunt caribou. The community of Dot Lake mostly hunted along the road system, which is why the landscape condition model score was so low for their subsistence use area.

Table E-20. The percent of the subsistence use area that occurs within the highest ranking landscape condition category (i.e., most pristine). Only communities with available data were analyzed.

Community	Caribou			Moose			Sheep		
	Current	Near	Long	Current	Near	Long	Current	Near	Long
Alatna	99	99	97	99	99	98	NA	NA	NA
Allakaket	99	99	97	99	98	97	100	100	100
Anaktuvuk Pass	100	99	98	100	100	91	100	100	99
Beaver	NA	NA	NA	94	94	94	NA	NA	NA
Bettles	100	100	100	100	100	96	NA	NA	NA
Dot Lake	NA	NA	NA	7	7	7	NA	NA	NA
Dry Creek	NA	NA	NA	53	52	47	NA	NA	NA
Evansville	NA	NA	NA	85	85	71	NA	NA	NA
Healy Lake	60	60	60	59	59	59	NA	NA	NA
Noatak	100	100	99	100	100	99	100	100	99
Noorvik	100	100	99	100	100	98	100	100	100
Tok	67	67	67	65	65	65	100	99	94
Wiseman	7	7	6	38	38	36	48	47	45

Section E. Anthropogenic Change Agents

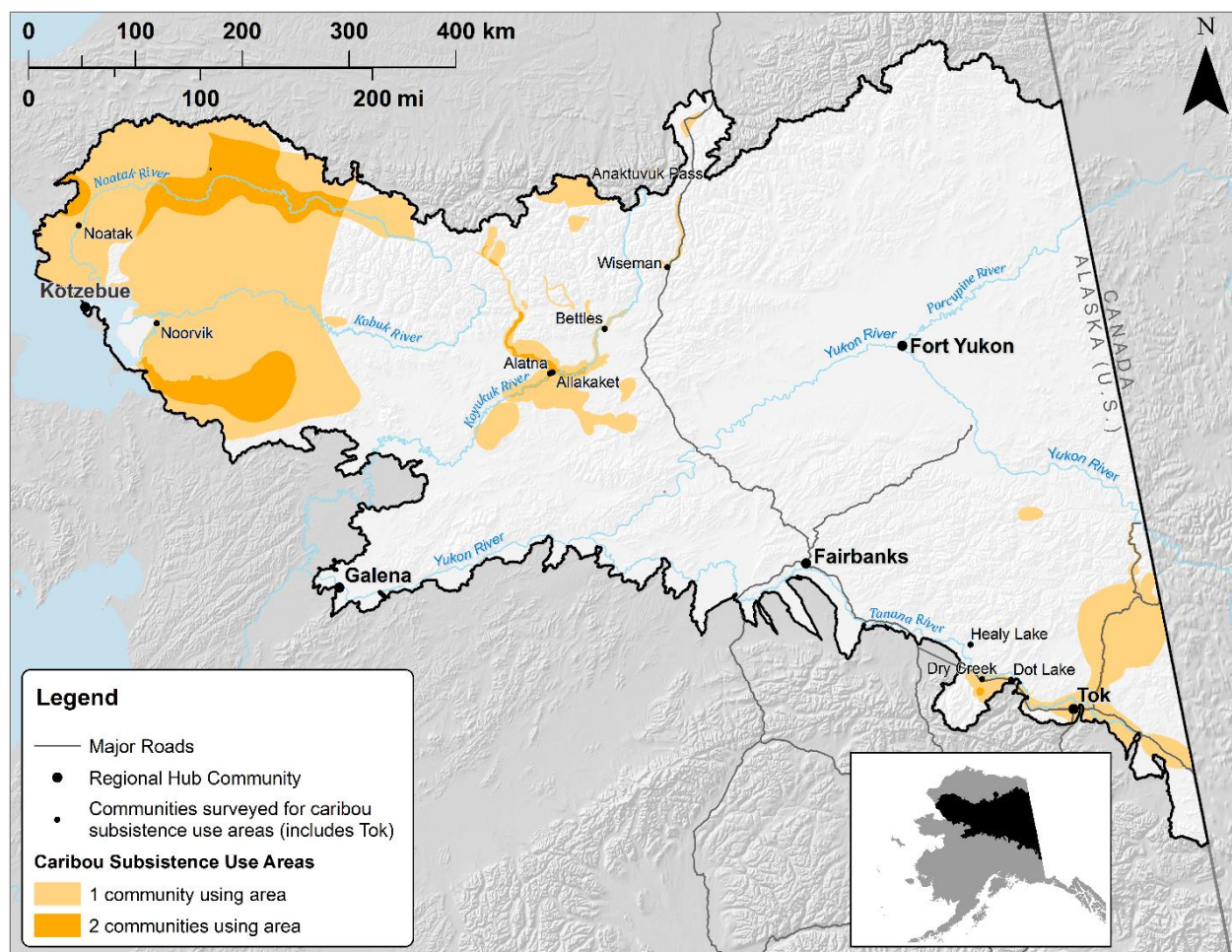


Figure E-32. Caribou subsistence use areas and number of communities utilizing areas.

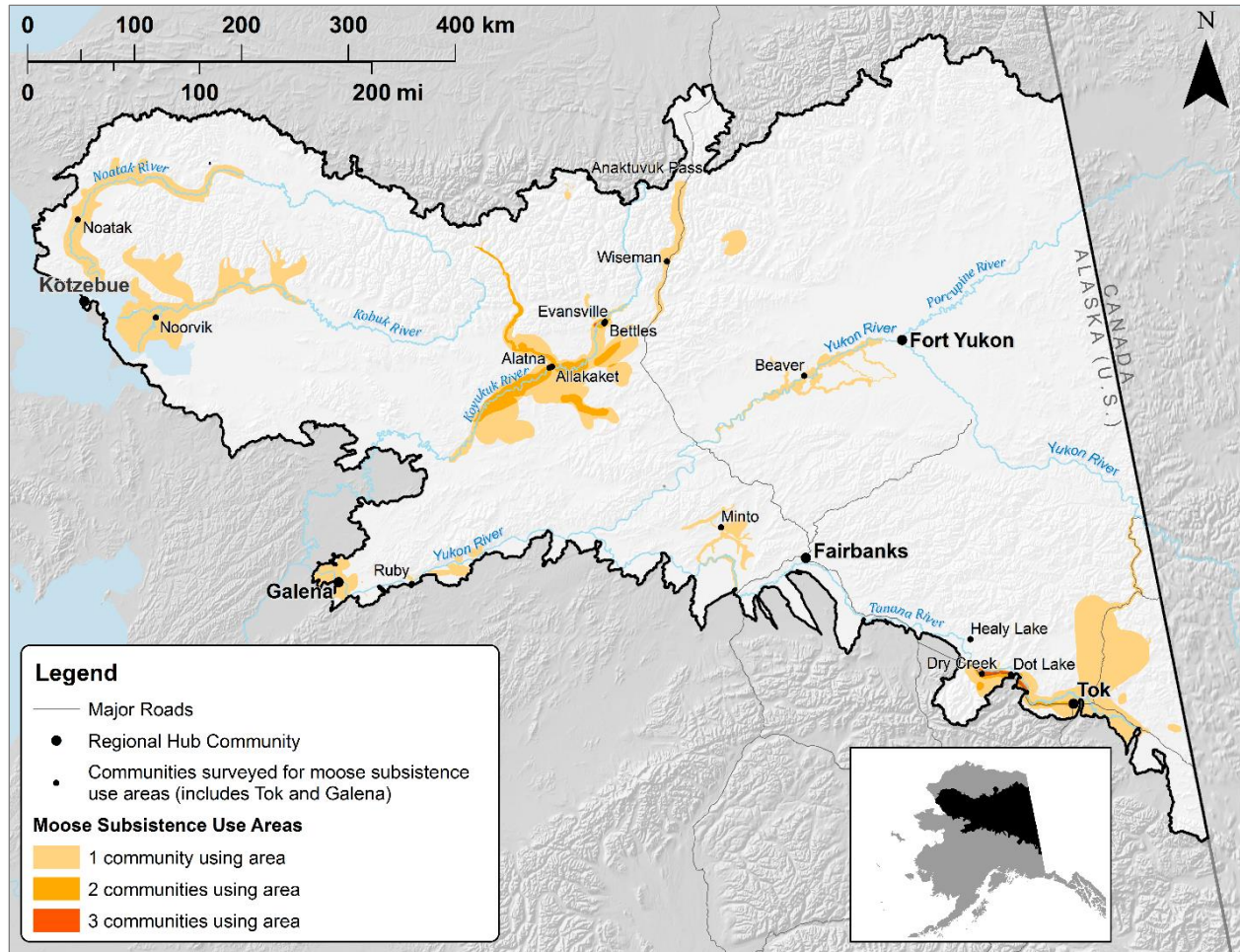


Figure E-33. Moose subsistence use areas and number of communities utilizing areas.

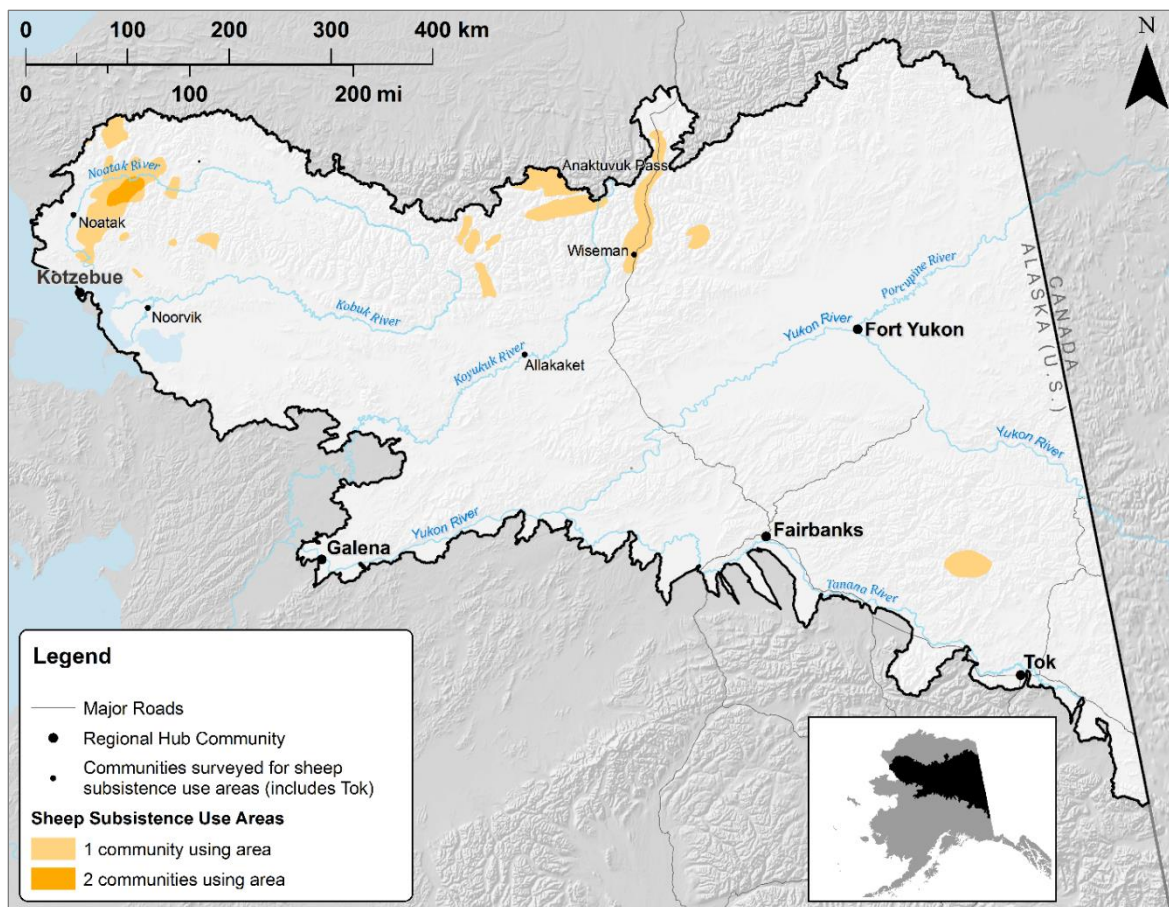


Figure E-34. Dall sheep subsistence use areas and number of communities utilizing areas.

3.4 Recreation

There are several federal and state recreation areas within the CYR study area (Figure E-35). Many communities occur within or adjacent to the Yukon Flats National Wildlife Refuge. Subsistence and hunting activities are less restricted in National Wildlife Refuges and National Preserves than in National Parks. Development across federal recreation areas requires scrutiny according to the National Environmental Policy Act (NEPA) as was mentioned as a reason for selecting the preferred road to Ambler (AKDOT 2010a). Visitation information is only available from the National Park Service (NPS) and visitation rates and comments from NPS employees, which were very useful to help explain the data, are only available for the mid-2000s and later. Overall, visitation has increased (Figure E-36). Since 1982 summer (June–August) visitation has risen by 93 visitors per year ($p > 0.001$) while winter (December–March) visitation has only increased by 12 ($p = 0.03$). However, the peak in 2005 through 2007 was largely due to changes in visitation during summer. There is no known reason for the large peak towards the end of the time series. Since it is so large we suspect a change in data collection methods. Attendance to the Parks and Preserves and differences among them are influenced by a number of factors. First, some NPS Parks and Preserves have headquarters that are accessible by roads including Gates of the Arctic National Park and Preserve (Fairbanks and Coldfoot), Noatak National Preserve, Kobuk Valley National Park, and Cape Krusenstern National Monument (Kotzebue), and Yukon-Charley Rivers National Preserve (Eagle). Access is

important and likely increases visitation given that this area typically had the most visitors of all the areas (Figure E-36) and visitors are counted at four different locations: Anaktuvuk Pass, Bettles, Coldfoot, and Fairbanks. Tourism is also important for Gates of the Arctic National Park and Preserve and Yukon-Charley Rivers with guided tour visitors counted in the former and Yukon Quest associated visitors in the latter. The influence of tourism, or lack thereof is clearly seen in the Yukon-Charley Rivers National Preserve. In 2010, the Taylor Highway to the Yukon-Charley Rivers area was severely damaged and closed to only essential travel. The following year, tour buses stopped going to the park headquarters in Eagle, resulting in fewer visitors (Figure E-36). One goal of NWAB is to increase tourism opportunities and part of this could include increasing visitation to the surrounding NPS areas. In 2014, they provided more certification and capabilities for local people to pursue local entrepreneur opportunities that are not related to mining, such as tourism (NWAB 2015). Additionally, access to wildlife and guiding activity can influence visitation of parks. For example, during the Fortymile caribou herd migration herd crossed into preserve hunting ranges and caused an increase in the number of visitor/hunters in the Yukon-Charley Rivers National Preserve during 2013. Yukon-Charley Rivers National Preserve is the only NPS area to count visitors staying by hunting guides or business permits in their statistics. Other preserves are certainly used by hunting guides; however, these data are not included so counting methods differ among NPS areas. Overall, the ecological impact from recreational visitors is likely minimal, but visitors can contribute to local economies through businesses and purchase of handicrafts.

Section E. Anthropogenic Change Agents

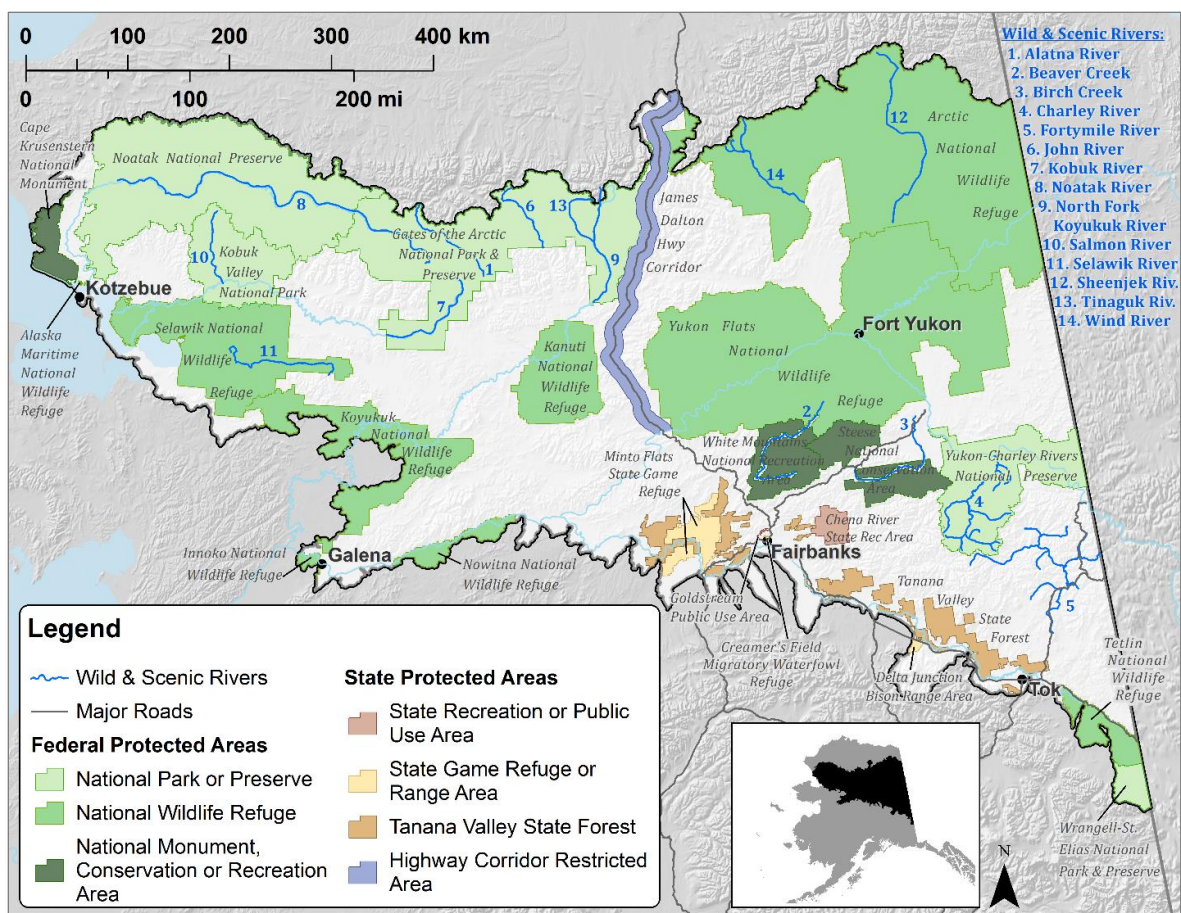


Figure E-35. Designated federal- and state-protected areas within the CYR study area used for recreation and public use and visitation.

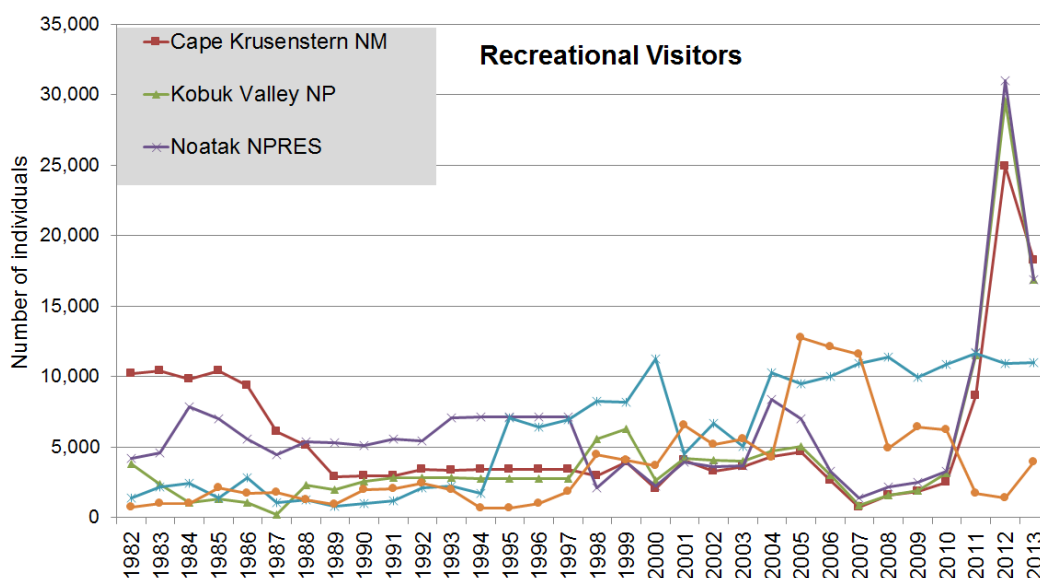


Figure E-36. Visitor statistics for the National Parks, Preserves, and Monuments within the CYR study area. Who qualifies as a visitor and how visitors are counted vary by area (see Results).

3.5 State and Federal Subsistence Hunting and Sport Fishing

Most of the data presented here are ADF&G data collected via harvest tickets or sport fish surveys. Thus, it does not capture much of the subsistence hunting and fishing in the CYR study area. Sometimes as little as 30% of the harvest is captured with harvest tickets and potentially less (Schaeffer et al. 1986, Schmidt and Chapin 2014). We do use the federal subsistence database because it includes both state (e.g., ADF&G) and federal subsistence hunts with residency information. Publicly available ADF&G harvest ticket data do not include residency so to address the management question of who harvests what where, we needed to use the federal subsistence database.

Overall, the federal harvests make up a small portion of harvests in the CYR study area and before 1994 there were no moose, caribou, or Dall sheep on federal subsistence harvest tickets. Between 1994 and 2010, only 1.2% of moose were harvested on a federal subsistence ticket. However, from 1994 and 2010 individual GMUs did have a much higher proportion of moose harvested, such as GMU 24A, and 25D had the highest annual percent of moose harvested with federal subsistence tickets, 11.3% and 20.2%, respectively. Only GMU 13B and 13C had caribou harvested on a federal subsistence permit, 34.6% and 15.4%, respectively, and overall less than 0.01% of caribou were harvested on a federal subsistence database. Even fewer Dall sheep were harvested on a federal subsistence ticket ($n = 46$; 0.8%) between 1994 and 2010. Six GMUs had Dall sheep harvested on a federal permit: GMU 24A (6.8%), 24B (2.8%), 25A (1.0%), 26A (2.0%), 26B (0.8%), and 26C (1.4%). The percentage of animals harvested on federal subsistence permits did not change between 1994 and 2010. Again, all numbers have been adjusted based on the percentage of the GMU within the CYR study area.

Predicting future change in numbers of hunts and harvests was not possible. Resource managers attempt to balance maintaining ecosystem function and hunter satisfaction within the constraints of politics and legislative mandates. Habitat can only support a limited number of animals, so harvests cannot increase ad infinitum. However, changes in habitat and access can influence near-term and long-term hunting activity. We examined trends and changes in moose, caribou, and Dall sheep hunting from 1990 to 2013. Because the ADF&G data only provided number of hunts, it was not possible to determine number of hunters. Thus, most of the information presented is on harvests because it is less influenced by changes in number of permits per person and also represents actual animals removed from the landscape. Harvests should be interpreted as a minimum because some people fail to report harvests. All of the data in this section are based on ADF&G harvest tickets (e.g., state-only sport hunting, 1990-2013) or federal subsistence hunt database (e.g., state-only sport hunting and federal subsistence hunting, 1990–2010).

State Harvest Ticket Hunting

A large number of moose were harvested from GMU 20B, and the number of moose harvests in GMU 20B increased significantly over the last 30 years (Figure E-37; $\beta = 23.1$, $R^2 = 0.73$, $p < 0.001$).

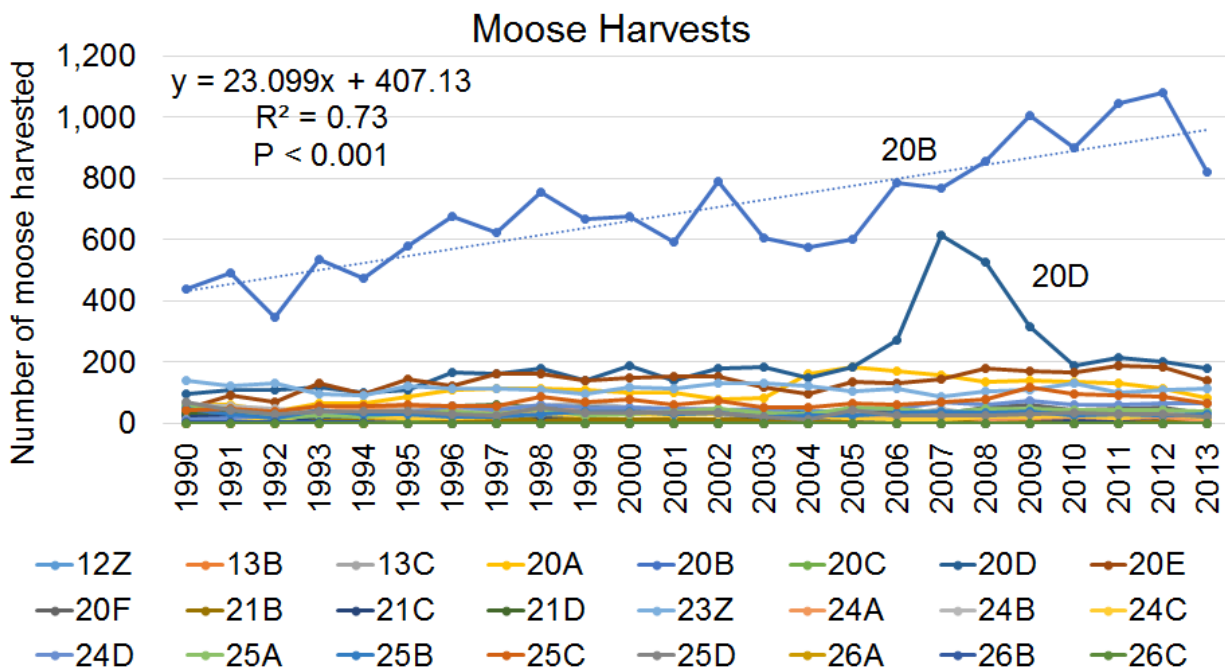


Figure E-37. Sport harvest of moose by GMUs.

Unlike most GMUs in the CYR study area, GMU 20B encompasses a large human population (Fairbanks North Star Borough), it is easily accessible by roads, rivers, and trails, and its moose density has doubled since 1990 (Hollis 2012), all of which contributed to the increased harvest activity. Browsed surveys indicated a high removal rate, and antlerless hunts were initiated in RY2010 in an attempt to limit moose population growth. However, this action resulted in a large increase in the number of hunters and subsequent decrease in success. Another factor that allows for such a high intensity use in 20B is the higher harvest of predators (i.e., bears and wolves) that does not normally occur in rural Alaska. However, this action resulted in a large increase in the number of hunters and subsequent decrease in success. Moose habitat in GMU 20B and migration corridors could potentially be impacted by the Alaska Railroad Corporation Northern Rail Extension Project (ADF&G 2012). The number of moose likely cannot continue to increase and harvest levels will likely decrease in the near-term future. Harvest did decrease by over 200 moose between 2012 and 2013. If the higher levels of harvest and productivity observed during the 2000s are desirable in the future, then likely some type of habitat manipulation, either man-made or natural, will need to occur. Finally, since reporting rates are known to be low among rural resident, harvests in GMUs away from the FNSB are probably underrepresented.

The number of hunts and harvests slightly decreased from 1990 to 2013 along the Dalton Highway corridor, where use of off-road vehicles and firearms for hunting within five miles of the road has been prohibited except for federally qualified rural residents (Figure E-38). The five-mile road corridor has been in place since at least 1990 and was not likely the reason for the decrease in hunting activity. Rather, more lucrative areas, like GMU 20B, became available due to both increases in access and moose density. Increases in the number of sport hunters and harvests north of Galena were feasible due to the increase in the attractiveness of this area to trophy hunters due to the larger antlered bulls, especially by non-residents and those seeking

trophy animals (Stout 2012). The decrease in sport harvest of moose in the Yukon Flats (GMUs 25B, D) is likely due to the declining moose population correlated with predation and harvest of cows (Caikoski 2012).

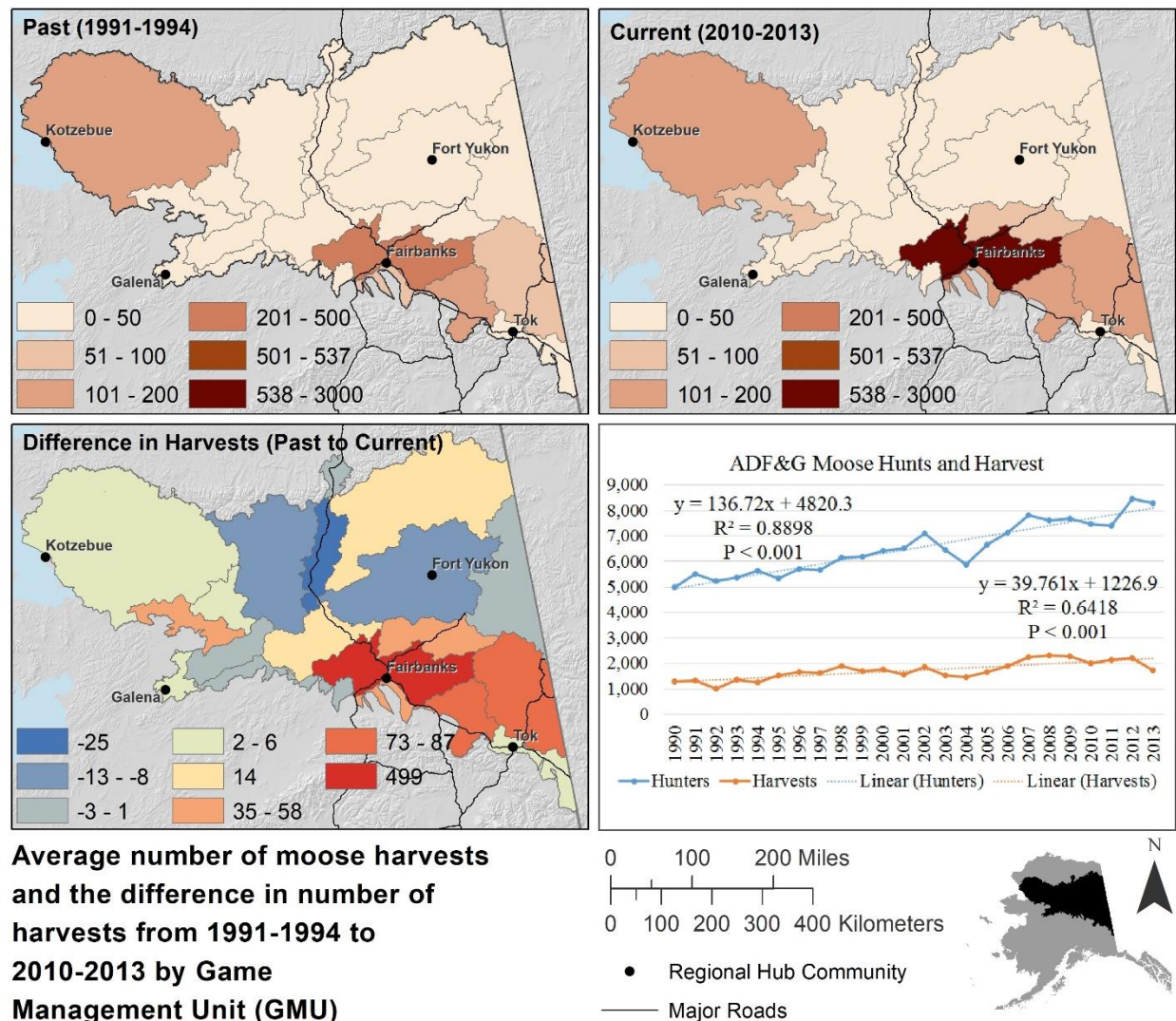
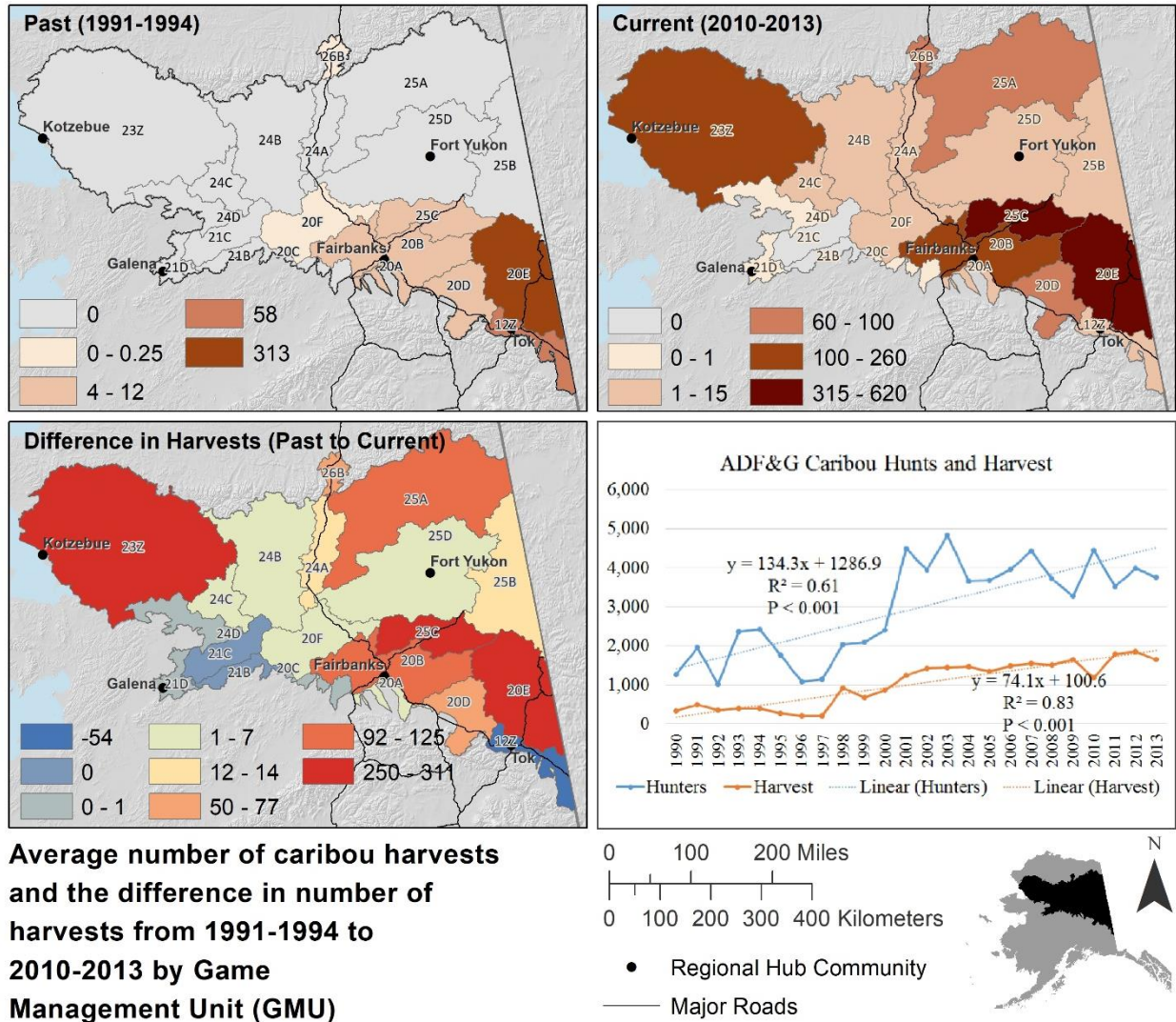


Figure E-38. Sport harvest of moose based on harvest tickets collected by the Alaska Department of Fish and Game, Division of Wildlife Conservation. Units are number of moose.

State harvest tickets and federal subsistence moose harvest occurred in GMUs, which are accessible by major roads and have larger human settlements, with the exception of previously mentioned 24D. Based on data from the federal subsistence database, which allows us to look at harvest by community residency for federal subsistence and state sport hunts, from 1990 to 2010, residents from communities along the road system annually harvested on average eight times the number of moose (64) than Alaska residents from non-roaded communities (8), which could simply be due to higher reporting rates along the road system where enforcement of rules is more common.

Harvests have also increased, but at a slower rate than hunts. Caribou hunts decreased the most in GMU 20E, but harvests increased there (Figure E-39, Figure E-40). Data on caribou

were based on reports from hunters living south of the Yukon River and non-residents. Residents north of the Yukon River were not required to report their hunting activity. The reason for the lack of harvest data in a majority of the GMUs in the early 1990s is unknown. Part of it is surely due to underreporting and not needing to report, but non-resident and harvests by residents below the Yukon River should have been documented (Figure E-39). Part of the reason for the increase in caribou hunts in the northern portion of the study area must be attributed to improvements or changes in reporting requirements. Caribou hunts and harvests were greatest in areas accessible by roads or in GMUs where caribou are known to congregate during the hunting season. For GMU 23Z, which encompassed the home range for the Western Arctic herd, is far from the road system but still a popular caribou hunting area for residents and non-residents. In fact this area has had one of the longest controlled use areas in the State to minimize conflict and regulate harvest (e.g., Noatak control use area). The Western Arctic herd grew by 1–3% annually from 1990 through 2003 with a peak size of 490,000 in 2003 (Dau 2011). However, since 2003 the herd has decreased by nearly 50%, numbering 235,000 in 2014. Since the early 1990s, the number of caribou harvests have significantly increased in 20E, 25C, and 23Z (Figure E-39). Winter habitat for the Nelchina caribou herd occurs in northeast 12Z and this herd increased in size in the early 1990s but as habitat grew poor they shifted in 20E. This shift could partially explain the change in harvests. Additionally, in 2004 fires destroyed caribou habitat in 20E, and as a result caribou now congregate in unburned areas, but whether this makes them an easier target for hunters is unknown. The annual range of the Fortymile herd overlaps several GMUs (20B, 20C, 20D, 20E, and 25C). The population of this herd was stable but low from 1990 through 1995 at 22,000 individuals, but predator control efforts from 1996–2002 resulted in a doubling in population size and an increase in human harvest (ADF&G 2013).



Average number of caribou harvests and the difference in number of harvests from 1991-1994 to 2010-2013 by Game Management Unit (GMU)

Figure E-39. Sport harvest of caribou based on harvest tickets collected by the Alaska Department of Fish and Game, Division of Wildlife Conservation. Units are number of caribou.

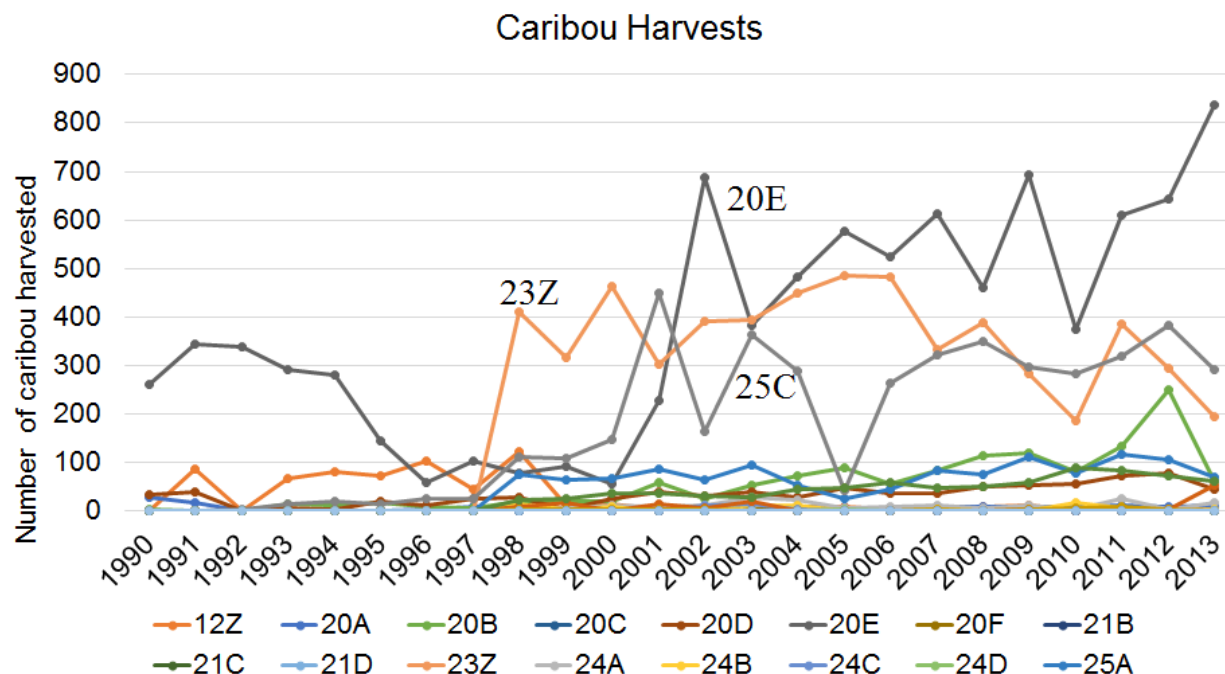


Figure E-40. Sport harvest of caribou by GMU. Data from the Alaska Department of Fish and Game.

The trend in the number of Dall sheep hunts has not changed since 1990, but harvests have slightly increased (Figure E-41). Use of multiple harvests is less common among sheep hunting than moose or caribou hunting partly because sheep exhibit a metapopulation structure so the target area for hunting is typically smaller. Overall harvests have remained stable since the early 1990s with the exception of a large increase in the northeastern portion of the study area (GMU 25C) and a decrease around Tok (GMU 12Z). From 1989 to 2000, there was a statewide full-curl bag limit, which resulted in fewer sheep hunts than in the 1980s. Sheep harvests have remained relatively static, largely due to severe weather events that have reduced many sheep populations (ADF&G 2014). After 2004, hunters started to target the northern portion (GMU 25A) of the CYR study area (Figure E-42) for unknown reasons. Regulations did not change between 2004 and 2005.

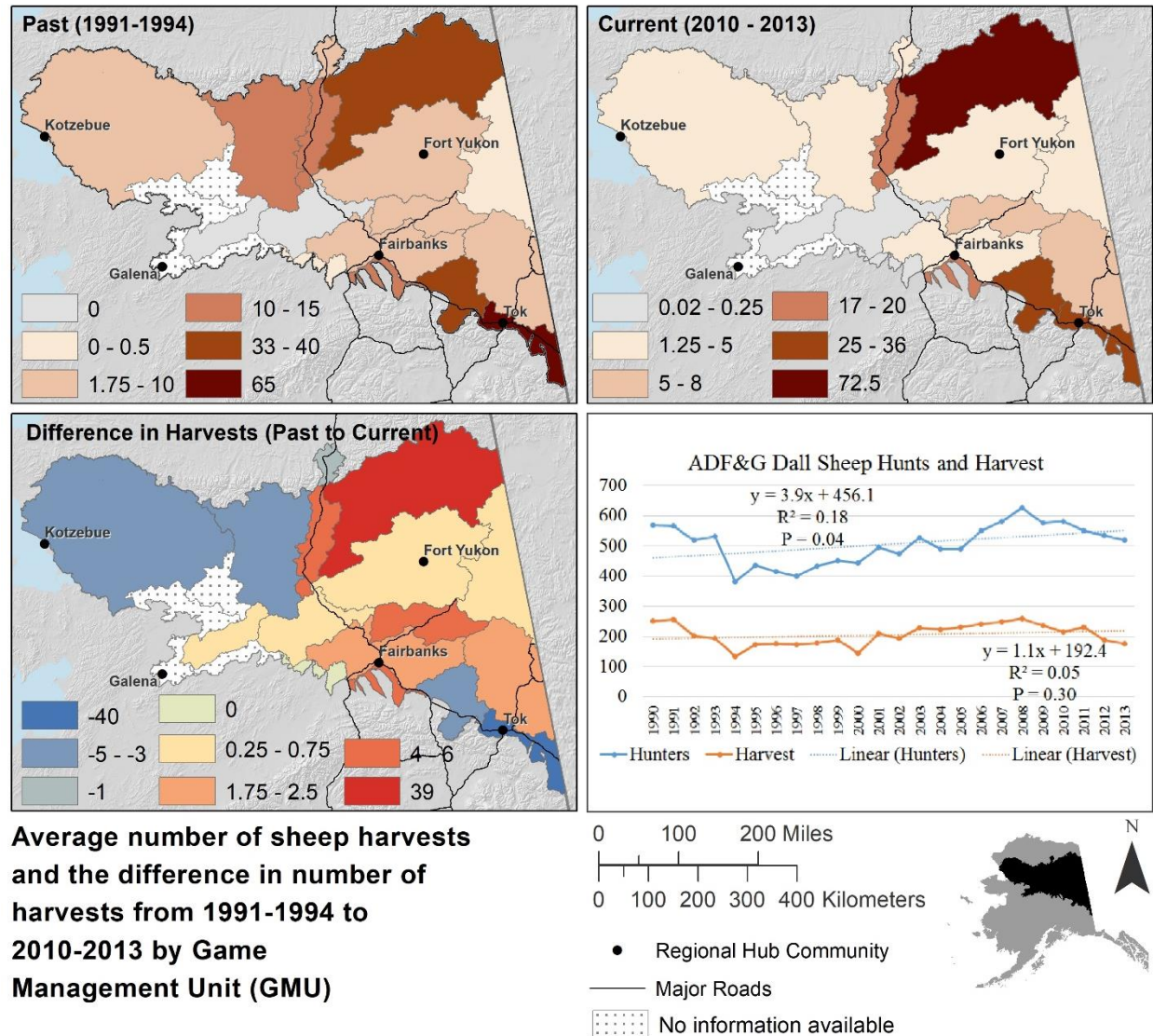


Figure E-41. Sport harvest of Dall sheep based on harvest tickets collected by the Alaska Department of Fish and Game, Division of Wildlife Conservation. Units are number of Dall sheep.

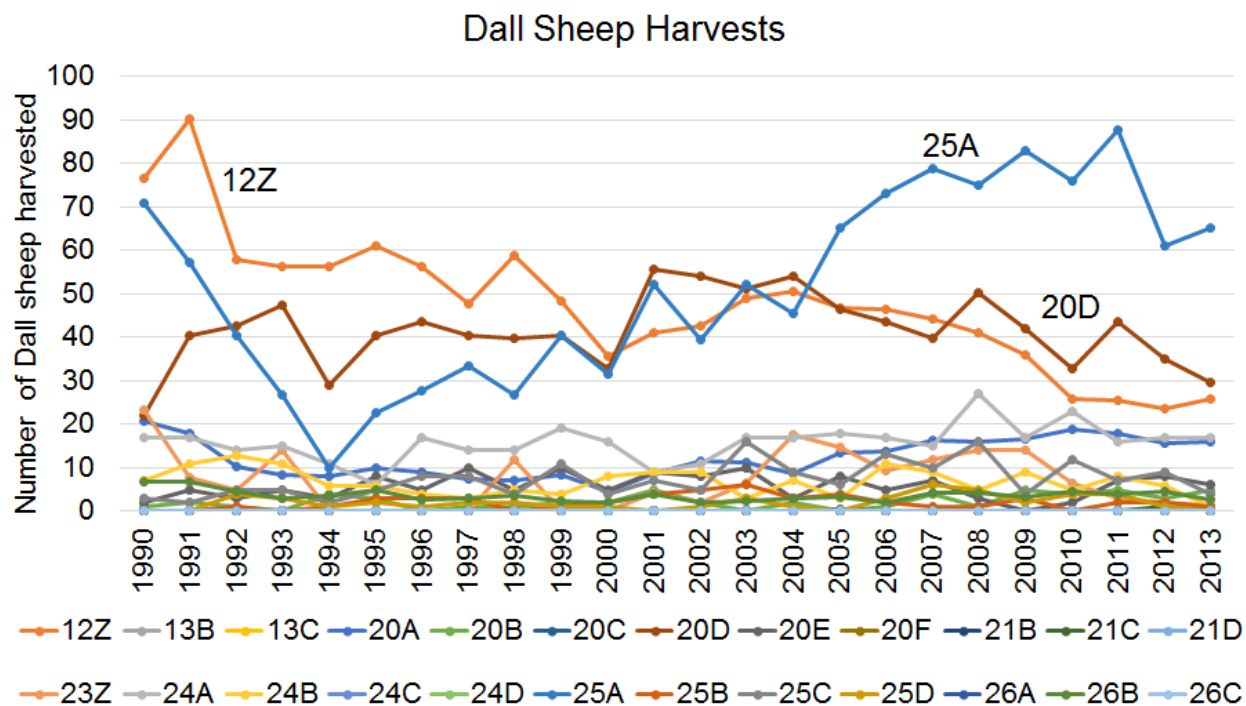


Figure E-42. Sport harvest of Dall sheep by GMU. Data from the Alaska Department of Fish and Game.

Data from state harvest tickets and the federal subsistence harvests indicate that from 1990 to 2010, Dall sheep make up a slightly larger portion of total harvest in the western portion of the study area (Figure E-42; e.g., Kotzebue and Koyukuk) than in the eastern portion. Overall, moose and caribou harvests have increased while Dall sheep harvests have remained static (Figure E-43). Since the majority of residents in the CYR study area live within FNSB (100,243 residents living within FNSB versus 12,744 residents living outside FNSB in 2013), it is important to look at harvest trends by FNSB residents (Figure E-44).

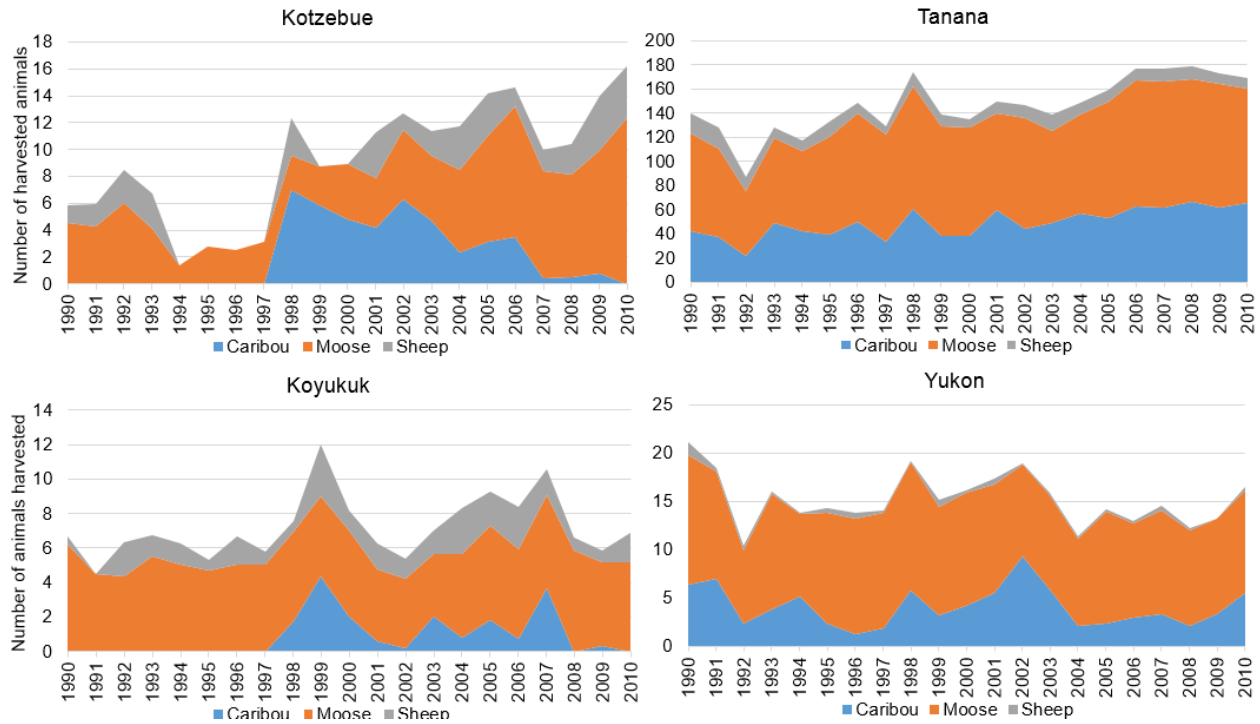


Figure E-43. Harvests by Alaska residents in the communities within four watersheds based on the federal subsistence data, which include both ADF&G harvest tickets and federal subsistence harvest tickets. Units are the number of animals harvested.

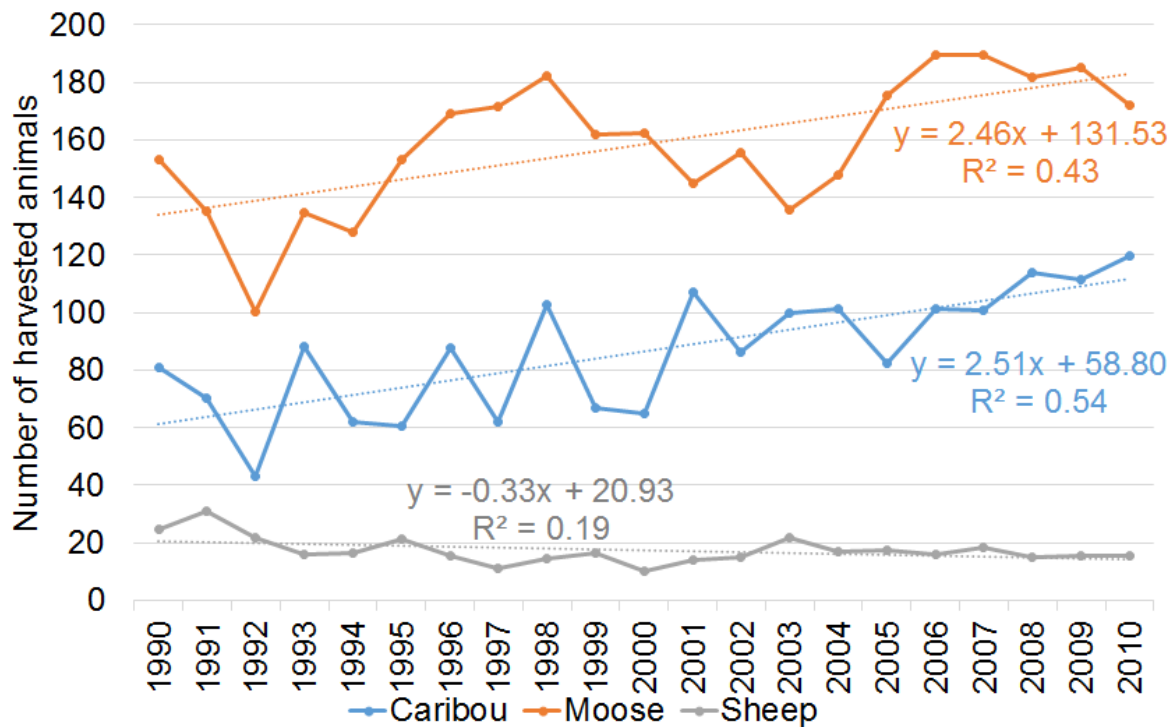


Figure E-44. Harvest of caribou, moose, and sheep by residents of the FNSB based on state harvest ticket and federal subsistence data.

The increase in caribou harvest was most strongly correlated with increases in the number of FNSB residents (Figure E-45), one reason could be because caribou are smaller animals than moose and can be handled and transported more easily by newer residents or inexperienced hunters. Additionally, caribou migrate across roads in large numbers, providing easier access than sheep and moose.

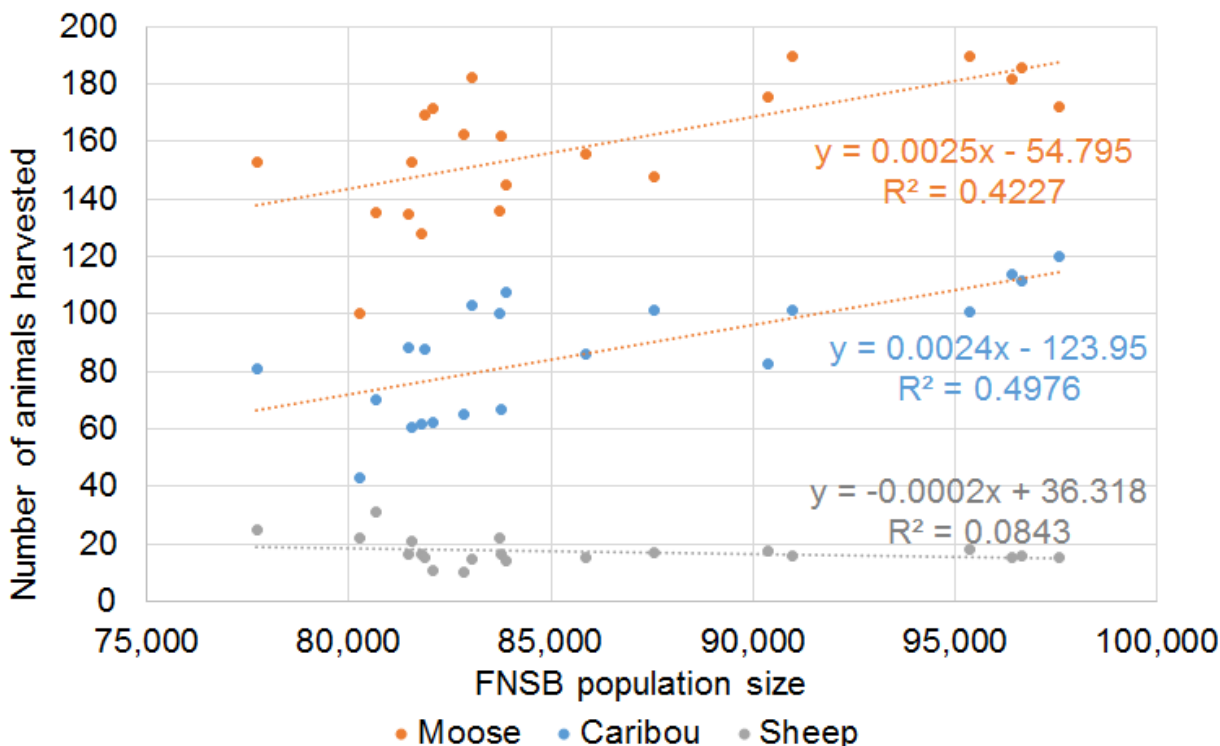


Figure E-45. Harvest of caribou, moose, and sheep by residents of the FNSB versus human population size of the FNSB. Data are from the state harvest ticket and federal subsistence data.

Fishing

There are several rivers in the CYR study area with sport fish harvest data (Table E-21, Figure E-46). Data are collected on the number of fish by species caught, which includes catch and release and harvested, which is only those fish kept. Non-Alaska residents, urban (i.e., Fairbanks, Anchorage, Wasilla, etc.), and military were the largest group of sport anglers. However, 78.8% of the sport fish reported harvested were done by residents of the CYR study area and mostly by residents of Fairbanks, North Pole, Eielson Air Force base, and Fort Wainwright in decreasing order. Slightly less than half of the communities in the CYR study area ($n = 32$) reported sport fishing activity, so harvests reported with this database do not reflect subsistence harvest, even subsistence harvest done with a rod and reel.

Most sport fish harvesting occurs near the urban center of Fairbanks (Figure E-47); a majority of these fish harvests are rainbow trout. Harvest of Arctic grayling dominates the other Interior rivers except for Birch Creek, which has more pike harvests. In the northwest portion of the study area, harvests are more mixed with inconnu dominating harvest on the Selawik River and Dolly Varden and Arctic char dominating harvest on the Noatak River (Figure E-47). Overall, the most commonly caught fish in the CYR study area was Arctic grayling (annual average of 92,122); the most frequently harvested fish was rainbow trout (annual average of 22,219). The

Tanana River had the largest number of fish caught (annual average of 110,562) and harvested (annual average of 29,727) followed by the Chena River (annual averages of 58,451 caught and 3,129 harvested) and Chatanika River (annual averages of 24,208 caught and 3,129 harvested). Overall, the number of fish caught (Figure E-48) and harvested (Figure E-49) decreased between 1996 and 2013. No rivers had a significant increase in fish harvests (Figure E-49). The largest decreases occurred in more heavily fished rivers in the eastern part of the state. A total of 111 different communities within Alaska caught fish with 99 harvesting fish from the river drainages in the CYR study area.

It is likely that many of the trends in the sport angler data are greatly influenced by stocking done by ADF&G. In 2016 there were 88 lakes stocked in the Tanana River Management Area. For example, the number of Arctic char stocked at Harding Lake, which is a very popular lake near Fairbanks, sharply declined in 2009 and has remained below previous levels, which corresponds to a large drop in harvests (Figure E-50). The current data delivery system requires users to click on each lake to obtain stocking data and compiling these data is out of scope for this REA. However, it would be a worthwhile pursuit to examine the effects of stocking on anglers and the economy in Alaska.

Table E-21. Annual average number of sport fish tickets used to base trends in sport fish catch (includes catch and release) and harvest (catch only) in the CYR study area.

River Drainage	1996–2004	2005–2013
Birch Creek	68	68
Chandalar River	35	40
Chatanika River	235	170
Chena River	238	225
Kobuk River	160	103
Koyukuk River	113	137
Noatak River	112	105
Porcupine River	82	57
Rabbit Creek	15	15
Selawik River	45	19
Tanana River	415	293
Yukon River	245	160
Total	1,948	1,470

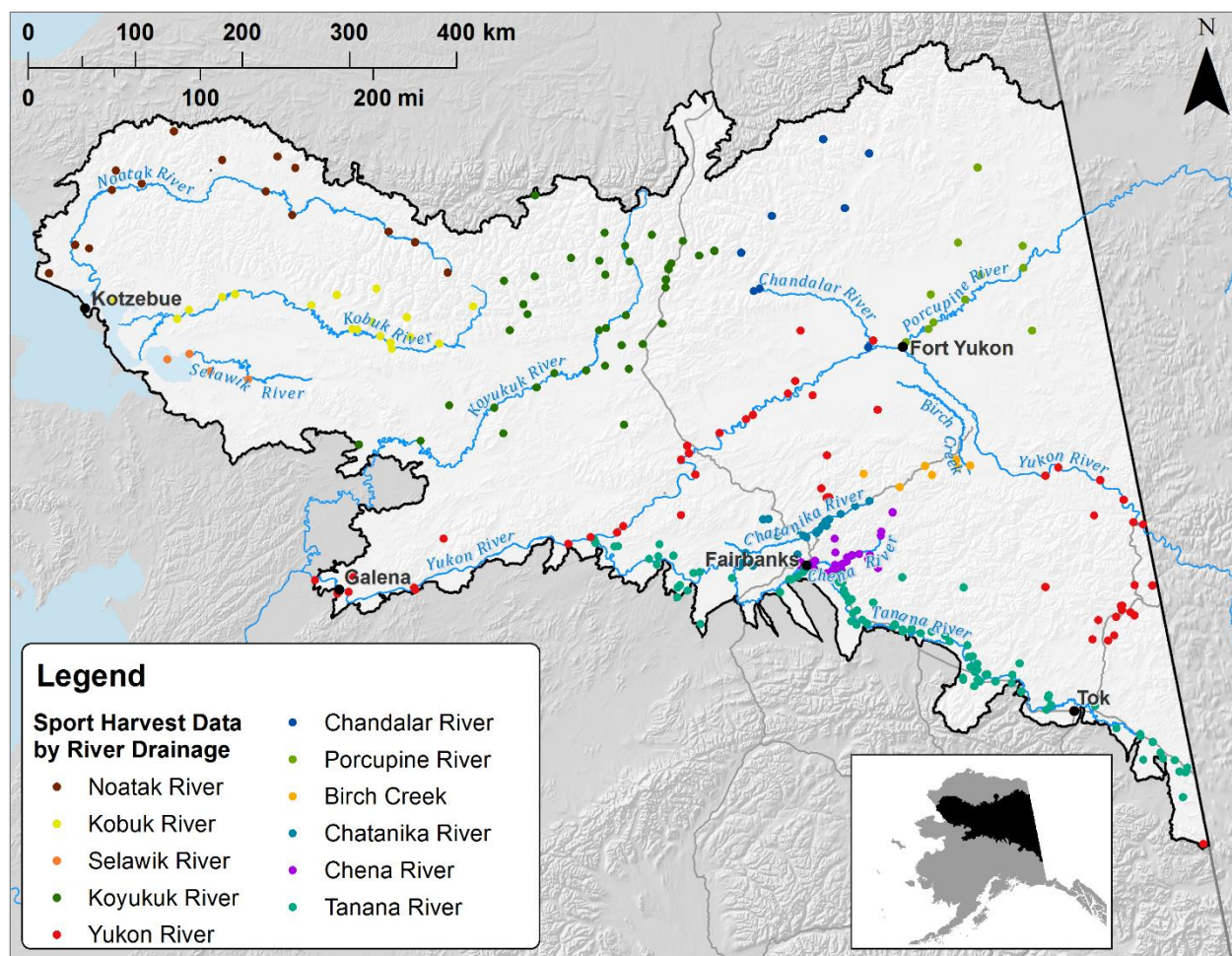


Figure E-46. Sport harvest of fish in rivers within the CYR study area.

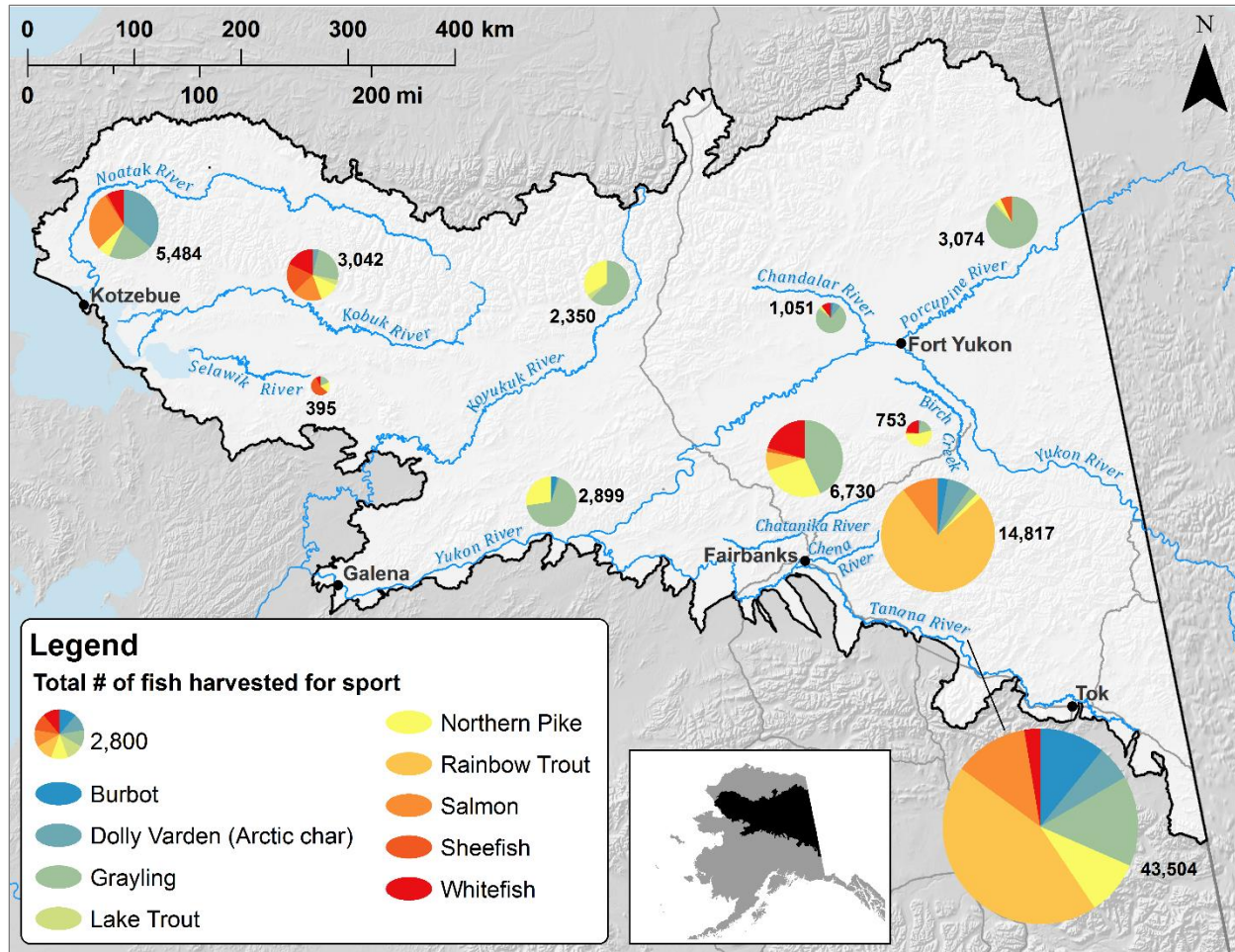


Figure E-47. Sport harvest distribution of fish species in rivers within the CYR study area. Circles represent the locations of survey data. Size of circle indicate relative amount of harvest among river drainages.

Catch in CYR Area

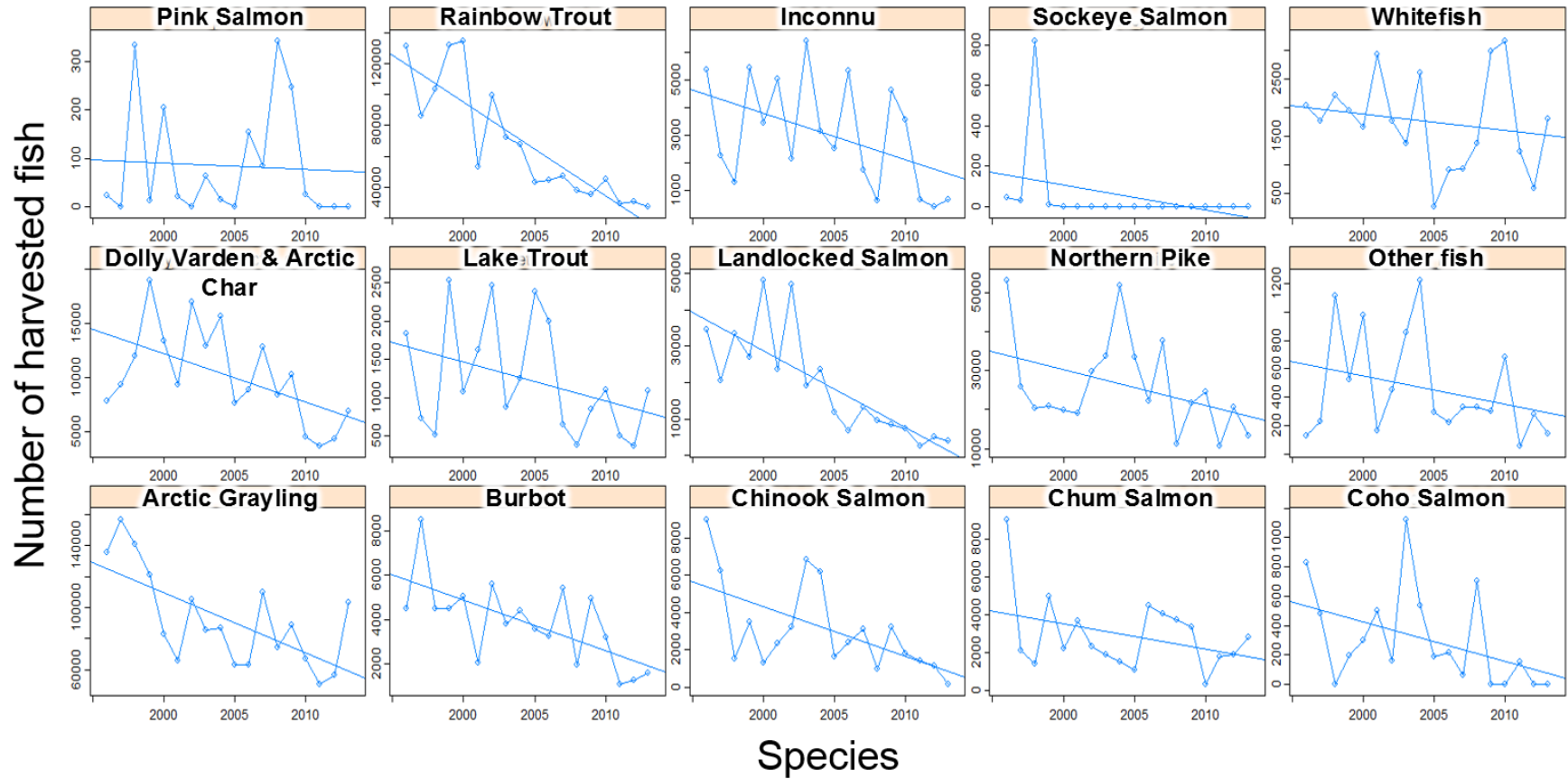


Figure E-48. Sport fish catch trends for fish species in rivers within the CYR study area.

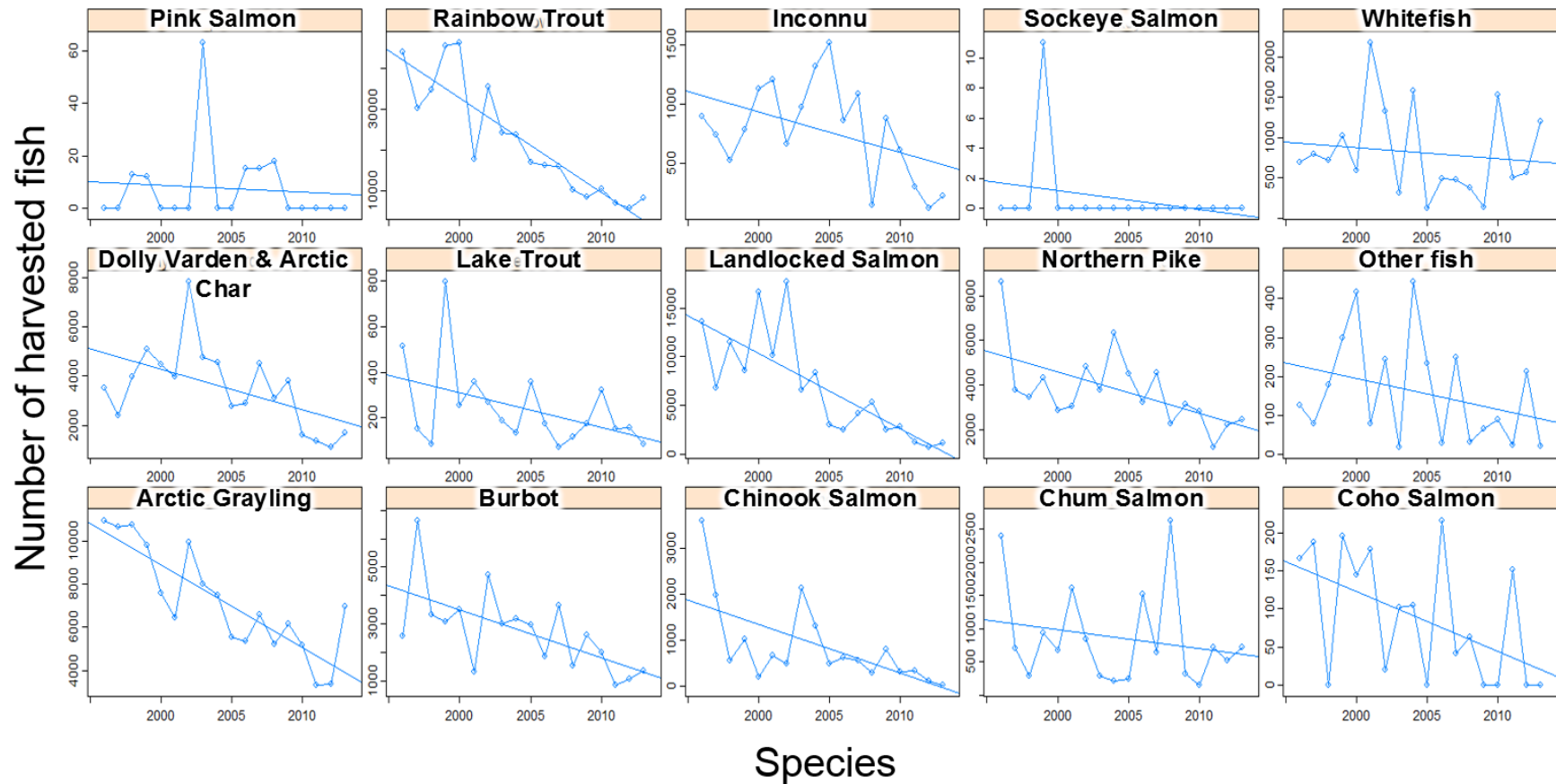


Figure E-49. Sport fish harvest trends for species of fish in rivers within the CYR study area.

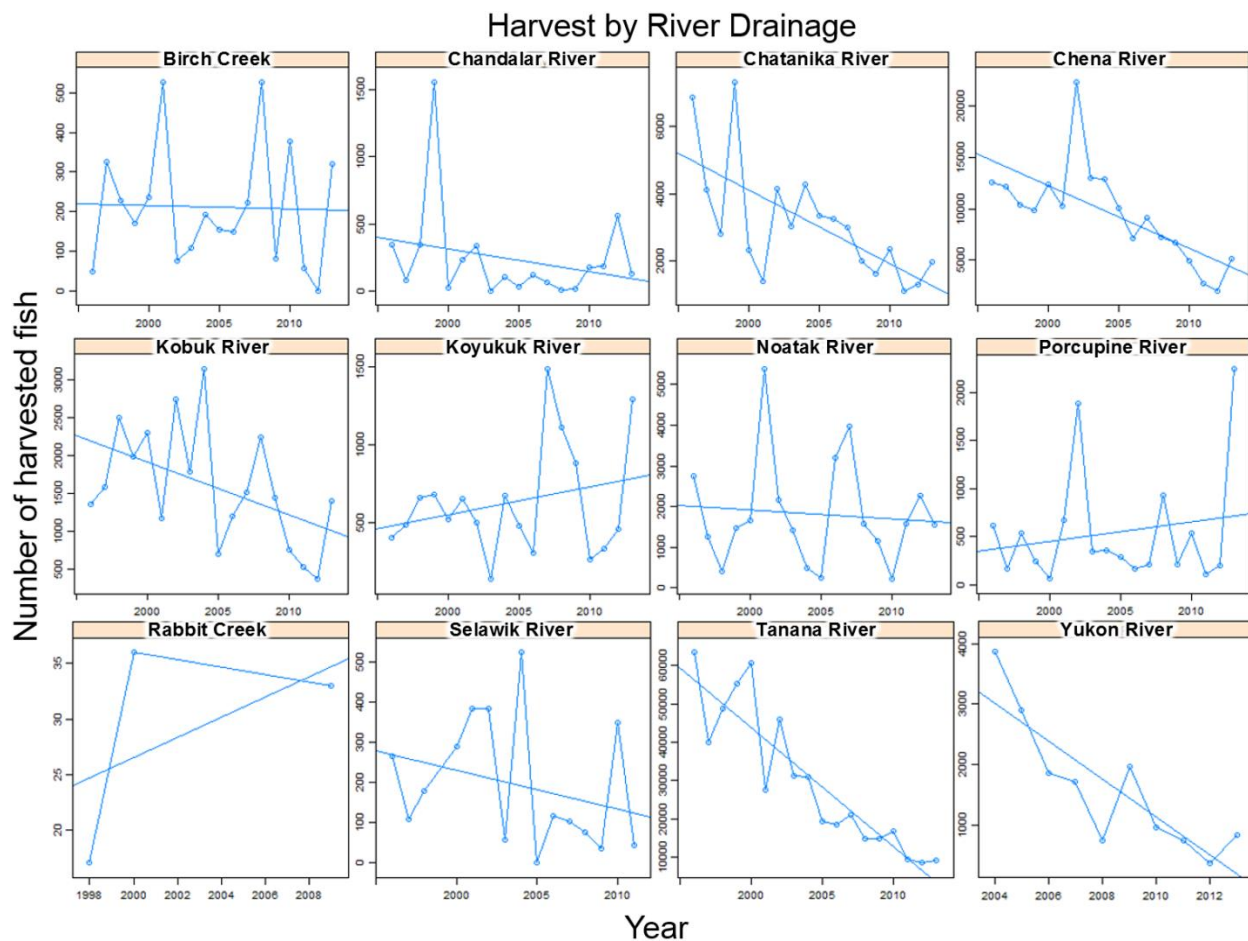


Figure E-50. Trends in sport harvest of fish in rivers within the CYR study area.

Drainages (in order from northwest to southeast)

Noatak River

On average 5,974 fish are caught annually and 1,816 are harvested annually on the Noatak River. The most commonly caught and harvested fish was Dolly Varden, which was grouped with Arctic char, followed closely by Arctic grayling (Figure E-51). A decrease in lake trout harvest was the only significant change from 1996 to 2013 (Figure E-52, $p = 0.0274$). Overall, fish harvests on the Noatak River have significantly decreased by 1%, or 22 fish per year (Figure E-53). Residents of the village of Noatak harvested the most fish (15,308) followed by non-Alaska residents (6,645) and Kotzebue residents (5,264). A peak in harvest in 2001 corresponded to a surge in whitefish, chum salmon, and Dolly Varden/Arctic char harvest; another surge in 2006–2007 was primarily due to an increase in harvest of Dolly Varden/Arctic char and chum salmon.

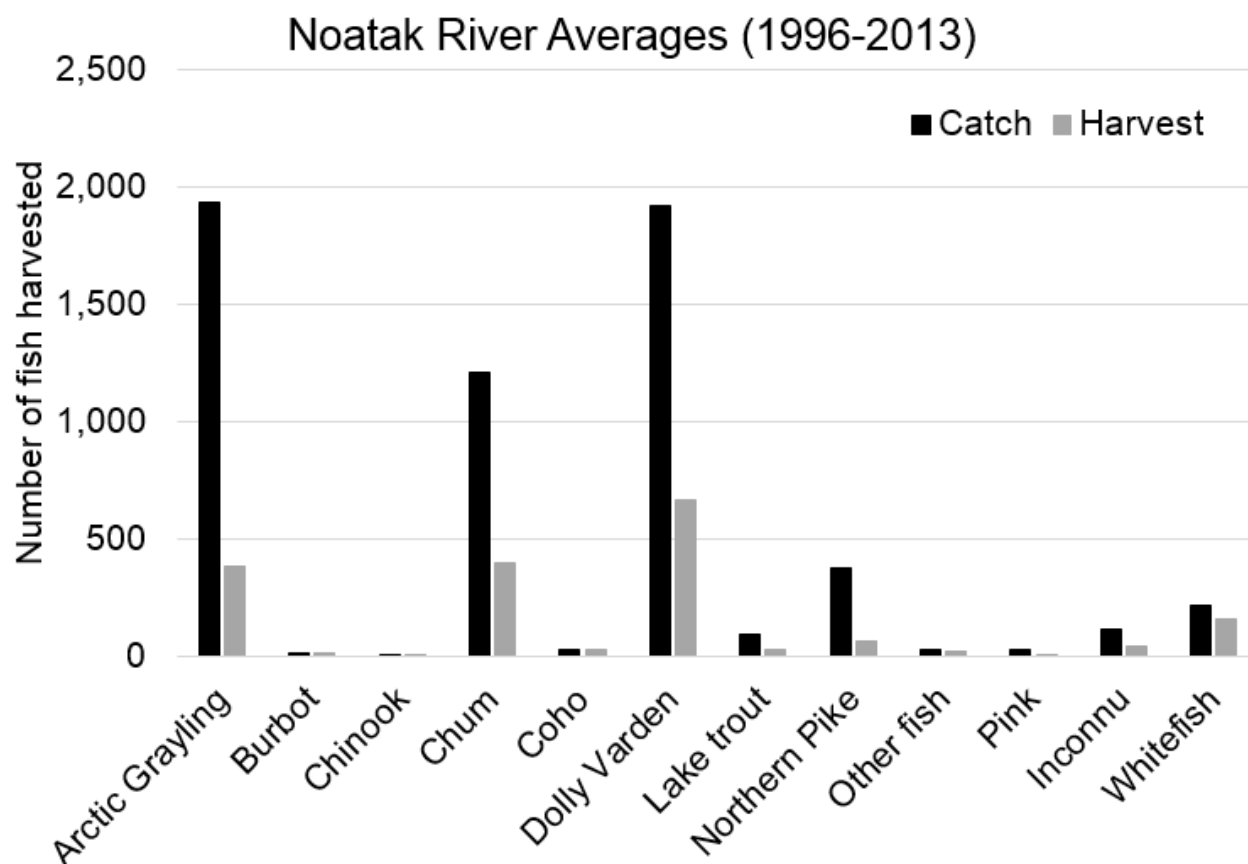


Figure E-51. Average annual catch and harvest by fish species in the Noatak River drainage. Dolly Varden includes Arctic char.

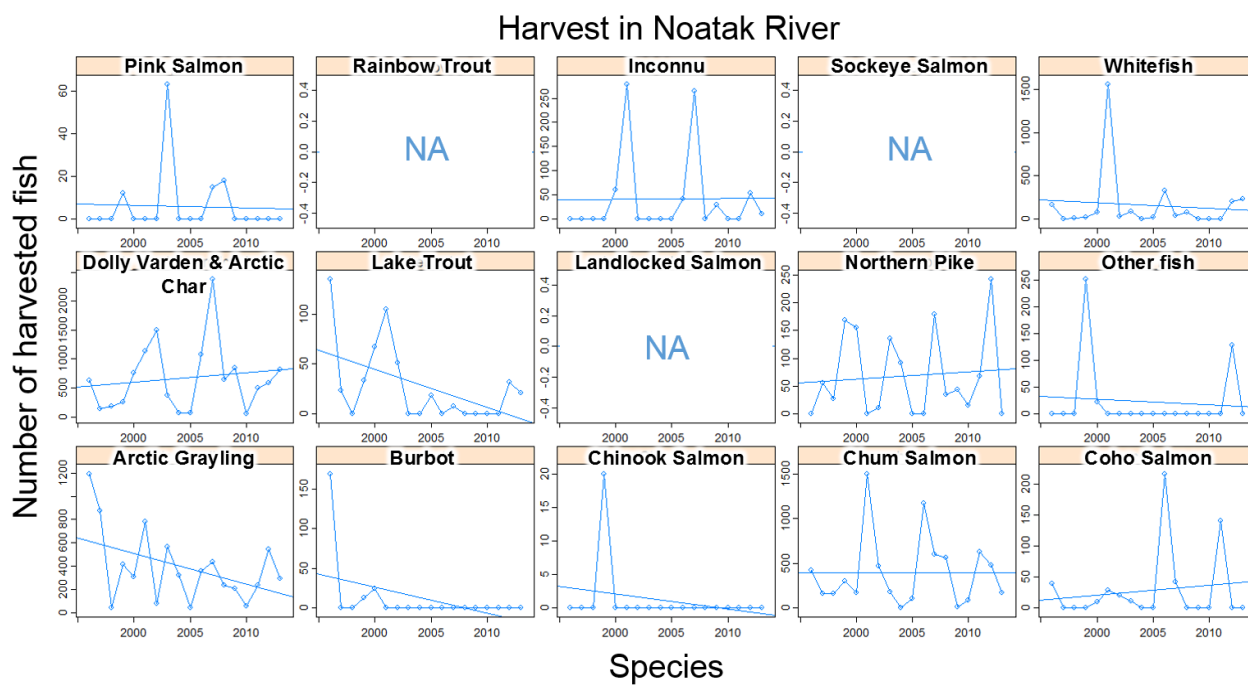


Figure E-52. Annual harvest trends by fish species in the Noatak River drainage.

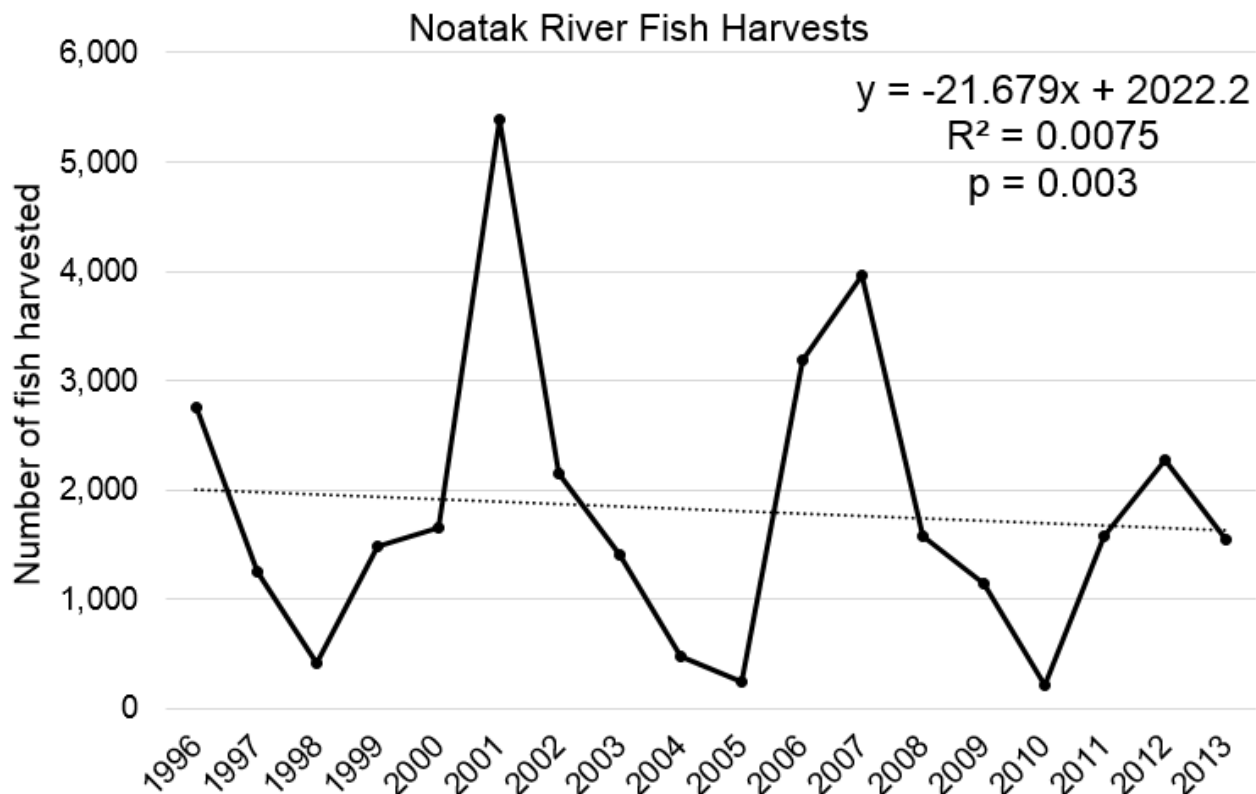


Figure E-53. Overall yearly fish harvest in the Noatak River drainage with trend line.

Kobuk River

On average, 9,103 fish are caught annually and 1,601 are harvested annually on the Kobuk River. The most commonly caught and harvested fish was Arctic grayling; inconnu were harvested in nearly equal amounts (Figure E-54). There was a significant decrease in harvest of Arctic grayling (Figure E-55; $p = 0.0112$). Overall, fish harvests on the Kobuk River have greatly decreased by 4%, or 22 fish per year (Figure E-56). Non-Alaskan residents harvested the most fish from the Kobuk River (5,173) followed by Shungnak residents (3,494). A sharp drop in 2005 was associated with a drop in Arctic grayling harvest by non-residents.

Kobuk River Averages (1996-2013)

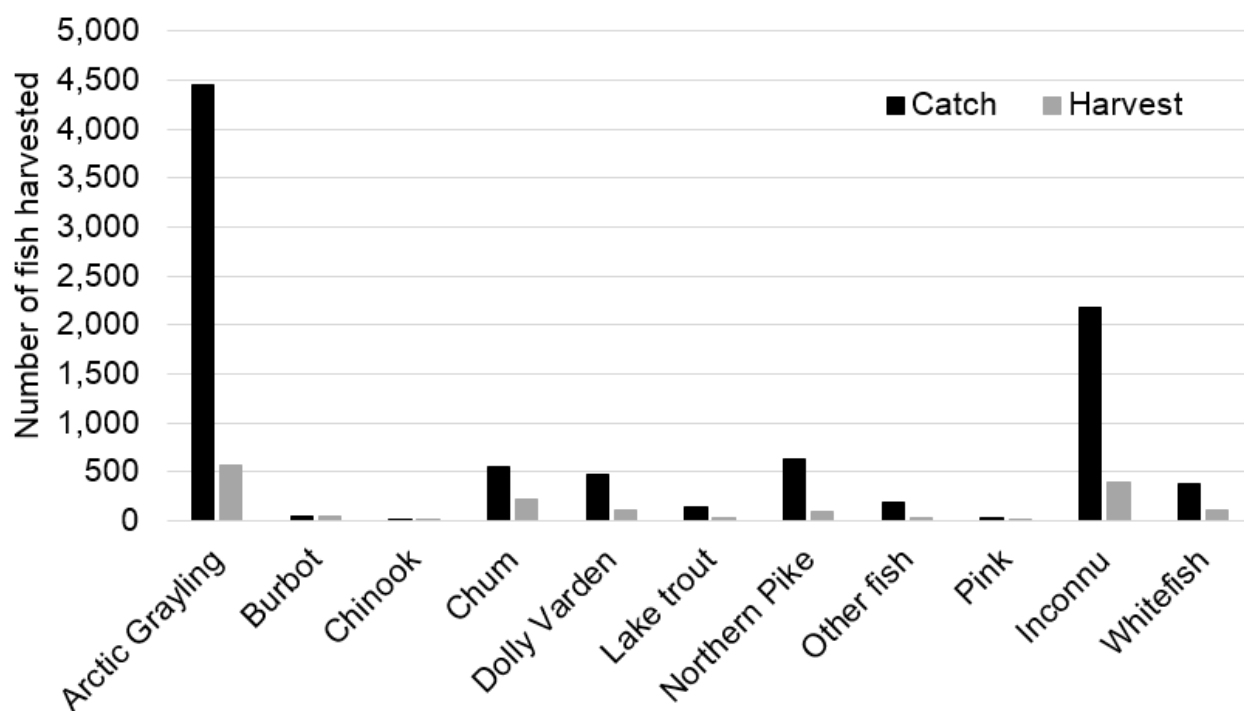


Figure E-54. Average annual catch and harvest by fish species in the Kobuk River drainage. Dolly Varden includes Arctic char.

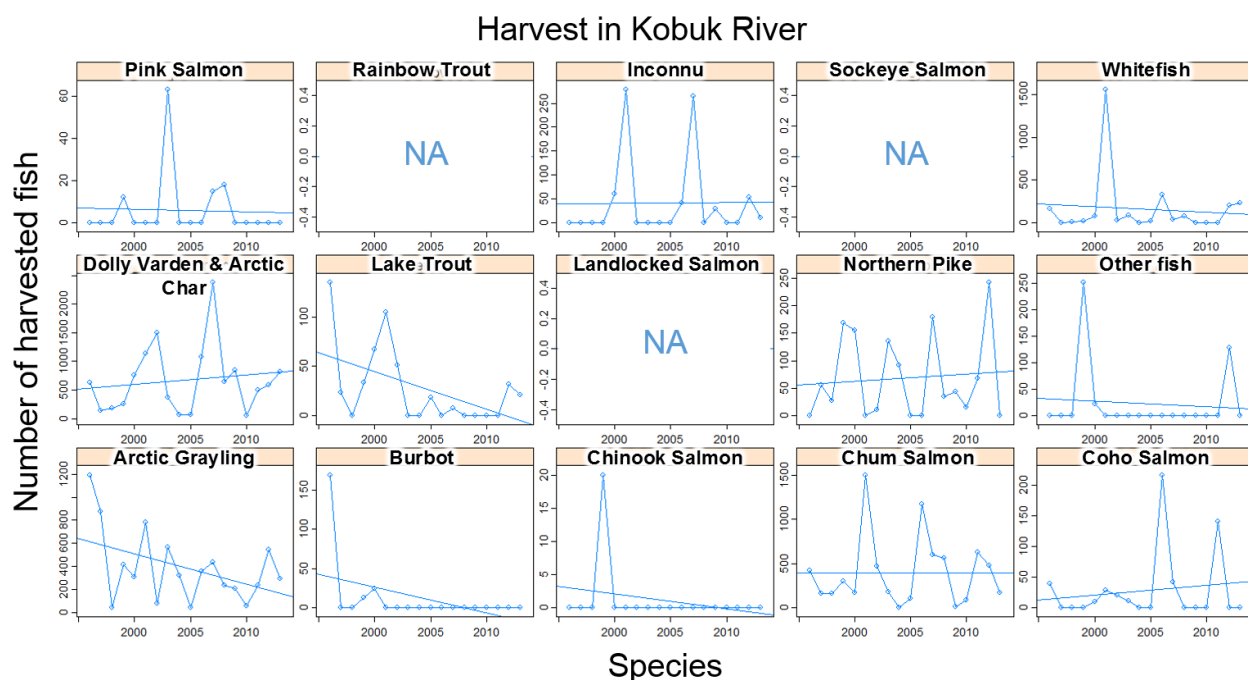


Figure E-55. Annual harvest trends by fish species in the Kobuk River drainage.

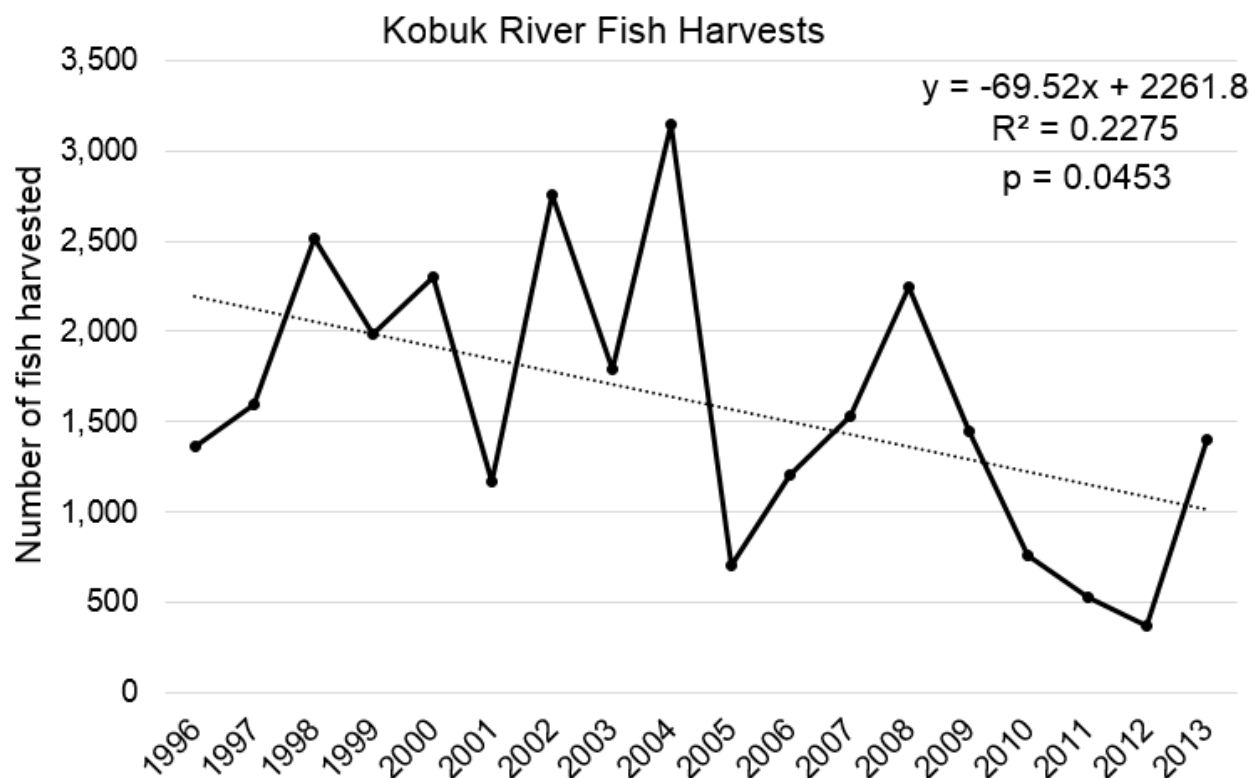


Figure E-56. Overall yearly fish harvest in the Kobuk River drainage.

Selawik River

On average 622 fish are caught annually and 195 are harvested annually on the Selawik River. The most commonly caught fish was Arctic grayling, but inconnu was the most commonly harvested (Figure E-57). Although there was a significant decline in inconnu harvests (Figure E-58), overall fish harvests on the Selawik River did not significantly decrease from 1996 to 2013 (Figure E-59). Residents of Selawik harvested the most fish (1,749) followed by Kotzebue (440 fish). Harvests by Selawik residents increased steadily until peaking in 2004 (495 fish) and then dropping to around 100 fish. Inconnu was the dominant species harvested by Selawik residents but harvest declined after 2000, with a brief increase in whitefish harvest in 2002, followed by a large spike in Northern pike harvest. No inconnu have been reported harvested since 2004.

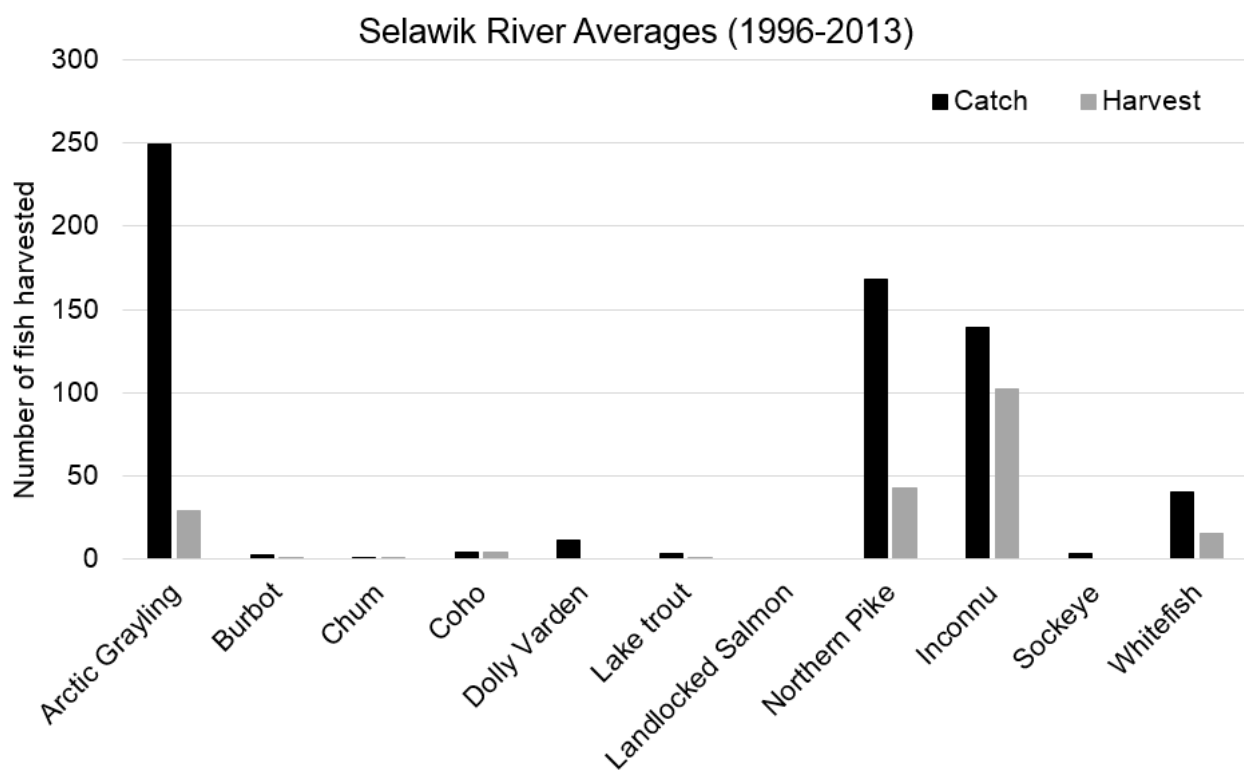


Figure E-57. Average annual catch and harvest by fish species in the Selawik River drainage. Dolly Varden includes Arctic char.

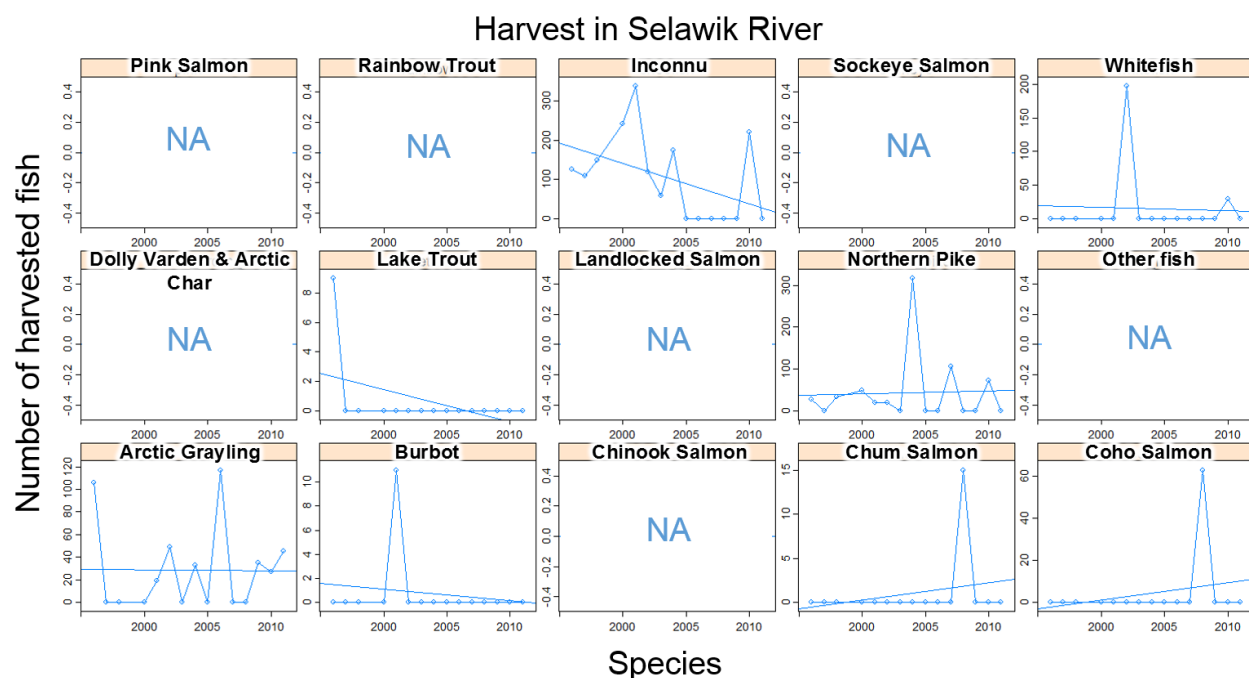


Figure E-58. Annual harvest trends by fish species in the Selawik River drainage.

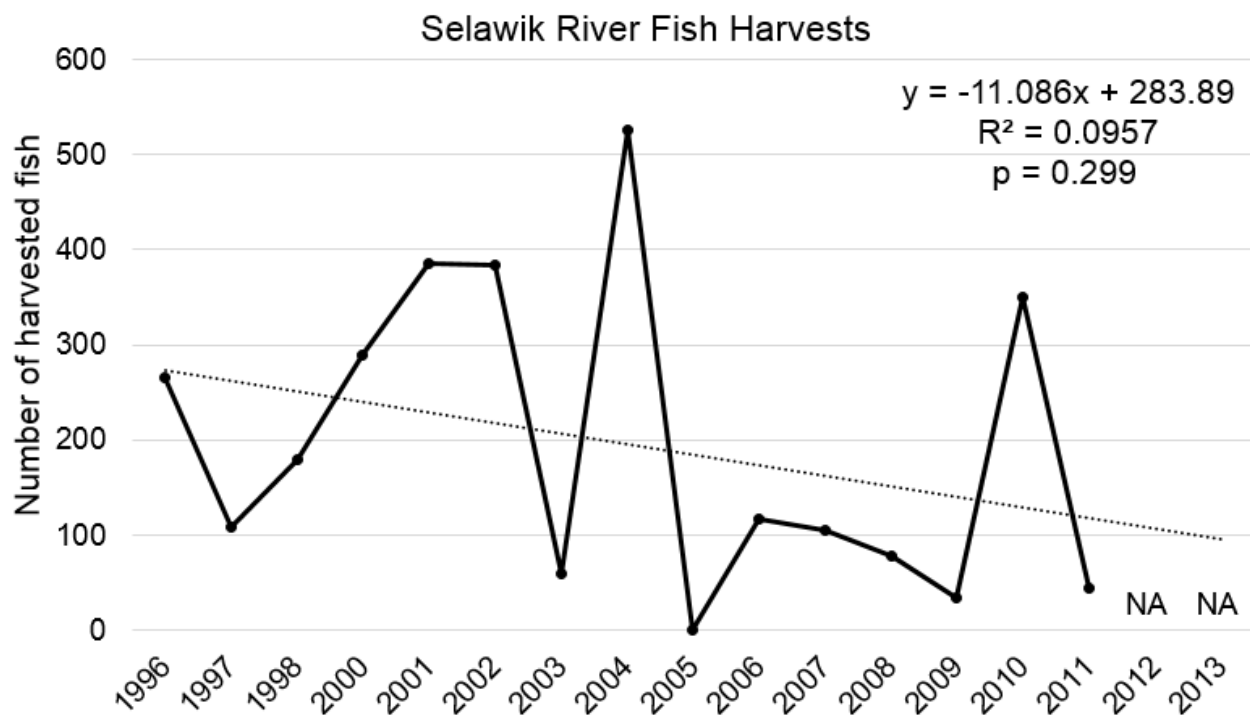


Figure E-59. Overall fish harvest in the Selawik River drainage.

Koyukuk River

On average, 4,524 fish are caught annually and 631 fish are harvested annually on the Koyukuk River. There was little diversity among species caught and harvested in the Koyukuk River by sport fishers with Arctic grayling dominating the catch and harvest (Figure E-60). No fish harvests significantly changed over the years (Figure E-61), and overall fish harvests on the Koyukuk River increased by 2% from 1996 to 2013 (Figure E-62). Non-residents harvested the most fish (4,686) followed by Fairbanks residents (2,088 fish). However, in 2008 and 2013, Kobuk residents harvested the majority of fish, which were Northern pike. Non-residents primarily harvested Arctic grayling.

Koyukuk River Averages (1996-2013)

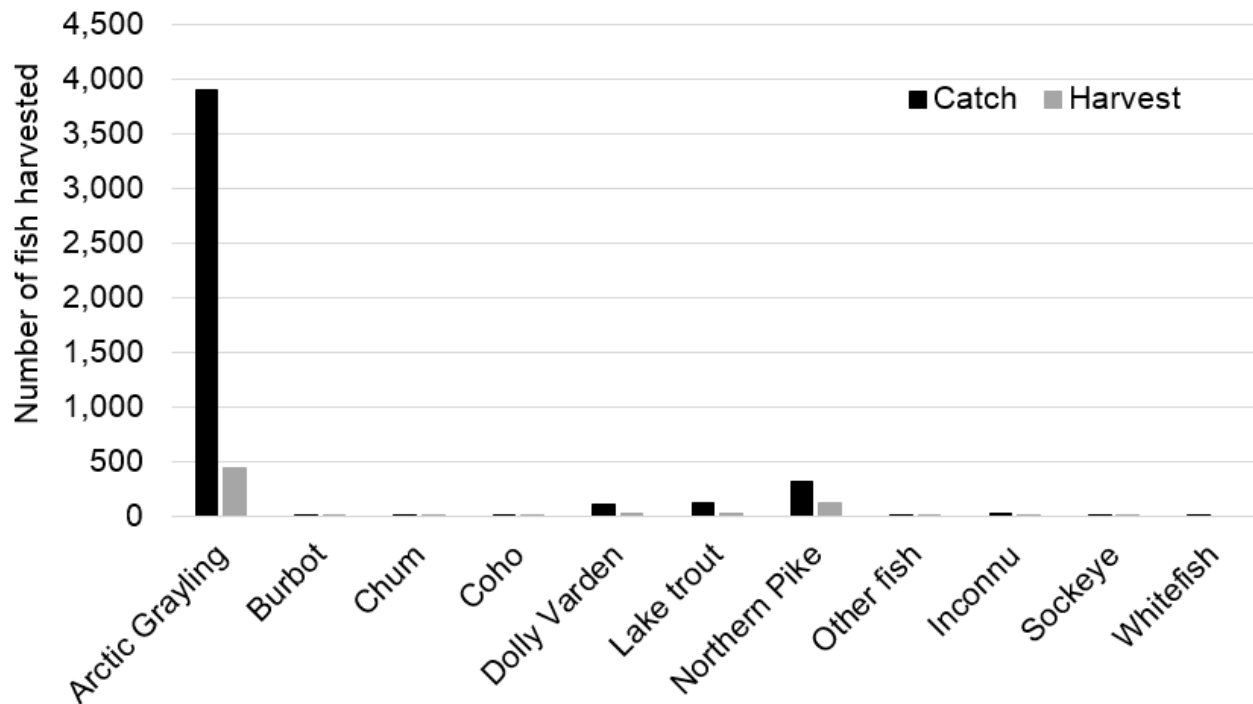


Figure E-60. Average annual catch and harvest by fish species in the Koyukuk River drainage. Dolly Varden includes Arctic char.

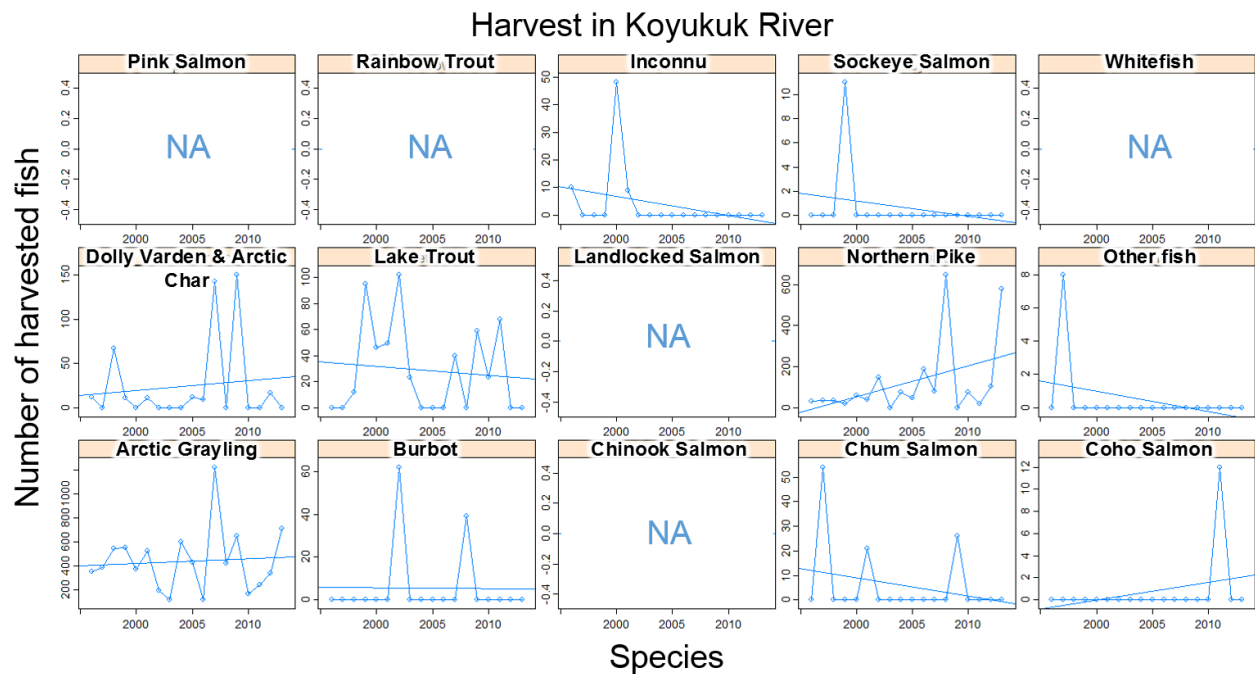


Figure E-61. Annual harvest trends by fish species in the Koyukuk River drainage.

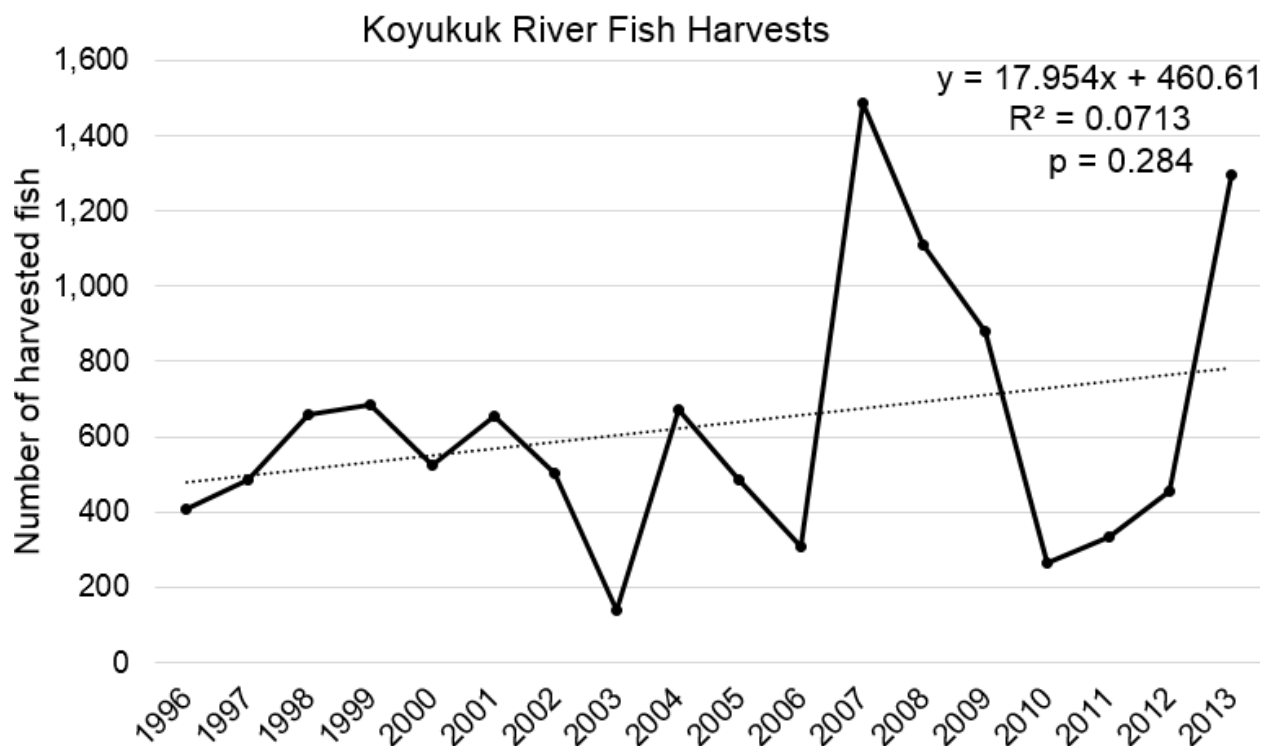


Figure E-62. Overall fish harvest in the Koyukuk River drainage.

Yukon River

On average, 898 fish are caught annually and 240 fish are harvested annually on the Yukon River. Arctic grayling dominated the catch, and both Arctic grayling and Northern pike were harvested the most (Figure E-63). There was a significant decline in four different fish species (Figure E-64): Arctic grayling ($p = 0.001$), Chinook ($p = 0.040$), Coho ($p = 0.298$), and Northern pike ($p = 0.026$). Overall, fish harvests on the Yukon River have greatly decreased by 7% or 131 fish per year (Figure E-65). Fairbanks residents harvested the most fish (11,850) followed by non-residents (6,874 fish). Harvest by Fairbanks residents was a mix among several species but Arctic grayling and Northern pike were the two most common. In 2004, harvest of Northern pike by Fairbanks residents spiked. Meanwhile, non-Alaskan residents primarily harvested Arctic grayling, but their numbers have decreased over the years with a peak in 2003.

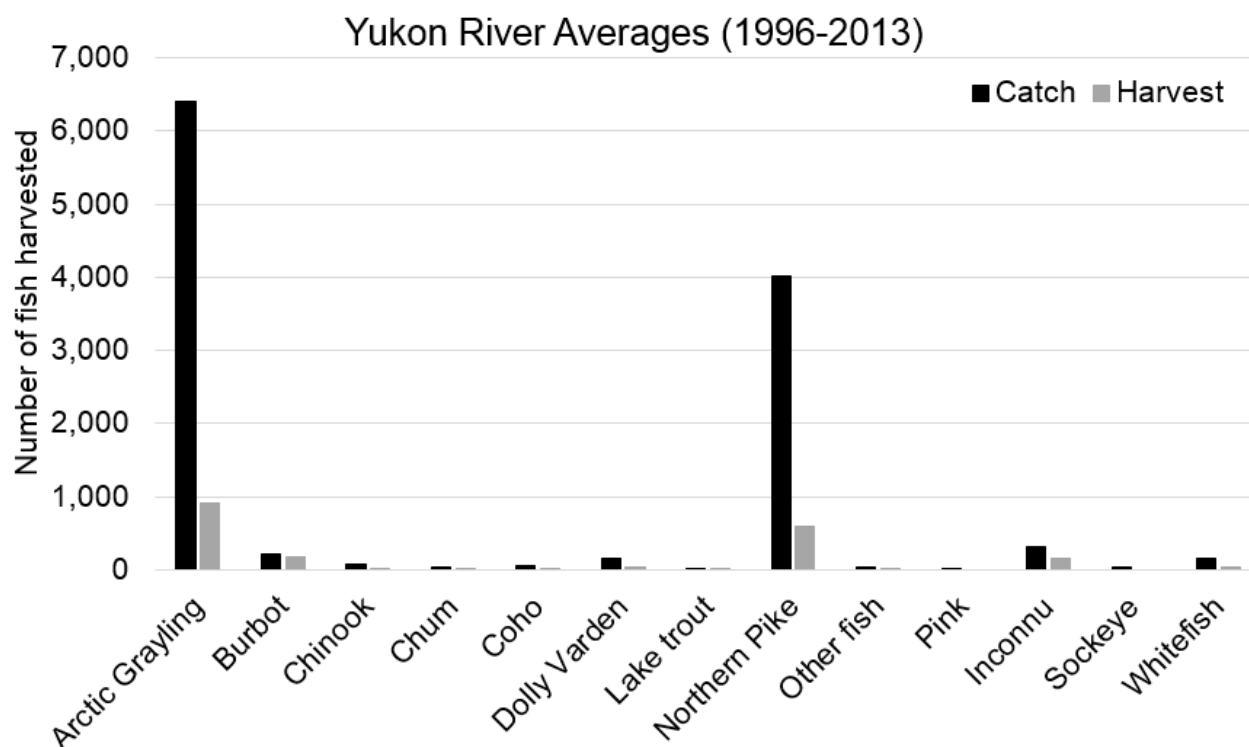


Figure E-63. Average annual catch and harvest by fish species in the Yukon River drainage. Dolly Varden includes Arctic char.

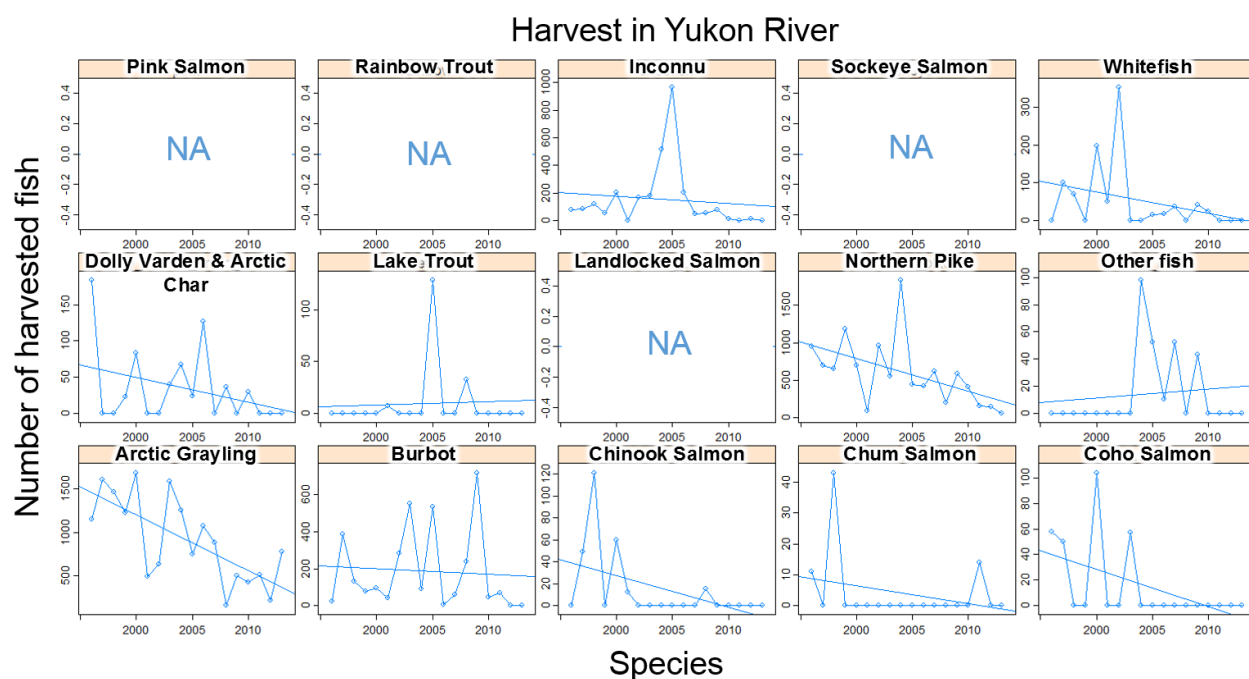


Figure E-64. Annual harvest trends by fish species in the Yukon River drainage.

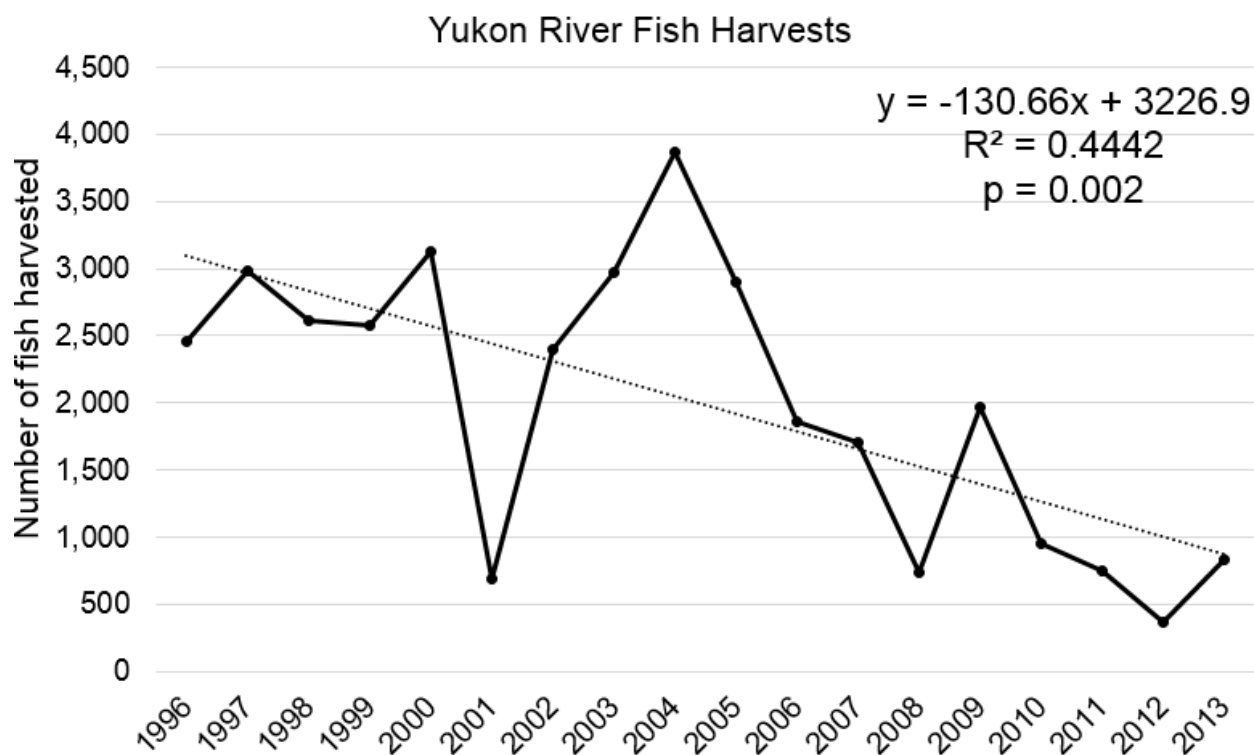


Figure E-65. Overall fish harvest in the Yukon River drainage.

Chandalar River

On average, 898 fish are caught annually, and 240 fish are harvested annually on the Chandalar River. Arctic grayling dominated the catch and harvest (Figure E-66), followed by lake trout, Northern pike, and Whitefish. No fish harvests drastically changed from 1996 to 2013 (Figure E-67, Figure E-68). The community with the most harvests was Coldfoot, which is primarily a truck stop with very few residents. Furthermore, all the harvests were in a single year, 1999, with whitefish, lake trout, and Northern pike as the top species harvested. Both Fairbanks residents and non-residents primarily targeted Arctic grayling.

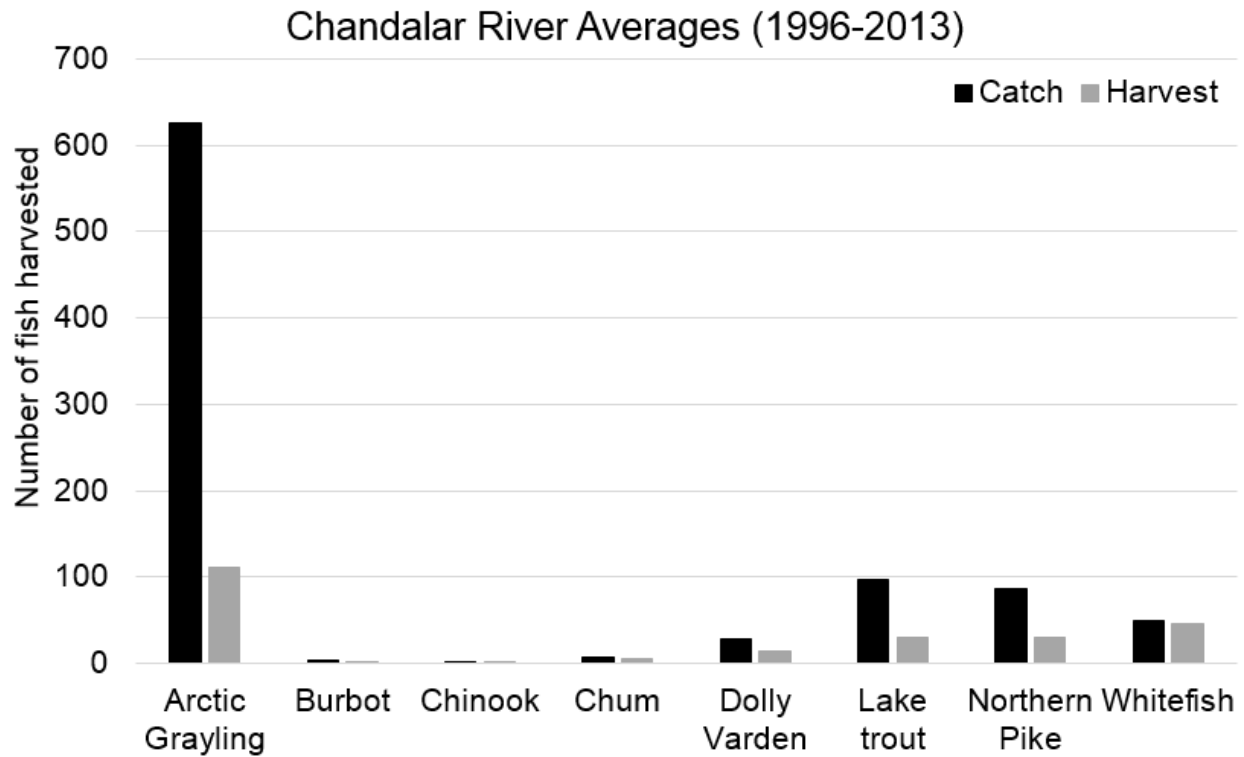


Figure E-66. Average annual catch and harvest by fish species in the Chandalar River drainage. Dolly Varden includes Arctic char.

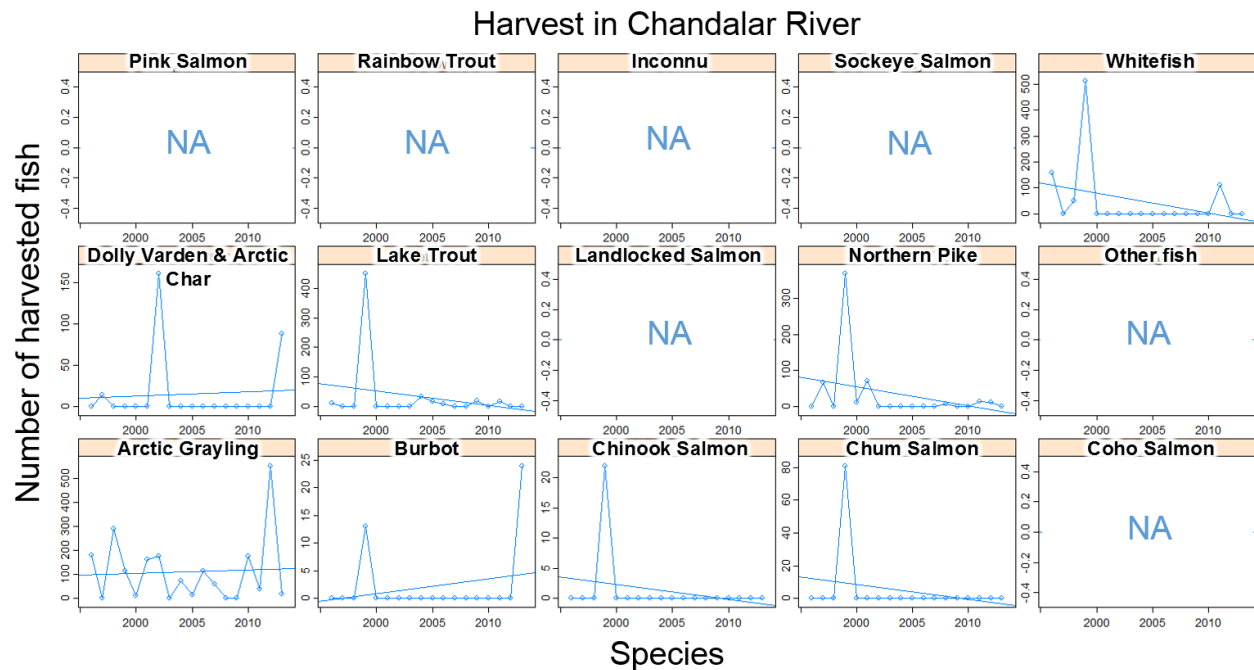


Figure E-67. Annual harvest trends by fish species in the Chandalar River drainage.

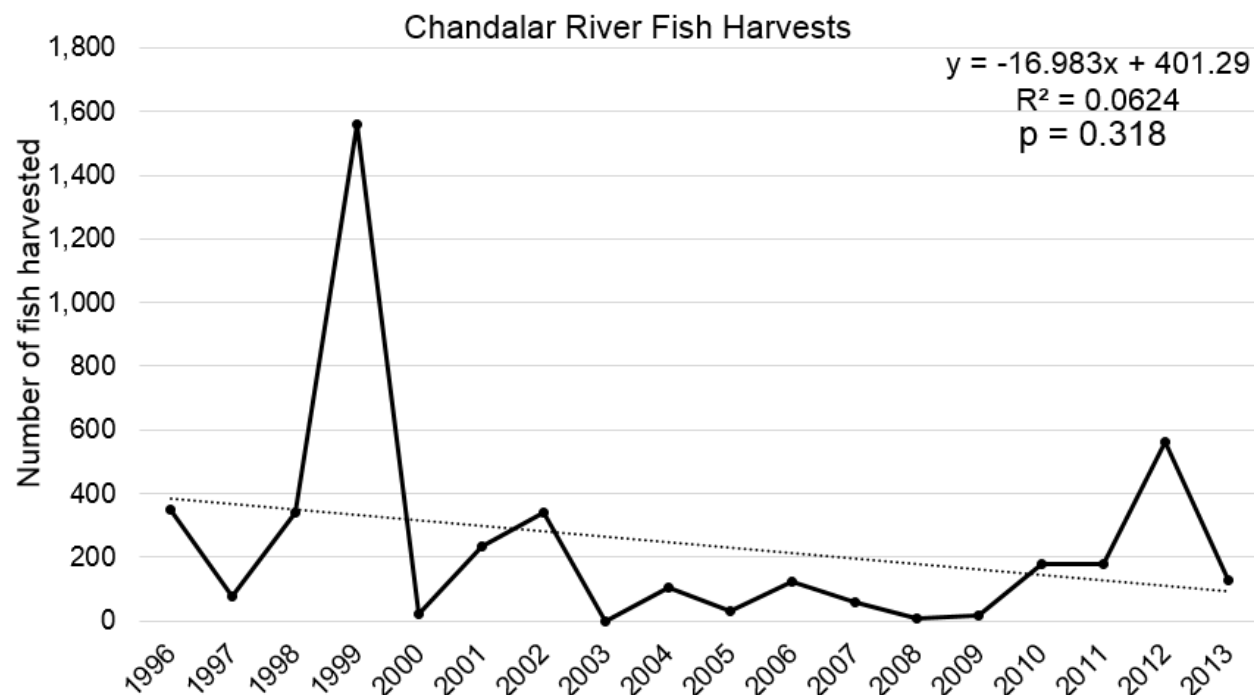


Figure E-68. Overall fish harvest in the Chandalar River drainage.

Porcupine River

Arctic grayling dominated the catch and harvest on the Porcupine River (Figure E-69). Anglers have started to harvest lake trout in the last few years (Figure E-70). No fish harvests significantly changed from 1996 to 2013, however, there are episodic spikes in harvest among the species (Figure E-71). Reasons for this are unknown but certainly availability of fish and interest by anglers play a factor. Non-residents harvested the most fish (4,541) from the Porcupine River, followed by Fort Yukon residents (1,720). Non-residents primarily harvested Arctic grayling and there was a spike in 2013. Most of the Fort Yukon harvests came during 2002 with a near equal harvest of burbot and Northern pike.

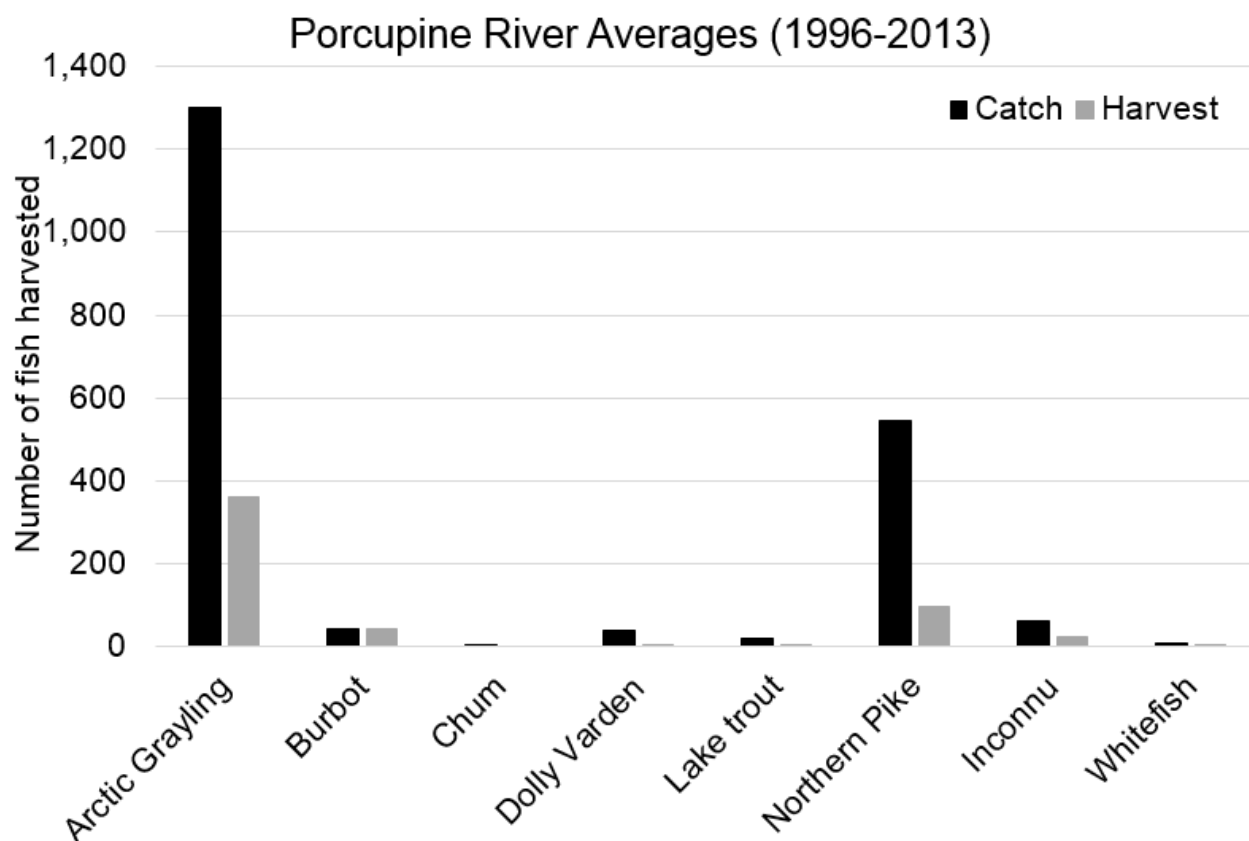


Figure E-69. Average annual catch and harvest by fish species in the Porcupine River drainage. Dolly Varden includes Arctic char.

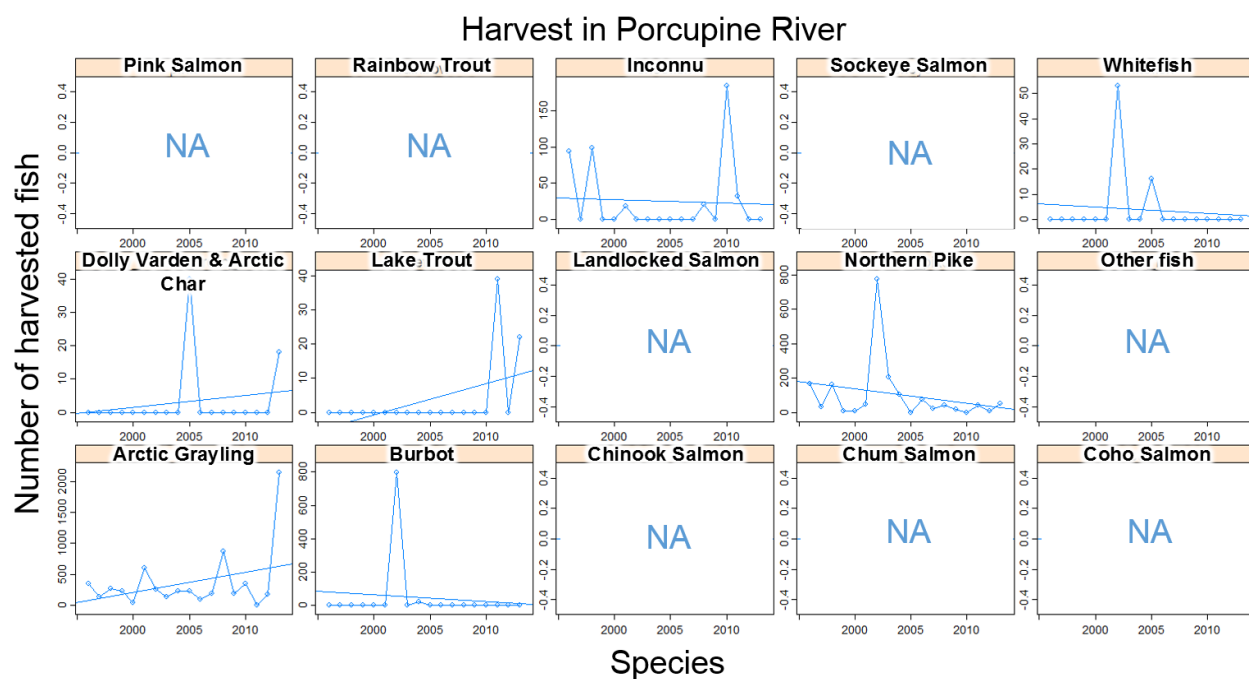


Figure E-70. Annual harvest trends by fish species in the Porcupine River drainage.

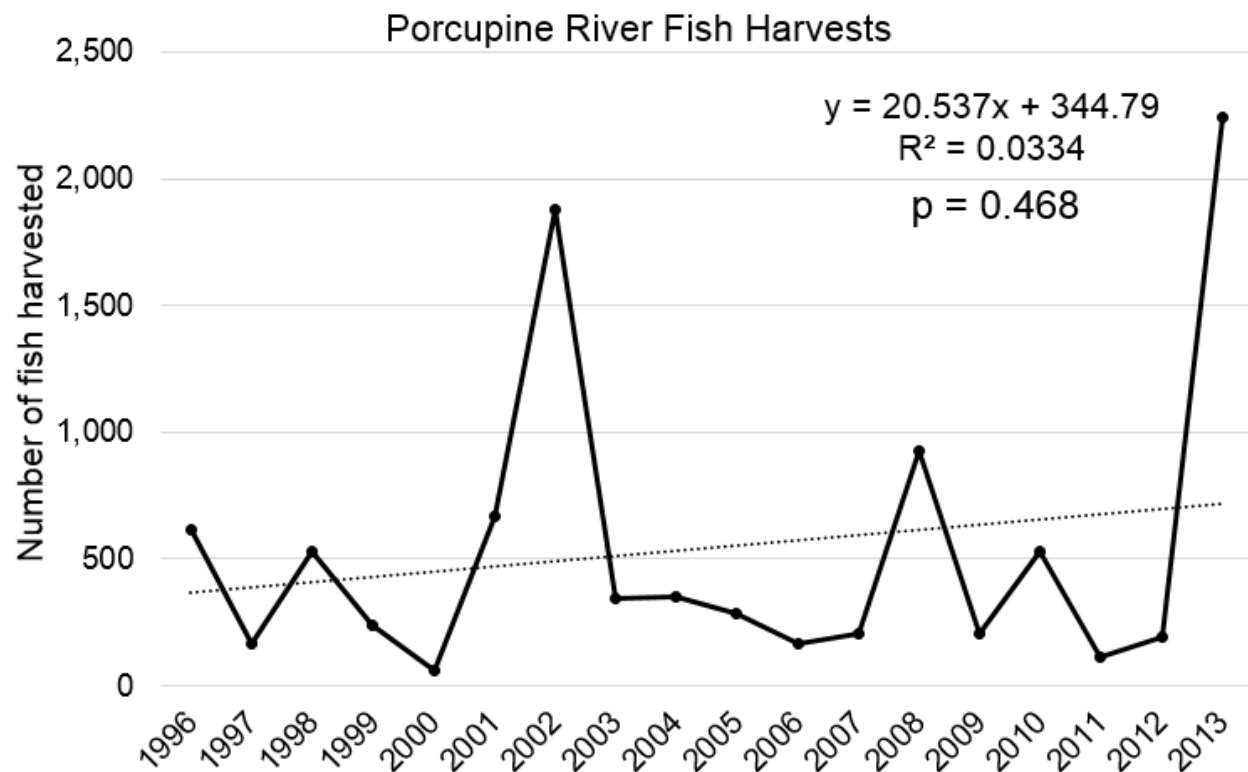


Figure E-71. Overall fish harvest in the Porcupine River drainage.

Birch Creek

Arctic grayling dominated the catch and harvest on Birch Creek (Figure E-72). Anglers harvested whitefish in 2008 for the first time and then in larger numbers in 2010 (Figure E-73). No fish harvests significantly changed from 1996 to 2013 (Figure E-73, Figure E-74). Fairbanks residents were the predominate anglers in Birch Creek (1,395 fish), followed by residents of Central (866 fish). Most harvests by Fairbanks residents were of Arctic grayling, but there was a spike in harvest of Northern pike in 2013. However, in 2008 Central residents harvested a large number of Northern pike (240) and Arctic grayling (198).

Birch Creek Averages (1996-2013)

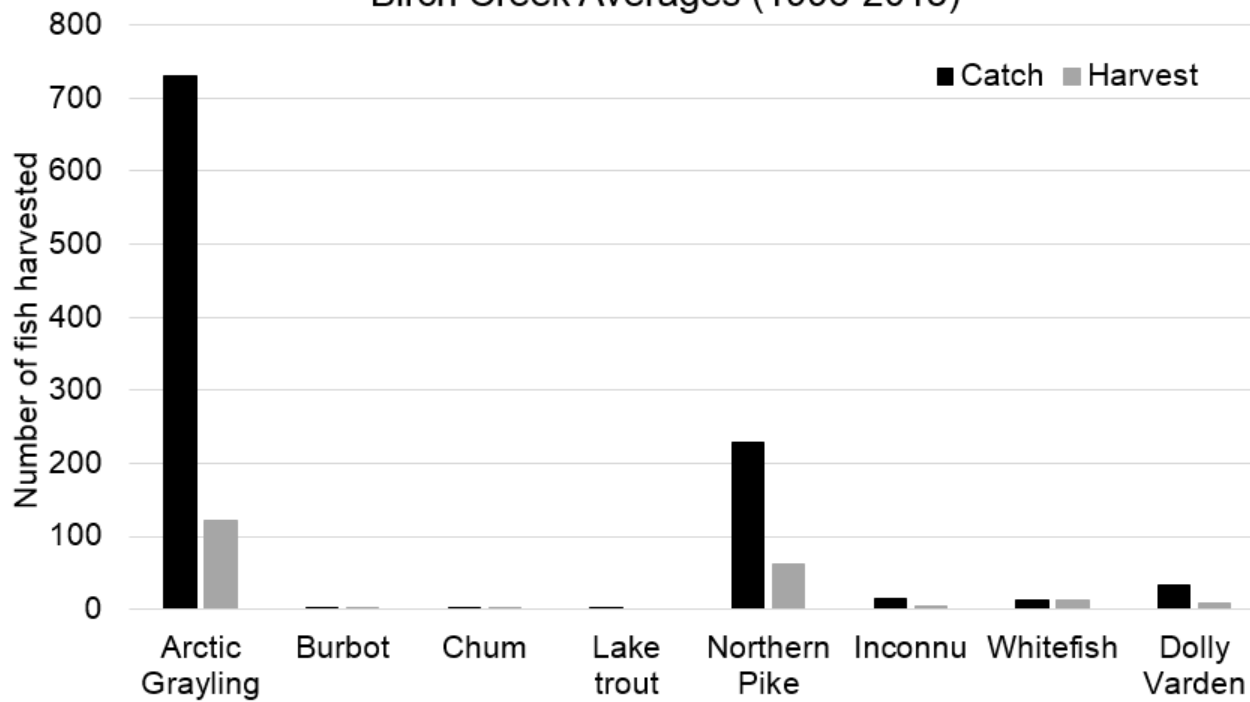


Figure E-72. Average annual catch and harvest by fish species in the Birch Creek drainage. Dolly Varden includes Arctic char.

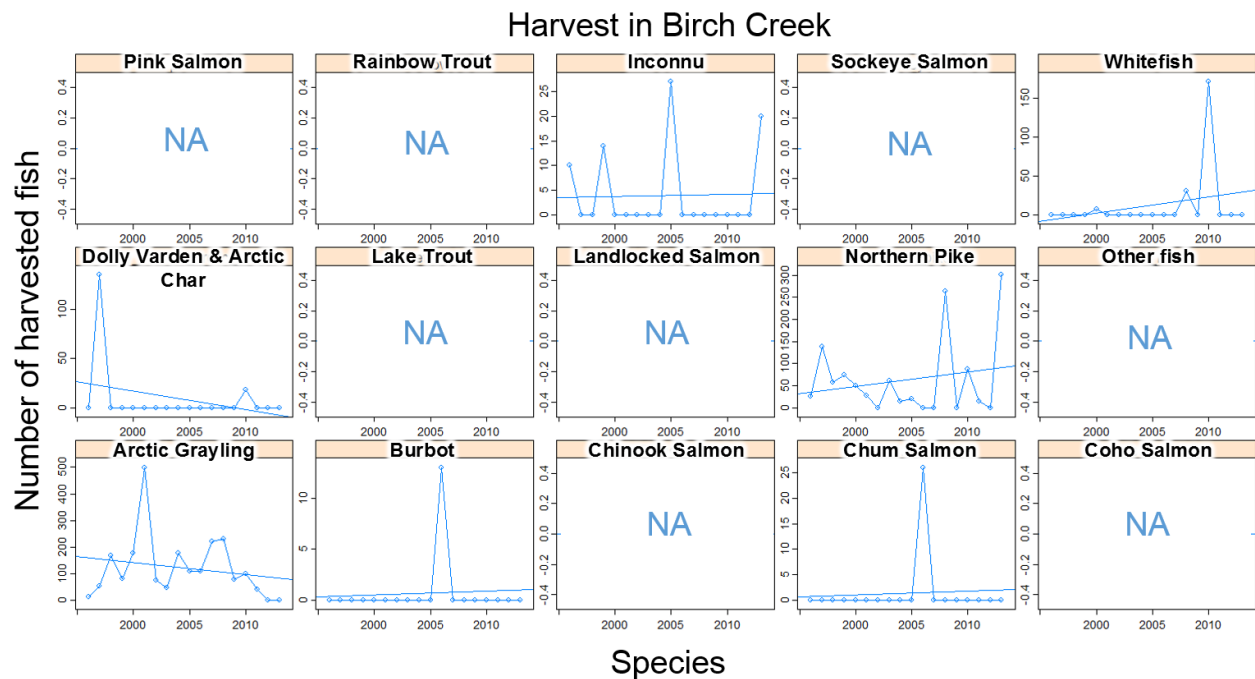


Figure E-73. Annual harvest trends by fish species in the Birch Creek drainage.

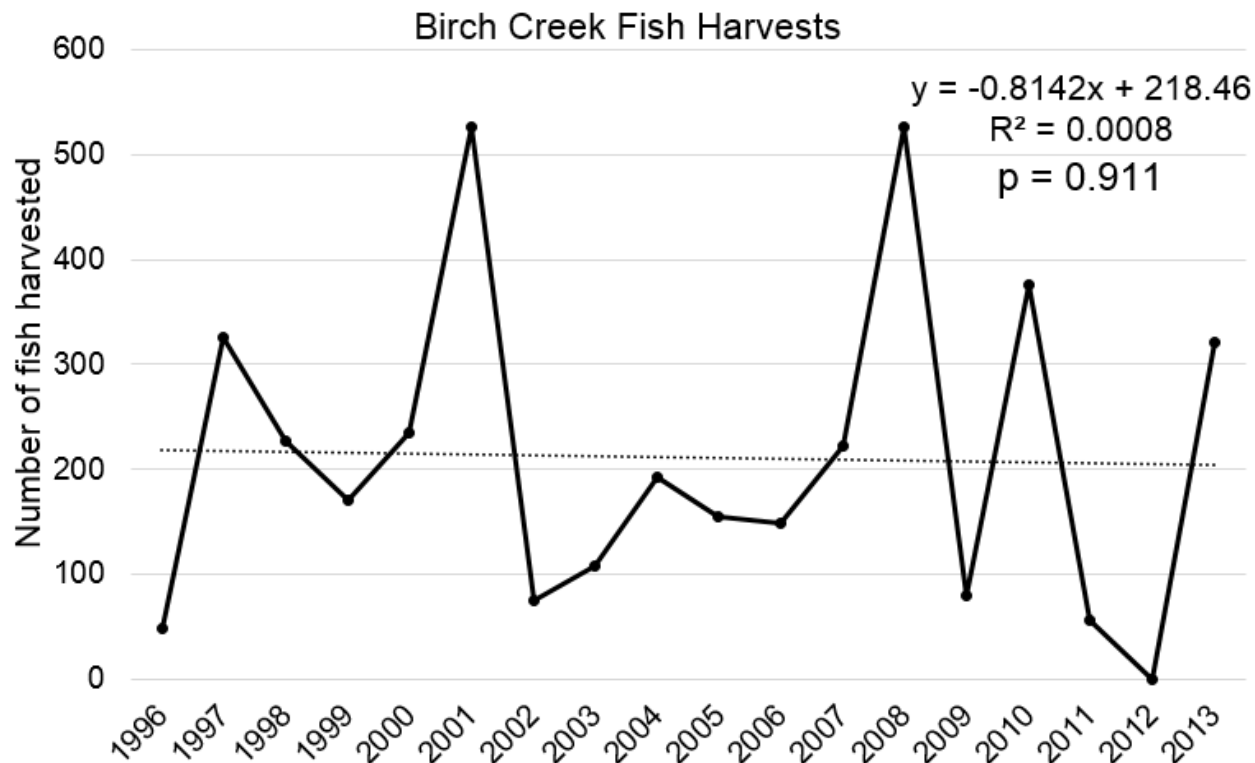


Figure E-74. Overall fish harvest in the Birch Creek drainage.

Chatanika River

Arctic grayling dominated the catch, but harvest was nearly equal between Arctic grayling and Northern pike on the Chatanika River (Figure E-75). Like in Birch Creek, Whitefish has become more popular in recent years. There was a significant increase in the number of whitefish harvested ($p = 0.008$), but a significant decrease in Arctic grayling ($p = 0.046$), Chinook ($p = 0.031$), and Northern pike ($p = 0.050$) (Figure E-76). Overall, fish harvests on the Chatanika River greatly decreased by 7% or 217 fish per year (Figure E-77). Fairbanks residents harvested the most fish (31,125) and 15 different species. There was a spike in rainbow trout harvest in 1999 (3,551) and in 2004 (1,531). Non-residents harvested Arctic grayling, rainbow trout, and Northern pike with a spike in grayling harvests in 2002 (840).

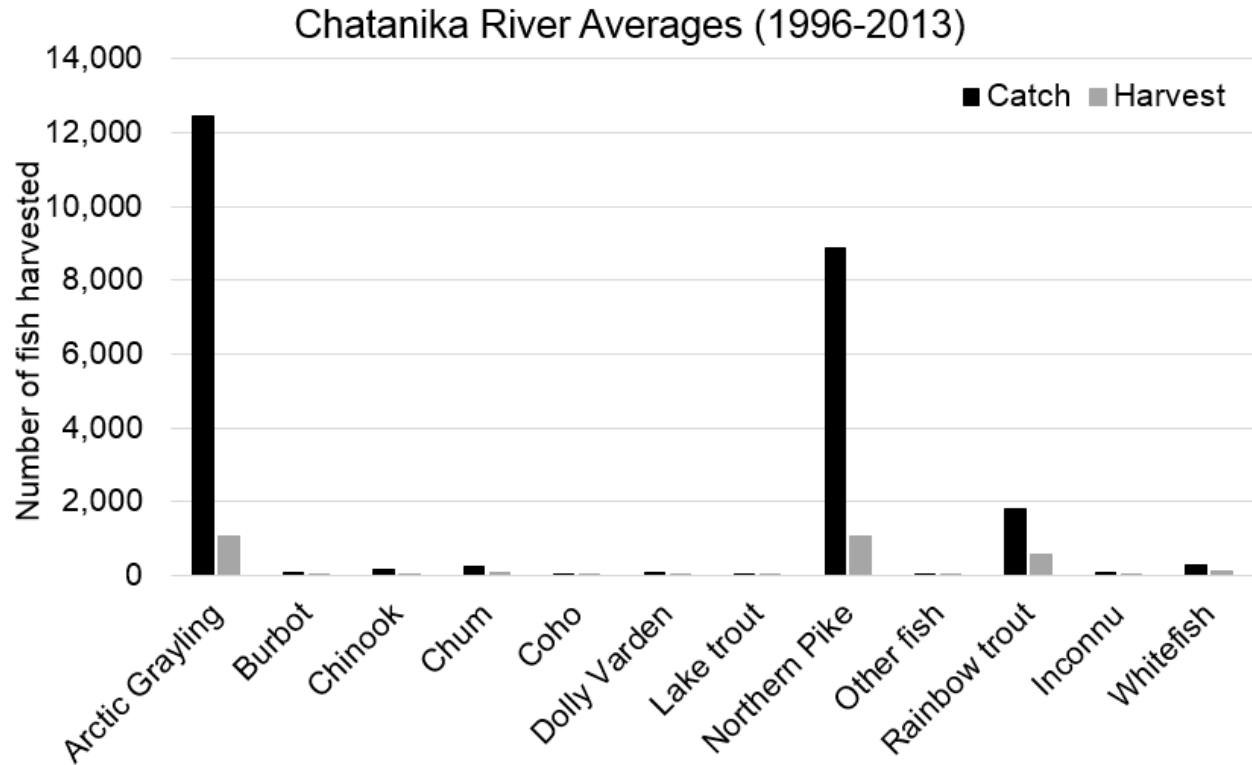


Figure E-75. Average annual catch and harvest by fish species in the Chatanika River drainage. Dolly Varden includes Arctic char.

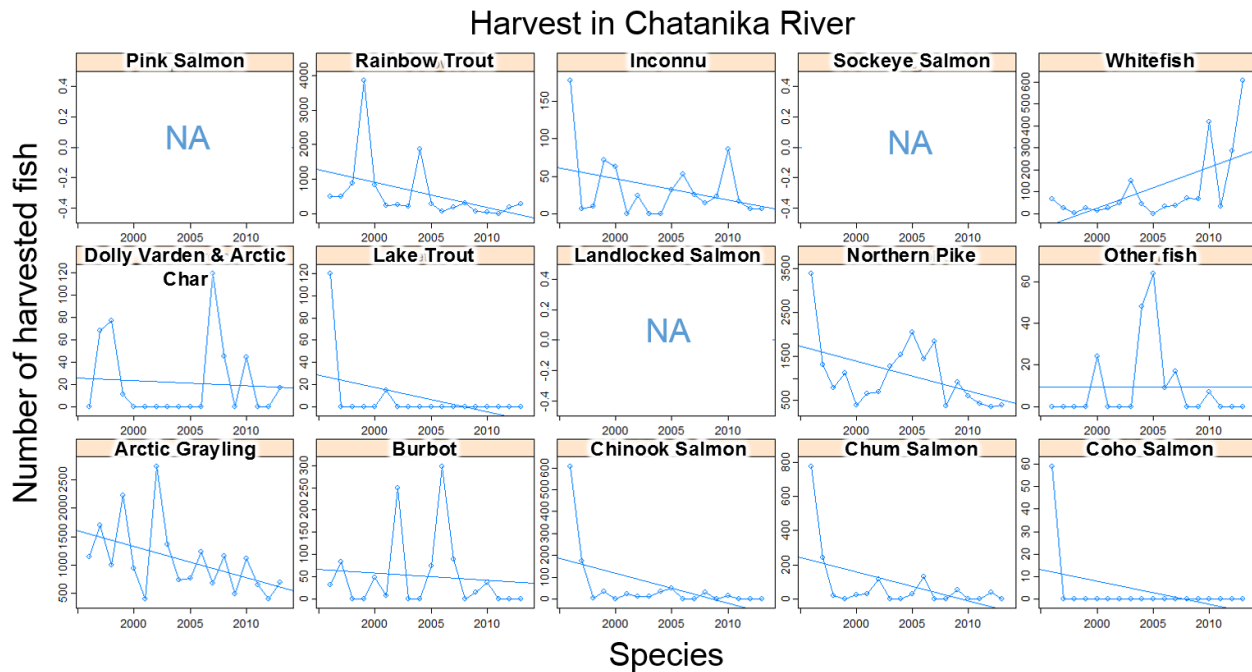


Figure E-76. Annual harvest trends by fish species in the Chatanika River drainage.

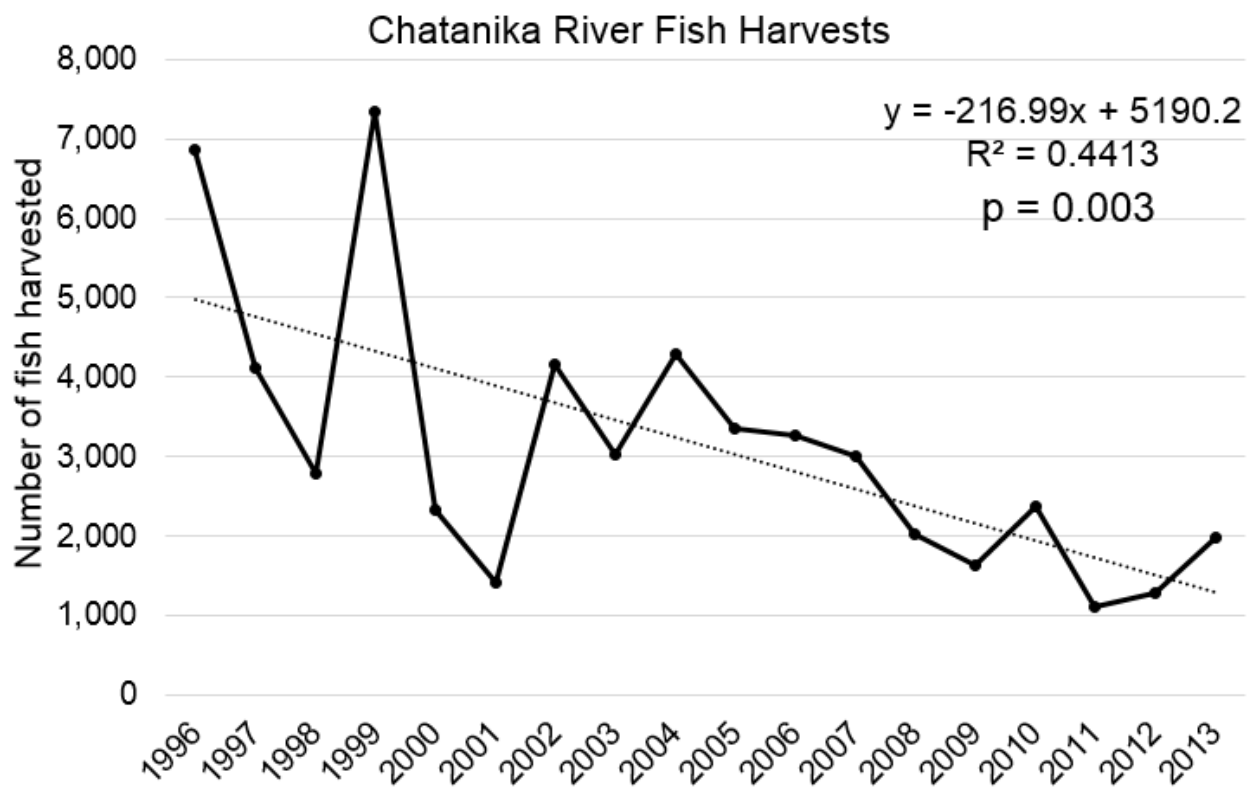


Figure E-77. Overall fish harvest in the Chatanika River drainage.

Chena River

Arctic grayling dominated the catch, but harvest was predominately of rainbow trout on the Chena River (Figure E-78). Like on Birch Creek and the Chatanika River, whitefish has become more popular in recent years. There was a significant decrease in a number of fish harvests (Figure E-79) including Arctic grayling ($p = 0.049$), Burbot ($p = 0.028$), Chinook salmon ($p = 0.031$), Chum salmon ($p = 0.031$), and rainbow trout ($p < 0.001$). Overall, fish harvests on the Chena River greatly decreased by 6% or 611 fish per year (Figure E-80). Fairbanks and North Pole residents harvested the most fish at 86,935 and 44,437 fish, respectively. Fairbanks residents primarily harvested rainbow trout while North Pole residents harvested both rainbow and landlocked salmon. The peak in 2002 was due to a large increase in harvest by North Pole residents, especially of landlocked salmon. Fairbanks residents slightly contributed to the increased harvests of landlocked salmon between 2001 and 2004.

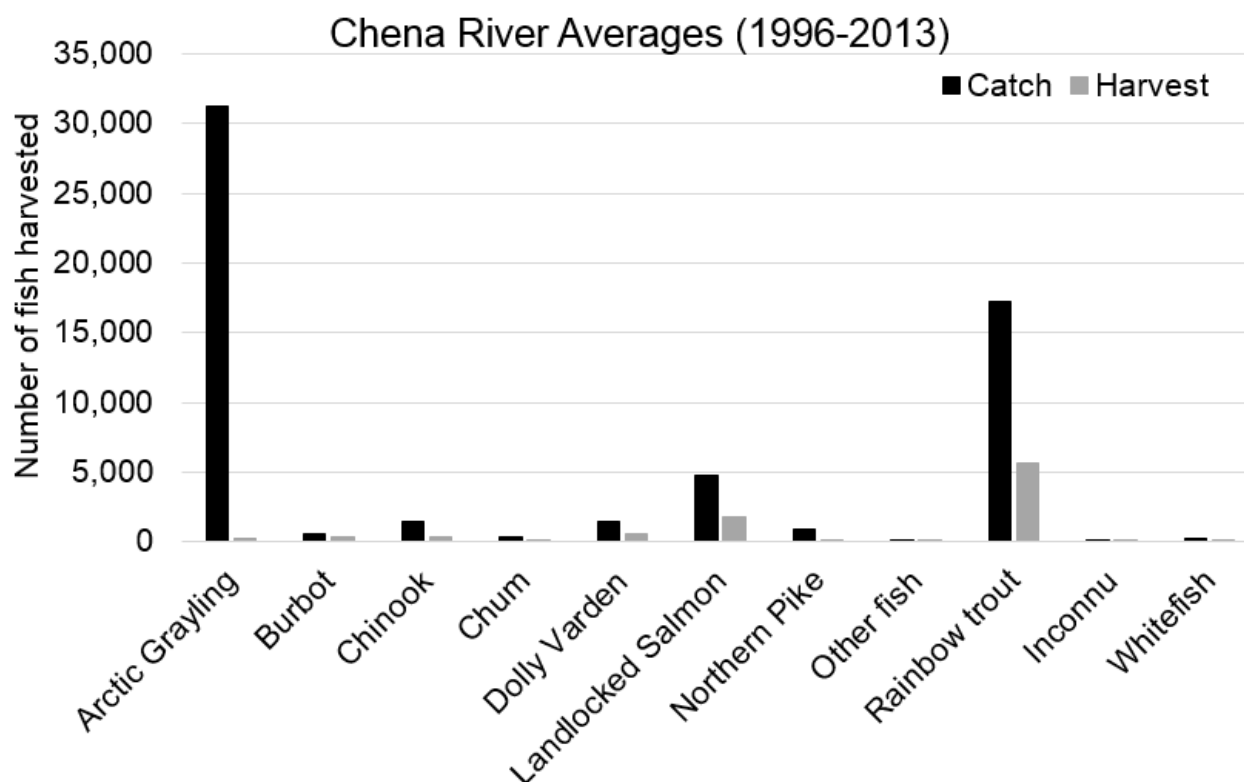


Figure E-78. Average annual catch and harvest by fish species in the Chena River drainage. Dolly Varden includes Arctic char.

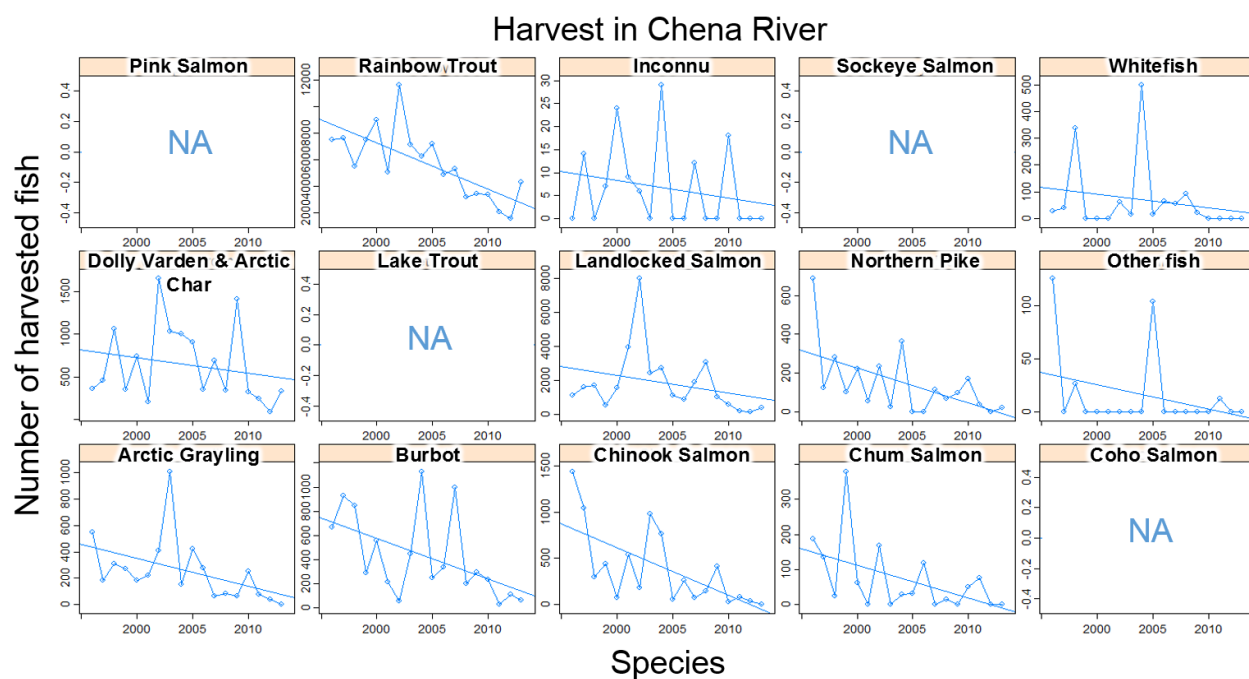


Figure E-79. Annual harvest trends by fish species in the Chena River drainage.

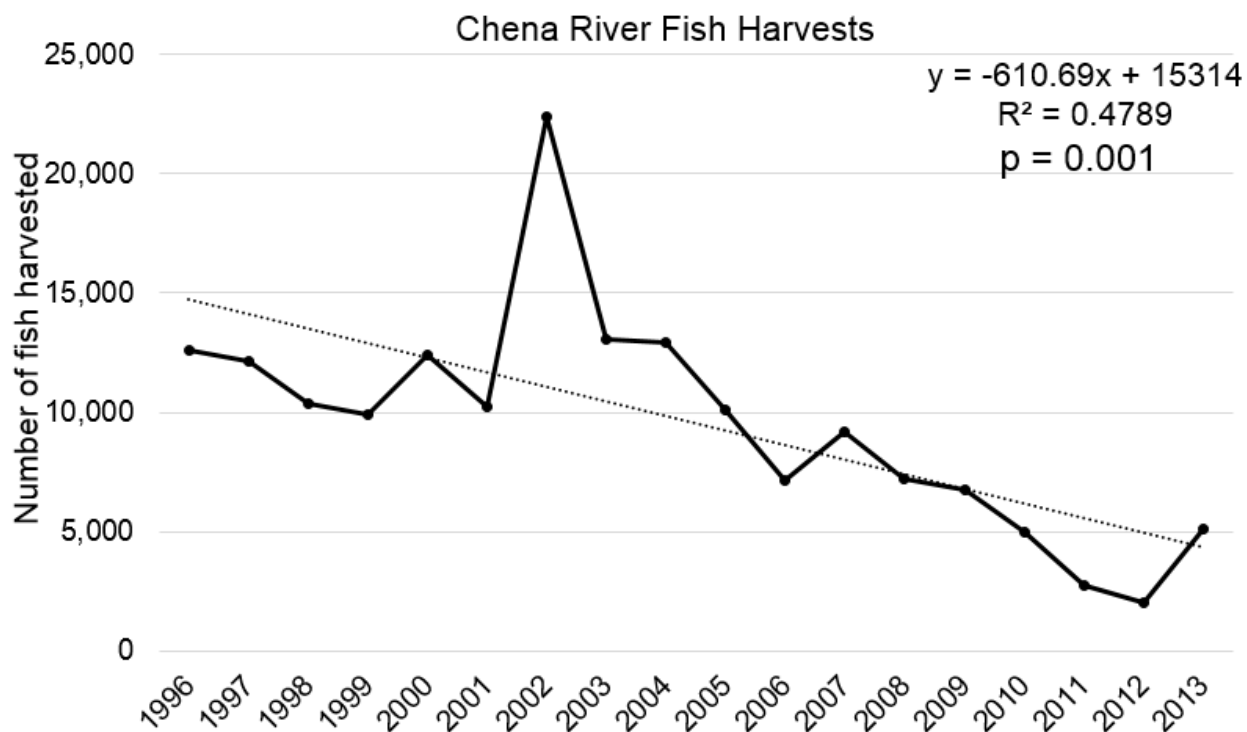


Figure E-80. Overall fish harvest in the Chena River drainage.

Tanana River

The Tanana River was the only river in the CYR study area where rainbow trout dominated the catch and harvest (Figure E-81). However, there were significant decreases in harvest for over half ($n = 8$) of the species with data (Figure E-84): Arctic grayling ($p < 0.001$), Burbot ($p = 0.007$), Chinook salmon ($p = 0.035$), Coho salmon ($p = 0.031$), Dolly Varden ($p = 0.002$), landlocked salmon ($p < 0.001$), Northern pike ($p = 0.028$), and rainbow trout ($p < 0.001$) (Figure E-82). Overall, fish harvests on the Tanana River significantly decreased by 10% or 3,104 fish per year (Figure E-83). Fairbanks residents harvested the most fish (224,546) followed by North Pole residents (88,081). The overall harvest trend in the Tanana River is driven by residents of Fairbanks and their harvest of rainbow trout and landlocked salmon. There was a small spike in Arctic grayling harvests in 2009.

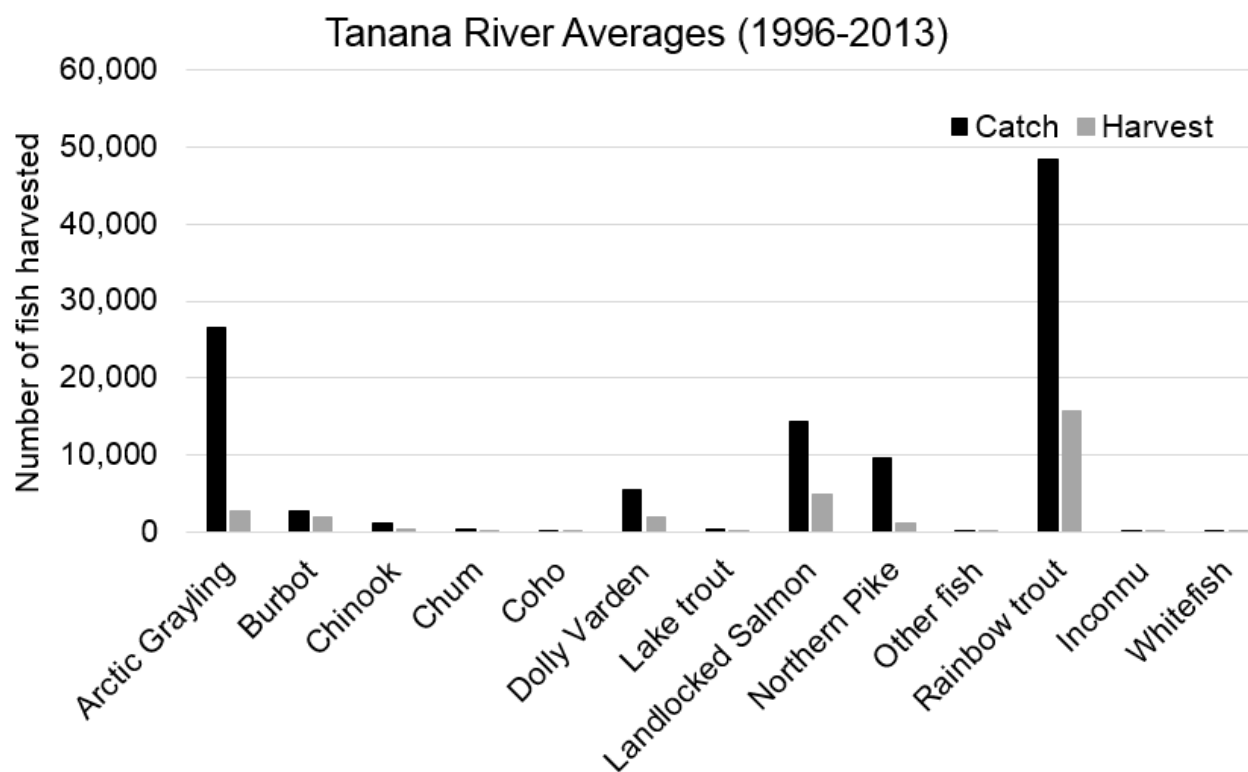


Figure E-81. Average annual catch and harvest by fish species in the Tanana River drainage. Dolly Varden includes Arctic char.

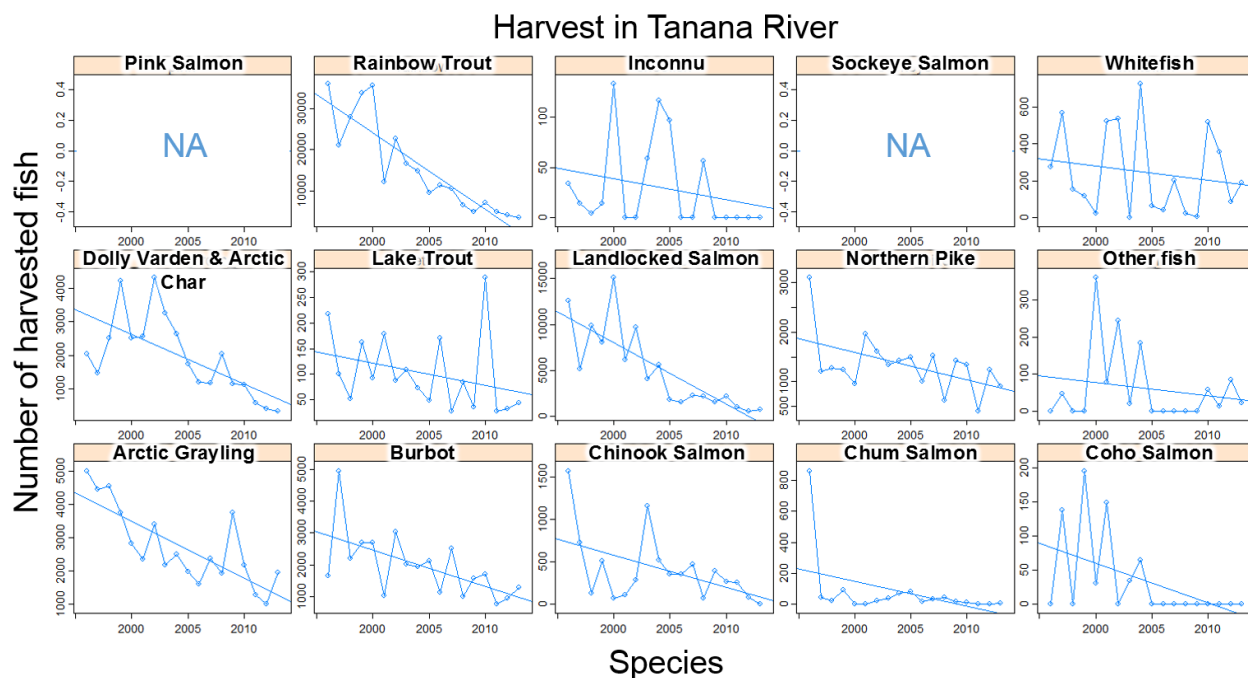


Figure E-82. Annual harvest trends by fish species in the Tanana River drainage.

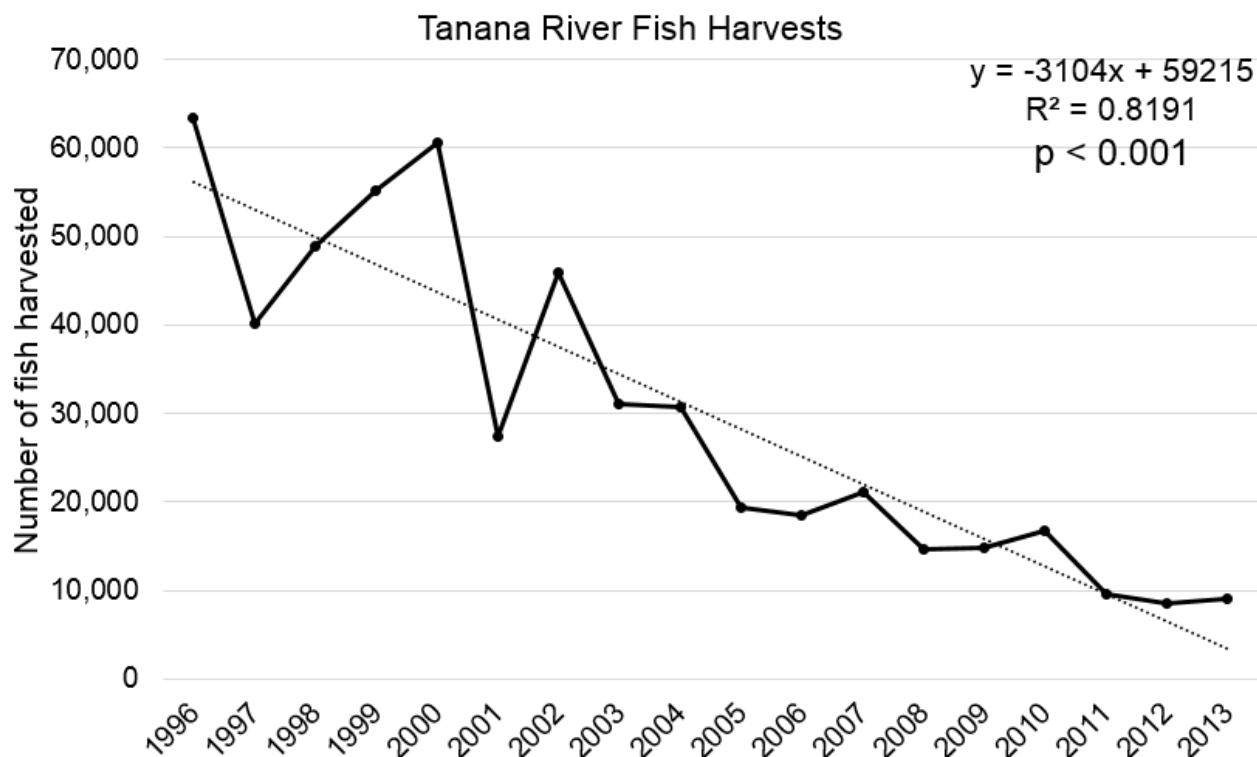


Figure E-83. Overall fish harvest in the Tanana River drainage.

3.6 Natural resource extraction

Placer mining, primarily for gold, has a long history in Alaska dating back to the 1890s and the gold rush. Most gold occurs in the sand and gravel bars of rivers and streams. Since gold is heavier than most other sediments in the water, it settles to the bottom making 90% of the recovered gold found in the lower 3 feet of gravel (USGS 1998). Birch Creek, the Forty Mile, and Yukon rivers have long been hotbeds for placer mining (Figure E-84). In 1984, there were mines along Gold Creek near Central (OMD 1985). According to the Alaska Resource Data File, 20 and 24 historic mines out of 368 occurred within federal- and state-protected areas, respectively. Currently, 19 mines out of 104 occur within state-protected lands, with most ($n = 16$) occurring within the Dalton highway corridor. The other three are in the Tanana Valley State Forest. Only two out of the 104 mines occur on federal protected lands and are located within the Yukon-Charley Rivers National Preserve.

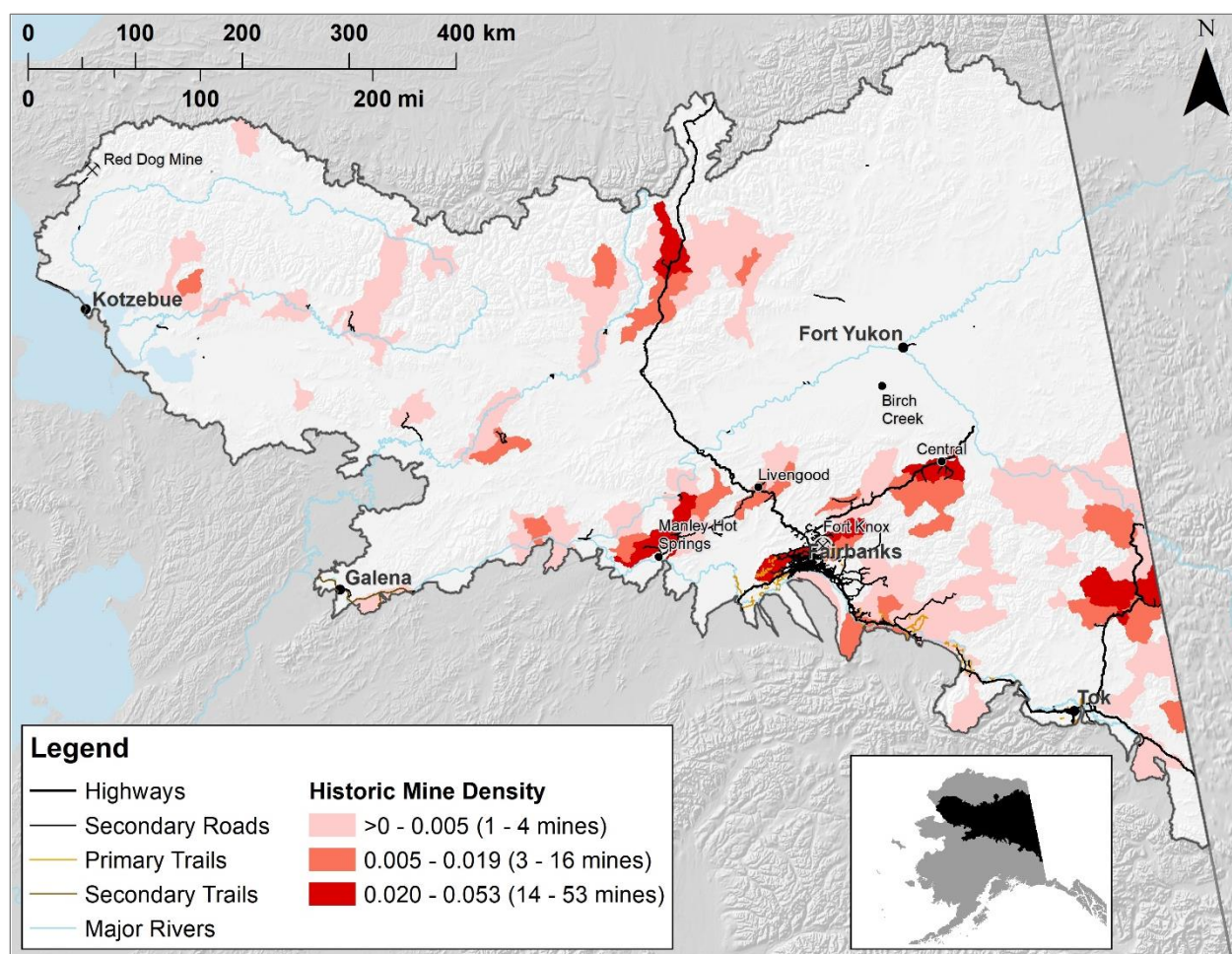


Figure E-84. Density of historic mining activity including various mineral occurrences and coal. Data are from the Alaska Resource Data File (ARDF) and Alaska various mineral occurrences Department of Natural Resource (ADNR) records in the CYR study region.

Currently there are two large mines operating with the Central Yukon study area, Red Dog (Zinc) and Fort Knox (Gold) (Figure E-85). Future mining activities are widespread but major ones include the Ambler mining district and Livengood Gold project. It has been estimated that the Livengood Project just north of Fairbanks would create 500 jobs (McDowell 2012).

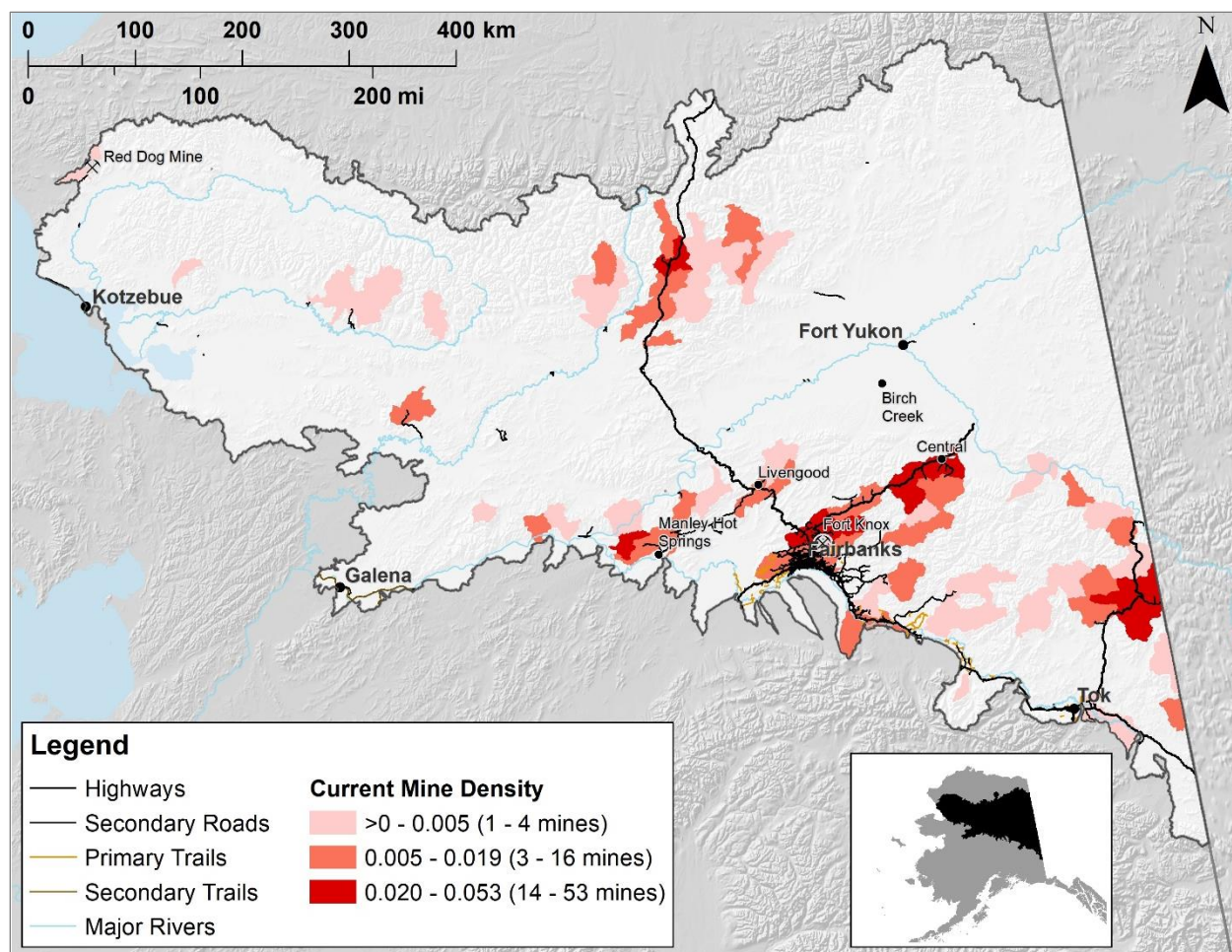


Figure E-85. Density of current mining activity of various mineral occurrences in the CYR study region. Data are from the Alaska Resource Data File (ARDF), Alaska Department of Natural Resource (ADNR), and Bureau of Land Management (BLM) records in the CYR study region.

Future mining activity is broken down by six mineral type in congruence with the USGS mineral report (Jones et al. 2015). The six mineral types are:

1. Placer and paleoplacer gold (Placer)
2. Rare earth elements (REE)
3. Sandstone uranium deposits (SandU)
4. Tin-tungsten-molybdenum-fluorspar deposits associated with specialized granites (SnGranite)
5. Platinum group element (PGE)
6. Carbonate-hosted copper deposits (CuCarb)

Placer Gold

Prices of gold peaked in 1980 and then declined precipitously which could be a pattern repeating itself in recent years (Figure E-86). Gold prices rose sharply between 2010 and 2011, which corresponded with an increase in placer mining permits from 288 to 536, and peaked at 694 permits in 2012. Since then they have decreased but not yet fallen to 2010 levels (646 permits in 2013).

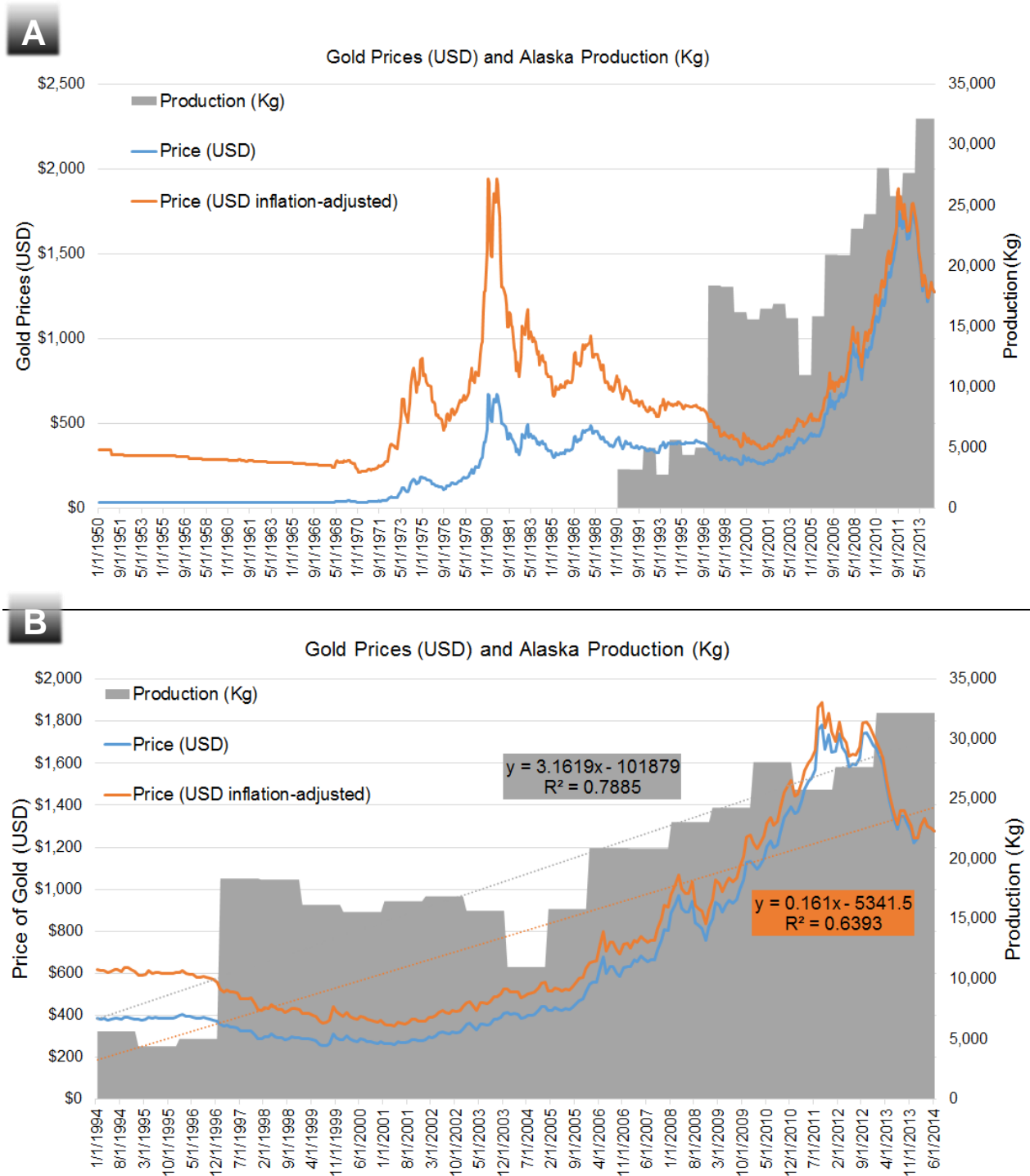


Figure E-86. Gold prices and production in Alaska from 1950 to 2013 (A) and from 1994 to 2014 (B).

A report in 2014 by the McDowell Group found that placer mining activity is closely linked to mineral price and production (Figure E-87). Fairbanks residents held a quarter (26%) of the statewide mining permits. On average, 47% of statewide permits are mined.

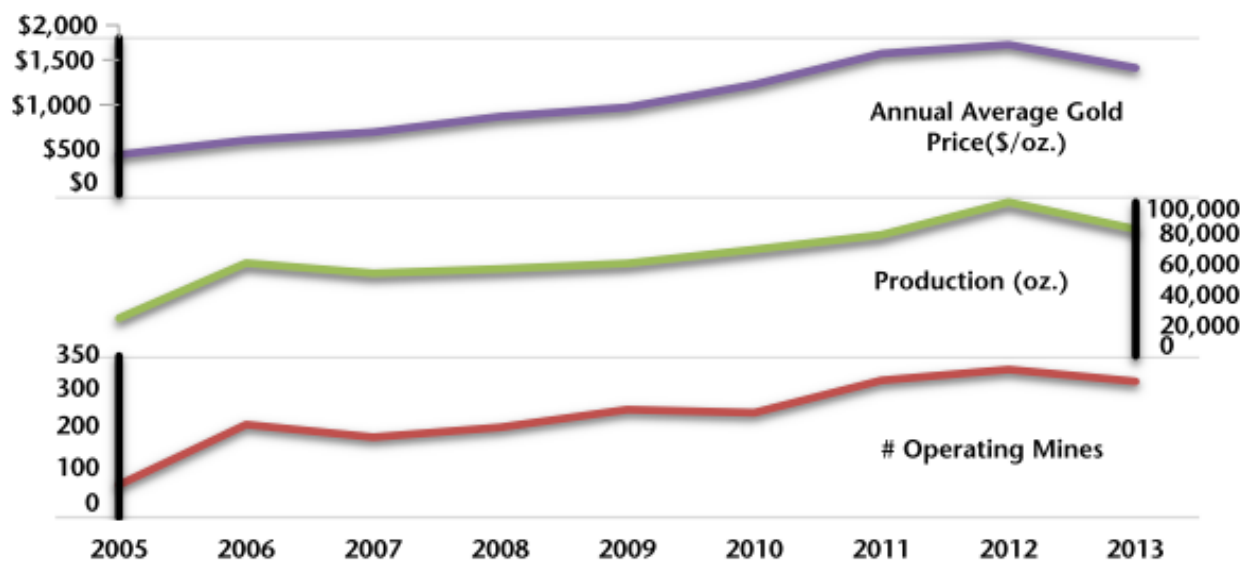


Figure E-87. Estimated placer operations, production, and annual average gold prices in Alaska, 2005-2013. Figure taken from McDowell (2014).

We combined the six different minerals examined in the USGS report to look at the total potential future mining activity (Figure E-89). Overall, the area classified as having a high potential for mineral exploration is minimal (22,717 km² or 5.7% of the CYR area), but in areas where it may occur socioeconomic effects can be significant. Of the areas identified in Figure E-88 only a small portion occurs within federal (7,412 km²) and state (6,731 km²) land. It is important to note that just because an area has high mineral potential does not mean it will be developed. There are several factors that go into starting up a mining endeavor. Also, areas with high mineral potential inside protected areas are not likely to be developed.

Local economic benefits are experienced when mining begins. For example, when Red Dog mine opened in 1990, employment and income soared providing high paying jobs and stability for local residents (Fried et al. 1999). Also, the percent of students obtaining high school degrees increased (Haley and Fisher 2012). In a recent analysis of the potential socioeconomic effects of the Ambler mine residents in Ambler could save \$188,000 a year on heating oil costs and \$27,000 on residential and community facility electricity costs due to lower diesel prices (Cardno 2015). However, many large scale natural resource projects in the Arctic have fly-in operations allowing residents to commute from outside the region. A potential downside of a large-scale mining operation is that it provides local residents with enough money to move to urban areas such as Anchorage and Fairbanks. There is limited support for this effect (Cardno 2015, Clemens 2014, Haley et al. 2009) but more research is needed.

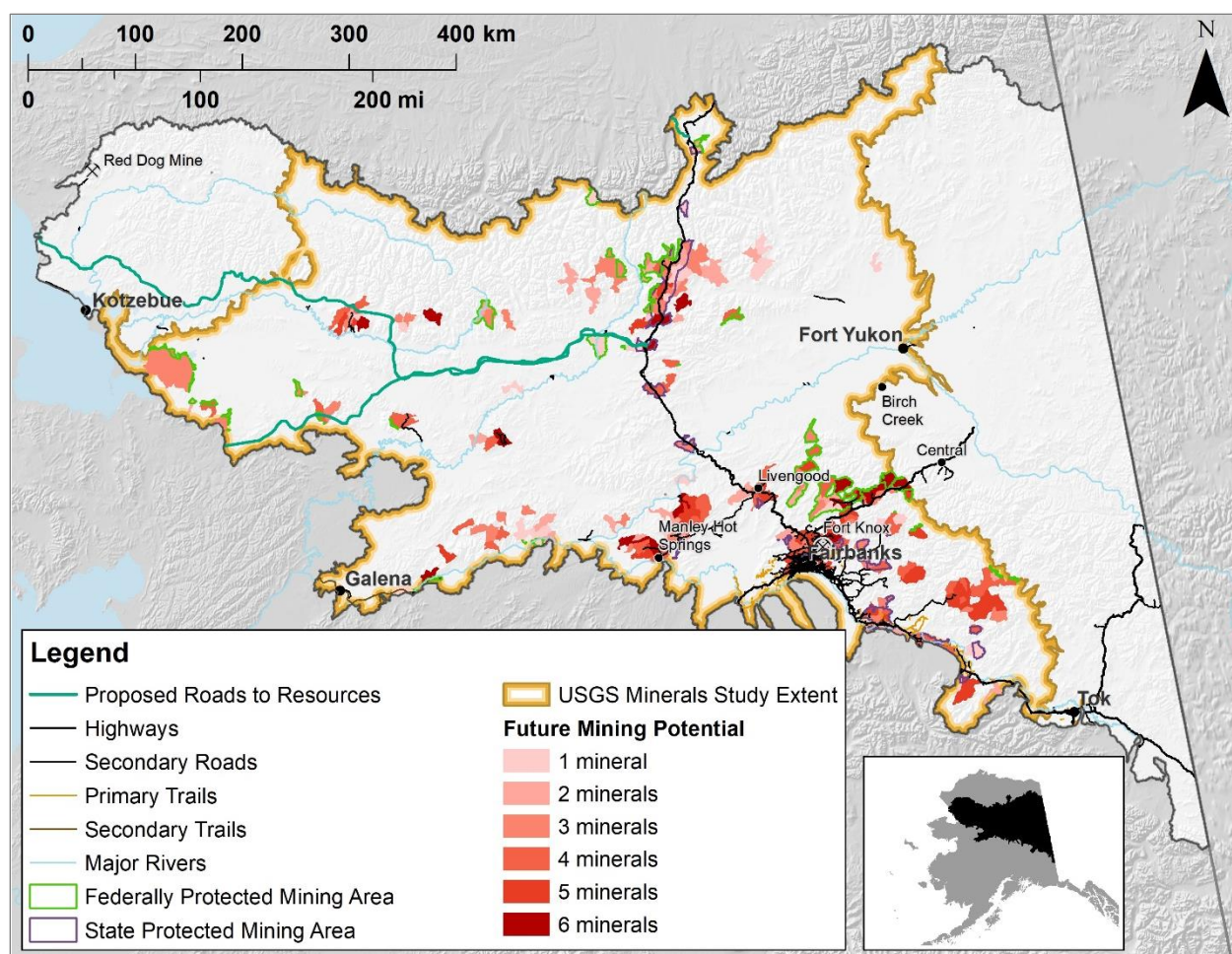


Figure E-88. Future mining potential in the CYR study region. Data are from the USGS mineral potential map; we further sub-selected areas to those with current and potential future access (see Methods).

Most future placer mining, mostly for gold, occurs in areas that historically and currently have such mining activity. (Figure E-89). Out of all the minerals examined by the USGS, placer mining has the largest area with the most likely future potential exploration. In 2009, Contango ORE, Inc. began exploration for gold near Tok on lands owned by Tetlin Village north of Tetlin Lake. In 2012, exploration was successful with gold, copper, and silver discovered. However, this activity is just outside the study area south of Tok but could still have socioeconomic effects on Tok. These areas are around Fairbanks, Central, and up along the Dalton Highway near Wiseman.

Section E. Anthropogenic Change Agents

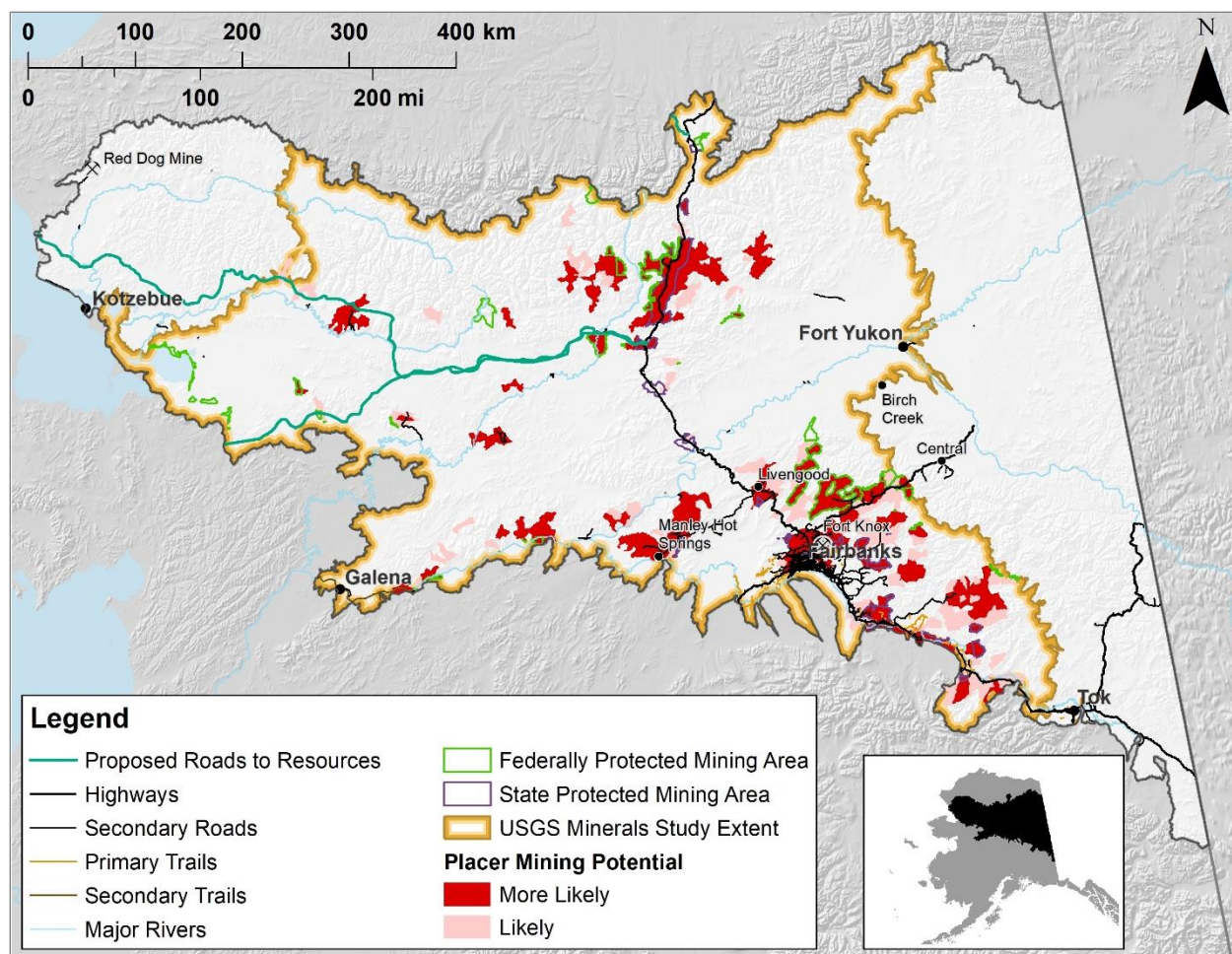


Figure E-89. Future placer and paleoplacer gold mining potential in the CYR study region. Data are from the USGS mineral potential map; we further sub-selected areas to those with current and potential future access (see Methods).

Rare Earth Elements (REE)

The potential for REE deposits occurs in the Hogatza plutonic belt (Figure E-90), which extends through the southern portion of the Selawik National Wildlife Refuge, the Ruby batholith area (i.e., Southcentral CYR) and Tofty, Alaska (Jones et al. 2015). However, mining on the Selawik National Wildlife Refuge is extremely unlikely. Tofty is near Manley Hot Springs and has road access, making it the most likely area for REE mining of the three locations. An undated report by Teseneer et al. found that there was low economic and development potential within the Selawik NWR.

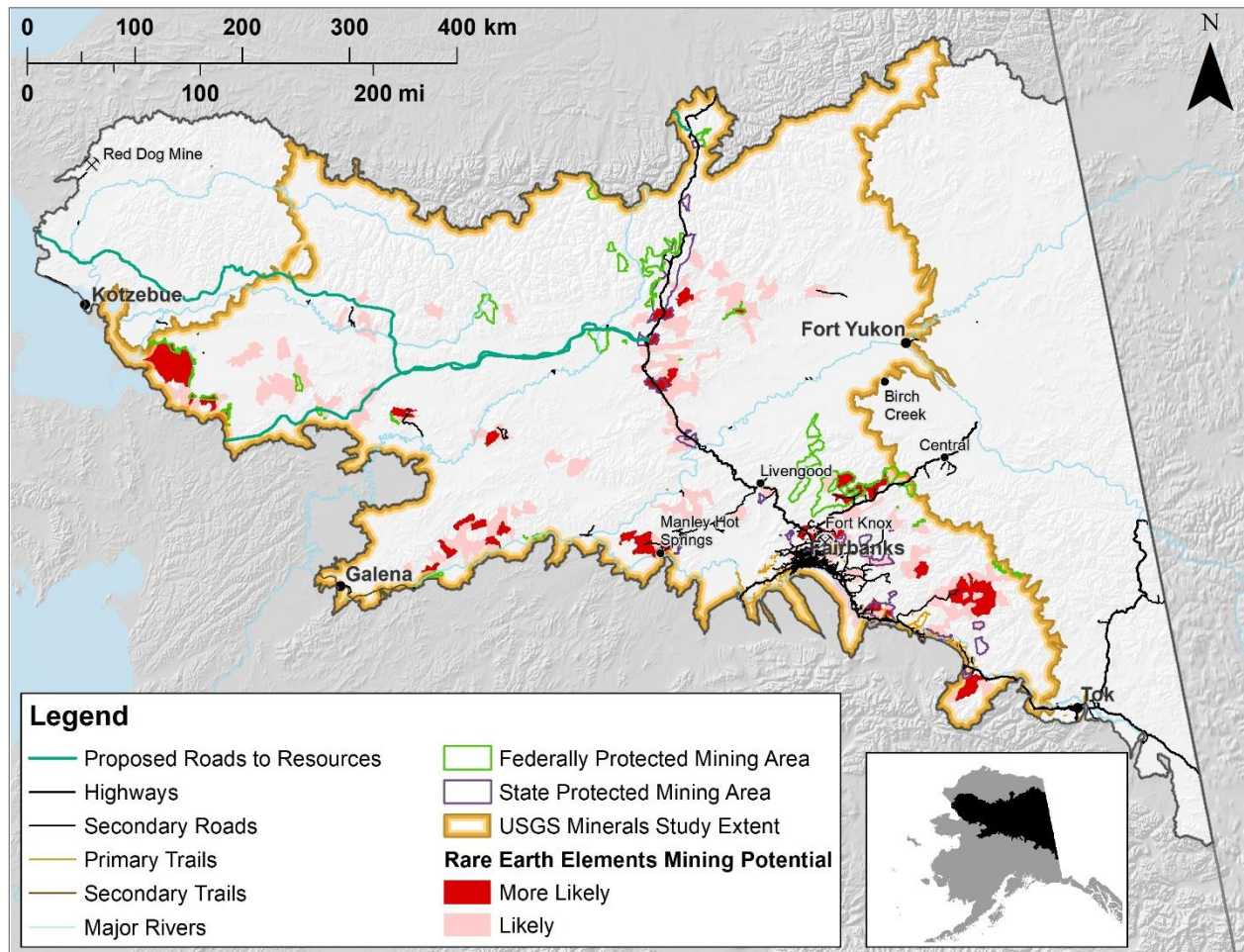


Figure E-90. Future rare earth elements mining potential in the CYR study region. Data are from the USGS mineral potential map; we further sub-selected areas to those with current and potential future access (see Methods).

Sandstone uranium deposits (SandU)

Potential for sandstone uranium is linked to types of rocks found in the Hogatza plutonic belt and Ruby batholith areas (Figure E-91; Jones et al. 2015). There fewer areas in the “more likely” category for sandstone uranium mining than the other mineral elements we examined.

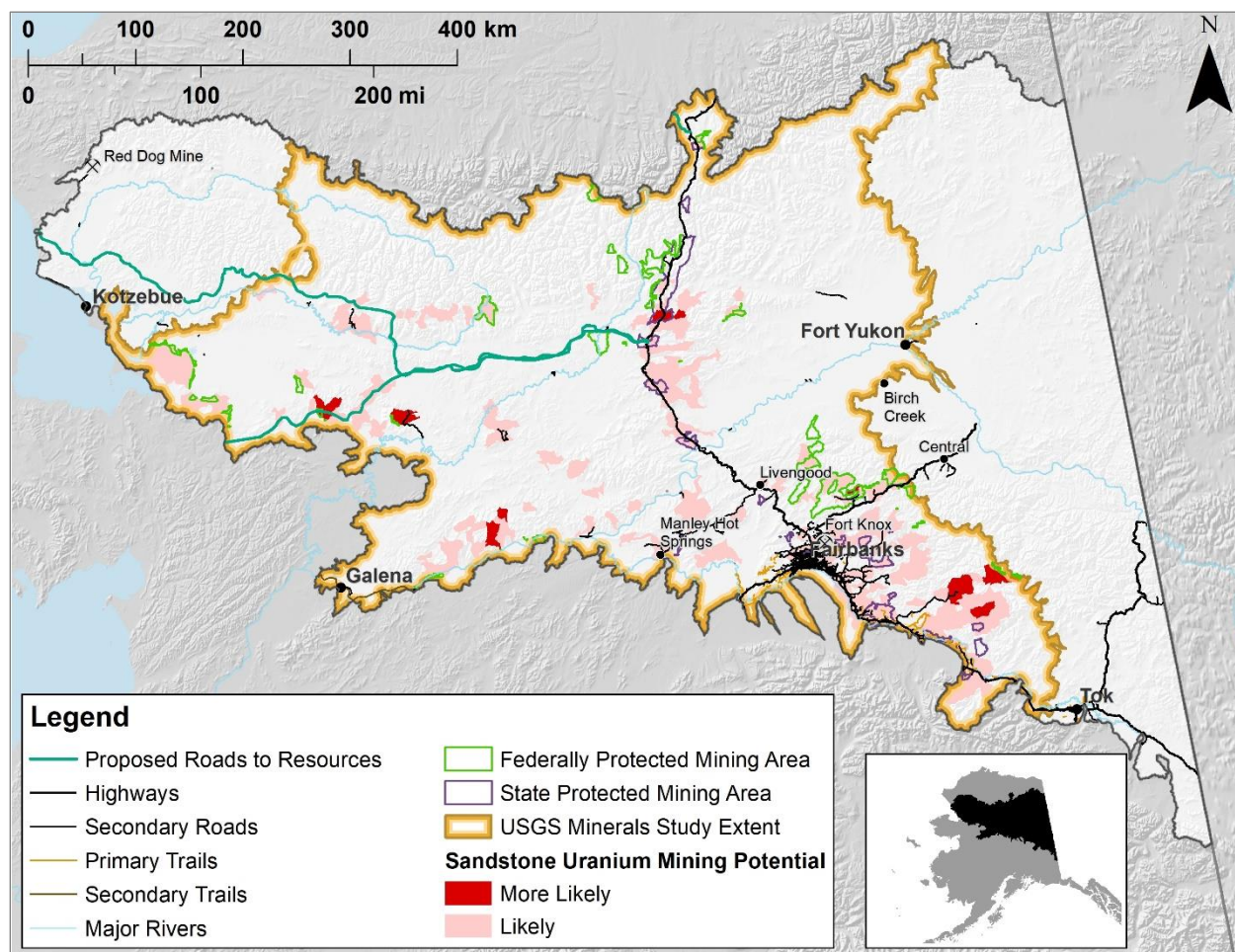


Figure E-91. Future sandstone uranium mining potential in the CYR study region. Data are from the USGS mineral potential map; we further sub-selected areas to those with current and potential future access (see Methods).

Tin-tungsten-molybdenum-fluorspar deposits associated with specialized granites (SnGranite)

Tin-tungsten-molybdenum-fluorspar deposits are also located in the Hogatza belt and Ruby batholith regions with high potential near Livengood (Figure E-92; Jones et al. 2015). Currently, there is road access to Tofty, north of Manley Hot Springs. Tin has been shipped out of this area since 1911 and the area was known as the Tofty Tin belt (Wayland 1961). Cache, Sullivan, and Woodchopper Creeks were strip-mined and a 20-mile road from the tin belt to Manley Hot Springs was established sometime between 1920 and 1940. Other areas impacted by historic tin exploration include Deep Creek, Sullivan Bench, and Miller, Idaho, Tofty, Lower Harder Harter Gulch, and Dalton Gulches (Wayland 1961).

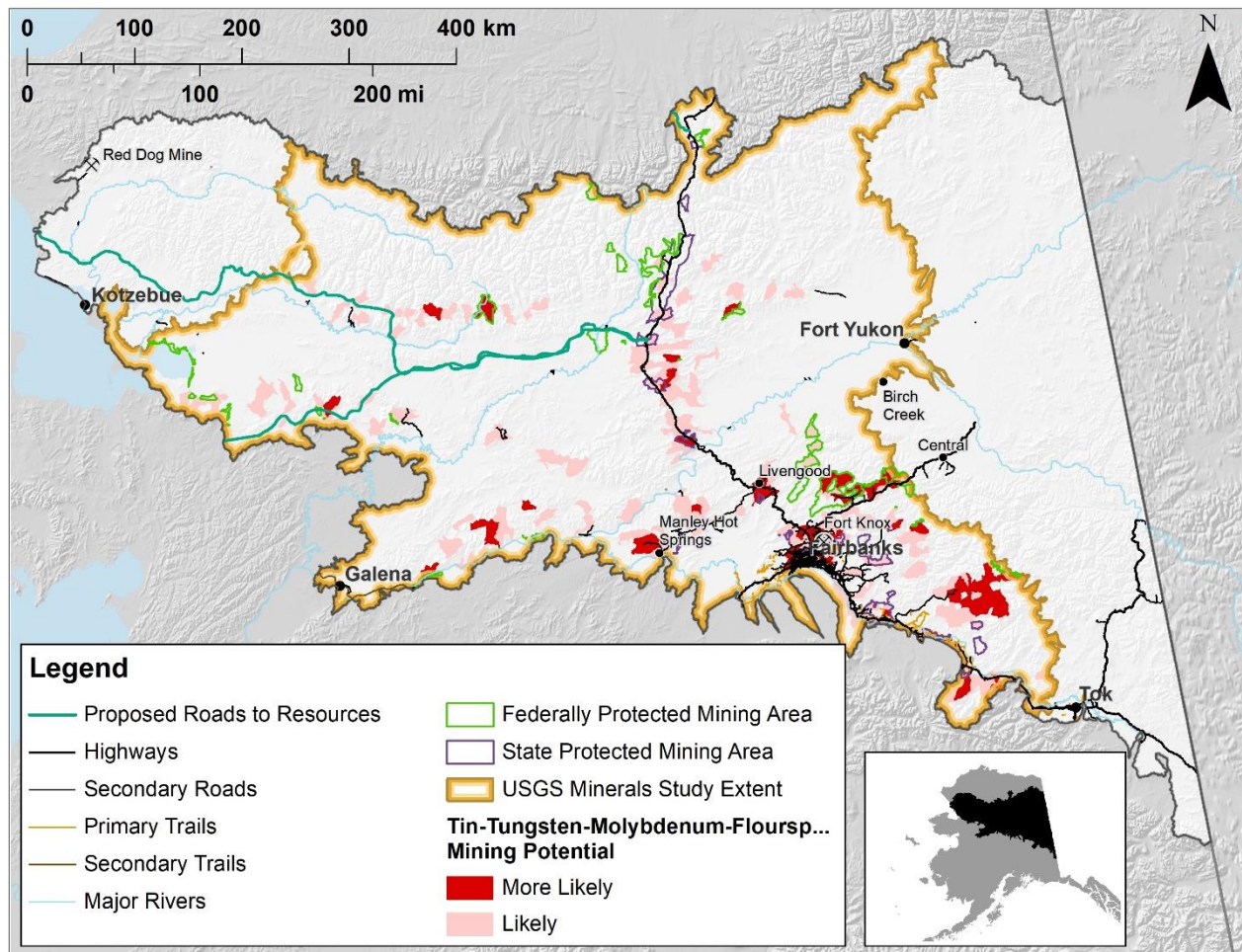


Figure E-92. Future tin-tungsten-molybdenum-fluorspar mining potential in the CYR study region. Data are from the USGS mineral potential map; we further sub-selected areas to those with current and potential future access (see Methods).

Platinum group element (PGE)

According to a 2015 USGS report, the northwest portion of the Brooks Range slightly outside of the USGS study area extent has a high potential for platinum group elements (PGE; Figure E-93). Also, like REE, the Ruby batholith area potentially is a source of platinum group elements (PGE; Figure E-93).

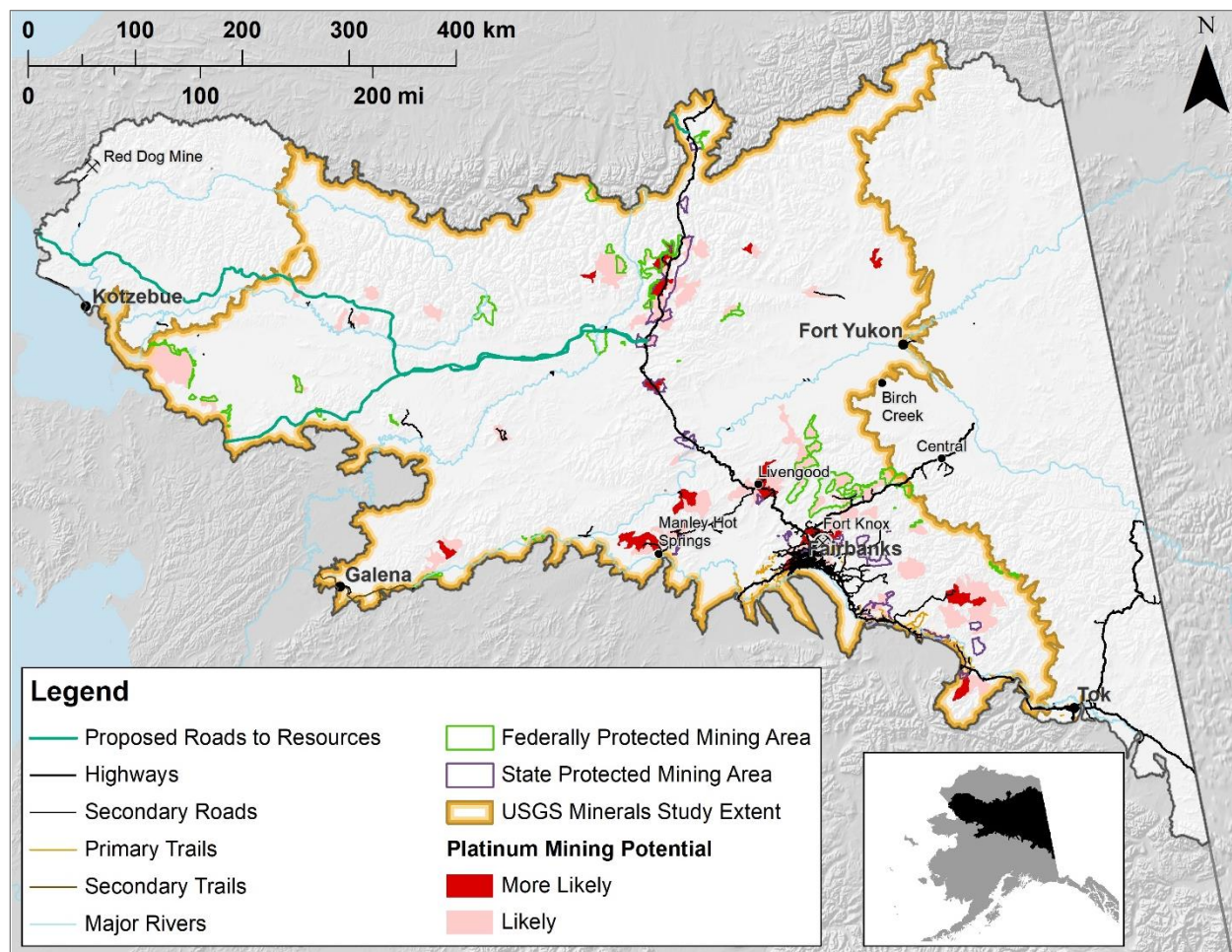


Figure E-93. Future platinum mining potential in the CYR study region. Data are from the USGS mineral potential map; we further sub-selected areas to those with current and potential future access (see Methods).

Carbonate-hosted copper deposits (CuCarb)

Copper deposits are mostly found north of the CYR study area but can be found in the study area distributed sporadically around Wiseman (Figure E-94). Copper is often found with PGE, but was separated out. Most copper harvest occurs in Southeast Alaska, outside the CYR study area.

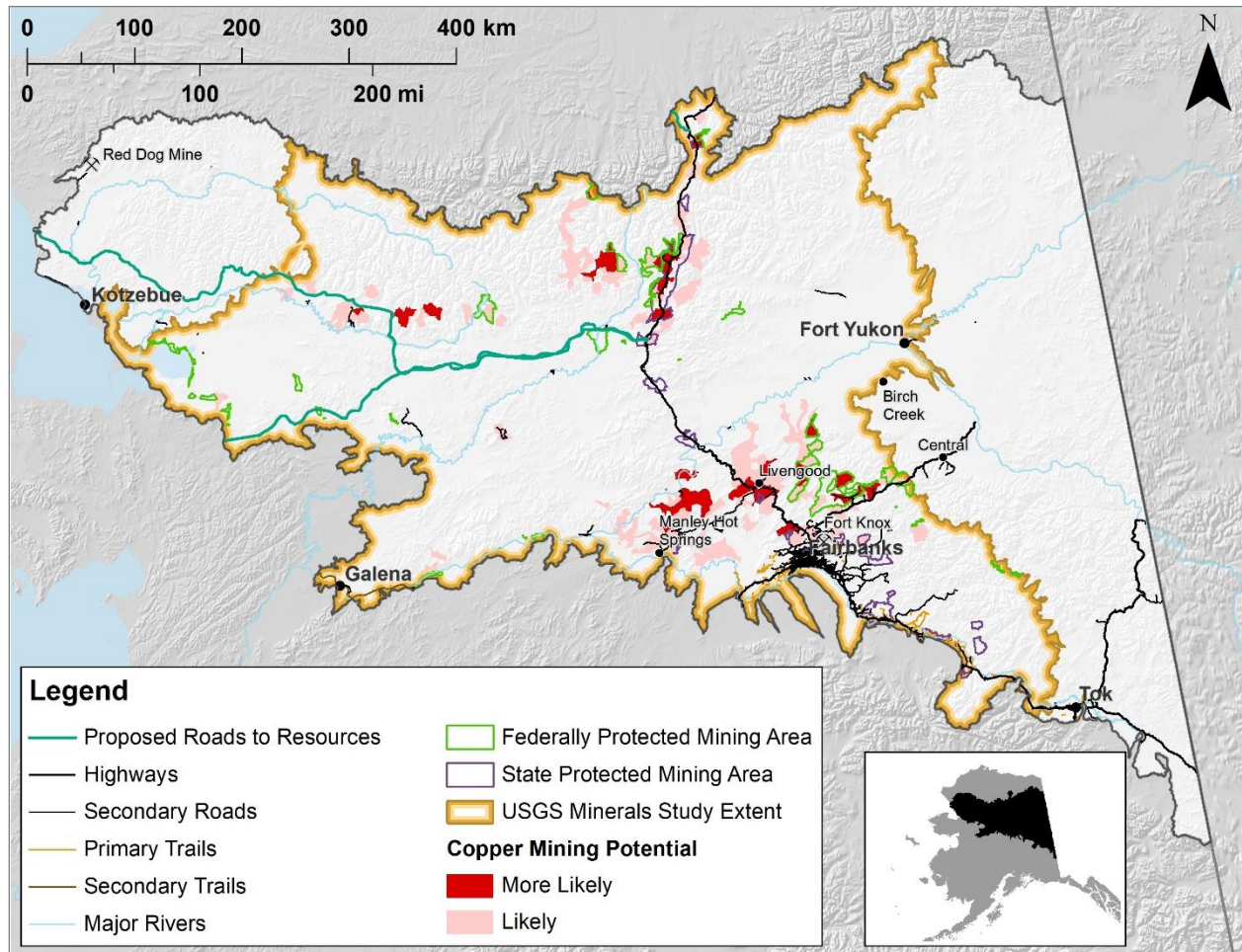


Figure E-94. Future carbonate-hosted copper mining potential in the CYR study region. Data are from the USGS mineral potential map; we further sub-selected areas to those with current and potential future access (see Methods).

Other mining activities likely to occur in the CYR that were either not covered in the previous maps or need further highlighting are the Nanushuk coal and the Ambler mining district, respectively (Figure E-95). Out of all the mining activity, the Ambler has been the most discussed and studied.

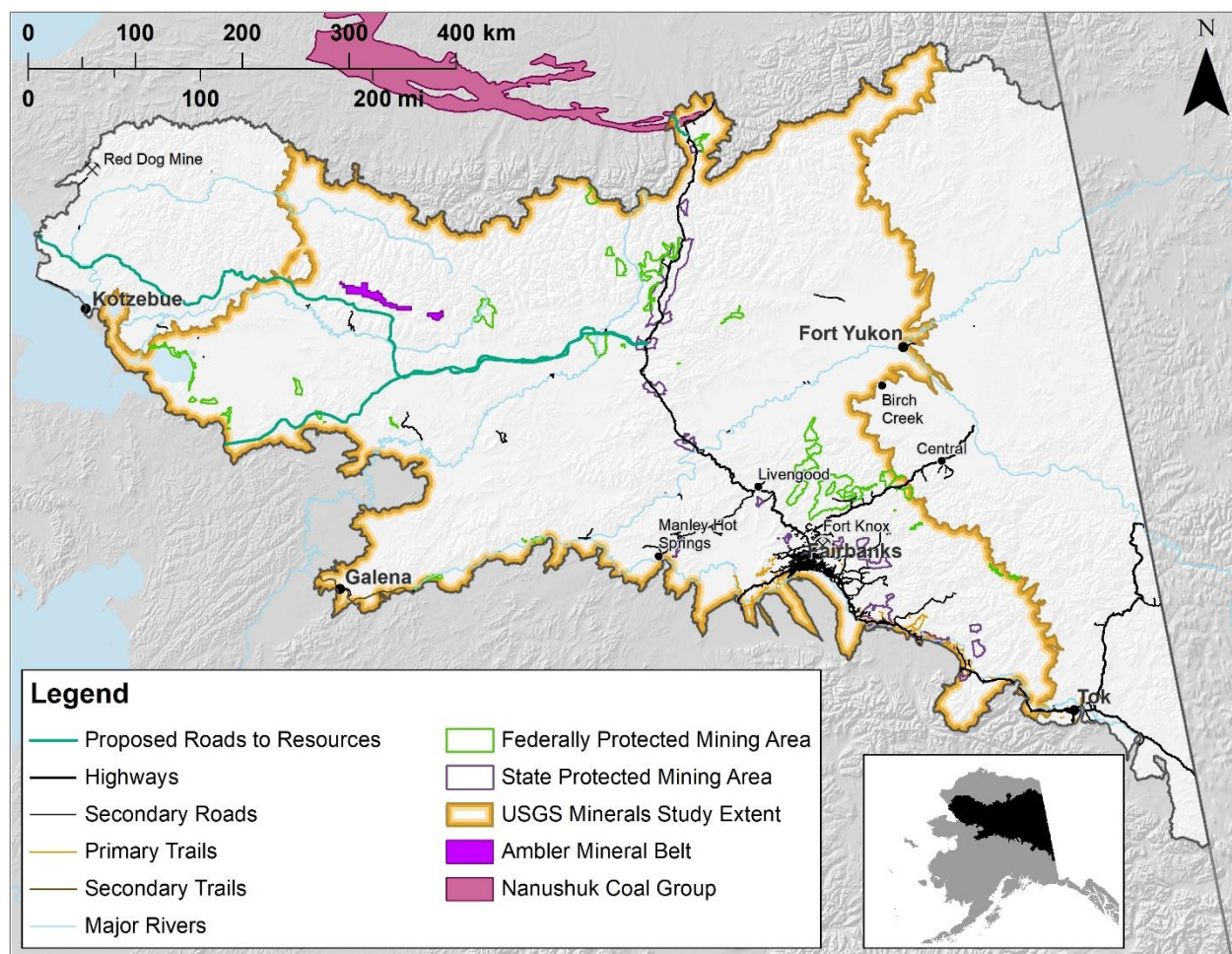


Figure E-95. Other future mining potential in the CYR study region, not represented in the USGS report (see Methods).

3.7 Oil and Gas

There are a number of oil and gas basins that lay within the CYR study region (Figure E-96). Selawik oil and gas basin is considered an eastern extension of the Kotzebue oil and gas basin. However, much of the Selawik basin is located in the Selawik National Wildlife Refuge, making development unlikely (Teseneer et al. Unknown date, BLM 2005). Exploration in the Selawik Basin has been minimal with no wells drilled. The Colville Basin runs along the northwestern edge of the CYR study area but exploration within this area is minimal. Wells and exploration in this basin are outside the CYR study area. Doyon has drilled Nunivak #1 and #2 exploratory wells between 2009 and 2013 in the Nenana Basin, and acquired 2-D seismic, gravity, magnetics, and lakebed geochemical surveys for the Yukon Flats Basin. Meanwhile the local Native Corporation (e.g., NANA) is evaluating prospects in the basins in that region (Feige et al. 2015).

With the spike in oil prices in the late 2000s, there was increased interest in a natural gas pipeline from the North Slope to southern regions of Alaska and the contiguous 48 states. The pipeline permits have been obtained (Figure E-96), but progress on the project has stalled with the plunge in oil prices and changes in political leanings of the state. The future of the pipeline is

still very much up in the air, but alternatives to heating fuel are still very much desirable especially in the greater Fairbanks area.

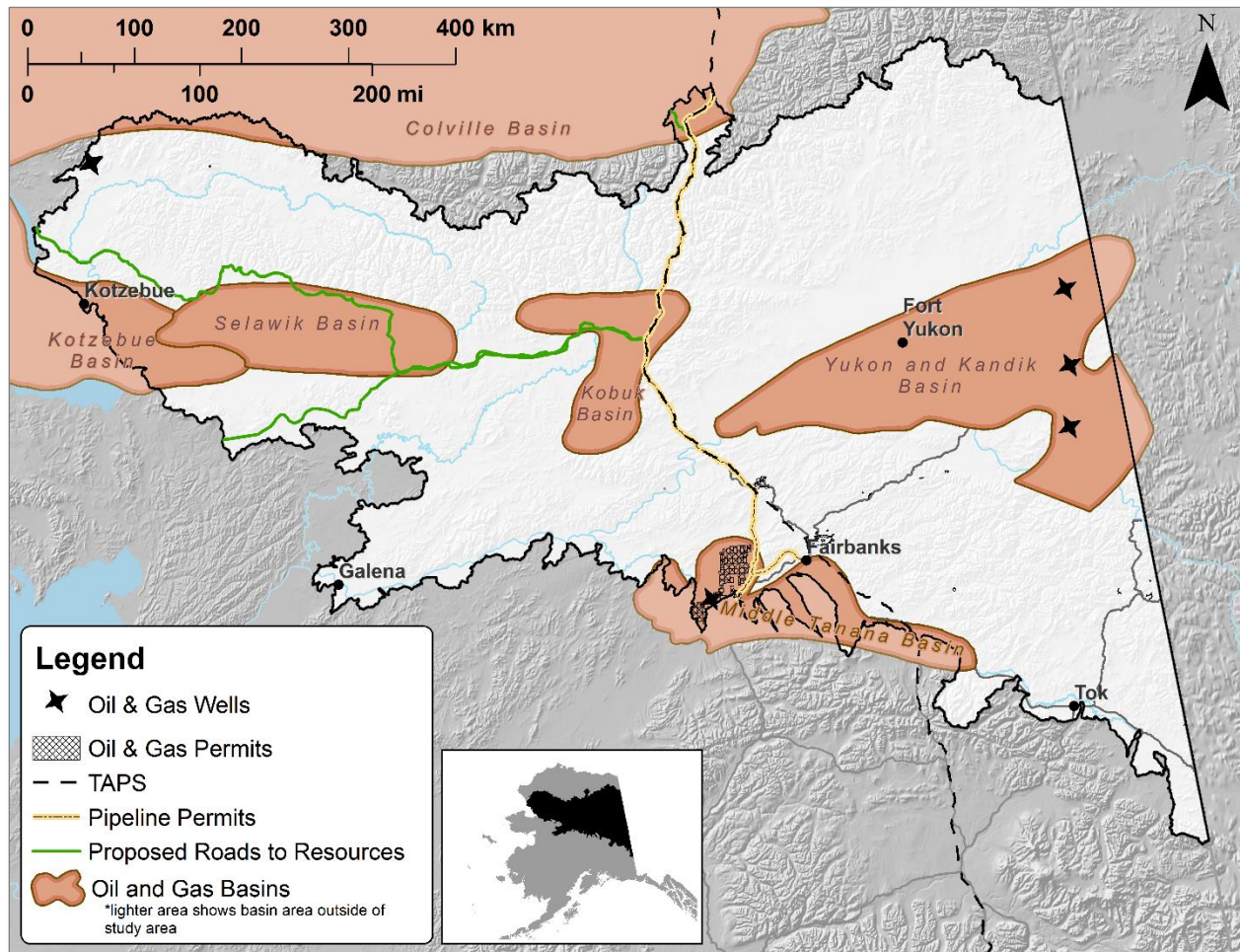


Figure E-96. Oil and gas basins and current wells and pipelines. Permits for pipelines may indicate future activities associated with oil and gas.

3.8 Forestry

In the 1980s, most timber harvest occurred only on the road system and the same pattern currently continues (Figure E-97; Sampson et al. 1988). Harvest in Interior Alaska is limited by a 100–120 year rotation length cycle and access (Koontz 2013, E. Geisler pers. comm.). A 1998 study found that softwood lumber was the best opportunity for timber production in Interior Alaska with white spruce (*Picea glauca*) most likely to meet local demand (Sampson et al. 1988). The Tanana Valley Forests are large expanses of land from Manley Hot Springs to the Canada border that are open to a variety of resource extraction activities including mining, gravel extraction, timber harvests, oil and gas leasing, and grazing (<http://forestry.alaska.gov/stateforests.htm>). In the 1980s, production was below 20 million board feet (Sampson et al. 1988); while the current desired production is 14 million board feet (Meany 2014). The main limiting factors for harvest are access, costs associated with extracting and shipping timber, and small diameter of the trees (Wurtz et al. 2006). Even though very little timber production actually occurs, climate change is threatening the future of upland white and

black spruce and lowland black spruce in Interior Alaska (Barber et al. 2000, Juday et al. 2005, Wilmking and Myers-Smith 2008), and forest fire activity has been increasing, both of which could hinder future timber production (Juday et al. 2005, Kasischke and Turetsky 2006, Calef et al. 2015).

Overall timber sales in the CYR study area are declining (Figure E-98). Within our study area there are 65 parcels from the Fairbanks office up for sale, but no parcels from the Delta Junction office during the five-year study plan (2014–2018). One limitation with harvesting timber is the cost to build roads, which can be more than the actual harvestable surplus (Sampson et al. 1988). In 1987 it cost \$115 to harvest one acre, while reforestation costs were \$142 per acre for spruce and \$38 per acre for deciduous forests. A return of \$257 per acre for spruce and \$153 per acre for deciduous forest would be needed to cover the costs associated with road building and habitat restoration (AKDNR Division of Forestry 1987).

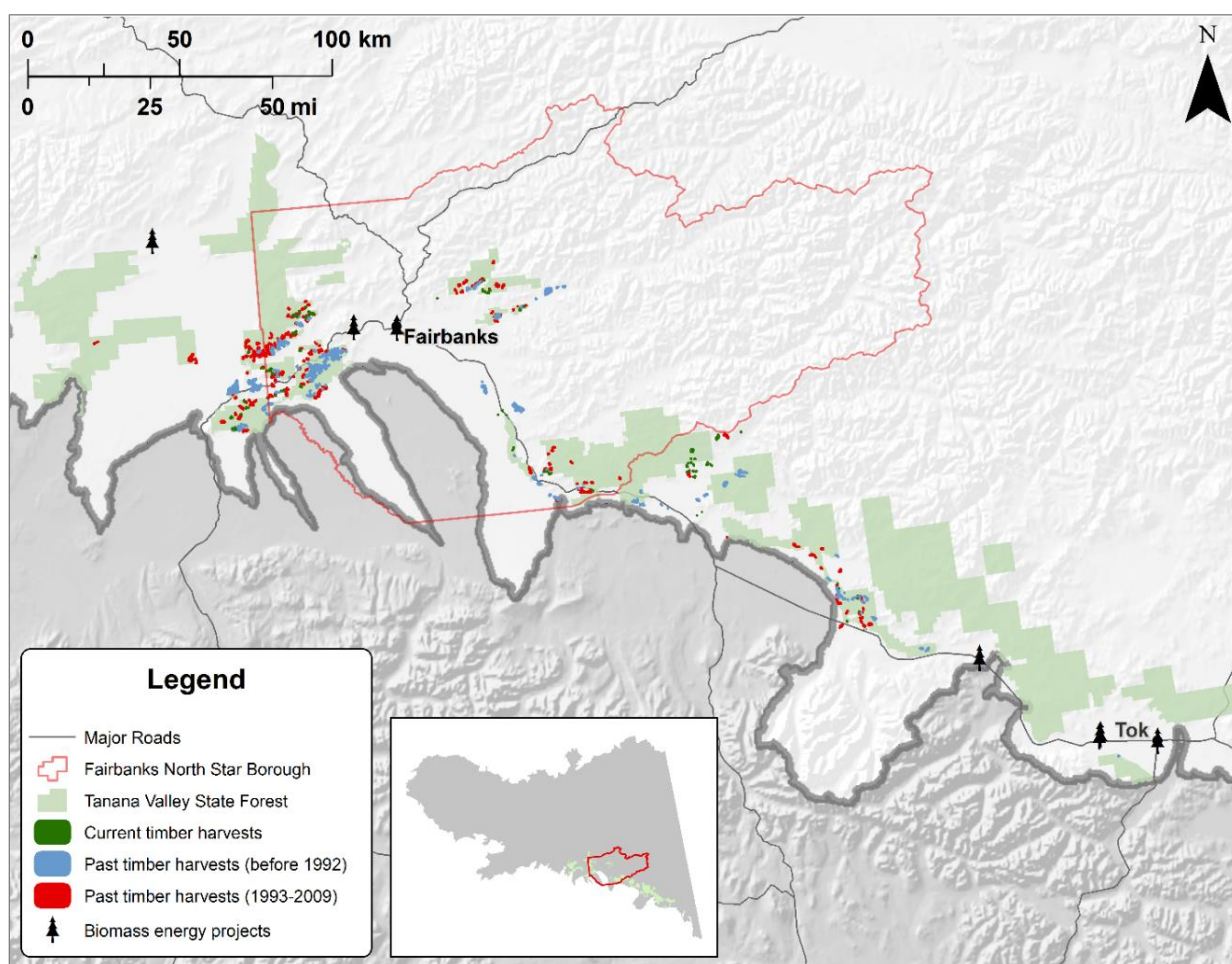


Figure E-97. Timber harvests within the CYR study region.

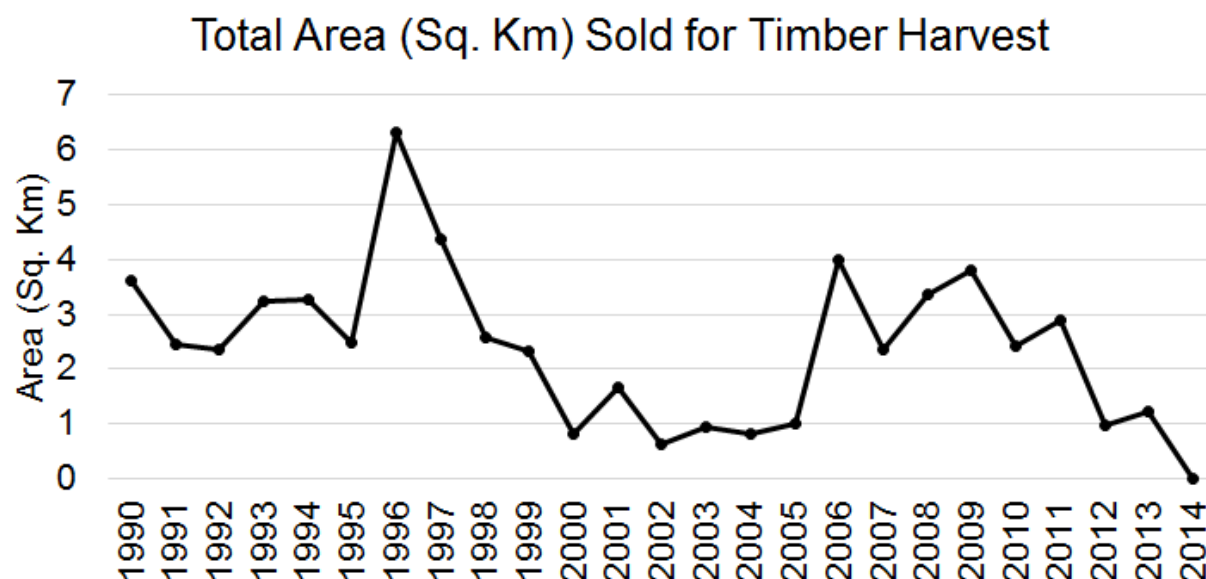


Figure E-98. Total timber sold within the CYR study region.

3.9 Renewable energy infrastructure

The AEA began the Renewable Energy Fund grant process in 2008 and since then applications for renewable energy projects peaked around 2010 and funds distributed have fallen. Crude oil prices in Alaska, excluding the North Slope, peaked in 2008 at \$128 a barrel (Energy Information Administration 2015). However, heating and fuel oil costs were much greater in rural Alaska and prices have not decreased as rapidly (Szymoniak et al. 2010). Still, many communities rely on diesel to generate electricity, which is becoming increasingly expensive; many communities in Alaska are seeking alternative options for energy production (Figure E-99, Figure E-100; Table E-22). During rounds 1 through 7, the Renewable Energy Fund granted funding to 37 projects in 32 communities with 18 of the projects either under construction or operational (Table E-22). Most renewable energy projects are biomass ($n = 13$) and biomass projects are the most common in communities ($n = 20$). Fairbanks has the most renewable energy projects ($n = 4$) followed closely by Ambler, Delta Junction, Kotzebue, and Tok ($n = 3$).



Figure E-99. Tok wood-fired boiler. Picture taken from Atlas of Alaska: a guide to Alaska's clean, local, and inexhaustible energy resources. April 2013.

Biomass projects are important because they will impact vegetation and potential habitat around communities. Galena and Tok have the most detailed biomass harvest plans (Kalke 2015). It is estimated that around Tok there is 109 km² of high-hazard fuels that can be harvested for biomass heating projects (AEA 2014). Inventory plots indicated 35–180 tons/acre of available fuel (Rogers and Hermanns 2010). Through harvesting fuels, the Tok School has already saved approximately \$100,000 per year on energy costs, which they have used to hire teachers (Jeffrey Hermanns per. comm.). Timber harvest and fuel reduction programs have also reduced fire hazards around the homes of senior citizens while supplying fuel for the school. Galena, a community of approximately 560 people with 190 houses occupied (2009–2013 average), has an annual heat load of 17.7×10^9 Btu and will require an estimated 1800 gt of Balsam poplar at 40% MCwb to satisfy that need. Use of a biomass technology (e.g., wood boiler) would result in a 50% reduction in fuel costs (Kalke 2015). Annual harvest needed to meet the demands of Galena is approximately 0.4 km², but this number is also dependent on a number of factors including volume of solid wood, moisture content, etc. (Koontz 2013, E. Geisler pers. comm.). Most harvest would be within a 40-km radius of the community. This harvest intensity likely would apply for larger communities like Tok, Delta Junction, and Tanana, with harvest patches between 0.08 to 0.16 km². Meanwhile, smaller communities will harvest roughly half that. This will result in larger communities requiring 10.5 km² by 2040 and 18.6 km² in total by 2060. It is hard to assess how future biomass harvesting projects might impact the landscape because often they are combined with other objectives such as fuel reduction, land clearing, habitat enhancement, etc. Thus, the wood that is harvested varies greatly in tonnage. Combined efforts such as this are likely to be more common in the future and research is needed to better understand which harvest or fuel reduction treatments provide products for multiple purposes.

Current research suggests an increase in fire activity that would facilitate a switch from hardwoods to deciduous (Mann et al. 2012, Johnstone et al. 2010; see Section G. Terrestrial Coarse-filter CE). This reduction in the median age of forests would result in less tonnage per acre potentially increasing the harvest area needed to support biomass projects.

Table E-22. Alaska renewable energy projects funded by the Alaska Energy Authority during rounds 1 through 7.

Name	Community	Technology	Status
Ambler Heat Recovery*	Ambler	Heat Recovery	Construction
Ambler Solar (PhotoVoltaic)	Ambler	Solar	Feasibility
Biomass Heat for Minto Community Buildings	Minto	Biomass	Design/Construction
Biomass-fired Organic Rankine Cycle System*	Fairbanks	Biofuels	Construction
Buckland, Deering, Noorvik Wind Farm*	Noorvik	Wind	Construction
Chalkyitsik Biomass Central Heating	Chalkyitsik	Biomass	Feasibility
City-Tribe Biomass Energy Conservation*	Tanana	Biomass	Construction
Cosmos Hills Hydroelectric	Kobuk, Shungnak	Hydro	Feasibility
Deering Wind System Assess Preconstruction	Deering	Wind	Final Design
Delta Area Wind Turbines*	Delta Junction	Wind	Construction
Delta Junction Wind*	Delta Junction	Wind	Feasibility
Delta Junction Wood Chip Heating Feasibility Study	Delta Junction	Biomass	Construction
Eagle Solar Array Project*	Eagle	Solar	Construction
Fairbanks Bio-Diesel-Waste Vegetable Oil	Fairbanks	Biofuels	NA
Fort Yukon Central Wood Heating*	Fort Yukon	Biomass	Final Design/Construction
Galena Renewable Energy*	Galena	Biomass	Final Design/Construction
Galena Wood Heating	Galena	Biomass	NA
Heat Recovery for the Water Treatment Plant for Noorvik*	Noorvik	Heat Recovery	Construction
Kotzebue Electric Heat Recovery*	Kotzebue	Heat Recovery	Construction
Kotzebue High Penetration Wind-Battery-Diesel Hybrid*	Kotzebue	Wind	Construction
Kotzebue Paper and Wood Waste to Energy Project	Kotzebue	Biofuels	Feasibility
Little Gerstle Hydro Assessment	Fairbanks	Hydro	Reconnaissance
Manley Hot Springs Geothermal Plant	Manley Hot Springs	Geothermal	Reconnaissance

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Name	Community	Technology	Status
Nenana Hydrokinetic	Nenana	Ocean/River	Reconnaissance
North Pole Heat Recovery*	North Pole	Heat Recovery	Construction
Organic Rankine Cycle Field Testing	Fairbanks	Heat Recovery	Reconnaissance
Ruby Hydrokinetic	Ruby	Ocean/River	Feasibility
Selawik Hybrid Wind Diesel System Turbine Upgrade	Selawik	Wind	Feasibility
Tanacross Woody Biomass Community Facility Space Heating Project*	Tanacross	Biomass	Construction
Tok Wind Resource	Tok	Wind	Feasibility
Tok Wood Heating*	Tok	Biomass	Construction
Upper Kobuk River Biomass	Ambler	Biomass	Feasibility/Construction
	Kobuk	Biomass	Feasibility/Construction
	Shungnak	Biomass	Feasibility/Construction
Upper Tanana Biomass CHP Project	Dot Lake	Biomass	Feasibility/Construction
	Tanacross	Biomass	Feasibility/Construction
	Tok	Biomass	Feasibility/Construction
Venetie Clinic Heat Recovery*	Venetie	Heat Recovery	Final Design/Construction
Venetie District Heating	Venetie	Biomass	Feasibility
Wood Heating in Interior Alaska Communities	Alatna	Biomass	Feasibility/Final Design
	Allakaket	Biomass	Feasibility/Final Design
	Beaver	Biomass	Feasibility/Final Design
	Ester	Biomass	Feasibility/Final Design
	Fort Yukon	Biomass	Feasibility/Final Design
	Hughes	Biomass	Feasibility/Final Design
	Northway	Biomass	Feasibility/Final Design
	Ruby	Biomass	Feasibility/Final Design
	Stevens Village	Biomass	Feasibility/Final Design
Yerrick Creek Hydroelectric Construction*	Tanacross, Tok	Hydro	Construction

* Indicates project is either under construction or active.

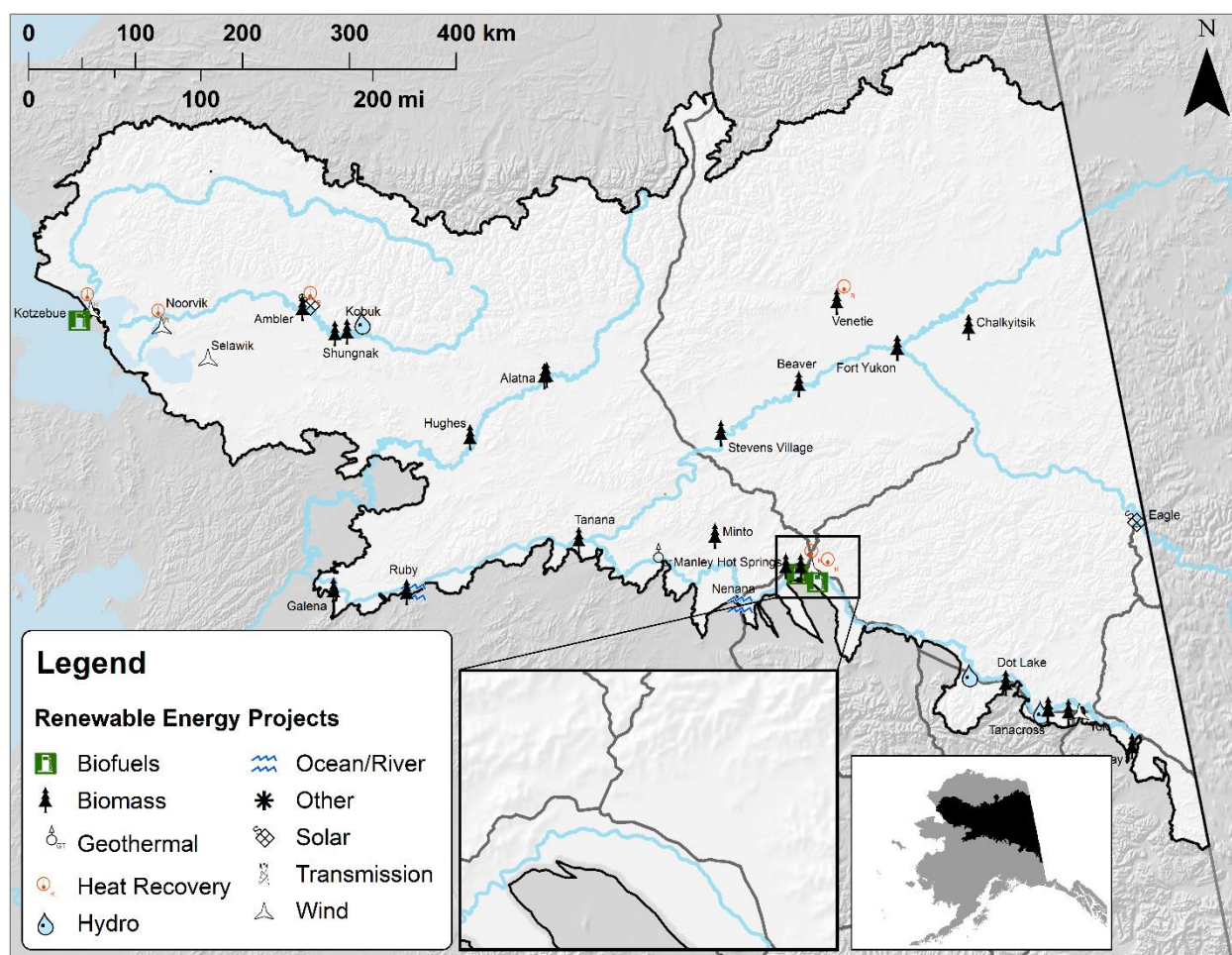


Figure E-100. Renewable energy projects within the CYR study region.

Hydroelectric projects can impact the landscape by altering stream flow, placing physical structures on the land and use of fill, and potentially altering fish habitat. However, benefits to the communities can be quite large. For example, the Yerrick Creek Hydroelectric plant is expected to save 375,000 gallons of diesel in the Tok and Upper Tanana region and reduce energy costs by 30%. The potential for renewable energy varies across the study region (Figure E-101, Figure E-102) and development of renewable energy projects depends greatly on the feasibility, funds (Table E-23), and desire of community members to turn this potential into actual sustainable projects.

Table E-23. Statewide applications and grant funding from the Alaska Energy Authority since 2008 through the current round of funding (Alaska Energy Authority 2015).

Round	Applications	Funded	Cash distributed (\$M)
I	115	80	\$84
II	118	30	\$21
III	123	25	\$15
IV	108	74	\$23
V	97	19	\$17
VI	85	23	\$14
VII	86	26	\$8

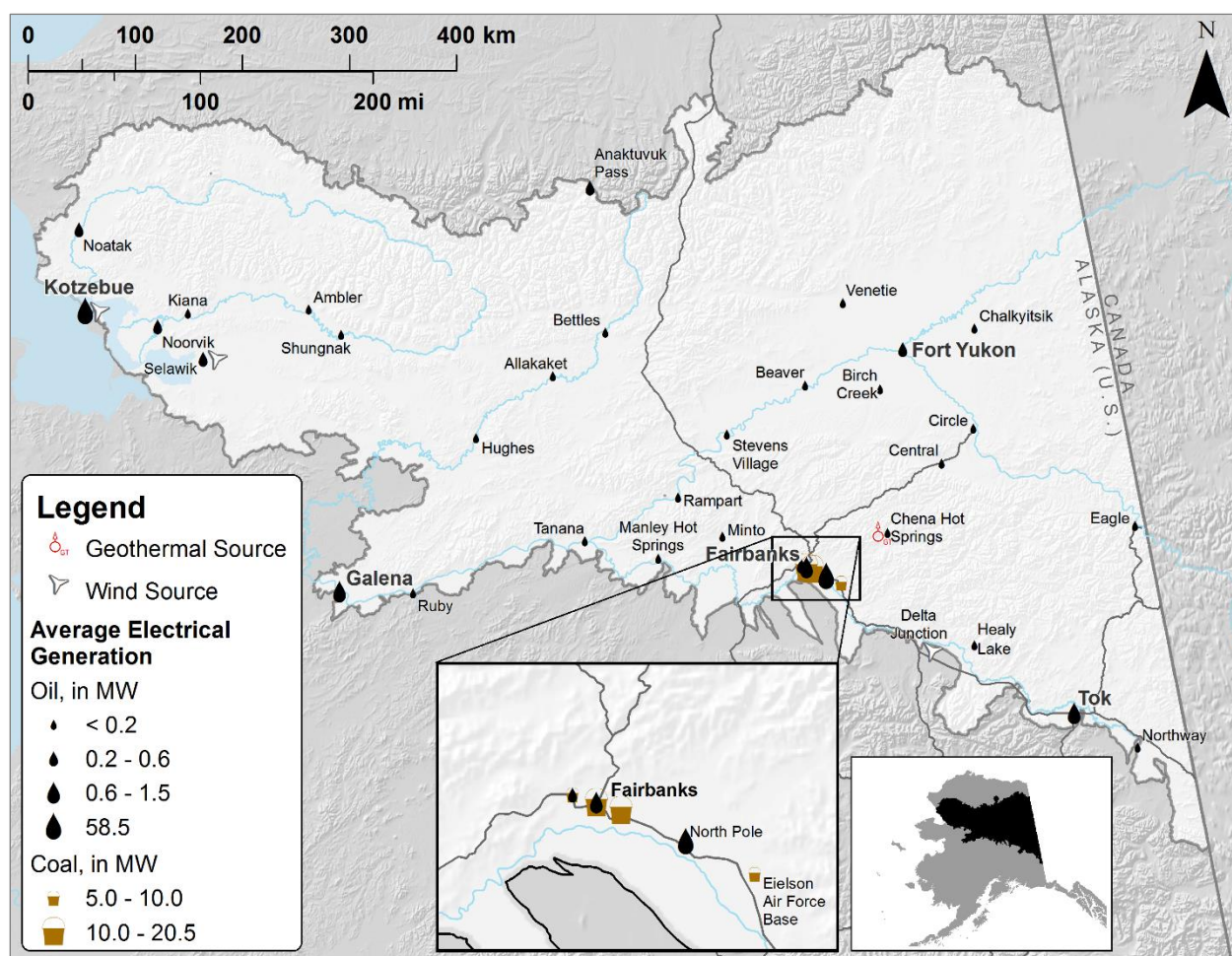


Figure E-101. Current geothermal and wind projects within the CYR study region.

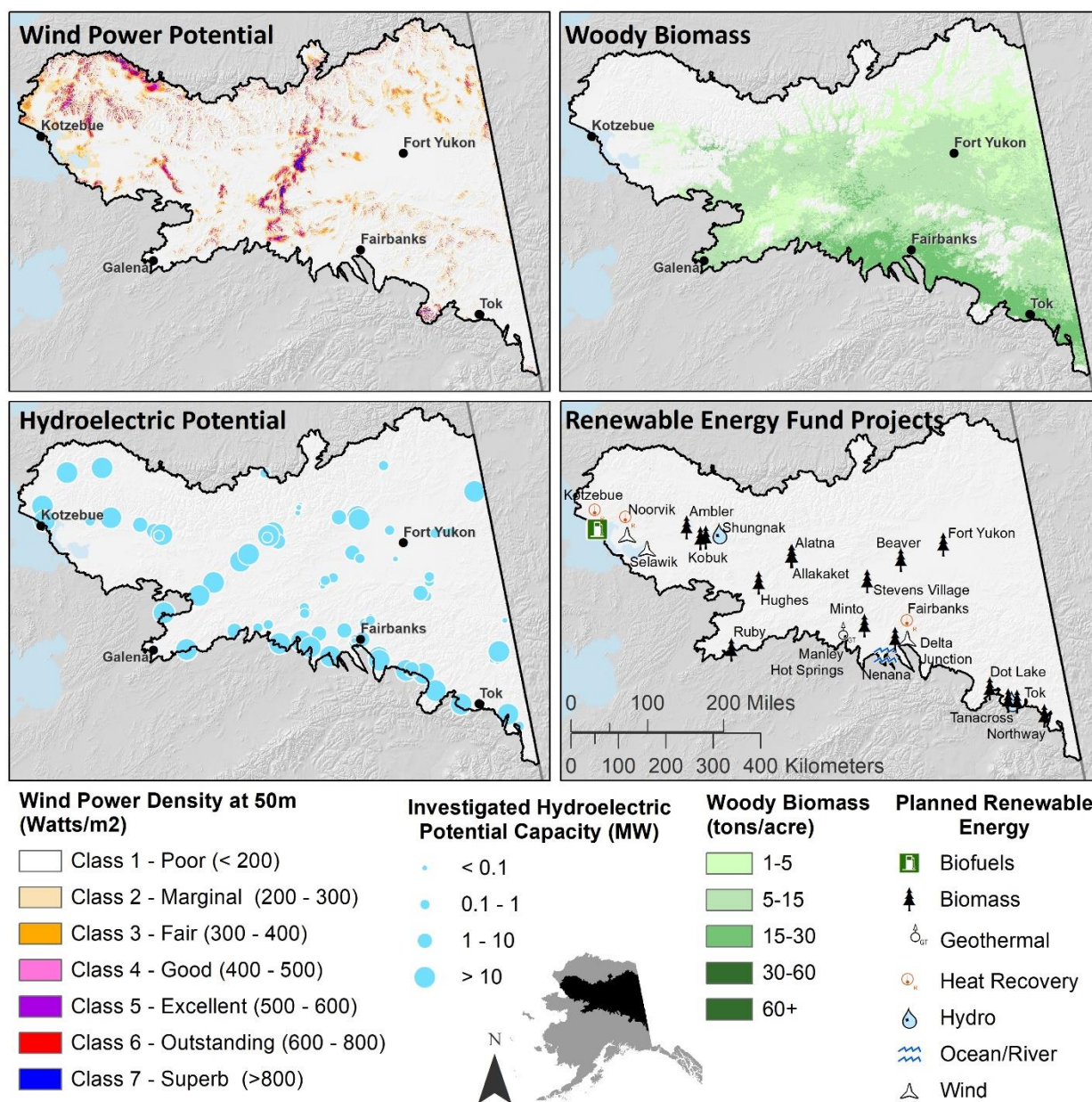


Figure E-102. Renewable energy potential in the Central Yukon study area. Data source: Alaska Energy Authority (AEA).

4. Human Footprint (MQs U1 and U3)

Various aspects of the current and long-term future human footprint are explained in the text above. The explanations provided here are intended as concise summaries.

MQ U1: Compare the footprint of all types of landscape and landscape disturbances (anthropogenic and natural changes) over the last 20 and 50 years?

A lot has changed on the landscape since 1963, but less since 1993. In 1963, Alaska had just become a state and was experiencing rapid population growth, and with that came development. The discovery of oil on the North Slope in the late 1970s had many ramifications for the CYR study area. The State was flush with money and several projects were initiated. The completion of the Dalton Highway from Fairbanks to the North Slope oil fields in 1974 was the last major highway construction project in the study area. In 1978, farmers around Delta Junction began clearing land for farming, which continues to influence the habitat and animals such as moose and bison in this area. Another major anthropogenic activity during that time period and location was the Chena River flood control levee, which has been operating since 1981. This project altered the habitat, and the design allowed the build-up of debris that has provided a source of firewood for local residents. The frequent flooding of the area also favors early successional habitat, which is preferred by moose and can provide habitat for waterfowl. Land ownership has changed greatly in the last 50 years with the establishment of several protected areas by the Alaska National Interest Lands Conservation Act (ANICLA). The ANICLA created 635,356 km² of protected areas and requires various levels of additional approval and permits to develop. Examination of the amount of infrastructure within and outside of protected lands did not reveal significant differences between roads, rails, and trails density, except for bridges of which there were only 78 inside protected areas versus 171 outside.

In the last 20 years there have been changes, but not to the same extent of the prior 30 years. Infrastructure has expanded but this is difficult to track because there are no centralized records of road, rail, electrical, and telecommunication expansions with dates. The ADNRC has built a forestry roads database with dates that we used to track smaller scale changes in road access. Roads certainly have expanded around the Fairbanks area as the population has grown from 40,616 in 1960 to 100,243 in 2013. A large portion of the timber harvest allocated out of the Fairbanks office in the last 20 years has occurred in the western portion along Standard Creek Road. Most harvested areas (465 of 492) occurred with 1 km of roads or trails, which illustrates the importance of access for timber harvest.

MQ U3: How and where is the anthropogenic footprint most likely to expand 20 and 50 years into the future?

Uncertainty surrounds predicting where humans will expand and impact the landscape, but it is more likely that anthropogenic footprints will radiate from existing infrastructure. However, there are a few known areas of active exploration for future development: the Ambler mining district, a rail extension southeast of Fairbanks, and oil and gas exploration in the Nenana basin. Predicting oil and gas development is extremely difficult, but leases indicate that future pipelines could spur off of the current trans-Alaska pipeline towards Nenana, especially given the community goal to be involved in oil and gas development in the future (Nenana 2013). Other potential natural gas development is in the Minto Flats, which may impact salmon habitat in the

Tanana River (Schmidt and Newland 2012). In general, forest harvests likely will not have a large impact in the overall CYR study area because many of the harvestable resources are in remote, difficult to reach locations and simply not economically feasible. Future timber sales, like in the past, will likely be within 1 km of a road or trail. Nonetheless, harvest of timber can have a large localized effect on fish habitat and if done for biomass projects, reduction of fuel use by communities.

Renewable energy is an attractive option for many communities in the CYR study area, especially since the spike in fuel costs in 2008. However, the expansion of renewable energy suffers from two issues: 1) renewable energy sources are remote and isolated, so development will be small scale (i.e., single-community scale), and 2) seasonality, in that energy may only be produced during a certain time of the year (ACEP 2012). Furthermore, the state of Alaska is a large source of funding for renewable energy so the overall economy will impact the rate at which development occurs. Though renewable energy sounds very attractive there are issues that may slow its expansion. Biomass is one type of renewable energy that is accessible year round and can be combined with other goals (i.e., fuel reduction, habitat enhancement, road/trail maintenance, etc.). For example, it is estimated that around Tok, there is 109 km² of high hazard fuels that can be harvested for biomass heating projects (Alaska Energy Authority 2014). These projects have become popular with the CYR study due to the availability of timber in the boreal forest. Forests around Galena, Delta Junction, and Tanana will continue to be impacted by biomass projects but how this will influence fish and wildlife is uncertain. The landscape around several other communities has the potential to be influenced by harvests for biomass: Chalkyitsik, Fort Yukon, Minto, Tanacross, Ambler, Kobuk, Shungnak, Dot Lake, Venetie, Alatna, Allakaket, Beaver, Ester, Hughes, Northway, Ruby, and Stevens Village. Communities with biomass projects will likely have some level of deforestation within a 40-km radius of their community.

Mineral exploration and extraction is extremely difficult to predict due to the highly volatile price of minerals, cost of fuel and equipment, and demand. The Ruby batholith area in the Northwest has high potential for several minerals: REE, PGE, and carbonate-hosted. Other potential mineral developments include the Ambler area including the road to Ambler, Umiat, Livengood mine prospect on Livengood Creek in the upper Tolovana River drainage, and a road from Tofty (near Manley) to near the Yukon River upstream from the confluence of the Tanana and Yukon rivers (Schmidt and Newland 2012). Gold mining has typically been concentrated along the major river drainages of the CYR study area, especially in the Fortymile country to the east. We estimate that 2–3 placer gold mines will be constructed annually based on gold prices and production during the last 20 years. A potential area of development for gold and other mineral resources (e.g., uranium, thorium, and REEs) is Tofty Ridge north of Manley Hot Springs. It is estimated that this road could save communities in the region \$2.4 million in shipping costs and would benefit the Fairbanks North Star Borough because Tanana would have road access to Fairbanks where residents can purchase supplies (Northern Economics 2013). Funds for this road were requested in the 2015 Alaska Legislative session.

The human population in the CYR study area is likely to continue to shift from rural Alaska to larger communities outside the study area (e.g., Anchorage, Matanuska-Susitna Valley) and to a smaller extent within (e.g., Fairbanks). The Tanana Valley Chiefs Conference, which represents several of the smaller communities in the study region, suggests that this could result in additional school closures (TCC 2015). Schools are a large employer within

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communities for both transient and local people, so their closure often has negative socioeconomic consequences.

5. Data Gaps and Limitations

The management questions posed during this REA were broad and far-reaching, and required the collection of various datasets. This highlighted issues with currently available data and gaps. Overall, the state of Alaska has excellent demographic and census data, but assessing the effect of specific industries (i.e., oil/gas, mining, tourism, etc.) can be difficult because secondary employment, expenditures, and spending are often uncoupled during data collection. One of the largest data gaps is the lack of a regularly maintained infrastructure dataset (i.e., land and air) that includes dates for expansion or contraction. Such a database would allow for better modeling of future development and assessment of impacts from development. This would require state, federal, and private agencies to work together and finding a stable source of funding.

Another data gap is the lack of historic resource extraction information. The ARDF attempts to capture past mining, but this database is a work in progress and, again, is not securely funded. However, the effort is notable and provides a start. Meanwhile, BLM has started to digitize their materials sites data; the GIS information prior to 2009 is only updated as needed. Also, one confusing issue with the material sites permits is that there are separate permitting numbers used by different agencies, Alaska Division of Lands (ADL #) and the Department of Natural Resources (MS #). Data can be looked up by the ADL # (AKDOT 2016) and ADNRR data are available by the MS# (Material Site Inventory 2016). Both sites provide good information, but they do not always provide the other's number to cross reference sites. The digital data contain the ADL #, but no MS #. Spatial datasets of forest harvest around the Fairbanks area are excellent, but datasets of forest harvest from the Tok area are inadequate because they do not capture timber harvest activities from the past 10 years. A digital spatial dataset would enable researchers to examine how harvest activities with different purposes influence the landscape and ecosystem services.

We used the USGS mineral potential report and spatial data as a proxy for potential future mining activity. This is a big assumption that the correlation between high potential and high development is not always true. Just because an area has high mineral potential does not mean it will be developed. Also, access is a major factor that we attempted to account for but rivers can also act as access routes, but we did not use these to modify the mineral potential provided by the USGS report. Even though nearly 110,000 samples were examined to develop the maps in the report, there are still large portions unsampled, so extrapolations and assumptions were used to assess mineral potential. Overall, future mining activity presented in this report should be viewed with caution. Lastly, the USGS mineral report does not cover the entire CYR study area so only the ARDF was used to examine areas outside of the report region.

While the distressed community list compiled by the Denali Commission is useful at identifying communities that are distressed, the underlying mechanisms are not captured because there is no documentation about which of the two criteria were not met by each community. Detailed information on financial criteria would provide additional insight on community financial distress. For example, distressed communities that did not qualify for the third criteria might be regional hubs where year-round employment is common but pay is often low. Communities that have few very high paying jobs might not qualify for criteria one, which could indicate that loss of a few high paying jobs would have severe financial consequences for the community. Examining

temporal and spatial trends in the financial criteria selected by the Denali Commission would provide a better understanding of conditions contributing to distress in communities in Alaska.

Data about recreation use on federal land, other than NPS, and state land are limited. The NPS data that were used have issues in that the definition of a visitor differs from place to place. Only one preserve counted guided hunting in their statistics, which may or may not be considered recreational use. Either way, this activity certainly occurs in the other preserves and its inclusion should be consistent. Also, since methods used to collect statistics have and will continue to change, a log of the changes would be an excellent resource. The Gates of the Arctic and Yukon-Charley Preserve had excellent employee comments going back to the mid-2000s that helped greatly with interpretation of the data, but the other areas were limited.

The sport and subsistence harvest data have various limitations, some of which are significant. Failing to report hunting activity or harvests is an issue with all self-reporting harvest data. In Game Management Unit 20A south of the CYR REA study area near Fairbanks, which is hunted mostly by urban residents, wildlife managers estimate that 20% of moose killed by hunters are not reported or die from wounding (Boertje et al. 2009). However, reporting rates among rural residents may be as low as 30% of the harvest reported (Schaeffer et al. 1986). This extremely poor reporting rate with ADF&G harvest tickets is one reason why the Division of Subsistence conducts household surveys. Either way, reported hunting and harvest data should be viewed as a minimum. The same can be said for the sport fish angler data. Especially given that slightly less than half of the communities in the CYR study area ($n = 32$) reported sport fishing activity. So harvests reported with this database do not reflect subsistence harvest, even subsistence harvest done with a rod and reel.

After 2010, the state harvest data were no longer included in the federal data due to security issues. This is very unfortunate in that now the federal database only captures a small portion of harvest activity in the CYR study area. Another reason this is unfortunate is because only the federal database reports harvest at the community level and residency (Alaska versus Non-Alaskan resident). State data are reported at the GMU level, which is too large to make inferences about community harvests or how certain development actions (i.e., access) might change harvest. Subsistence surveys typically include a mapping component, but they are not conducted in every community, there may only be a single year of data, and harvest activity can vary greatly from year to year. Household surveys are also not conducted that often in larger communities ($> 1,000$ people). The ADF&G Division of Subsistence has more spatial data, but currently there is no automated system for public access. Thus, employees must handle requests, which take time and money away from their current duties. Given the large number of communities in the CYR study area, this request was understandably too large without additional funding or other support for ADF&G. Other agencies, such as Native or Tribal entities, collect subsistence information but access is limited and data are scattered and can be lost. Misuse is a valid concern, but it may be worthwhile for Native or Tribal entities to work together to have a central repository for non-state or federal subsistence data collected in the State.

Changes in reporting methods and data collection can obscure trends as was seen with caribou harvests (Figure E-40). Harvests increased in the northern regions, but in the 1990s there were no harvests reported. Another data gap is the lack of caribou data from hunters living north of the Yukon River. Reporting rates are low by rural Alaska for all species, but use of special permits is trying to change that at least for moose hunting. Overall, the harvest data for residents of rural Alaska likely represent a minimum of actual harvest levels. Lastly, the ADF&G

data do not differentiate between hunters and hunts, which is an issue because the use of multiple permits (i.e., hunts) is becoming a problem and can overestimate the amount of hunting activity (Schmidt et al. 2015). The CSIS database contains a wealth of information on subsistence harvests in Alaska, but it is easy to misuse. Harvests can be overestimated because the data are reported multiple times at different scales with no clear guide how lower level resources fit into higher level categories. For example, herring is reported by type, then by total herring, and then non-salmon fish. This can get especially confusing for resources that are found in both salt and fresh water. Caution must also be used when examining the harvest amounts or per capita numbers from “All Resources,” which is all resources asked in that particular survey, so surveys that look at a subset of resources like non-salmon or large game will underestimate the overall use of the community. Surveys about subcategories, such as non-salmon, are important and useful, but comparisons must be made only between surveys that targeted the same types of resources. Surveys that only collected information on a subset of subsistence resources still say “All Resources” when the data are downloaded and give no indication that only a subset of resources was examined. Currently, there is no way to select only comprehensive surveys, which would give the more accurate estimate of harvest needs.

6. Literature Cited

- AKDCCED. 2015. Alaska fuel price report: current community conditions - July 2015. Department of Commerce, Community, and Economic Development. Available: https://www.commerce.alaska.gov/web/Portals/4/pub/FuelPriceReport_July2015.pdf
- AKDCRA. 2015. Alaska fuel price report: current community conditions July 2015. Alaska Department of Community and Regional Affairs. Available: <https://www.commerce.alaska.gov/web/dcra/>
- AKDHSS. 2015. Data and statistics. Available: <http://dhss.alaska.gov/dph/VitalStats/Pages/data/default.aspx>
- AKDLWD. 2016. Migration data and information. Available: <http://labor.alaska.gov/research/pop/migration.htm>
- AKDLWD. 2016a. Alaska population projections: 2015 to 2045. <http://live.laborstats.alaska.gov/pop/projections/pub/popproj.pdf>
- AKDLWD. 2016b. Migration data and information. Available: <http://live.laborstats.alaska.gov/pop/migration.cfm>
- AKDNR. 2015. Mineral sales in Alaska. May 2015. Available: http://dnr.alaska.gov/mlw/factsht/land_fs/material_sites.pdf
- AKDNR, Division of Forestry. 1987. Tanana Valley State Forest management plan public review draft. Fairbanks, Alaska. 226 pp.
- AKDOL. 2014. Alaska population projections: 2012 to 2042. Department of Labor and Workforce Development, Research and Analysis Section.
- AKDOT. 2010a. Western Alaska access planning study: corridor planning report executive summary. January 2010. Available: <http://www.westernalaskacopperandgold.com/news/January%202010%20ADOT%20Corridor%20Planning%20Report%20Executive%20Summary.pdf>
- AKDOT. 2010b. Foothills west transportation access: the road to Umiat. December 2010. Available: <http://northern.org/media-library/document-archive/arctic/western-arctic-npr-a/adot-the-road-to-umiat-presentation-12-2010>
- AKDOT. 2010c. Interim corridor analysis/matrix. Project No. 62210. May 2010. Available: <http://www.foothillsroad.alaska.gov/files/interim-corridor-analysis-matrix.pdf>
- AKDOT. 2012a. Alaska department of transportation and public facilities: ambler mining district access. Available: <http://dnr.alaska.gov/commis/cacfa/documents/MeetingInformation/2012Fairbanks/AmblerMiningAccessDOTPresentation.pdf>
- AKDOT. 2012b. Ambler mining district access summary report. Available: http://www.ambleraccess.org/projects/ambler/documents/summary_report_05_12_reportandref_2.pdf
- AKDOT. 2016. Case, Land, and Water Information. Available: <http://www.dot.state.ak.us/stwddes/desmaterials/matsiteportal/materialsitemap.cfm>
- Alaska Center for Energy and Power (ACEP). 2012. Stranded renewable energy resources of Alaska: a preliminary overview of opportunities and challenges to development. University of Alaska Fairbanks.
- Alaska Department of Fish and Game (ADF&G). 1986. Downstream effects of placer mining in the Birch Creek Basin, Alaska. Technical Report 86-7. Alaska Department of Fish and Game, Division of Habitat, July 1986.
- Alaska Department of Fish and Game (ADF&G). 2012. Moose management report of survey-inventory activities, 1 July 2009-30 June 2011. P. Harper, ed. Alaska Department of Fish and Game, Species Management Report, ADF&G/SMR/DWC-2012-5, Juneau.

- Alaska Department of Fish and Game (ADF&G). 2013. Caribou management report of survey-inventory activities 1 July 2010 – 30 June 2012. P. Harper, ed. 2013. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2013-1, Juneau.
- Alaska Department of Fish and Game (ADF&G). 2014. Trends in Alaska sheep populations, hunting, and harvests. Division of Wildlife Conservation, Wildlife Management Report ADF&G/DWC/WMR-2014-3, Juneau.
- Alaska Department of Fish and Game, Division of Sport Fish (ADF&G Sport Fish). 2016. Alaska Sport Fishing Survey Database. Anchorage, Alaska. Available:
<http://www.adfg.alaska.gov/sf/sportfishingsurvey/index.cfm?ADFG=main.home>
- Alaska Department of Fish and Game, Division of Wildlife Conservation (ADF&G Wildlife Conservation). 2016. Alaska hunting information. Available:
<http://www.adfg.alaska.gov/index.cfm?adfg=hunting.regulations>
- Alaska Energy Authority. 2014. Appendix Alaska renewable energy fund status report rounds I-VI. February 12, 2014. Alaska Energy Authority.
- Alaska Energy Authority. 2015. Renewable energy fund: status report and round VIII recommendations. Available:
<http://www.akenergyauthority.org/Content/Programs/RenewableEnergyFund/Documents/REFReport/AEAOnlineFinal051915.pdf>
- Alaska Mapped. 2016. Alaska Mapped: WMS, WFS, and WCS web services. Available:
<http://www.alaskamapped.org/data/wms-wfs-wcs-web-service-feeds>
- Andersen, D. B., and C. L. Alexander. 1992. Subsistence hunting patterns and compliance with moose harvest reporting requirements in rural Interior Alaska. Division of Subsistence, Alaska Department of Fish and Game.
- Applied Development Economics. 2016. Fairbanks North Star Borough comprehensive economic development strategy. Applied Development Economics. Available:
<http://co.fairbanks.ak.us/mayor/Documents/FNSB%20CEDS%202016-Final.pdf>
- Arctic Social Indicators (ASI). 2010. Page 519 in J. N. Larsen, P. Schweitzer, and G. Fondahl, eds. TemaNord. Copenhagen: Nordic Council of Ministers.
- Barber, V. A., G. P. Juday, and B. P. Finney. 2000. Reduced growth of Alaskan white spruce in the twentieth century from temperature-induced drought stress. *Nature* 405:668-673.
- BLM. 2005. Reasonable foreseeable development scenario for oil and natural gas resources in the Kobuk-Seward Peninsula planning area, Alaska. October 2005. U.S. Department of the Interior Bureau of Land Management, Alaska State Office, Division of Energy and Solid Minerals.
- Boertje, R. D., M. A. Keech., D. D. Young, K. A. Kellie, and C. T. Seaton. 2009. Managing for elevated yield of moose in interior Alaska. *Journal of Wildlife Management* 73:314–327.
- Brown, C. L., and A. Godduhn. 2015. Socioeconomic effects of declining salmon runs on the Yukon River. Alaska Department of Fish and Game, Division of Subsistence, Technical Paper No. 398, Fairbanks.
- Brown, C. L., J. S. Magdanz, D. S. Koster, and N. M. Braem. 2012. Subsistence harvests in 8 communities in the central Kuskokwim River drainage, 2009. Alaska Department of Fish and Game, Division of Subsistence, Technical Paper No. 365, Fairbanks. Available:
<http://www.adfg.alaska.gov/techpap/TP%20365.pdf>
- Caikoski, J. R. 2012. Units 25A, 25B, and 25D moose. Pages 623–654 in P. Harper, ed. Moose management report of survey and inventory activities 1 July 2009–30, June 2011. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2012-5, Juneau.
- Calef, M. P., A. Varvak, A. D. McGuire, F. S. Chapin, and K. B. Reinhold. 2015. Recent changes in annual area burned in Interior Alaska: the impact of fire management. *Earth Interactions* 19:1-17.
- Cardno. 2015. Ambler mining region economic impact analysis. Cardno Project Number E514004900. Portland, Oregon.

Section E. Anthropogenic Change Agents

- Carlson, T. R., S. Yoon, and R. G. Dulla. 2010. 2010 Fairbanks home heating survey. Sierra Research, Inc., Sacramento, California.
- Christie, K. S., R. W. Ruess, M. S. Lindberg, and C. P. Mulder. 2014. Herbivores influence the growth, reproduction, and morphology of a widespread Arctic willow. *PLoS ONE* 9:e101716.
- Clemens, M. 2014. Does development reduce migration? Working Paper 359, Center for Global Development. Available: <http://www.cgdev.org/sites/default/files/does-development-reduce-migration-final-0.pdf>
- Dau, J. 2011. Units 21D, 22A, 22B, 22C, 22D, 22E, 23, 24, and 26A caribou management report. Pages 187-250 in P. Harper, ed. Caribou management report of survey and inventory activities 1 July 2008-30, June 2010. Alaska Department of Fish and Game, Juneau.
- DOWL HKM. 2010. Western Alaska access planning study: corridor planning report executive summary. January 2010. DOT and PF Project No. 60800.
- Durbin, J., and S. J. Koopman. 2001. Time series analysis by state space methods. Oxford University Press, Oxford.
- Energy Information Administration. 2015. Domestic crude oil first purchase prices by area. Available: <https://www.eia.gov/state/data.cfm?sid=AK#Prices>
- Fairbanks Economic Development Corporation. 2010. Eielson Air Force Base and its impact on Interior Alaska. Available: <https://investfairbanks.com/sites/default/files/documents/Eielson%20brochure%20med-res.s.pdf>
- Feige, C., and P. Decker. 2015. Frontier basins overview: senator Giessel working group presentation. November 20, 2015. Available: <https://www.alaskasenate.org/2016/files/6914/4889/6403/Alaska-Div-Oil-Gas-Frontier-Basin-11-20-2015.pdf>
- FNSB. 2014. Geographic allocation of household and commercial acre growth within the FMATS travel demand model area. Methodology and calculations developed and performed by the FNSB in consultation with the Alaska DOT&PF and Kittelson and Associates. April 3, 2014.
- Ford, J. D., and C. Furgal. 2009. Forward to the special issue: climate change impacts, adaptation and vulnerability in the Arctic. *Polar Research* 28:1–9.
- Fried, N. 2013. The military and Alaska's economy. *Alaska Economic Trends Magazine*. Available: <http://laborstats.alaska.gov/trends/dec13art1.pdf>
- Fried, N., B. Windisch, and G. Haynes. 1999. The Northwest Arctic Borough. January 1999. *Alaska Economic Trends Magazine*. <http://labor.alaska.gov/trends/trendspdf/jan99.pdf>
- Georgette, S., D. Caylor, and S. Tahbone. 2003. Subsistence salmon harvests summary Northwest Alaska 2002. Alaska Department of Fish and Game, Division of Subsistence, and Kawerak, Inc.
- Georgette, S., and H. Loon. 1991. Subsistence hunting of Dall's sheep in northwest Alaska. Technical paper number 208. Division of Subsistence, Alaska Department of Fish and Game. Juneau, Alaska.
- Government Accountability Office. 2004. Alaska native villages: villages affected by flooding and erosion have difficulty qualifying for federal assistance. Government Accountability Office. 21 pp.
- Ground Truth Trekking. 2012. Alaska coal history. Available: <http://groundtruthtrekking.org/Issues/AlaskaCoal/AlaskaCoalHistory.html>
- Gustine, D., T. Brinkman, M. Lindgren, J. I. Schmidt, T. Rupp, and L. Adams. 2014. Climate-driven effects of fire on winter habitat for caribou in the Alaska-Yukon Arctic. *PLOS ONE*: 9:e100588. doi:10.1371/journal.pone.0100588
- Haley, S., and D. Fisher. 2012. Indigenous employment, training and retention: successes and challenges at Red Dog Mine. In E. Gilberthorpe, and G. Hilson, eds. *Natural resource extraction and indigenous livelihoods: development challenges in an era of globalization*. Ashgate Publishing, United Kingdom.
- Haley, S., F. Ginny, F. Hannah, and B. Saylor. 2009. Red Dog Mine Extension Aqqaq Project, Appendix G Social Conditions, Institute of Social and Economic Research. Available: http://www.iser.uaa.alaska.edu/Publications/8%28a%29/background%20info/RedDog-Appendix_G.pdf

- Hezel, P. J., X. Zhang, C. M. Bitz, B. P. Kelly, and R. Massonnet. 2012. Projecting decline in spring snow depth on Arctic sea ice caused by progressively later autumn open ocean freeze-up this century. *Geophysical Research Letters* 39, doi:10.1029/2012GL052794.
- Himes-Cornell, A., and S. Kasperski. 2015. Assessing climate change vulnerability in Alaska's fishing communities. *Fisheries Research* 162:1-11.
- Holen, D., S. M. Hazell, and D. S. Koster. 2012. Subsistence harvests and uses of wild resources by communities in the Eastern Interior of Alaska, 2011. Alaska Department of Fish and Game, Division of Subsistence, Technical Paper No. 372, Anchorage. Available: <http://www.adfg.alaska.gov/techpap/TP%20372.pdf>
- Hollis, A. L. 2012. Unit 20B moose. Pages 356–378 in P. Harper, ed. Moose management report of survey and inventory activities 1 July 2009–30 June 2011. Alaska Department of Fish and Game, Species Management Report, ADF&G/DWC/SMR-2012-5, Juneau.
- Howe, E. L. 2009. Patterns of migration in Arctic Alaska. *Polar Geography* 32:69-89.
- Huskey, L., M. Berman, and A. Hill. 2004. Leaving home, returning home: migration as a labor market choice for Alaska Natives. *Annals of Regional Science* 38:75-92.
- Ikuta, H., A. R. Brenner, and A. Godduhn. 2013. Socioeconomic patterns in subsistence salmon fisheries: historical and contemporary trends in five Kuskokwim river communities and overview of the 2012 season. Alaska Department of Fish and Game, Division of Subsistence, Technical Paper No. 382, Fairbanks.
- Immediate Action Work Group. 2009. Recommendations to the governor's subcabinet on climate change. The State of Alaska, Juneau, Alaska. Available: http://climatechange.alaska.gov/docs/iaw_finalrpt_12mar09.pdf
- Inkley D. B., M. G. Anderson, A. R. Blaustein, V. R. Burkett, B. Felzer, B. Griffith, J. Price, and T. L. Root. 2004. Global climate change and wildlife in North America. The Wildlife Society, Bethesda, Maryland.
- Johnson W. C., B. V. Millett, T. Gilmanov, R. A. Voldseth, G. R. Guntenspergen, and D. E. Naugle. 2005. Vulnerability of northern prairie wetlands to climate change. *BioScience* 55:863–872.
- Johnstone, J. F., T. N. Hollingsworth, F. S. Chapin III, and M. C. Mack. 2010. Changes in fire regime break the legacy lock on successional trajectories in Alaskan boreal forest. *Global Change Biology* 16:1281-1295.
- Jones, J. V., S. M. Karl III, K. A. Labay, N. B. Shew, M. Granitto, T. S. Hayes, J. L. Mauk, J. M. Schmidt, E. Todd, B. Wang, M. B. Weldon, and D. B. Yager. 2015. GIS-based identification of area with mineral resource potential for six selected deposit groups. Bureau of Land Management central Yukon planning area, Alaska. U.S. Geological Survey. Report 2015-1021.
- Juday, G. P., V. Barber, P. Duffy, H. Linderholm, S. Rupp, S. Sparrow, E. Vaganov, and J. Yarie. 2005. Forests, land management, and agriculture. Pages 781-862 in *Arctic Climate Impact Assessment*.
- Kalke, T. R. 2015. Sustainable energy for Galena, Alaska: timber harvest management plan. Dissertation for master of natural resources, Oregon State University.
- Kasischke, E. S., and M. R. Turetsky. 2006. Recent changes in the fire regime across the North American boreal region—spatial and temporal patterns of burning across Canada and Alaska. *Geophysical Research Letters* 33.
- Kofinas, G. P., F. S. Chapin, S. BurnSilver, J. I. Schmidt, N. L. Fresco, K. Kielland, S. Martin, A. Springsteen, and T. S. Rupp. 2010. Resilience of Athabaskan subsistence systems to interior Alaska's changing climate. *Canadian Journal of Forest Research* 40:1347-1359.
- Koontz, P. 2013. Wood based district heating for Galena City School District. Available: http://www.uaf.edu/files/acep/2013_REC_A%20Community%20Wood%20Heat%20Project%20For%20Galena_Phil%20Koontz.pdf
- Larsen, J. N., P. P. Schweitzer, A. Petrov, and G. Fondahl. 2014. Tracking change in human development in the Arctic. Pages 15-53 in J. N. Larsen, P. P. Schweitzer, and A. Petrov, eds. *Arctic social indicators: ASI II: implementation*. Nordic Council of Ministers, Akureyri, Iceland.

Section E. Anthropogenic Change Agents

- Loring P. A., and S. C. Gerlach. 2010. Food security and conservation of Yukon River salmon: are we asking too much of the Yukon River? *Sustainability* 2:2965–2987.
- Magdanz, J. S., N. S. Braem, B. C. Robbins, and D. S. Koster. 2010. Subsistence harvests in northwest Alaska Kivalina and Noatak, 2007. Alaska Department of Fish and Game, Division of Subsistence. Available: <http://www.subsistence.adfg.state.ak.us/techpap/tp354.pdf>
- Magdanz, J. S., J. Greenberg, J. M. Little, and D. S. Koster. 2016. The persistence of subsistence: wild food harvests in rural Alaska, 1983–2013. Available: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2779464
- Mann, D. H., T. S. Rupp, M. A. Olson, and P. A. Duffy. 2012. Is Alaska's boreal forest now crossing a major ecological threshold? *Arctic Antarctic and Alpine Research* 44:319–331.
- Marcot, B. G., M. T. Jorgenson, J. P. Lawler, C. M. Handel, and A. R. DeGange. 2015. Projected changes in wildlife habitats in Arctic natural areas of northwest Alaska. *Climatic Change* 130:145–154.
- Material Site Inventory. 2016. Available: <http://www.dot.state.ak.us/stwddes/desmaterials/matsiteportal/materialsitemap.cfm>
- McDowell. 2008. The economic impacts of the University of Alaska. February 2008. McDowell Group, Inc., Anchorage, Alaska.
- McDowell. 2012. The economic impacts of Alaska's mining industry. January 2012. McDowell Group, Inc., Anchorage, Alaska. Available: https://investfairbanks.com/sites/default/files/documents/Mining%20Impact%202011_0.pdf
- McDowell. 2014. The economic impacts of placer mining in Alaska. October 2014. McDowell Group, Inc., Anchorage, Alaska.
- McNeeley, S. M. 2012. Examining barriers and opportunities for sustainable adaptation to climate change in Interior Alaska. *Climatic Change* 111:835–857.
- McNeeley S, M., and M. D. Shulski. 2011. Anatomy of a closing window: vulnerability to changing seasonality in Interior Alaska. *Global Environ Chang* 21:464–473.
- Meany, K. 2014. 5 years schedule of timber sales. Available: http://forestry.alaska.gov/Assets/uploads/DNRPublic/forestry/pdfs/timber/fbkstimber/2014/FYSTS_14_18_2_5_14_final.pdf
- Moerlein K. J., and C. Carothers. 2012. Total environment of change: impacts of climate change and social transitions on subsistence fisheries in northwest Alaska. *Ecology and Society* 17. doi:10.5751/ES-04543-170110.
- Moore, S. E., and H. P. Huntington. 2008. Arctic marine mammals and climate change: impacts and resilience. *Ecological Applications* 18:S157–S165.
- NANA Pacific. 2008. Distributing Alaska's power: a technical and policy review of electric transmission in Alaska. Prepared for: the Denali Commission, submitted December 4, 2008.
- Nenana Native Village. 2013. Nenana community development plan: where the river meets the crossroads of the Interior 2013–2018. Prepared by Nenana residents assistance from Tanana Chiefs Conference Community Planning Program.
- Neuswanger, J. R., M. S., Wipfli, M. J. Evenson, N. F. Hughes, and A. E. Rosenberger. 2015. Low productivity of Chinook salmon strongly correlates with high summer stream discharge in two Alaskan rivers in the Yukon drainage. *Canadian Journal of Fisheries and Aquatic Science* 72:1125–1137.
- Northern Economics. 2013. Economic effects of proposed road: Manely Hot Springs to Tanana Road. January 2013. Available: <http://www.tozitna.com/resources/Manley%20to%20Tanana%20Economic%20Effects%20Final%20Report.pdf>
- Nowak, M. 1975. Subsistence trends in a modern Eskimo community. *Arctic* 28:21–34.
- NWAB. 2015. Northwest Arctic Borough comprehensive economic development strategy. Northwest Arctic Borough and the Economic Commission of Northwest Alaska, August 2015.

- OMD. 1985. Alaska's mineral industry 1985. Office of Mineral Development, Division of Mining, Division of Geological and Geophysical Surveys. Special Report 39.
- Riordan, B., D. Verbyla, and A. D. McGuire. 2006: Shrinking ponds in subarctic Alaska based on 1950–2002 remotely sensed images. *Journal of Geophysical Research* 111, G04002, doi:10.1029/2005JG000150. Available: <http://onlinelibrary.wiley.com/doi/10.1029/2005JG000150/pdf>
- Rogers, M., and J. Hermanns. 2010. Alaskan community to benefit for years to come from local wood energy project. Available: http://forestry.alaska.gov/Assets/uploads/DNRPublic/forestry/pdfs/wood/DOF_Tok_School_Wood_Energy_Article_2011-16-10.pdf
- Sampson, G. R., W. W. S. VanHees, T. S. Setzer, and R. C. Smith. 1988. Potential for forest products in Interior Alaska. Resource Bulletin, PNW-RB-153, Portland, Oregon: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 28 pp.
- Schaeffer, P., D. Barr, and G. Moore. 1986. Kotzebue Fish and Game advisory committee regulation review: a review of the game regulations affecting northwest Alaska. Kotzebue, AK, USA: Kotzebue Fish and Game advisory committee.
- Schmidt, J. I., and F. S. Chapin. 2014. Relationship of community characteristics to harvest reporting: comparative study of household surveys and harvest tickets in Alaska. *Human Dimensions of Wildlife* 19:334-346.
- Schmidt, J. I., K. A. Kellie, and F. S. Chapin III. 2015. Detecting, estimating, and correcting for biases in harvest data. *Journal of Wildlife Management* 79:1152-1162.
- Schmidt, S. N., and E. Newland. 2012. Yukon River king salmon stock status, action plan and summer chum salmon fishery, 2012; a report to the Alaska board of fisheries. Alaska Department of Fish and Game, Division of Sport Fish and Commercial Fisheries. Anchorage, Alaska.
- Schultz, C. 2015. The '80s recession: are we in a similar position today? *Alaska Economic Trends Magazine*. Available: <http://labor.alaska.gov/trends/sep15.pdf>
- Shanks, A. 2009. Northwest Arctic Borough: a look at an economy in the remote North. *Alaska Economic Trends*, August 2009.
- Springer, A. M., and G. B. vanVliet. 2014. Climate change, pink salmon, and the nexus between bottom-up and top-down forcing in the subarctic Pacific Ocean and Bering Sea. *Proceedings of the National Academy of Sciences of the United States of America* 111, doi: 10.1073/pnas.1319089111.
- Stout, G. W. 2012. Unit 21D moose. Pages 496–533 in P. Harper, ed. Moose management report of survey and inventory activities 1 July 2009–30 June 2011. Alaska Department of Fish and Game, Species Management Report, ADF&G/SMR/DWC-2012-5, Juneau, Alaska.
- Stroeve, J. C., M. C. Serreze, M. M. Holland, J. E. Kay, J. Malanik, and A. P. Barrett, 2012: The Arctic's rapidly shrinking sea ice cover: A research synthesis. *Climatic Change* 110:1005-1027, doi:10.1007/s10584-011-0101-1. Available: <http://link.springer.com/content/pdf/10.1007%2Fs10584-011-0101-1.pdf>
- Szymoniak, N., G. Fay, A. Villalobos-Melendez, J. Charon, and M. Smith. 2010. Components of Alaska fuel costs: an analysis of the market factors and characteristics that influence rural fuel prices. University of Alaska Anchorage, Institute of Social and Economic Research. Prepared for: the Alaska State Legislature, Senate Finance Committee. 77 pp.
- Tanana Valley State Forest. 2001. Tanana Valley State Forest: forest roads information. Available: <http://forestry.alaska.gov>
- Tape, K. K., D. D. Gustine, R. W. Ruess, L. G. Adams, and J. A. Clark. 2016. Range expansion of moose in arctic Alaska linked to warming and increased shrub habitat. *PLOS One* 11:e0160049, DOI:10.1371/journal.pone.0152636.
- Tape, K. D., R. Lord, H.-P. Marshall, and R. W. Ruess. 2010. Snow-mediated ptarmigan browsing and shrub expansion in Arctic Alaska. *Ecoscience* 17:186-193.

Section E. Anthropogenic Change Agents

- TCC. 2015. Strategic plan 2015-2020. Tanana Chiefs Conference. Available: <https://www.tananachiefs.org/wp-content/uploads/2015/02/TCC-2015-2020-Strategic-Plan.pdf>
- Teseneer, R., R. Foland, A. Seidlitz, J. Borkoski. Unpublished Report. Selawik National Wildlife Refuge Oil and Gas Assessment. USDOI, BLM. 12 pp.
- USFWS. 2014. Management regulation for the harvest of wildlife on federal public lands in Alaska. Available: https://www.doi.gov/sites/doi.opengov.ibmcloud.com/files/uploads/2014-2016%20Wildlife%20Reg%20Book%20low%20Resolution_0.pdf
- USGS. 1998. Rivers of gold – placer mining in Alaska. Fact Sheet -058-98. Available: <http://pubs.usgs.gov/fs/1998/0058/report.pdf>
- Wayland, R. 1961. Tofty tin belt Manley Hot Springs District, Alaska. Mineral Resources of Alaska. Geological Survey Bulletin 1058-I. Available: <http://pubs.usgs.gov/bul/1058i/report.pdf>
- Wiebold, K. 2015. Rent over a decade: an overview of trends in four major Alaska rental markets. Pages 12 - 13 in S. Whitney, ed. Alaska Economic Trends - August 2015. Available: <http://labor.state.ak.us/trends/aug15.pdf>
- Wilmking, M., and I. Myers-Smith. 2008. Changing climate sensitivity of black spruce (*Picea mariana* Mill.) in a peatland-forest landscape in interior Alaska. *Dendrochronologia* 25:167-175.
- Wilson, N. J. 2014. The politics of adaptation: subsistence livelihoods and vulnerability to climate change in the Koyukon Athabascan Village of Ruby, Alaska. *Human Ecology* 42:87-101.
- Wilson, R., D. D. Gustine, and K. Joly. 2014. Evaluating potential effects of an industrial road on winter habitat of caribou in North-central Alaska. *Arctic* 67:472-482.
- Wolfe, R. J., and V. Fischer. 2003. Methods for rural/non-rural determination for federal subsistence management in Alaska. Institute of Social and Economic Research, University of Alaska Anchorage. Available: <http://www.iser.uaa.alaska.edu/Publications/Rural%20Final%20Report2.pdf>
- Wurtz, T. L., R. A. Ott, and J. C. Maisch. 2006. Timber harvest in Interior Alaska. In F. S. Chapin, M. W. Oswood, K. Van Cleve, L. A. Viereck, and D. L. Verbyla, eds. *Alaska's changing boreal forest*. Oxford University Press.

F. Landscape and Ecological Integrity

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Summary

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

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1. Introduction

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

The BLM originally proposed an ecological integrity assessment as one of the integrated datasets created for the Rapid Ecoregional Assessments (REAs). Due to the reasons stated above, most REAs have assessed what they call ecological intactness. Working with the Assessment Management Team (AMT) and representatives at the BLM National Operations Center (NOC), we focus most of our modeling on understanding Landscape Integrity (LI) instead of ecological intactness. Given that Alaskan landscapes are largely intact, landscape integrity better captures the impacts of human modification on the landscape without assuming that ecological integrity is compromised.

We define Landscape Integrity to include three different descriptions of the landscape: landscape condition, landscape intactness, and potential cumulative impacts (Figure F-1). Although we do not present a specific model of ecological integrity, the three metrics of LI can be used to infer key elements of ecological integrity. It should also be noted that landscape condition is used in other sections to provide a measure of status for each Conservation Element (CE). More information and interpretation of CE status can be found in Sections G., H., I., and J. Details and methods for each of these are described in more detail below.

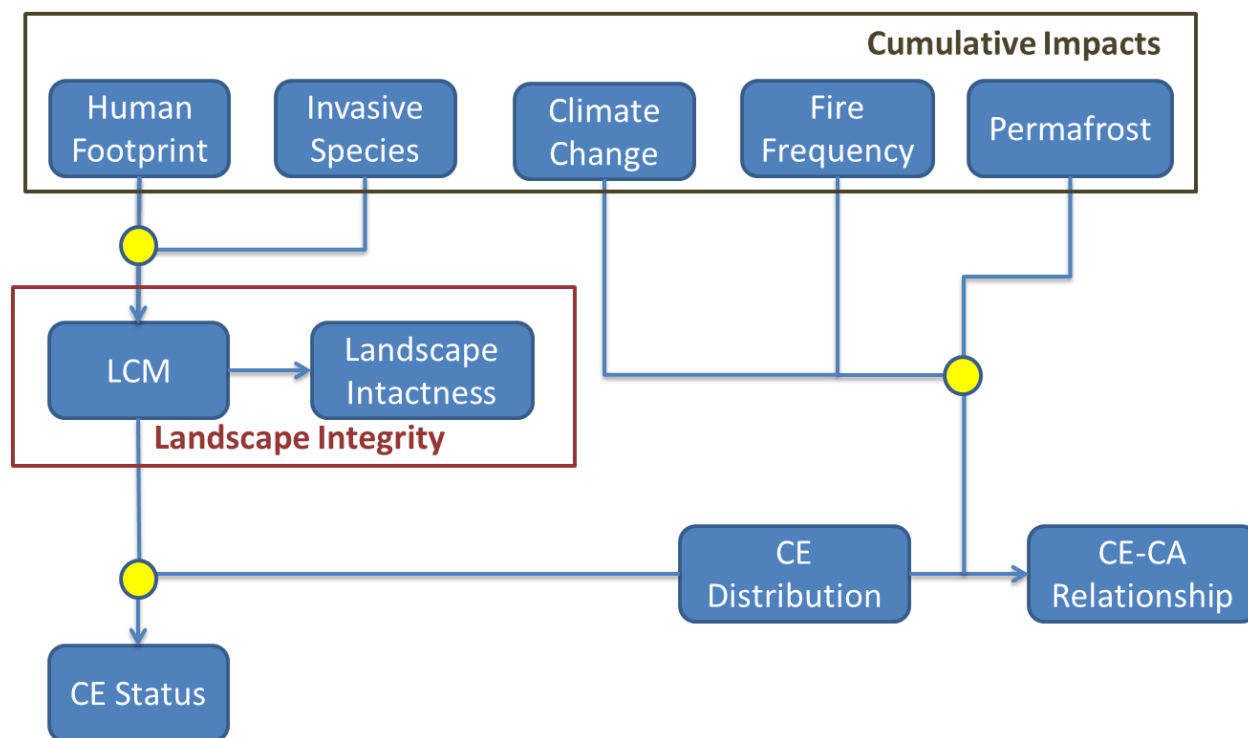


Figure F-1. Process model describing the various integrated products developed in this REA to explore the integrity of this region.

2. Landscape Condition

2.1 Introduction

The Landscape Condition Model (LCM) is a simple yet robust way to measure the impact of the human footprint on a landscape (Comer and Hak 2009). The LCM weights the relative influence of different types of human footprints based on factors such as permanence and the nature of the activity. Permanent human modification is weighted the lowest condition (highest impact), while temporary uses receive a higher condition score (e.g., Yukon River snow machine routes). Intensive land uses like mining are also weighted to imply a higher impact than less intensive land uses, such as railroads or trails. These weights are summed across the landscape and coalesced into a single surface identifying how impacted a given area is due to human modification. The LCM is scaled from 0, representing the most impacted and lowest condition landscape, to 1, representing the highest condition landscape. The LCM was specifically requested by AMT members for this REA to complement the LCM developed for the other REAs in Alaska. The LCM, unlike the other models in this section, is provided at both its native resolution (60 m) and at a 5th-level HUC resolution.

2.2 Methods

Human Land Use Data

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

Table F-1. Source datasets for analysis of Landscape Condition. Description of many of these datasets can be found in Section E. Anthropogenic Change Agents.

Timeframe	Category	Theme	Source
Historical	Alternative Transportation	Forestry	Digitized from aerial and satellite imagery
Historical	Alternative Transportation	Historical Trail	AKDNR Information Resources Management
Historical	Mining	Mining	U.S. Department of the Interior, Office of surface mining reclamation and enforcement
Current	Agriculture	Agriculture	USGS NLCD
Current	Alternative Transportation	Forestry	AKDNR Information Resources Management
Current	Alternative Transportation	Northern Rail Line Expansion	HDR

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Timeframe	Category	Theme	Source
Current	Alternative Transportation	Rail Road	AKDNR Information Resources Management
Current	Alternative Transportation	Trail	AKDNR Information Resources Management, Bureau of Land Management, Digitized
Current	Alternative Transportation	Yukon River	Digitized from aerial and satellite imagery
Current	Contaminated Sites	Contaminated Sites	Alaska Department of Environmental Conservation (ADEC)
Current	Contaminated Sites	Formerly Used Defense Sites	U.S. Army Corps of Engineers
Current	Contaminated Sites	Material Sites	AKDNR Information Resources Management
Current	Development Area	Community (Medium Development)	Digitized from aerial and satellite imagery
Current	Development Area	High Development	USGS National Land Cover Dataset
Current	Development Area	Low Development	USGS National Land Cover Dataset
Current	Development Area	Medium Development	USGS National Land Cover Dataset
Current	Highways	Highway (Dalton Highway included)	AKDNR Information Resources Management, Bureau of Land Management
Current	Industrial Lines	Industrial Lines	AKDNR Information Resources Management
Current	Invasive Plants	AKEPIC	Alaska Center for Conservation Science
Current	Mining	Mining	AKDNR Information Resources Management
Current	Secondary Roads	Secondary Road	AKDNR Information Resources Management
Near-Term & Long-Term	Mining	Mining	USGS Mineral Potential, Ground Truth Trekking
Near-Term & Long-Term	Alternative Transportation	Northern Rail Line Expansion	HDR
Near & Long-Term	Alternative Transportation	Forestry	AKDNR Information Resources Management
Near & Long-Term	Alternative Transportation	Trails	AKDNR Information Resources Management
Near & Long-Term	Contaminated Sites	Material Sites	AKDNR Information Resources Management
Near & Long-Term	Development Area	Population Projection	Fairbanks North Star Borough
Near & Long-Term	Industrial Lines	Future Pipeline	AKDNR Information Resources Management

Timeframe	Category	Theme	Source
Long-Term	Secondary Roads	Nome Road	Alaska Department of Transportation
Long-Term	Secondary Roads	Road to Umiat	Alaska Department of Transportation
Long-Term	Secondary Roads	Secondary Roads (Ambler Route)	Alaska Department of Transportation

Model Parameters

There are two key parameters in the LCM that determine how a defined human modification of the landscape impacts the condition of that landscape. The first is the site impact score that indicates how intense a human modification is to the landscape. The impacts are normalized to be on a score of 0 (for biggest impact, or lowest condition score) to 1 (least impact, or highest condition score). The second is the decay distance that indicates the distance at which the impact to the landscape is no longer experienced from the disturbance. Both of these parameters are defined in the original LCM through an exhaustive literature and expert review (Comer and Faber-Langendoen 2013). The limitation is that these impacts are generally implemented across the contiguous U.S. and Alaska through previous REAs, and therefore, do not include the potentially unique impact that land uses have on systems in Alaska. However, when available, we updated both the site impact score and decay distance values based on literature of impacts to systems in Alaska. Specifically, the decay distance associated with major roads is thought to be much larger due to the extensive use of ATVs and snow machines by Alaskans (Strittholt et al. 2006). We extend this increase to some of the other road types as well as the urban land uses, as snow machine and ATV use is not exclusive to major roads. Additionally, under guidance from our AMT, we split some footprint types and assigned different impact scores based on expert knowledge. For example, mineral sites are categorized differently than mining, and assigned different decay distances based on the nature of the data. Mineral sites are available as polygon data, while mining sites are only available as points. To ensure compatibility when rolled together in the LCM, we reduced the decay distance applied to the mineral sites, even though they have as much, if not more, perceived impact to ecological resources.

Table F-2. List of datasets and parameters assigned to different human land uses for use in the Landscape Condition Model. Values with (*) indicate Alaska-specific decay distances.

Theme	Site Impact Score	Decay Distance (m)
Transportation		
Highways (Dalton Highway included)	0.05	5,000*
Secondary Road	0.2	500
Nome Road	0.2	500
Road to Umiat	0.2	500
Yukon River	0.7	500
Trails	0.7	500*
Historical Trails	0.8	250

Theme	Site Impact Score	Decay Distance (m)
<i>Urban and Industrial Development</i>		
High Development	0.05	2,000
Medium Development	0.5	1,000*
Low Development	0.6	1,000*
Current & Future Mining	0.05	1,500*
Historic Mining	0.5	500
Future Pipeline	0.5	500
Industrial Lines	0.5	500
Contaminated Sites	0.5	100
Formerly Used Defense Sites	0.5	100
Material Sites	0.5	100
Northern Rail Line Expansion	0.7	500
Rail Road	0.7	500
<i>Managed and Modified Land Cover</i>		
Forestry	0.9	200
Invasive Species	0.5	200
Agriculture	0.3	200

Surface Creation

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

Table F-3. Classification of Landscape Condition Model.

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

Future Landscape Condition

Utilizing a mixture of local and regional-level future development estimates (see Section E. Anthropogenic Change Agents for complete details), we estimated near-term and long-term landscape condition. This consisted largely of increases in mining activity, including the potential development associated with the Ambler mining district, as well as projected growth and anticipated infrastructure in and around Fairbanks and the North Star Borough. Change is fairly minimal in the near-term future, with some new placer and hard rock mines anticipated, as well as some forestry roads and railroad expansions. In the long-term future, the human footprint is expected to increase substantially in response to the development of the Ambler mining district. Using mining claims datasets, we modeled the footprint of the Amber mining region, including the preferred road leading to the district from Fairbanks. In addition to the preferred Ambler road, the long-term future also included the preferred route for the Road to Nome. Aside from those two projects, additional placer and hard rock mines are anticipated in the long-term future, as is modest residential growth in the North Star Borough (see Section E. Anthropogenic Change Agents for complete details).

2.3 Results

Current and Future Human Footprint

As expected for this region, the landscape condition is very high, and is expected to remain very high in the future (Figure F-2). Especially when considered at the scale of the CYR study area, landscape condition in all time periods would be considered pristine in other parts of the U.S. Although the study area is bisected by the Dalton Highway, average landscape condition score for the current landscape is 0.975. In the near-term future, landscape condition is anticipated to decrease to 0.973 and in the long-term future to 0.964 in response to the large-scale mining developments. However, the degree of human modification is highly localized and can be intense compared with the surrounding landscape.

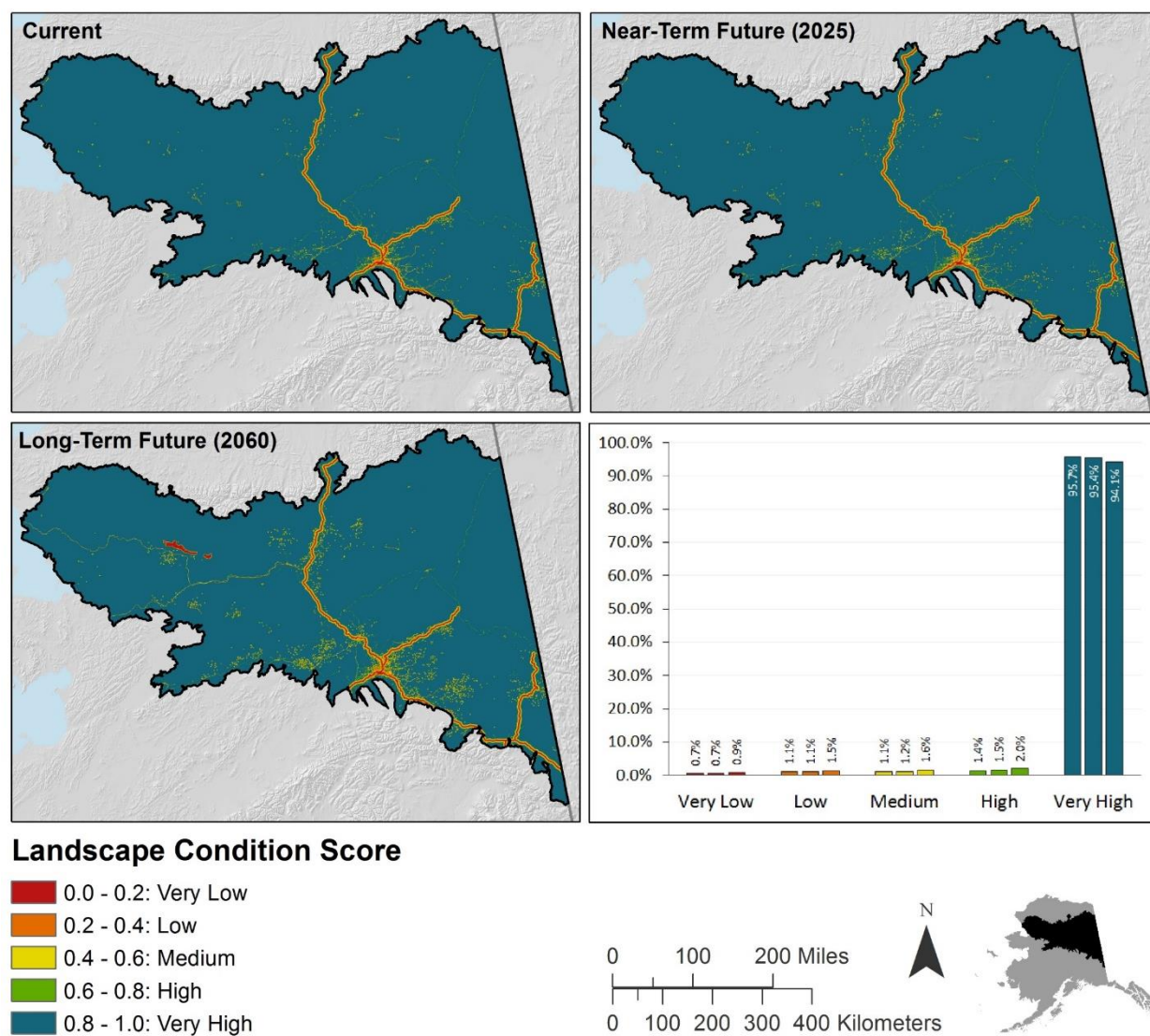


Figure F-2. Current (2015), near-term (2025), and long-term (2060) landscape condition.

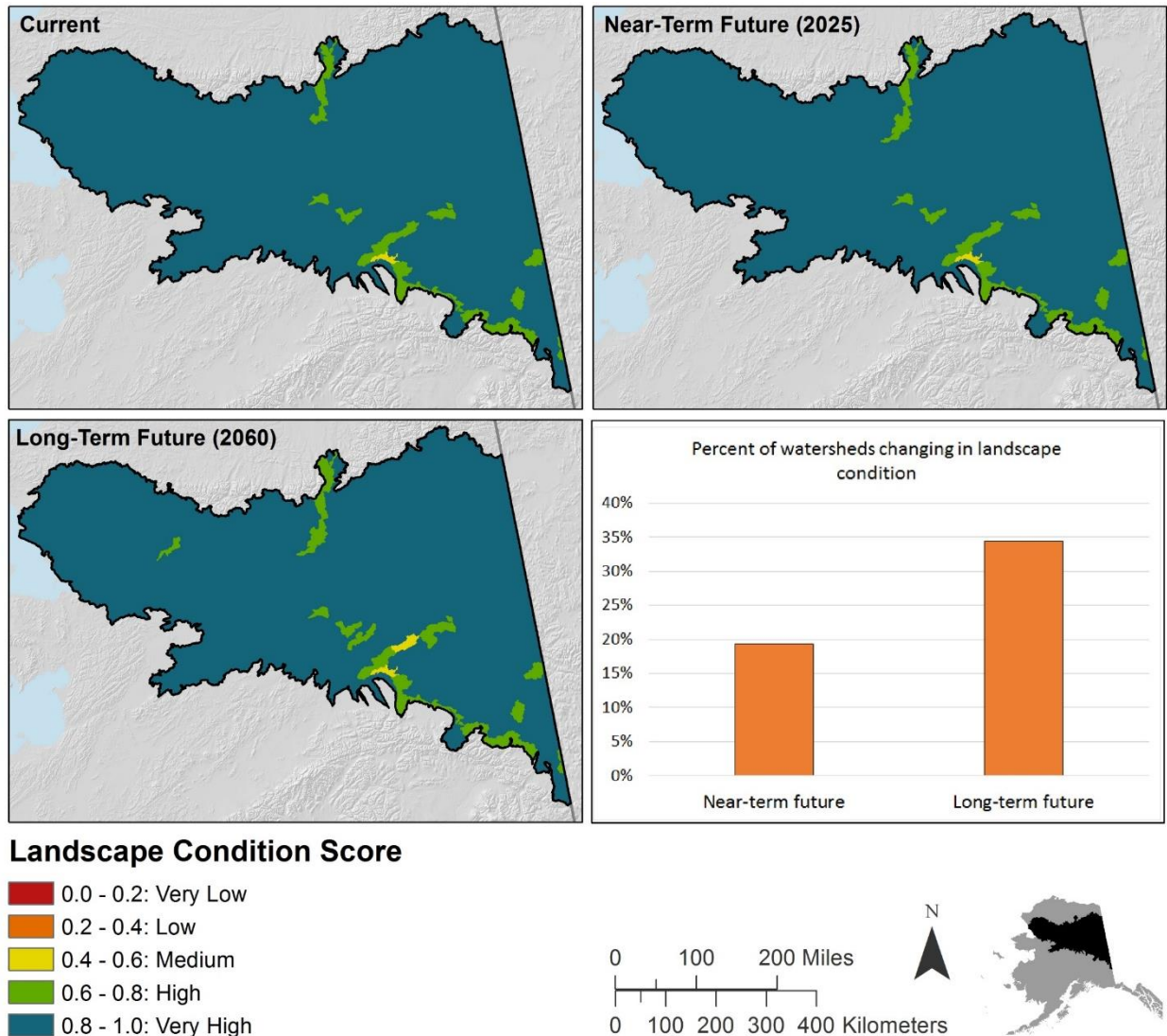


Figure F-3. Current (2015), near-term (2025), and long-term (2060) landscape condition summarized at the 5th-level watershed. Although a large number of watersheds are expected to see a change in landscape condition, when averaged across the watershed the change is minimal except where major developments are expected (i.e., Ambler mining district).

Summarized LCM

When summarized at the 5th-level HUC, patterns in the landscape condition become more apparent. The impact of the Dalton Highway varies depending on the size of the watershed, but generally leads to the most impacted HUCs in the study area for the current and near-term landscapes. In the long-term future, the addition of the Ambler mining district and associated infrastructure leads to some relatively low condition watersheds, especially the Shungnak basin. Average watershed landscape condition score is 0.975, 0.973, and 0.964 for the current, near-term, and long-term development scenarios, respectively. The current minimum watershed landscape condition score is 0.439. In the near-term and long-term future, the minimum decreases to 0.427, indicating that there are already some fairly impacted watersheds in the region (Figure F-3). However, when categorized into the five relative condition categories, we

see that the majority of watersheds are considered to have high or very high condition. Currently there is one watershed (Lower Chena River) that has a mean landscape condition score of less than 0.6 (medium condition category) and 20 watersheds classified as high condition. In the near-term future, only the Lower Chena River watershed is classified as medium condition and 21 watersheds are classified as high condition. In the long-term future, both the Lower Chena River and the Headwaters Chatanika River watersheds are classified as medium condition and 27 watersheds are classified as high condition. Across all time periods we expect 95% of the watersheds in the region to maintain an average landscape condition of 0.8 or higher.

2.4 Applications

Given the highly pristine condition of the CYR study area, management needs in this study area are quite different than those in the contiguous U.S. Instead of monitoring and managing for increasing ecological condition, managers in Alaska can monitor how their land use plans impact the current condition. The current condition of landscapes creates some novel opportunities for monitoring the impacts of various land uses, as the baseline condition can also be considered the reference condition, which is not true of most landscapes in the U.S. The LCM provides a robust way to quickly weigh the potential impacts of a new project on the overall condition of a landscape, providing a useful planning tool for designing Resource Management Plans (RMPs).

As seen in Table F-4, landscape condition varies by land status classification. Although most of the lands managed by the State of Alaska have very high condition, it is apparent that the State manages the majority of the lands in very low, low, and moderate conditions. The BLM also manages a large portion of the very low, low, and moderate condition areas; however, in both cases the very low, low, and moderate condition lands represent a very small portion of the total area managed by each agency. Proportionally, private and military lands are the most degraded landscapes in the CYR study area, but they both account for less than 1% of the study area. Overall, landscape condition by land status mirrors the regional patterns. A map of land management status for reference is provided in Figure F-4.

Table F-4. Current landscape condition relative to land management status (areas in km²).

Land Management Status	Very Low Condition	Low Condition	Moderate Condition	High Condition	Very High Condition
Bureau of Land Management	636	852	884	994	44,951
Fish and Wildlife Service	7	35	56	234	102,672
Military	68	163	152	201	2,450
National Park	1	16	39	135	66,768
Native Patent or IC	453	638	608	1,022	46,791
Native Selected	17	23	40	75	7,068
Private	56	108	28	10	37
State Patent or TA	1,482	2,453	2,371	2,948	84,503
State Selected	19	38	46	91	19,915

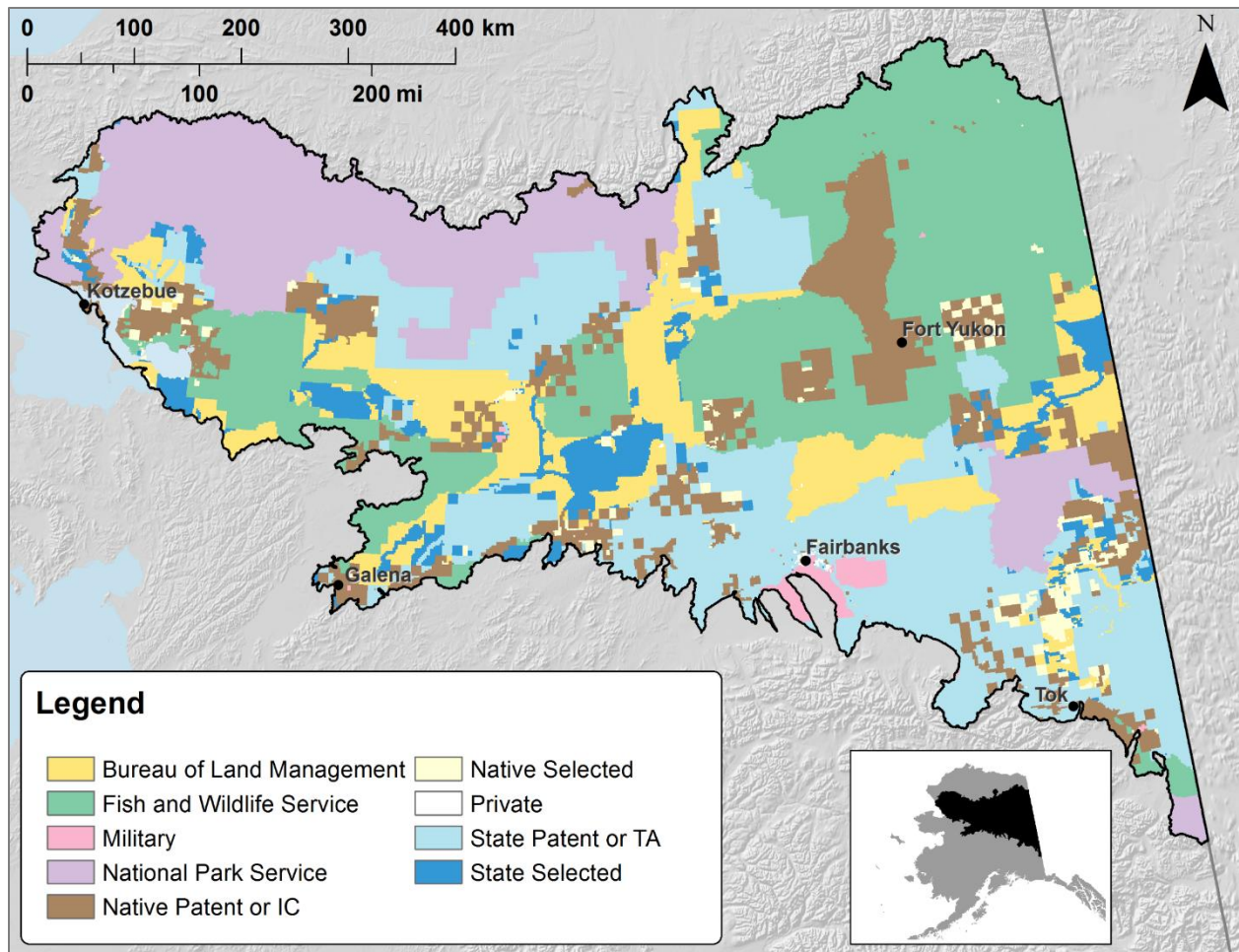


Figure F-4. Land management status for 2015 in the CYR study area.

2.5 Limitations and Data Gaps

Although the LCM utilizes our best available knowledge related to impacts of human land use on a landscape, there are some necessary generalizations made. Not all landscapes respond the same way to specific land uses (i.e., roads likely have a larger impact on wetlands than uplands), and thus, the LCM serves as a relative measure of impact. Along these lines, little empirical data exist for the impacts of specific land uses on ecosystem components that exist in Alaska. Additionally, substantial effort was put into updating and improving road data in the Alaska Department of Transportation dataset. However, accurately mapped local and community road data are identified as a data gap. Finally, although these data are provided at a 60-m resolution, results and analysis should be interpreted at a broader scale. The LCM, like other datasets from this REA, is best considered in the context of the entire assessment area, or summarized at the 5th-level HUCs.

3. Landscape Intactness

3.1 Introduction

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

3.2 Methods

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

Large Intact Blocks

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

Additionally, following advice from the AMT, we assessed which LIB met the criteria as a minimum dynamic reserve (MDR) as estimated by the CONSERV model (Leroux et al. 2007) produced by the [Canadian BEACONS](http://www.beaconsproject.ca/home)¹ group. The BEACONS group is currently (at the time of writing) finalizing results from their efforts to model MDR in the boreal systems of Alaska. Their draft results suggest that, on average, ecoregions in the CYR study area need to have MDR of 6,820 km² (1,685,150 acres) to maintain ecological function.

¹ See <http://www.beaconsproject.ca/home>

3.3 Results

Results from the landscape intactness models largely mirror the results from the LCM. However, a substantial amount of small, fragmented areas was indeed identified throughout the region (Table F-5). Most of these fragmented habitats are located around communities and associated with forestry and mineral extraction road networks (Figure F-5).

Table F-5. Current and future landscape intactness categories for the CYR study area.

Designation	Size Threshold (acre)	Current (km ²)	Near-Term (km ²)	Long-Term (km ²)
Highest Landscape Integrity	≥ 50,000	376,386	375,488	370,010
High Landscape Integrity	< 50,000 ≥ 10,000	1,552	1,363	1,266
Vulnerable to change	< 10,000	883	981	1,153
Not Intact	N/A	17,033	18,022	23,425

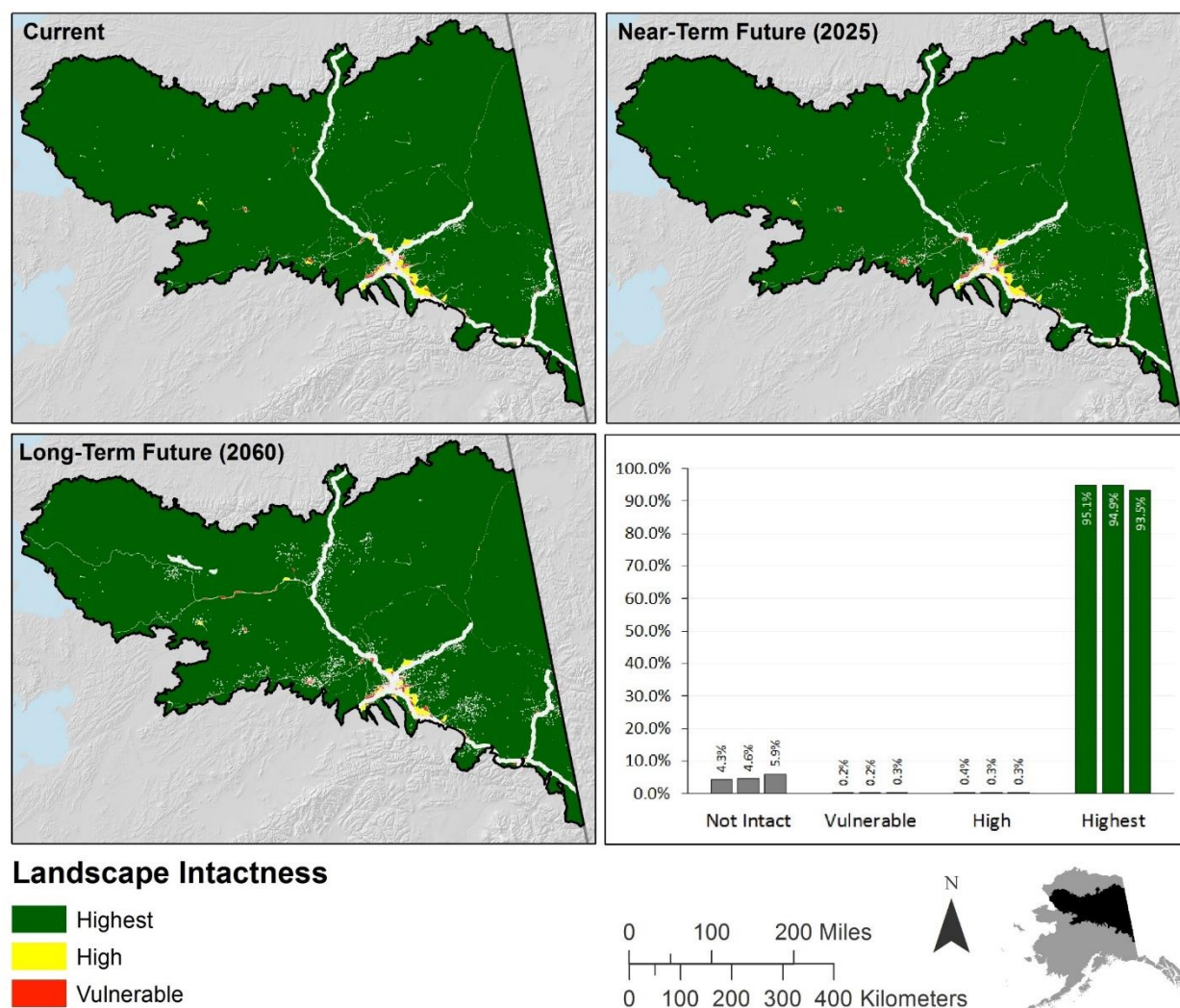


Figure F-5. Current (2015), near-term (2025), and long-term (2060) landscape intactness for the CYR study area.

Utilizing the BEACONS model estimates, we see that currently the large majority (91.9%) of the CYR study area meets the required minimum dynamic reserve (MDR) size to maintain ecological functionality. In the near-term and long-term future, we see slight reductions in areas meeting the MDR requirements, resulting in 4.6% of the study area not meeting the requirements by the long-term future. Most of the increased fragmentation is centered near and to the west of Fairbanks, largely driven by the proposed railroad expansion (**Error! Reference source not found.**).

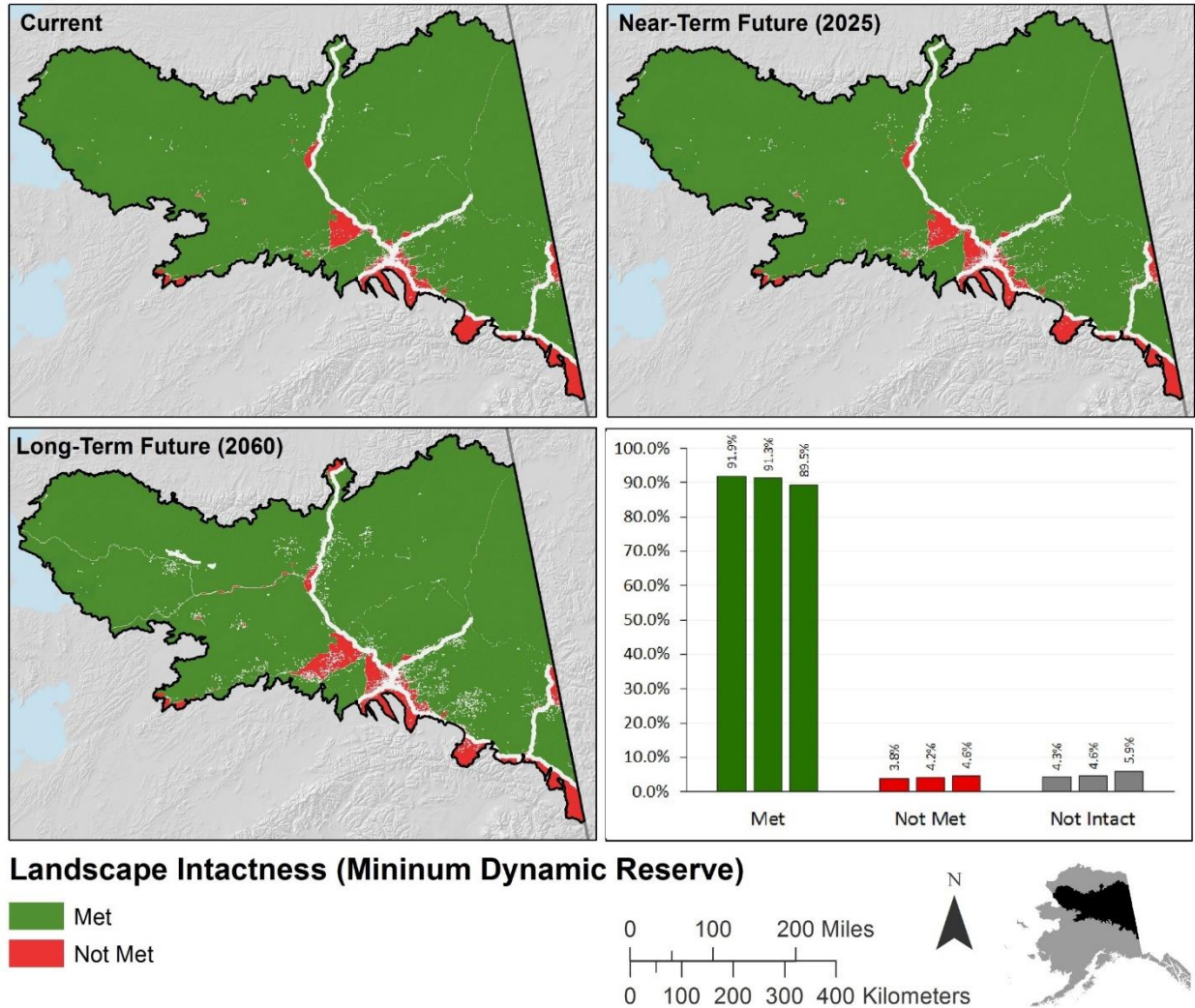


Figure F-6. Current, near-term future, and long-term future landscape intactness according to the minimum dynamic reserve estimates generated by the BEACONS model for the CYR study area.

3.4 Applications

Landscape integrity mirrors the landscape condition for this region, but also highlights the potential to fragment even the largest regional resources. Most areas in the CYR study area have very high condition, high intactness and are large and contiguous, leading us to conclude that the landscape integrity is currently quite high. However, expected future development does show the potential for increased fragmentation. Most notable is that over 6,000 km² of the

highest integrity landscapes could be lost between the near-term and long-term future. There is also a steady decrease in the high integrity landscapes, and a steady increase in the amount of intact, but potentially vulnerable, landscapes across time. The increase in vulnerable areas can be used to help identify new monitoring locations to understand the role of fragmentation in the larger landscape, and could be an important finding when considering other stressors that may act upon those regions. Additionally, the loss of areas meeting the MDR estimates near Fairbanks could have significant implications for large game that are important for residents in the region.

3.5 Limitations and Data Gaps

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

4. Cumulative Impacts

4.1 Introduction

To provide a more comprehensive measure of potential impacts to the ecoregions, we summarize all the potential impacts to CEs (generalized to the 5th-level HUC) under what we call cumulative impacts. The measurement of cumulative impacts has become increasingly emphasized both in the academic literature (Walker 1987, Theobald et al. 1997, Nellemann and Cameron 1998, Belisle and St. Clair 2001), as well as through regulatory requirements (National Environmental Policy Act, Regional Mitigation Strategy, etc.). Essentially, the cumulative impacts assessment presents a rolled-up dataset of all potential changes to the landscape to identify the locations within the REA that are likely to experience the greatest change. The cumulative impacts assessment does not indicate directionality (increase or decrease in any factor) or assume any specific impacts (positive or negative). Additionally, it does not assess the collinearity of some of the change agents (CAs), but rather considers each CA as a separate stressor that will differentially impact CEs and other resources in the study area. When put in the context of landscape integrity, this dataset could be seen as a landscape vulnerability index that could be used to assist in future resource planning efforts.

4.2 Methods

The cumulative impacts analysis included what we considered the primary CA variables that are likely to have the largest and most direct impact on the overall ecoregion (Figure F-7). However, in order to “sum” the impacts we had to define meaningful changes in each variable. Given that the cumulative impacts analysis is not targeted on any one CE, we defined a “change” in the CA based on model variability (see Section C. Abiotic Change Agents) and the potential to impact management decisions:

- Mean January Temperature
 - Variation in January temperature was high between models (see Section C. Abiotic Change Agents), and varied by decade. The threshold for meaningful change in the near-term future was set at 2.2 °C, while long-term change needed to be greater than 2.55 °C to be considered meaningful.
- Mean July Temperature
 - Variation in July temperature was much lower between models, so meaningful July temperature change in the near-term future was estimated at > 0.65 °C and 1 °C in the long-term future.
- Annual Precipitation
 - Variation in precipitation estimates between models was relatively minor, so meaningful change in annual precipitation was set at > 10 mm.
- Change in Permafrost
 - Change in permafrost was calculated based on the change in mean annual ground temperature (see Section C. Abiotic Change Agents). Specifically, 5th-level HUCs where mean annual ground temperature was forecasted to increase to above 0 °C at 1-m depth (i.e., the change from continuous to discontinuous permafrost) for more than 10 cells (40 km²) were identified as regions of meaningful permafrost change.

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- Change in Active Layer
 - Change in the thickness of active layer was calculated based on the mean active layer thickness dataset (see Section C. Abiotic Change Agents). Specifically, 5th-level HUCs where the active layer thickness was expected to increase by 10 cm or more for 40 km² were identified as regions of meaningful active layer change.
- Change in Relative Flammability
 - An increase in relative flammability (see Section C. Abiotic Change Agents) of 2% or more, as compared to the average relative flammability during the entire 20th century, was considered meaningful. This factor was only calculated for the long-term future given the long return intervals of the boreal forest.
- Landscape Condition
 - Any changes in landscape condition at the 5th-level HUC were considered a meaningful change.
- Invasive Species Vulnerability
 - Any changes in invasive species vulnerability at the 5th-level HUC were considered meaningful change.

Cumulative Impacts Model

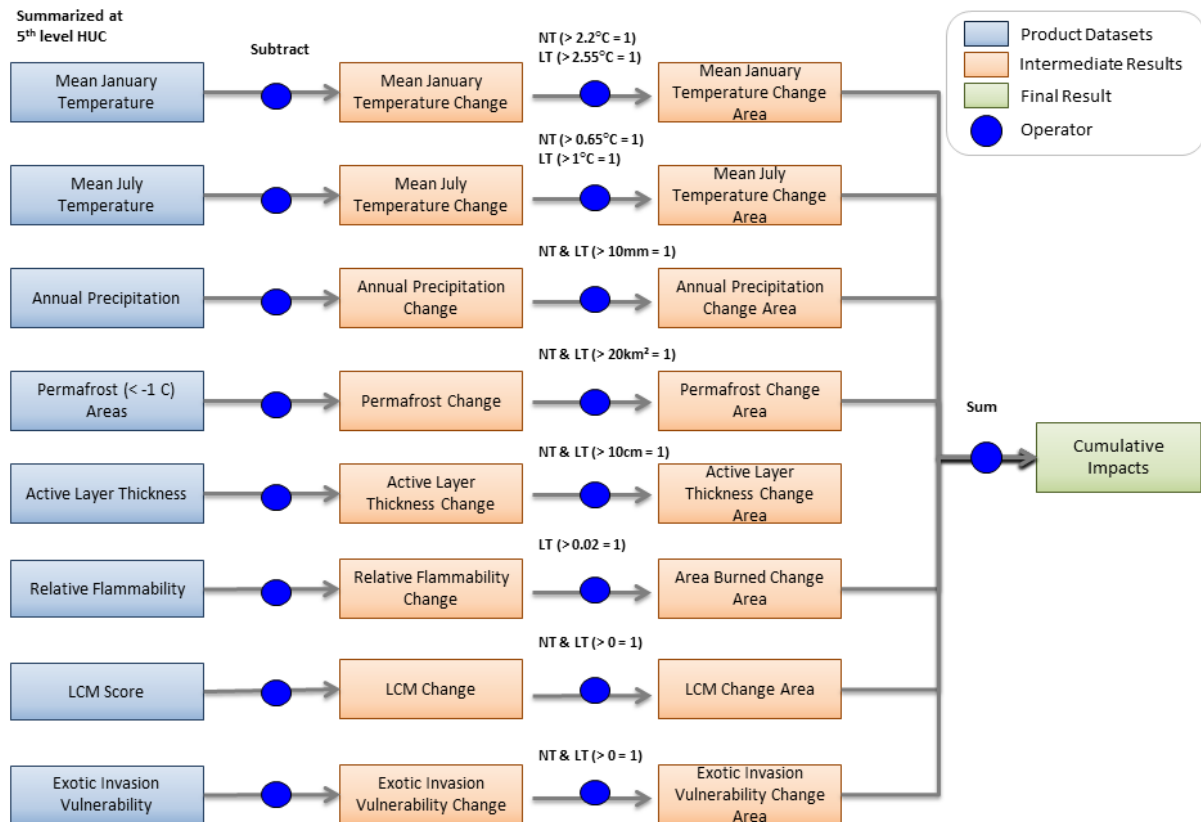


Figure F-7. Process model for cumulative impacts assessment in the CYR REA. Each product dataset was first summarized at the 5th-level HUC for the near-term future (NT), and long-term future (LT) to calculate areas of change.

4.3 Results

When taken together, the cumulative impacts of the various CAs identify some key areas where change to the landscape is likely to be the greatest. Compared to other REAs completed in the state, it is important to note that only 34 watersheds (~6% of total) are not expected to see any significant changes in CAs, even in the near-term. Seventeen watersheds, almost all near Fairbanks, are expected to see significant change in four different change agents. In all, 95% of the watersheds in the CYR study area are not expected to see a significant change in more than 2 change agents in the near-term future (Table F-6).

Table F-6. Number of watersheds expected to see significant changes in the CYR study area. CI = number of CA variables expected to change significantly by the near-term and long-term future.

Watersheds	CI = 0	CI = 1	CI = 2	CI = 3	CI = 4	CI = 5	CI = 6	CI = 7	CI = 8
Near-Term	34	380	131	11	17	0	0	0	0
Long-Term	0	0	0	26	159	102	175	106	5

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In the long-term future, significant changes are expected across all watersheds. Fifty percent ($n = 286$) of the watersheds in the CYR study area are expected to see at least six different CAs significantly changing, and those areas near the Ambler mining district and along the Kobuk river are expected to see all eight change significantly (Figure F-8). However, when isolated, the cumulative effects of human-related activities (anthropogenic footprint and invasive species vulnerability) are relatively minor in both the near-term and long-term future (Figure F-9). The cumulative impact of all the abiotic factors (air temperature, wildfire, etc.) is far more obvious in both the near-term and long-term future (Figure F-10).

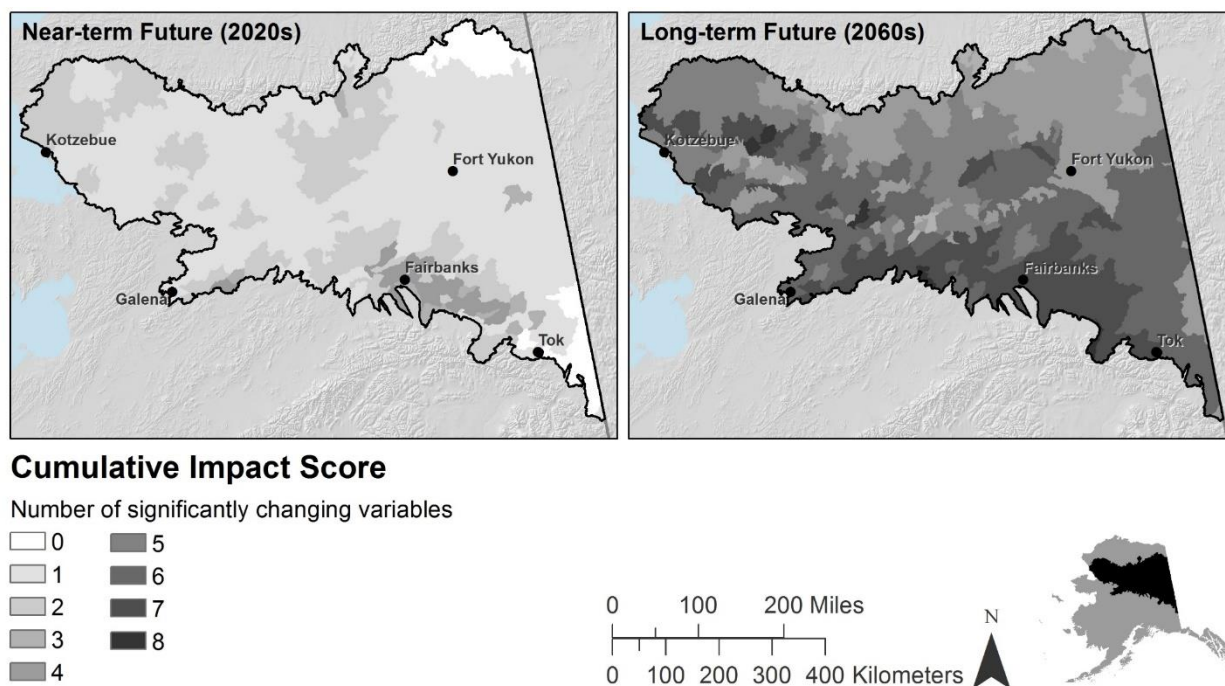


Figure F-8. Cumulative impact assessment using all CAs for the CYR study area summarized at the 5th-level HUC (moderate-sized watershed).

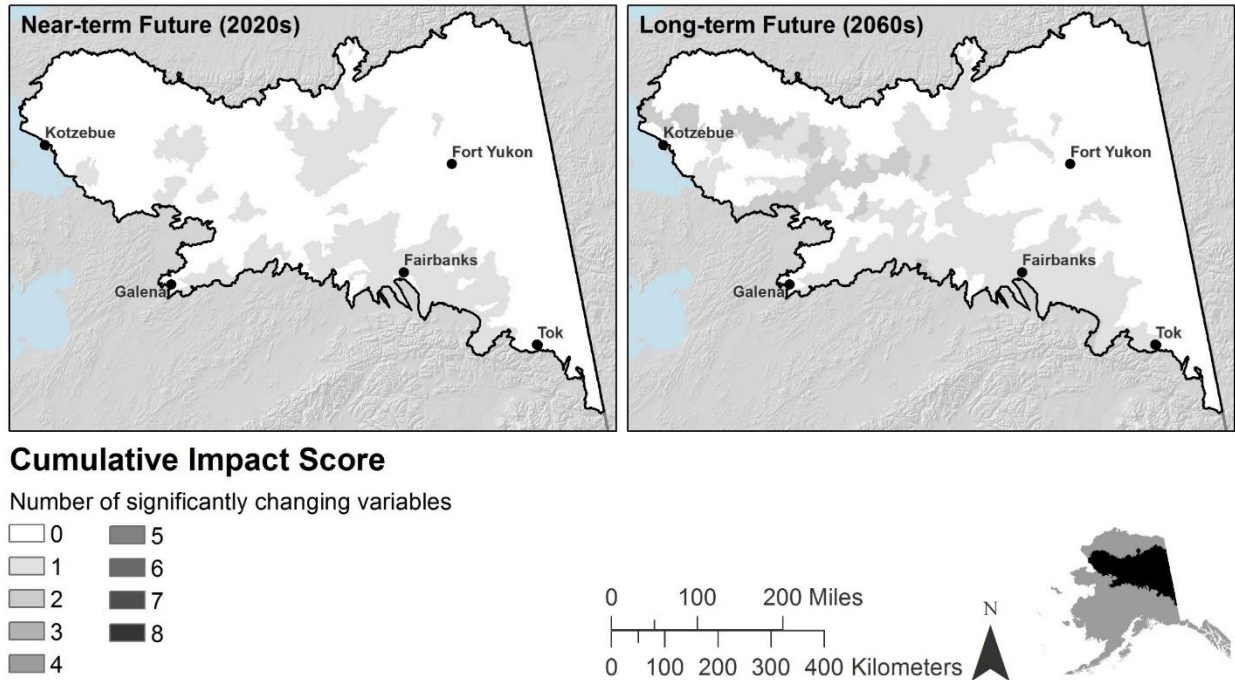


Figure F-9. Cumulative anthropogenic impact assessment for the CYR study area summarized at the 5th-level HUC (moderate-sized watershed).

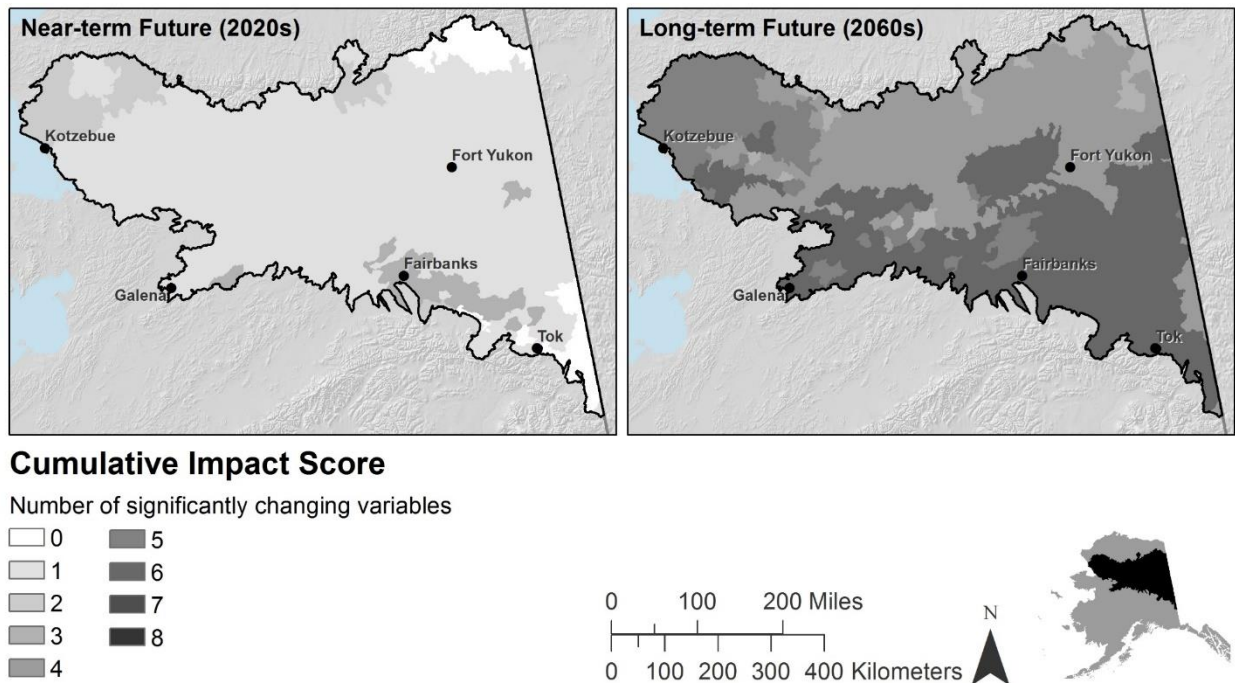


Figure F-10. Cumulative abiotic impact assessment for the CYR study area summarized at the 5th-level HUC (moderate-sized watershed).

4.4 Applications

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

As shown in Table F-7, all land management agencies in the CYR study area will likely have to address the cumulative impacts of the CAs in the future. Proportionally, military and privately managed lands have the most amount of area expected to see seven or more CAs changing. On average 70% of the lands for any given land management agency are expected to have at least five CAs changing on the landscape by the 2060s (Table F-7). The exception is land managed by Fish and Wildlife Service, where meaningful change in 3–4 CAs is expected in 59% of managed lands by the 2060s.

Table F-7. Percent area expected to undergo meaningful change by the long-term future per land management agency. A CI score of 3 means only three CA variables are anticipated to change meaningfully by the 2060s. Regions with a lower score can be interpreted as having less potential landscape changes than areas with higher scores.

Land Management Agency	CI = 3	CI = 4	CI = 5	CI = 6	CI = 7	CI = 8
BLM	2%	9%	30%	48%	11%	1%
FWS	11%	48%	3%	33%	5%	0.1%
Military	0%	1%	0.3%	2%	96%	1%
NPS	2%	31%	39%	16%	9%	2%
Native Patent	0.3%	28%	12%	37%	21%	2%
Native Selected	2%	18%	12%	47%	19%	1%
Private	0%	1%	11%	4%	83%	0%
State Patent	1%	12%	15%	30%	41%	1%
State Selected	5%	9%	21%	51%	14%	0.2%

4.5 Limitations and Data Gaps

The collinearity between the different CAs means that this analysis could overestimate impacts to the landscape (i.e., active layer thickness is certainly correlated to mean July temperature, but both are included as distinct stressors in this analysis). However, impacts to any given CE from changes in mean July temperature are certainly different than impacts to the same CE from changes in active layer thickness. Thus, while two variables may be correlated, the respective impacts to regional resources can in fact be different. Additionally, some CAs are spatially restricted (i.e., active layer is only available with continuous permafrost) and is, therefore, not correlated with climatic variables across the entire region. Thus, although the cumulative impacts assessment ignores the collinearity between CAs, it still provides a

cumulative assessment of potential landscape changes that would require different resource management strategies.

Additionally, while some of the thresholds for meaningful change are derived from a statistical analysis, similar robust estimates of actual change were not available for all CAs. For example, an increase or decrease of 5% in area burned may or may not significantly impact the region. Thus, this analysis should be used primarily as a landscape planning tool, and not an impact model that would guide specific management actions without further work to define those meaningful thresholds.

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

5. Literature Cited

- Alberti, M. 2010. Maintaining ecological integrity and sustaining ecosystem function in urban areas. *Current Opinion in Environmental Sustainability* 2:178–184.
- Anderson, J. E. 1991. A conceptual framework for evaluating and quantifying naturalness. *Conservation Biology* 5:347–352.
- Baldwin, R. F., S. C. Trombulak, and E. D. Baldwin. 2009. Assessing risk of large-scale habitat conversion in lightly settled landscapes. *Landscape and Urban Planning*.
- Belisle, M., and C. C. St. Clair. 2001. Cumulative effects of barriers on the movements of forest birds. *Conservation Ecology* 5:9.
- Comer, P. J., and D. Faber-Langendoen. 2013. Assessing ecological integrity of wetlands from national to local scales: exploring the predictive power, and limitations of spatial models. *National Wetlands Newsletter* 35:20-22.
- Comer, P. J., and J. Hak. 2009. NatureServe landscape condition model. Technical documentation for NatureServe Vista decision support software engineering. NatureServe, Boulder, Colorado.
- Comer, P. J., and J. Hak. 2012. Landscape condition in the conterminous United States. Spatial Model Summary prepared for: Western Governors Association. NatureServe, Boulder, Colorado.
- Danz, N. P., G. J. Niemi, R. R. Regal, T. Hollenhorst, L. B. Johnson, J. M. Hanowski, R. P. Axler, J. J. H. Ciborowski, T. Hrabik, V. J. Brady, J. R. Kelly, J. A. Morrice, J. C. Brazner, R. W. Howe, C. A. Johnston, and G. E. Host. 2007. Integrated measures of anthropogenic stress in the US Great Lakes basin. *Environmental Management* 39:631–647.
- Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics* 29:207–231.
- Geck, J. 2007. A GIS-based method to evaluate undeveloped BLM lands in Alaska. Science and stewardship to protect and sustain wilderness values. Eight World Wilderness Congress Symposium, Anchorage, AK, USDA Forest Service.
- Girvetz, E. H., J. H. Thorne, A. M. Berry, and J. A. G. Jaeger. 2008. Integration of landscape fragmentation analysis into regional planning: a statewide multi-scale case study from California, USA. *Landscape and Urban Planning* 86:205–218.
- Leroux, S. J., F. K. A. Schmiegelow, R. B. Lessard, and S. G. Cumming. 2007. Minimum dynamic reserves: a framework for determining reserve size in ecosystems structured by large disturbances. *Biological Conservation* 138:464-473.
- Nellemann, C., and R. D. Cameron. 1998. Cumulative impacts of an evolving oil field complex on the distribution of calving caribou. *Canadian Journal of Zoology* 76:1425–1430.
- Noss, R. F. 2004. Some suggestions for keeping national wildlife refuges healthy and whole. *Natural Resources Journal* 44:1093-1111.
- Sanderson, E. W., M. Jaiteh, M. A. Levy, K. H. Redford, A. V. Wannebo, and G. Woolmer. 2002. The human footprint and the last of the wild. *Bioscience* 52:891–904.
- Scott, J., T. Loveland, K. Gergely, J. Strittholt, and N. Staus. 2004. National wildlife refuge system: ecological context and integrity. *Natural Resources Journal* 44:1041–1066.
- Steinitz, C. 1990. Toward a sustainable landscape with high visual preference and high ecological integrity—the loop road in Acadia Nation Park, USA. *Landscape and Urban Planning* 19:213–250.
- Strittholt, J. R., R. Nogueron, J. Bergquist, and M. Alvarez. 2006. Mapping undisturbed landscapes in Alaska: an overview report. Washington, D.C., World Resources Institute.
- Theobald, D. M. 2001. Land-use dynamics beyond the American urban fringes. *Geographical Review* 91:544-564.
- Theobald, D. M. 2004. Placing exurban land-use change in a human modification framework. *Frontiers in Ecology and the Environment* 2:139–144.

- Theobald, D. M. 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. *Ecology and Society* 10:32.
- Theobald, D. M. 2010. Estimating natural landscape changes from 1992 to 2030 in the conterminous US. *Landscape Ecology* 25:999–1011.
- Theobald, D. M., J. R. Miller, and N. T. Hobbs. 1997. Estimating the cumulative effects of development on wildlife habitat. *Landscape and Urban Planning* 39:25–36.
- Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18–30.
- Walker, D. A. 1987. Cumulative impacts of oil fields on northern Alaskan landscapes. *Science* 238:757.

G. Terrestrial Coarse-filter Conservation Elements

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Summary

Section G. *Terrestrial Coarse-filter Conservation Elements* provides detailed descriptions, methods, datasets, results, and limitations for the assessments of the potential impacts of Change Agents on selected terrestrial habitats considered to be of high ecological importance in the Central Yukon study area.

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1. Introduction to Terrestrial Coarse-Filter Conservation Elements

In this summary, we provide methods, datasets, results, and discussion of the expected impacts of Change Agents (CAs) across the Terrestrial Coarse-filter Conservation Elements (CEs). Individual accounts for each CE, in which we describe change agent impacts to specific habitats, follow this summary section.

Northern ecosystems are undergoing major shifts related to climate change. Because the Boreal and Arctic are warming at nearly twice the global rate, the impacts are expected to disproportionately affect these biomes (Hinzman et al. 2005, Winton 2006, Scheffer et al. 2012). Understanding the drivers of this change and the consequences across diverse landscapes is critical to anticipating the range of ecological responses that can be expected. The goal of the Terrestrial Coarse-filter assessment is to identify key ecosystems and drivers, and to provide baseline data that will help predict anticipated effects of climate change across a wide range of boreal habitats. Altered fire regime, loss of permafrost, changes to the rate of thermokarst and subsidence, treeline migration, and expansion in shrub height and cover are some examples of the important habitat changes that are expected to affect boreal ecosystems.

Terrestrial Coarse-filter CEs are defined as regionally important habitat types that share similar vegetation and biophysical site characteristics, such as permafrost characteristics, surficial deposit, disturbance, and succession. After several iterations of review by the AMT and Tech Team, seven CEs were selected for analysis: floodplain forest and shrub, lowland woody wetland, upland mesic spruce-hardwood forest, upland mesic spruce forest, upland low and tall shrub, alpine and Arctic tussock tundra, and alpine dwarf shrub tundra. Together, these CEs represent the majority of the terrestrial landscape, covering 86% of the Central Yukon (CYR) study area.

2. Methods

For each Terrestrial Coarse-filter CE, we evaluated CAs targeted for analysis in the conceptual models by comparing CE distributions to the current, near-term future, and long-term future status of the CAs. The intersection of the CAs with the individual CE distributions is considered the core analysis of the REA. In this section we present the methods and results for the core analysis for all Terrestrial Coarse-filter CEs collectively, and we answer two management questions that are addressed directly through this analysis:

MQ B2: What are the expected associated changes to dominant vegetation communities and CE habitat in relation to altered permafrost distribution, active layer depth, precipitation regime, and evapotranspiration?

MQ F3: How are major vegetation successional pathways likely to change in response to climate change, with special emphasis on increased shrub cover and treeline changes?

Additionally, three MQs related to rare ecosystems follow the individual CE accounts:

MQ G1: Where are refugia for unique vegetation communities (e.g., hot springs, bluffs, sand dunes) and what are the wildlife species associated with them?

MQ AH1: What rare, but important habitat types that are too fine to map at the REA scale and are associated with Coarse- (or Fine-) Filter CEs that could help identify areas where more detailed mapping or surveys are warranted before making land use allocations (such as steppe bluff association with dry aspen forest)?

MQ G2: Which unique vegetation communities (and specifically, which rare plant species) are most vulnerable to significant alteration due to climate change?

For each Terrestrial Coarse-filter CE we:

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

2.1 Distribution

The overall process for delineating Terrestrial Coarse-filter CEs involved first identifying the best representation of each CE from existing source datasets, then developing a process for extracting the CE from the available information.

The CEs were delineated in the following order:

- 1) Floodplain delineation and CE extraction
- 2) Forested CE extraction
- 3) Non-forested CE extraction

The vegetation layers were extracted from two source maps: National Landcover Database (NLCD) and the Vegetation Map of Northern, Western, and 5th Alaska (Table G-1). This second map is a mosaic of the various regional 30-m landcover maps for the boreal and Arctic portions of the state. The mosaic was compiled and cross-walked by the ACCS ecology program and is served on the Alaska Center for Conservation Science website at UAA. Three datasets were used to develop the floodplain boundary: Northern Alaska Subsections, the Circumboreal Vegetation Map, and the National Hydrography Dataset Flowlines (Table G-1).

Table G-1. Summary of datasets used to develop the Terrestrial Coarse-filter CEs.

Dataset Name	Abbr.	Data source
Vegetation Map of Northern, Western, and Interior Alaska	AKVM	Alaska Center for Conservation Science
National Landcover Database (2011)	NLCD	Multi-Resolution Land Characteristics Consortium
Northern Alaska Subsections	NoAK	North Slope Science Catalog
Circumboreal Vegetation Map (June 2015 Draft)	CBVM	Arctic Council Publications
National Hydrography Dataset Flowlines	NHD	USGS

We developed the floodplain layer from the following sources: Northern Alaska Subsections map (NoAK), the Circumboreal Vegetation Map (CBVM), and the National Hydrography Dataset (NHD). The NoAK subsections map provided floodplain boundaries for large and mid-sized rivers and streams across the northern portion of the CYR study area, approximately 3rd to 7th order streams. The CBVM provided coarsely delineated floodplain boundaries for the largest rivers across the majority of the study area (stream orders 6–8). For portions of the CYR study area without mapped floodplain boundaries, we used NHD named flowlines with buffers corresponding to stream length (stream length range in km / buffer distance in meters: 50–100 km / 250 m, 100–200 km / 300 m, 200–400 km / 450 m, and 400+ km / 600 m). Using stream buffers ensured that more of riparian habitat was captured in the model; however, the buffers do not correspond directly to true floodplain boundaries (Figure G-1). To finalize the floodplain forest and shrub CE distribution we extracted forest, shrub, and barren NLCD landcover classes from within the floodplain polygon.

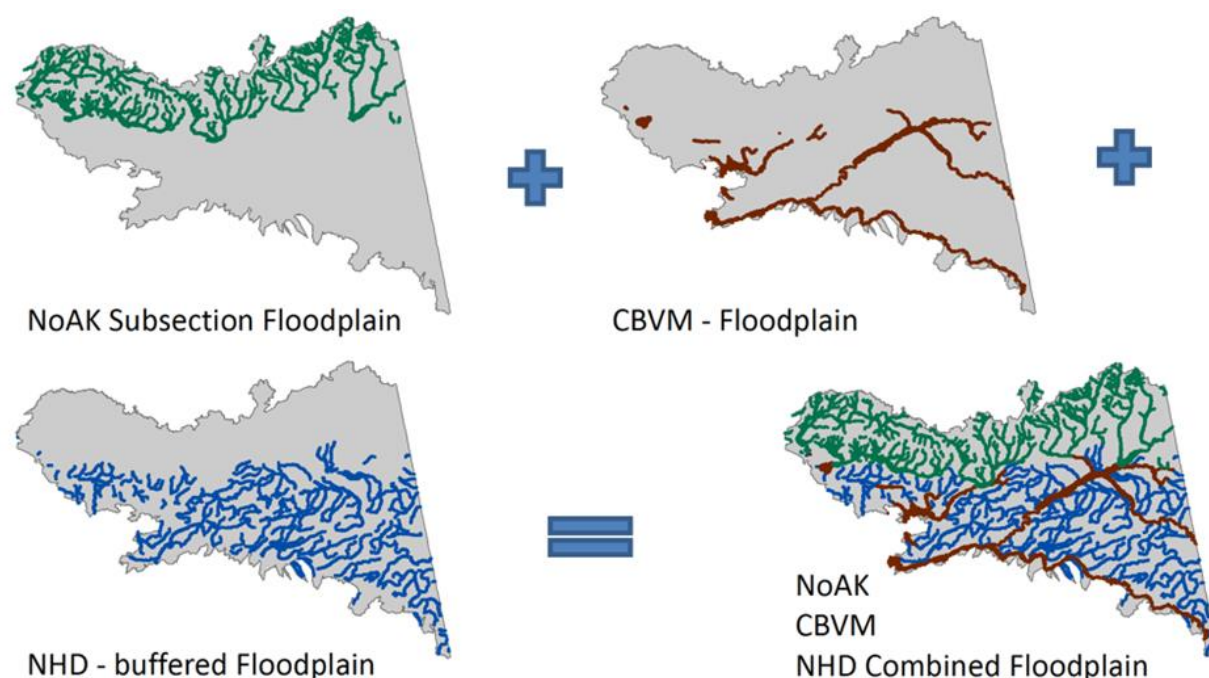


Figure G-1. Data layers used to develop floodplain boundaries for the CYR study area.

After extracting the floodplain layer, we used the 2011 NLCD vegetation map to define the remaining forested CEs: woody wetland, upland mesic spruce-hardwood forest, and upland mesic spruce forest. Recently burned areas were assigned to the appropriate forested CE using the 2011 NLCD change layer, which identified pixels that changed from one class to another between 2001 and 2011. Evergreen forest pixels that shifted to shrub/scrub or grassland were added to upland mesic spruce forest, and mixed or deciduous forest pixels that shifted to shrub/scrub or grassland were added to upland mesic spruce-hardwood forest.

We used the Alaska Vegetation Mosaic (AKVM) to define the alpine and Arctic tussock tundra and alpine dwarf shrub tundra CEs because AKVM provided a better representation of those classes than did NLCD. The final CE, low and tall shrub tundra, was delineated using the NLCD shrub/scrub class after extracting all of the above CEs. Shrub/scrub pixels in NLCD that were burned and shifted to grassland between 2001 and 2011 were added to the upland low and tall shrub CE distribution (Table G-2). We had initially proposed using the AKVM to define this class, but several large burned areas occurring within or adjacent to this class were mapped only as “burned” in AKVM, and as such, could not be assigned to a CE. The final CE distribution includes both low and tall shrub classes.

Table G-2. Data source and summary of Terrestrial Coarse-filter CEs.

Landscape Position		Coarse-filter CE Name	% Area of CYR	Source Map
Lowland	Floodplain	Floodplain forest and shrub	5	NoAK subsections, CBVM, NHD, NLCD
	Wetland forest, shrub, and woody peatlands	Lowland woody wetland	7	NLCD
Upland	Upland forest	Upland mesic spruce-hardwood forest	11	NLCD
		Upland mesic spruce forest	25	NLCD
	Upland shrub and tussock tundra	Upland low and tall shrub	22	NLCD
		Alpine and Arctic tussock tundra	8	AKVM
		Alpine dwarf shrub tundra	9	AKVM

2.2 Conceptual Models

Conceptual models based on literature review were developed for each Terrestrial Coarse-filter CE depicting the effects that CAs and natural drivers are expected to impose on key ecological components and processes. These models provided the foundation for identifying important ecological relationships and guided the selection of CA variables with high ecological and management relevance for the core analysis.

2.3 Core Analysis: CE x CA Intersections

The purpose of the core analysis was to describe the current distribution of each CE at the ecoregional scale and to investigate how its status may change in the future as a result of CAs. For each Terrestrial Coarse-filter CE, the current, near-term future (2020s), and long-term future (2060s) impacts of the individual CA variables were evaluated. Overall results for intersections between CAs and all CEs are presented in this section either spatially or in tabular format; additional intersections are presented between CEs and CAs in the individual Coarse-filter CE accounts. In many cases spatial overlays of the CAs on CEs did not provide additional information beyond that already illustrated in the CA models, and thus, the individual spatial distributions were not selected for inclusion in the core analysis. For example, the results of the intersection of precipitation models with CE distributions were summarized in tabular format instead of mapped distributions because the spatial display did not contribute more information than a condensed table. Thus, for this report, our discussion of the impacts of CAs on the individual CEs includes a combination of spatial analysis, summary tables, and literature review.

The key CA variables evaluated in this analysis include: temperature, precipitation, length of growing season, summer warmth index, permafrost (active layer thickness and thermokarst potential), fire (ALFRESCO and vegetation change), invasive plants, and insects and disease. Modeled climate, permafrost, and fire data were developed by the Scenarios Network for Alaska

and Arctic Planning (SNAP) at the International Arctic Research Center at the University of Alaska Fairbanks. Detailed information about the methods used to develop these models can be found in Section C. Abiotic Change Agents. Detailed information about the methods used to develop CA models for invasive plants and insects and disease can be found in Section D. Biotic Change Agents.

Methods for MQs B2 and F3

Two MQs (MQ B2 and MQ F3) were addressed as part of the core analysis of the abiotic CAs. They are integrated with the abiotic CAs core analysis results and discussion, and their process models are shown in Figure G-2 and Figure G-3, below. Three additional MQs (MQ G1, G2, and AH1) are addressed at the end of this document.

MQ B2: What are the expected associated changes to dominant vegetation communities and CE habitat in relation to altered permafrost distribution, active layer depth, precipitation regime, and evapotranspiration?

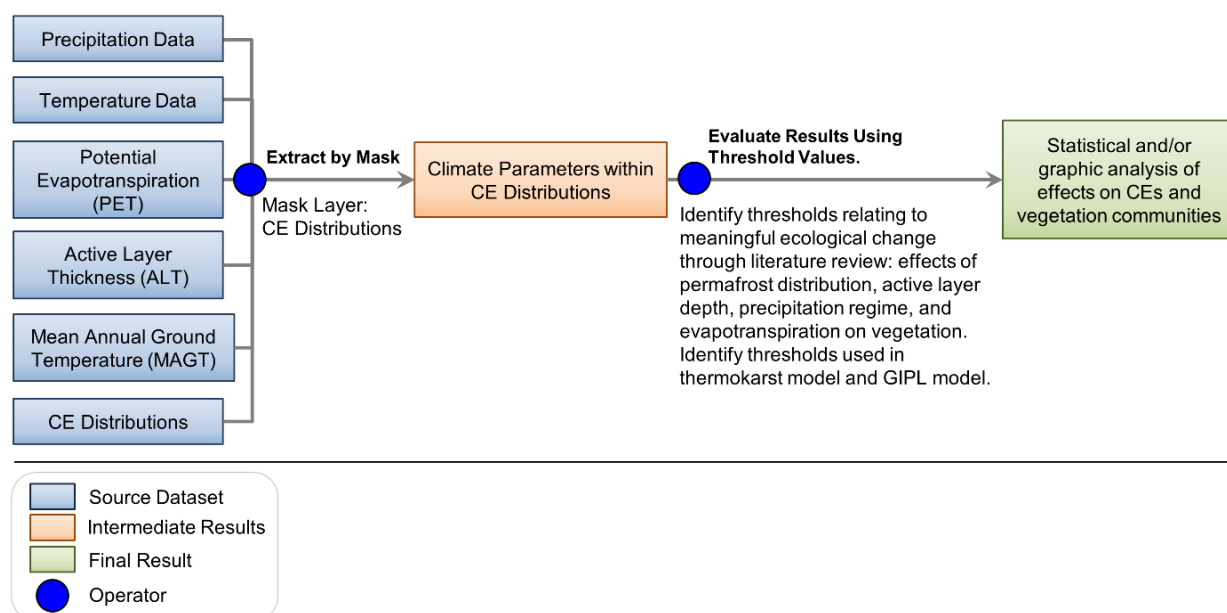


Figure G-2. Process model for MQ B2.

MQ F3: How are major vegetation successional pathways likely to change in response to climate change, with special emphasis on increased shrub cover and treeline changes?

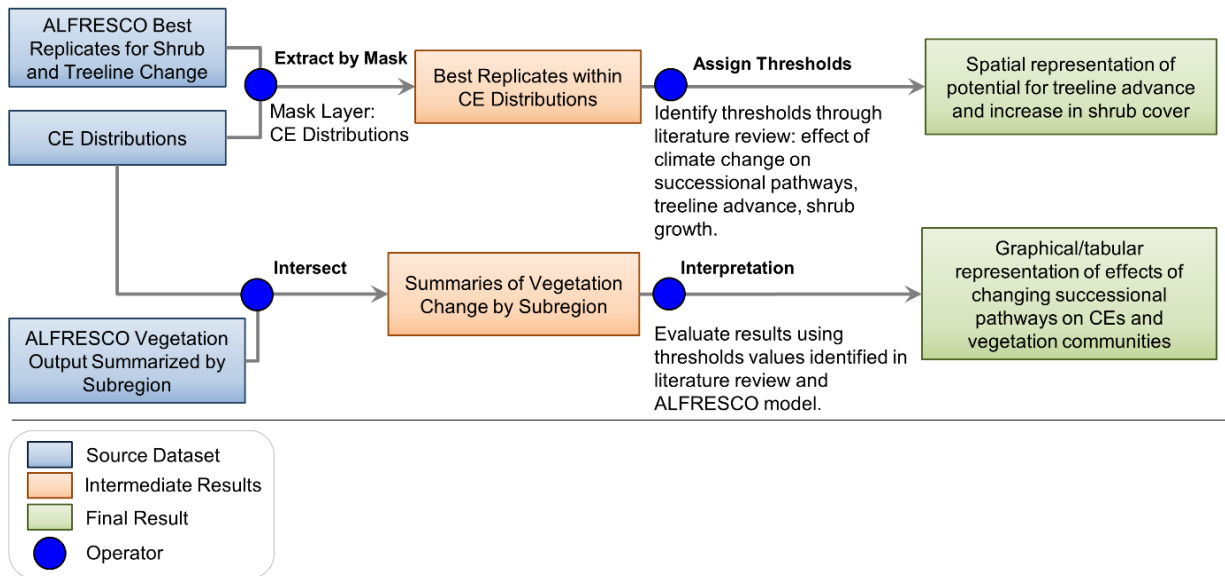


Figure G-3. Process model for MQ F3.

Insect- and Disease-related Forest Damage

Insect- and disease-related forest damage was summarized by tree- and shrub-dominated CE. Because not all CEs were surveyed equally, impacted proportion was measured as the proportion of CE area damaged to CE area surveyed rather than the proportion of CE area damaged to total CE area.

$$\text{Impacted Proportion} = \frac{\text{Area of CE Damaged}}{\text{Area of CE Surveyed}}$$

Impacted proportion was the relative proportion of CE area that was damaged by insect and disease agents, not the proportion of observed damage located within a particular CE. Impacted proportion represented the amount of ecosystem pressure insect and disease agents have exerted on a particular CE. The distributions of five Terrestrial Coarse-filter CEs were compared to the extent of observed insect- and disease-related forest damage in the CYR study area. Alpine Arctic tussock tundra and alpine dwarf shrub tundra were omitted from the comparison because these CEs lack or have low cover of trees and low/tall shrubs and have mostly not been surveyed for damage by USDA Forest Service aerial surveys. For further detail on the methods used to evaluate insect and disease impacts, please refer to Section D. Biotic Change Agents.

2.4 Status Assessments

The overall status of each CE was assessed by intersecting the Landscape Condition Model (LCM) for the current condition, near-term future, and long-term future with the CE distribution.

The LCM is a way to measure how human modification of a landscape impacts the condition of that landscape and involves two key parameters: site impact and decay distance. The former, site

impact, quantifies the intensity of human modification and ranges from 0 (biggest impact) to 1 (smallest impact). Decay distance estimates the distance from a given modification at which it no longer impacts the landscape. Section F. Landscape and Ecological Integrity provides a detailed description of parameter development methods.

2.5 Relative Management Responsibility

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

3. Core Analysis–Summary Results

3.1 Distribution

Distributions of the Terrestrial Coarse-filter CEs are shown in Figure G-4, and the relative contribution of the two source vegetation layers, the Alaska Vegetation Mosaic (AKVM) and the National Landcover Dataset (NLCD), is shown in Figure G-5. The AKVM provided a superior classification for the non-forested alpine and subalpine classes, while the NLCD provided a consistently mapped coverage for the forested classes. Because the definition of “forest” used in the NLCD classification differs from that used in the AKVM, we found that the NLCD shrub/scrub class provided a better and more seamless connection between the forested and alpine classes than did the shrub classes in the AKVM. Forest classes in NLCD are defined by trees at least 5-m tall with at least 20% canopy cover, and thus, woodland classes and short-statured trees may be included within the shrub/scrub class. Maps of each distribution are also provided in the individual CE accounts.

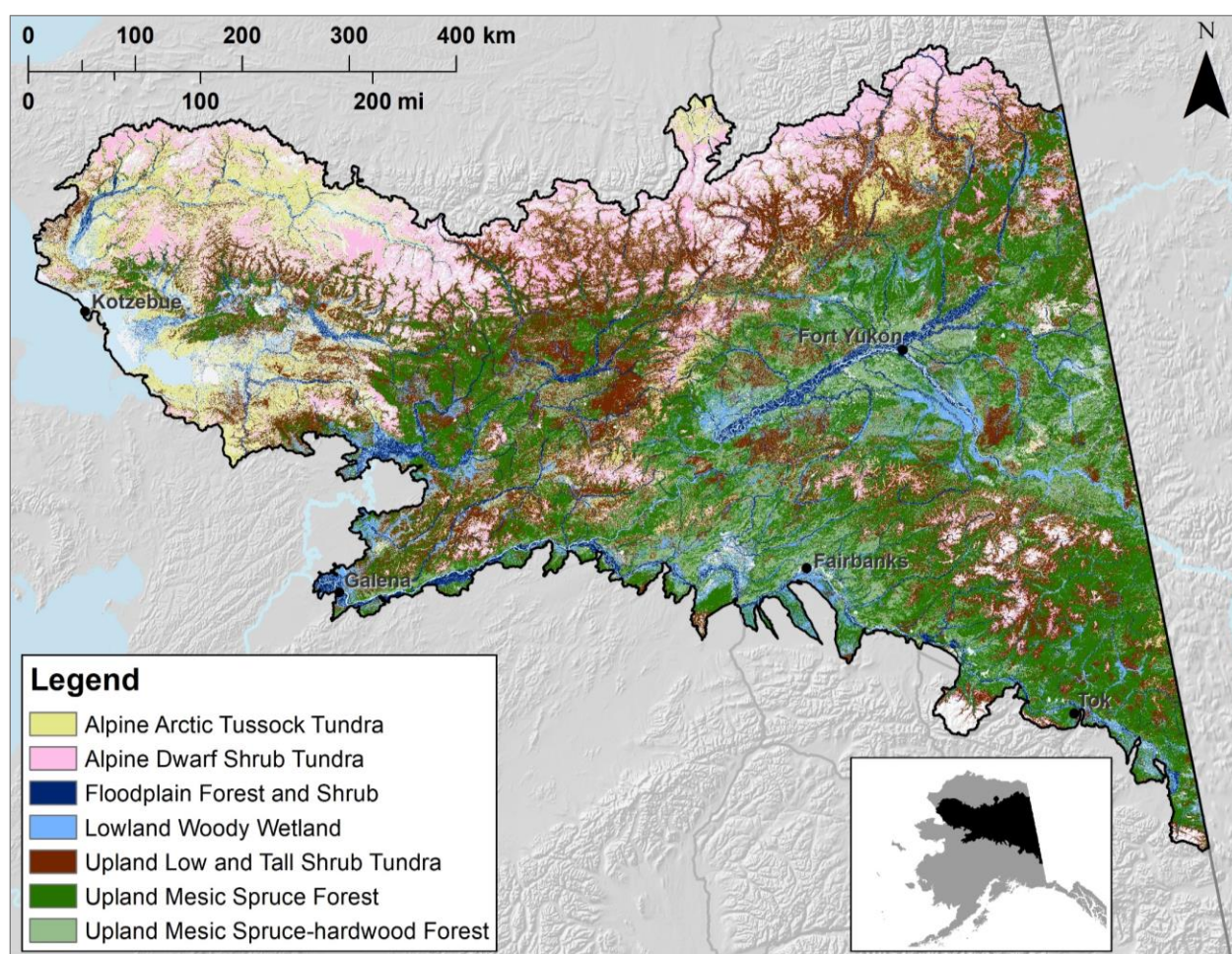


Figure G-4. Distribution of Terrestrial Coarse-filter CEs within the CYR study area.

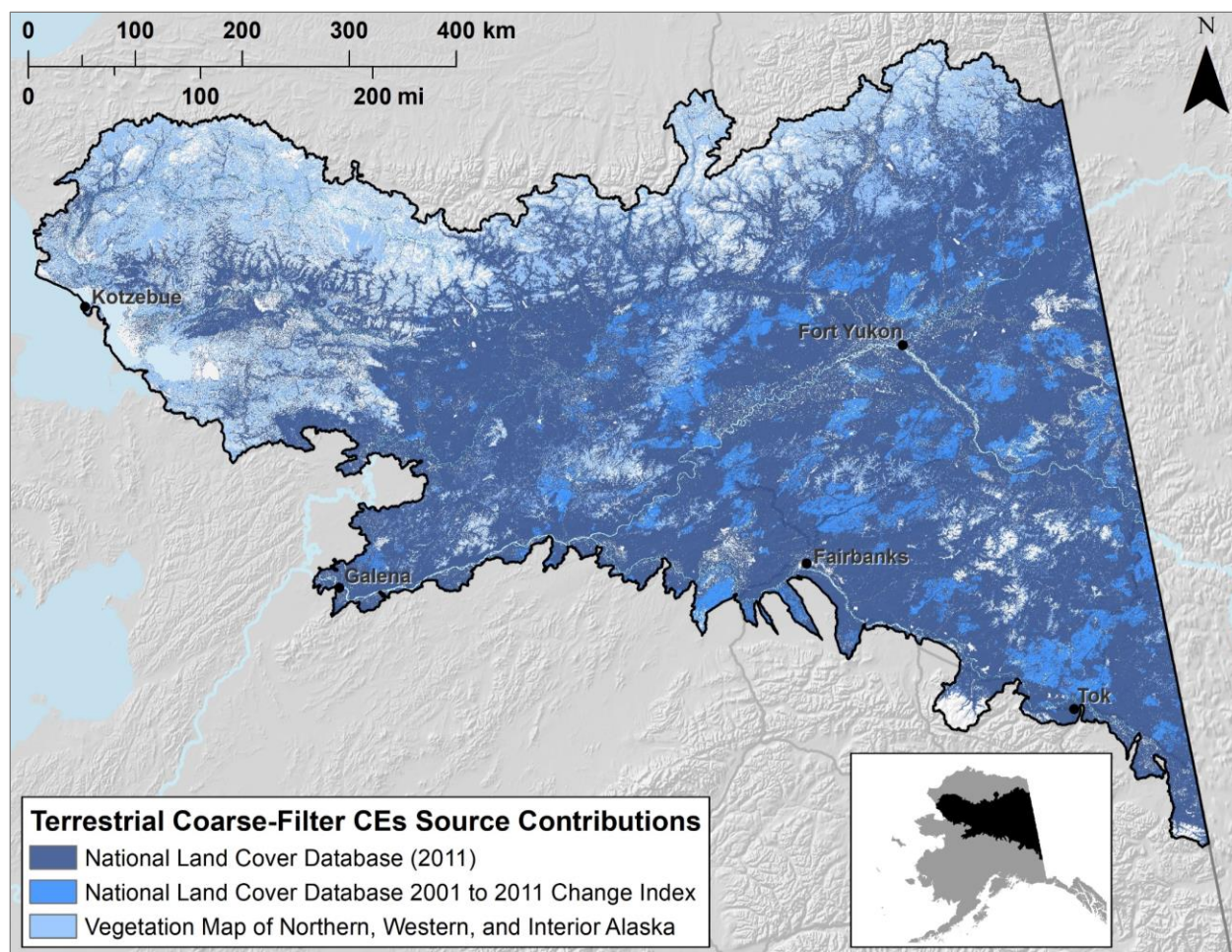


Figure G-5. Relative contribution of the major landcover source maps to the Terrestrial Coarse-filter CE distributions.

3.2 Temperature

Temperature projections based on climate models developed by SNAP are shown for each CE in Table G-3. We focused our results on the hottest month (July), the coldest month (January), and annual mean temperatures. Temperature is projected to increase across the CYR study area for all CEs, but the pattern of increase differs greatly between summer and winter means. Between the current condition and long-term future, mean July temperature is projected to increase by 1.5 °C (range by CE is 1.5–1.6 °C), while January temperature is projected to increase by 3.9 °C (range by CE is 3.8–4.1 °C). Although the amount of increase in terms of degrees is similar for each CE for July, January, and annual, the relative increase differs according to a gradient in elevation. For example, both floodplains and alpine dwarf shrub are projected to see a mean July increase of 1.5 °C, but because the current July temperature is 15.7 °C for floodplains and 10.9 °C for alpine dwarf shrub, the alpine environment will see a proportionally greater increase in temperature. This trend holds true for January and annual temperatures as well.

Table G-3. Mean July, January, and annual temperature by CE for the current condition, near-term future, and long-term future. Change is given as the difference between current and long-term future values.

Terrestrial Coarse-filter CEs	Mean July Temperature (°C)				Mean January Temperature (°C)				Mean Annual Temperature (°C)			
	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change
Floodplain Forest and Shrub	13.9	13.8	15.4	+1.5	-21.5	-19.6	-17.8	+3.7	-5.2	-4.9	-3.4	+1.7
Lowland Woody Wetland	11.5	11.5	13.1	+1.6	-22.3	-17.9	-18.5	+3.8	-5.6	-5.4	-5.4	+0.3
Upland Spruce-Hardwood Forest	15.7	16.0	17.3	+1.5	-22.5	-21.8	-19.0	+3.5	-4.1	-3.9	-2.1	+2.0
Upland Spruce Forest	16.1	16.1	17.6	+1.5	-21.8	-21.7	-18.3	+3.5	-3.8	-3.6	-1.6	+2.3
Upland Low-Tall Shrub	14.2	14.5	15.8	+1.5	-21.7	-19.3	-18.1	+3.6	-4.1	-3.9	-2.8	+1.3
Alpine and Arctic Tussock Tundra	15.5	15.6	17.0	+1.5	-21.5	-20.4	-18.0	+3.5	-3.5	-3.3	-1.5	+1.9
Alpine Dwarf Shrub Tundra	15.9	16.1	17.5	+1.5	-21.8	-20.1	-18.3	+3.5	-3.2	-3.0	-1.5	+1.7
CYR Study Area	14.5	14.6	16.0	+1.5	-21.7	-19.8	-18.2	+3.6	-4.2	-4.0	-2.7	+1.5

To evaluate the effect of climate warming on each CE, we calculated the area of each CE expected to undergo a significant increase in temperature in the near-term and long-term (Table G-4). A temperature uncertainty analysis was performed to determine significance level for each time step based on model averages (see Section C. Abiotic Change Agents for more information about the uncertainty analysis). Projected shifts of > 1 standard deviation from the mean can be considered significant.

In the near-term, the increase in July temperature in forested and lowland CEs is not predicted to be significant (97–100% of CE area with no significant increase); however, in alpine dwarf shrub and tussock tundra, a significant increase is predicted for 9 and 15% of each distribution, respectively. By the long-term future, significant change in July temperature is predicted for 100% of all CE area. January temperature increases are not significant in the near-term, but are significant across 100% of all CE area by the long-term future. Mean annual temperature increases are not significant in the near-term, but are significant across most of the area of each CE area by the long-term future (88–100%).

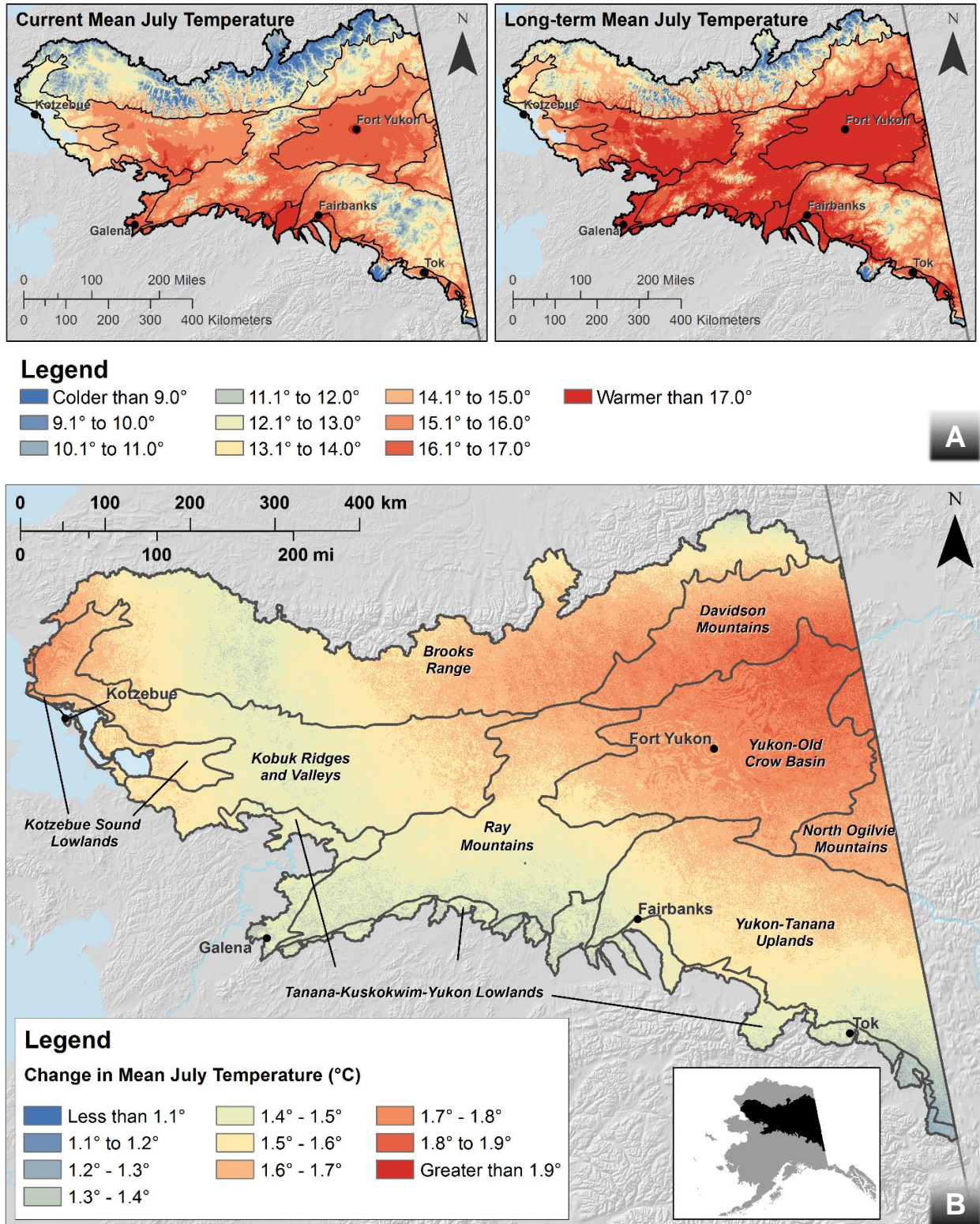
Table G-4. Percent area of each CE that are predicted to undergo a significant (> 1 SD) temperature increase by the near-term future (2025) and long-term future (2060).

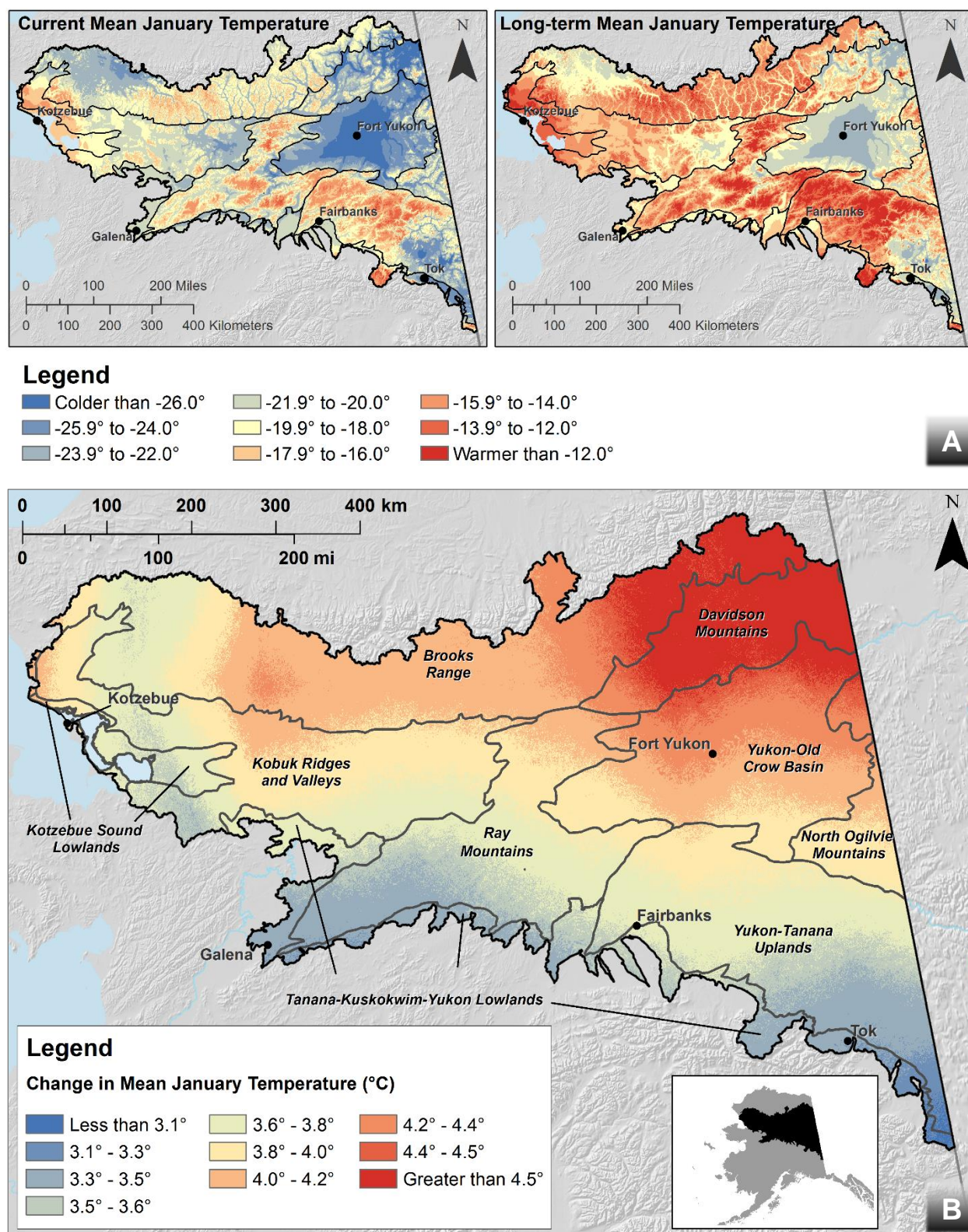
Terrestrial Coarse-filter CE		Δ July Temp	Δ January Temp	Δ Annual Temp
		% significant increase ¹	% significant increase ²	% significant increase ³
Floodplain Forest and Shrub	Near	3	0	0
	Long	100	100	98
Lowland Woody Wetland	Near	1	0	0
	Long	100	100	98
Upland Spruce-Hardwood Forest	Near	0	0	0
	Long	100	100	100
Upland Spruce Forest	Near	0	0	0
	Long	100	100	99
Upland Low-Tall Shrub	Near	2	0	0
	Long	100	100	98
Alpine and Arctic Tussock Tundra	Near	15	0	0
	Long	100	100	97
Alpine Dwarf Shrub Tundra	Near	9	0	0
	Long	100	100	88

¹Standard deviation for near = 0.8, long = 1.2²Standard deviation for near = 2.6, long = 2.5³Standard deviation for near = 1.3, long = 1.2

Figure G-6 shows temperature distribution and change for July. The hottest regions of the CYR study area include the Yukon-Old Crow basin ecoregion and the Tanana-Kuskokwim basin, and the region projected to see the greatest amount of increase in temperature includes the northern portion of the Yukon-Old Crow ecoregion and the Davidson Mountains.

Figure G-7 shows temperature distribution and change for January. The coldest region of the CYR study area is the Yukon-Old Crow basin ecoregion, and the areas projected to see the greatest amount of increase in January temperature include the Davidson Mountains and the eastern portion of the Brooks Range.

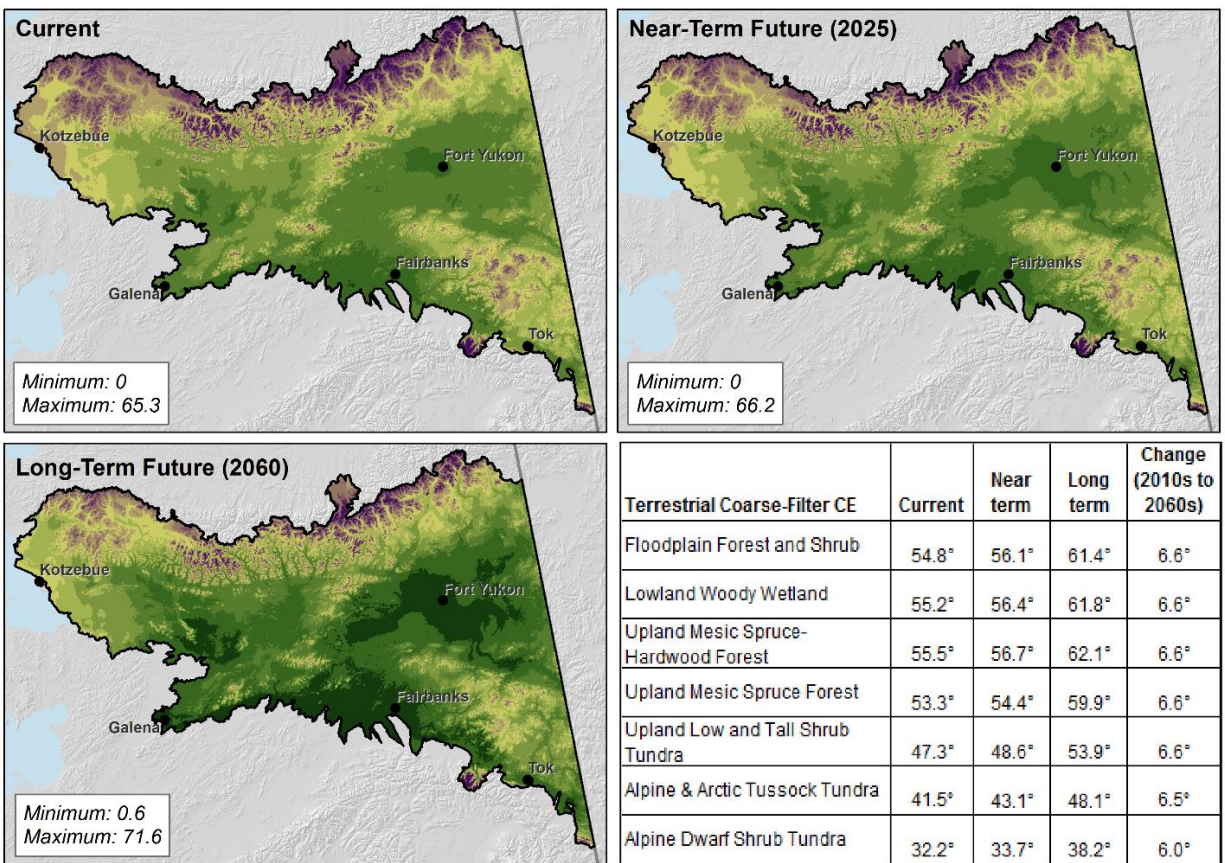




3.3 Summer Warmth Index and Growing Season Length

Summer warmth index (SWI) was calculated as the sum of mean monthly temperatures above freezing. It is similar in concept to growing degree days in that it provides an index of heat accumulation across the growing season. Unlike growing degree days, SWI is calculated based on monthly, not daily, means and there is no adjustment for base threshold temperatures. Summer Warmth Index is expressed in units of °C months.

Here we provide an overview of the changes to SWI from the current condition to the long-term future across the entire CYR study area (Figure G-8). In the individual CE accounts, we provide a spatial representation of the change in SWI across each CE between the current condition and the long-term future.



Summer Warmth Index (°C mos): A2 Scenario

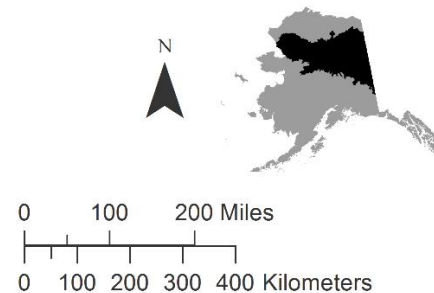
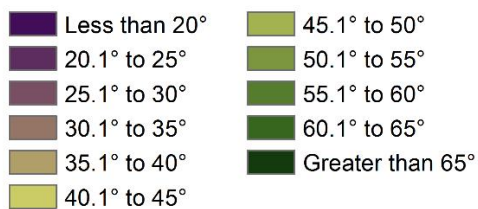


Figure G-8. Summer Warmth Index for the current condition, near-term future, and long-term future. Inset: mean SWI by CE and change from current to long-term future.

Similar to the July temperature pattern, the greatest amount of heat accumulation (calculated as SWI) occurs in lowland and forested habitats and the lowest SWI occurs in shrubland and alpine habitats across all time steps. The amount of change in SWI is similar across all habitats (6.5–6.6 °C mos) with the exception of the alpine dwarf shrub tundra CE which is projected to see less increase (6.0 °C mos) in summer heating than other habitats, reflecting the effect of elevation on temperature.

Length of growing season (LOGS) is another metric that is commonly used to describe the potential for plant growth and development. LOGS refers to the projected number of days between the monthly interpolated dates on which the temperature crosses the freezing point (0 °C) in the spring and in the fall, and it, thus, provides a theoretical index of the number of days during which plant growth would not be impeded by freezing temperatures. Length of growing season does not account for late spring or early autumn frosts that can greatly reduce the actual growing season during any given year, so it tends to overestimate the true length of growing season. Unlike SWI, LOGS provides no information about the cumulative seasonal temperature, which, in the absence of drought stress, may be a better indicator of potential productivity than growing season length for most boreal species.

Average projected increases in growing season by CE ranged from 8.8 days to 10.5 days, with the longest growing seasons in the lowland and forested habitats and the shortest growing seasons in alpine tundra (Figure G-9). The greatest change in LOGS, however, occurs in the shrublands and alpine habitats. The trend in LOGS in high elevation habitats differs from the SWI trend, which predicts less change in overall heat accumulation in alpine habitats despite a longer growing season.

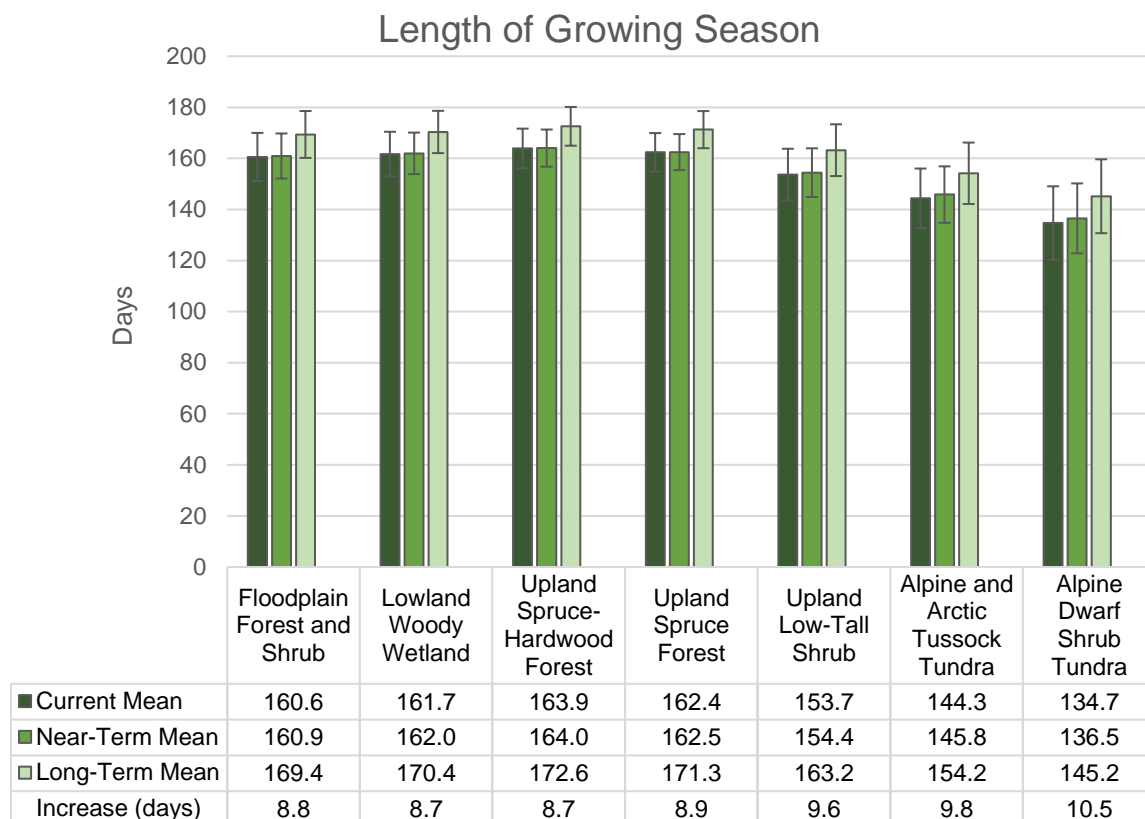


Figure G-9. Average Length of Growing Season (LOGS) by CE for the current condition, near-term future, and long-term future. Error bars indicate +/-1 standard deviation from the mean.

3.4 Precipitation

Precipitation projections based on climate models developed by SNAP are shown for each CE in Table G-5. We focused our results on mean annual precipitation, growing season precipitation (May, June, July, and August), and winter precipitation (November, December, January, February, and March). High elevation habitats currently receive a greater proportion of precipitation than low elevation habitats, and within the low elevation zone, the highly continental eastern portion of the CYR study area receives the least precipitation (Figure G-10). Precipitation is projected to increase across the CYR study area for all CEs, but the pattern of increase differs across the landscape according to gradients in elevation and continentality. High elevation habitats, including all of the non-forested CEs, are expected to continue to see more precipitation than lower elevation CEs. For example, between the current condition and long-term future, the greatest increase is projected to occur in alpine dwarf shrub tundra (66-mm increase), while lowland woody wetlands are projected to see the least amount of increase (39-mm increase). The percentage increase across all CEs is relatively consistent with 6–7% increase during the growing season, 14–16% increase during winter, and an annual increase of 11–13%.

Table G-5. Mean annual, growing season, and winter precipitation by CE for current, near-term future, and long-term future. Change between current and long-term is displayed in mm and as a percentage.

Terrestrial Coarse-filter CEs	Precipitation (mm)														
	Summer					Winter					Mean Annual				
	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change
Floodplain Forest and Shrub	154	157	164	+10	+6	59	66	69	+10	+17	351	366	394	+43	+12
Lowland Woody Wetland	151	154	160	+9	+6	55	62	64	+9	+16	336	351	376	+40	+12
Upland Spruce-Hardwood Forest	164	168	174	+9	+6	59	65	69	+9	+16	362	378	403	+41	+11
Upland Spruce Forest	173	177	182	+9	+5	58	65	68	+9	+16	374	389	415	+42	+11
Upland Low and Tall Shrub	189	192	201	+12	+7	69	76	81	+12	+18	424	442	477	+52	+12
Alpine and Arctic Tussock Tundra	178	179	190	+12	+7	69	78	81	+12	+17	415	431	470	+55	+13
Alpine Dwarf Shrub Tundra	235	236	251	+16	+7	83	92	99	+16	+19	519	536	585	+66	+13
CYR study area	183	186	195	+11	+6	66	74	77	+11	+17	409	425	458	+50	+12

To evaluate the effect of increased precipitation on each CE, we calculated the area expected to undergo a significant increase in precipitation in the near-term and long-term (Table G-6). A precipitation uncertainty analysis was performed to determine significance level for each time step based on model averages (see Section C. Abiotic Change Agents for more information about the uncertainty analysis). Projected shifts of > 1 standard deviation from the mean can be considered significant.

In the near-term future, very little significant change is projected during the summer season (May–August), but by the long-term future, significant change in summer precipitation is projected for 41–49% of forested and lowland CEs and 71–84% of non-forested and alpine CEs. During the winter months (November–March); however, significant change in precipitation is predicted during

the winter months across nearly all of the CE area for both the near-term and long-term future (Table G-6). This indicates that there is stronger agreement among models in winter precipitation increases than in growing season increases.

Figure G-10 shows the distribution of mean annual precipitation across the CYR study area. The areas that receive the least precipitation are coincident with the hottest July temperatures (Figure G-7) and include the Yukon-Old Crow basin ecoregion and the Tanana-Kuskokwim basin. Mountainous regions of the CYR study area are projected to see the most increase in precipitation, while low elevation areas, particularly in the eastern portion of the CYR study area are projected to see the least increase.

It should be noted, however, that uncertainty in precipitation projections is relatively high. Because precipitation is more variable than temperature across space and time, variability and uncertainty tend to be greater for precipitation than for temperature.

Table G-6. Percent area of each CE that will undergo a significant (> 1 SD) increase in precipitation in the near-term (2020s) and long-term (2060s).

Terrestrial Coarse-filter CE		Δ Growing Season Precip (MJJA)	Δ Winter Precip (NDJFM)	Δ Annual Precip.
		% significant increase ¹	% significant increase ²	% significant increase ³
Floodplain Forest and Shrub	Near	0%	98%	99%
	Long	49%	96%	100%
Lowland Woody Wetland	Near	0%	97%	99%
	Long	41%	95%	100%
Upland Spruce-Hardwood Forest	Near	1%	99%	100%
	Long	41%	99%	100%
Upland Spruce Forest	Near	0%	98%	100%
	Long	44%	97%	100%
Upland Low-Tall Shrub	Near	1%	99%	99%
	Long	71%	99%	100%
Alpine and Arctic Tussock Tundra	Near	1%	98%	97%
	Long	70%	100%	100%
Alpine Dwarf Shrub Tundra	Near	2%	99%	91%
	Long	84%	100%	100%

¹ Standard deviation for near = 10.97, long = 9.0

² Standard deviation for near = 3.89, long = 4.0

³ Standard deviation for near = 5.71, long = 5.96

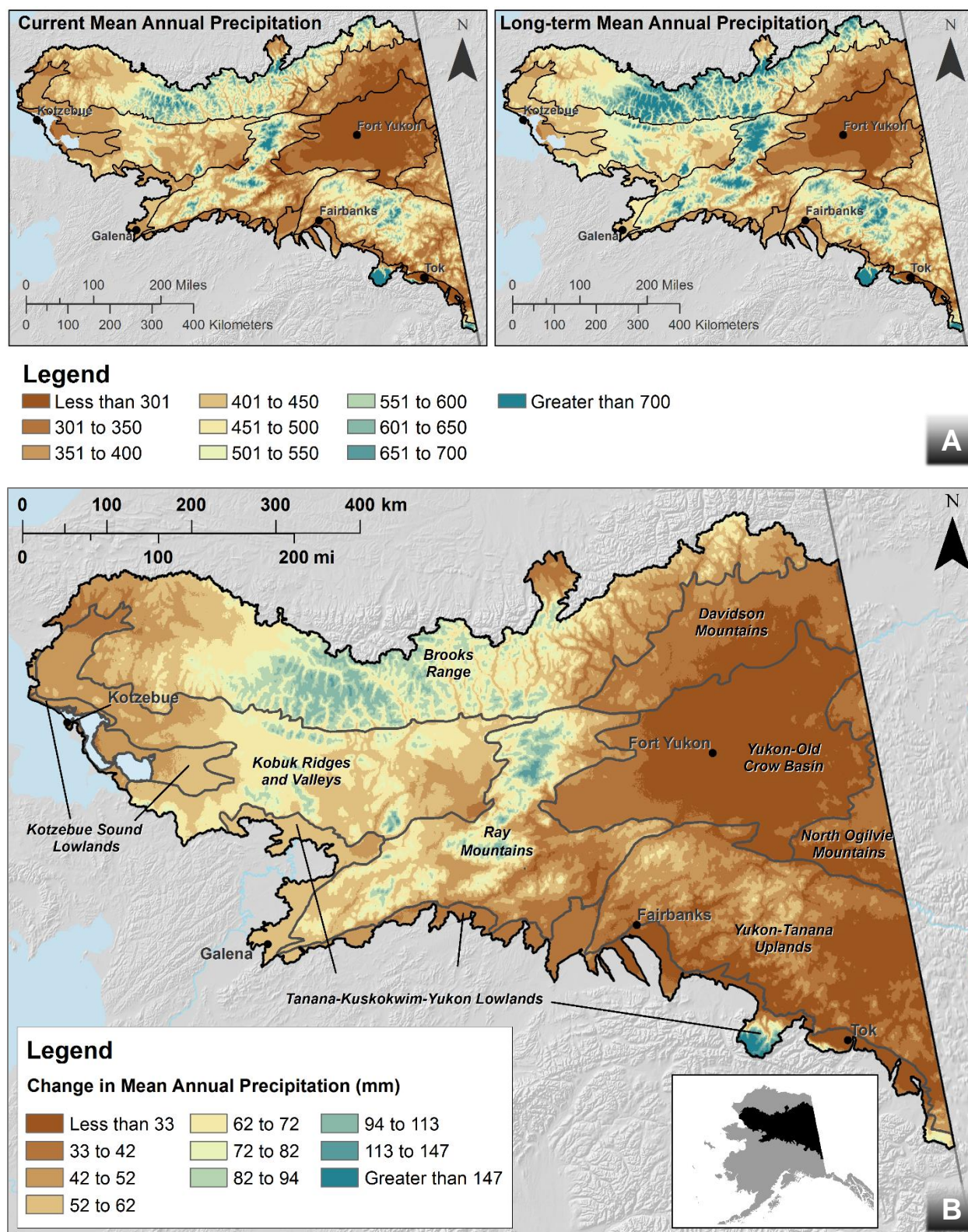


Figure G-10. Mean annual precipitation for the current condition and long-term future (A) and change in annual precipitation with ecoregions shown for reference (B).

3.5 Permafrost

Using models developed by SNAP and GIPL, we assessed the impact of changing permafrost conditions across all CE habitats. Our analysis focused on permafrost loss, changes to active layer thickness, and the potential for thermokarst.

Mean annual ground temperature (MAGT) is predicted to increase across the CYR study area, and this change will have dramatic effects on areas underlain by permafrost. When MAGT rises above 0 °C at 1-m depth, the soil is considered to be free of permafrost to that depth. Two percent of the CYR study area is currently permafrost-free to at least 1-m depth, but this proportion is projected to increase to 30% by the long-term future (2060s). A detailed description of changes through time to MAGT is provided Section C. Abiotic Change Agents. Forested and lowland CEs, which dominate the southern and eastern portion of the CYR study area, are projected to become 39% to 50% permafrost-free by the long-term future (2060s), while non-forested alpine and subalpine CEs, which dominate the western and northern portion of the CYR study area, are projected to be less impacted (Table G-7, Figure G-11). Of the forested CEs, upland spruce-hardwood, lowland woody wetland, and upland mesic spruce forest are expected to experience the greatest increase in permafrost-free area from current to long-term (Figure G-11). The pattern of permafrost loss in the non-forested CEs follows an elevation gradient, with less permafrost loss with increasing elevation.

Table G-7. Percentage area of each CE projected to be permafrost-free at 1-m depth in the current condition, near-term future, and long-term future.

Terrestrial Coarse-filter CEs	% Area Permafrost-free at 1-m depth		
	Current	Near-Term	Long-Term
Floodplain Forest and Shrub	7%	8%	9%
Lowland Woody Wetland	6%	7%	8%
Upland Spruce-Hardwood Forest	5%	6%	6%
Upland Spruce Forest	2%	3%	4%
Low and Tall Shrub Tundra	1%	1%	2%
Alpine and Arctic Tussock Tundra	0%	1%	1%
Alpine Dwarf Shrub Tundra	1%	3%	3%

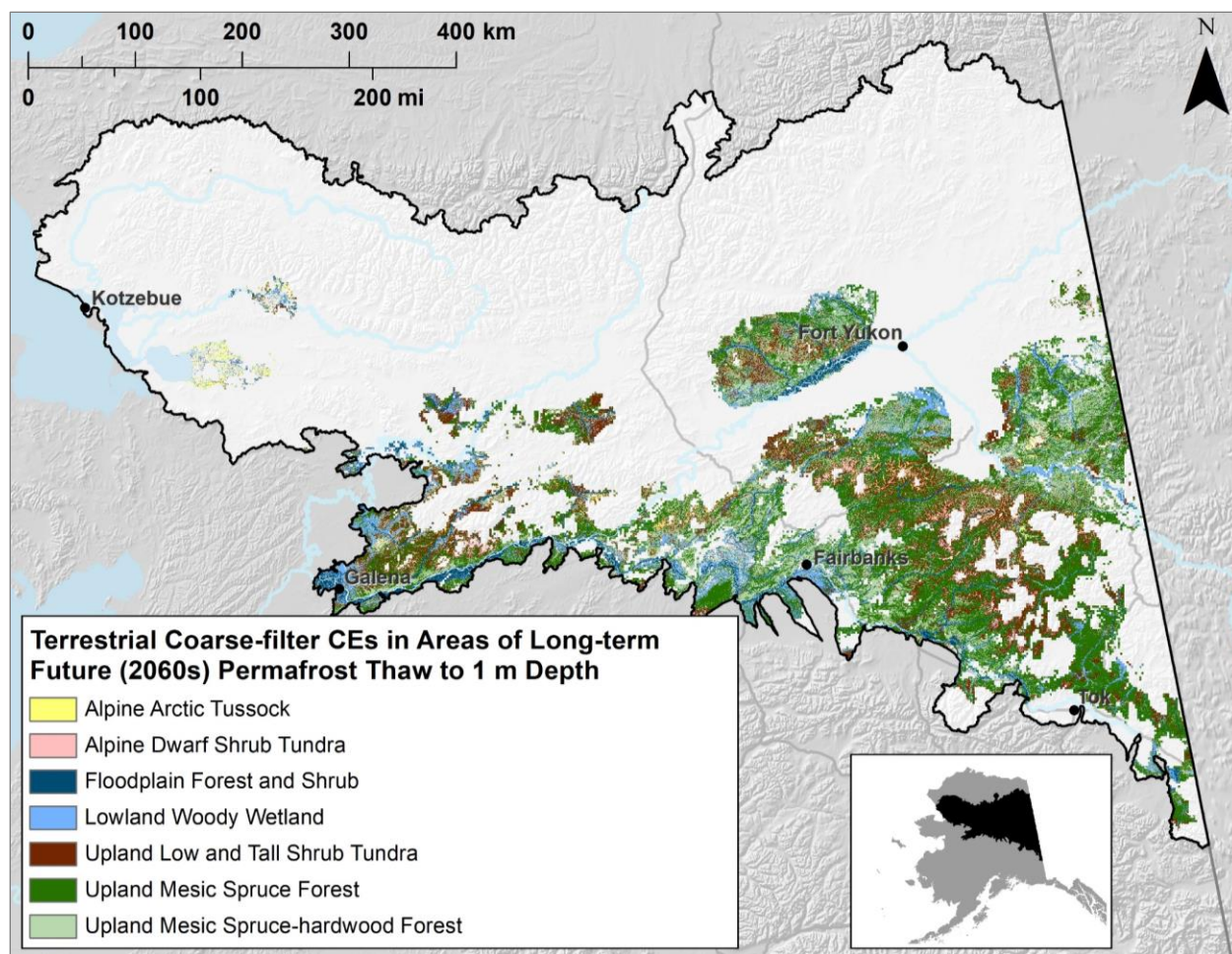


Figure G-11. Terrestrial Coarse-filter CEs in areas projected to have a mean annual ground temperature above 0 °C at 1-m depth by the long-term future (2060s).

In areas projected to retain permafrost, the active layer thickness is expected to increase, but the amount of increase varies across habitat types. Figure G-12 illustrates the pattern of permafrost loss and active layer increase across the landscape with a stacked bar chart summarizing the combined impact of permafrost loss and changes to the active layer within each CE between the current condition and long-term future. Figure G-13 illustrates the mean active layer thickness for each CE (for the areas with permafrost) and the projected change in the active layer between the current condition and long-term future. Summarizing the changes in both figures, forested and lowland habitats have deeper active layers and are projected to lose more permafrost, while alpine habitats will lose less permafrost but see a greater amount of change in the depth of the active layer. These changes will undoubtedly impact the distribution of vegetation and habitat types across the landscape.

Active Layer Thickness and Permafrost Thaw

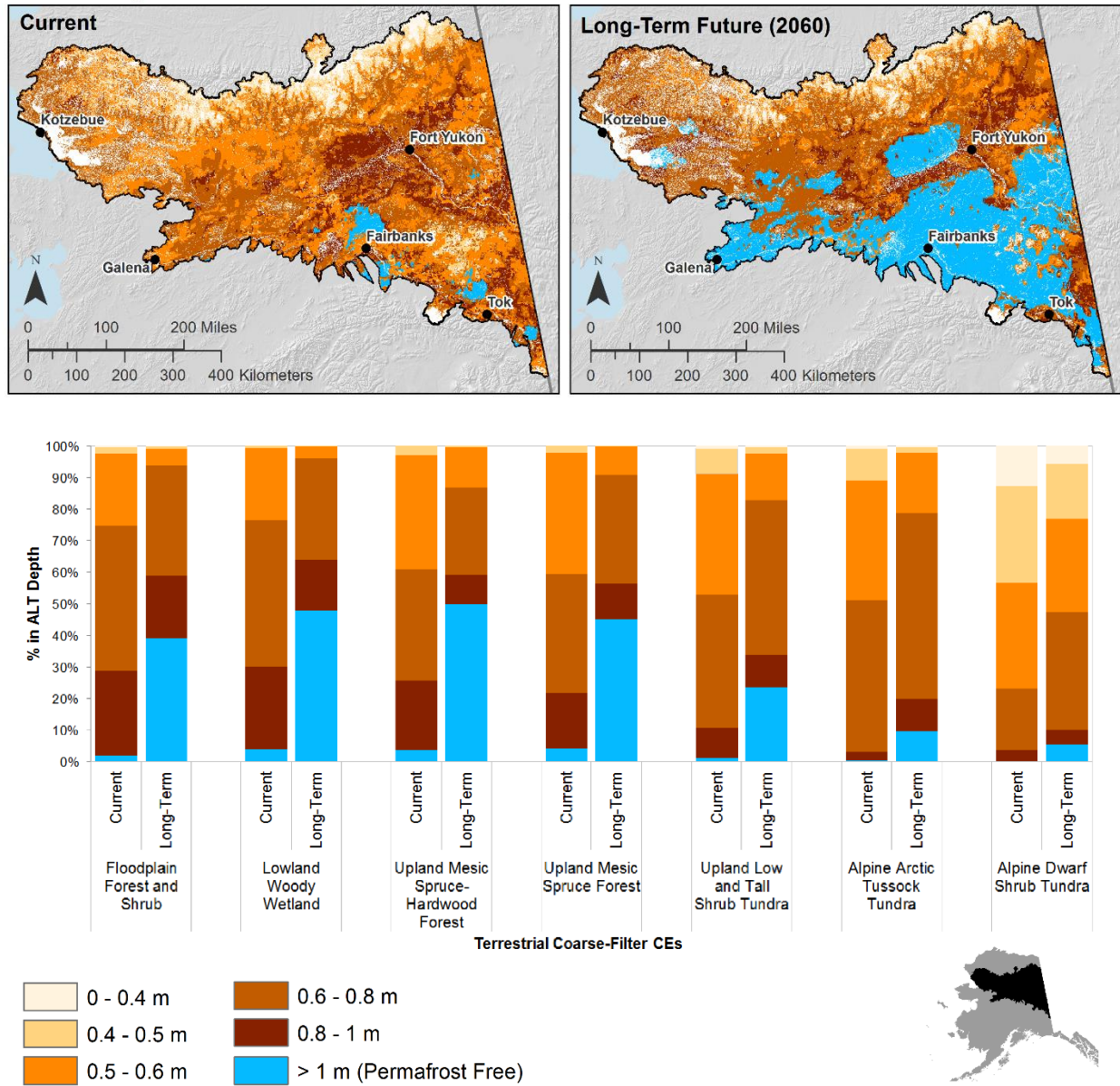


Figure G-12. Permafrost-free area of each CE in the current condition and long-term future, and the proportion of each CE in 5 active layer depth categories. “Permafrost-free” sites are defined as those without permafrost at 1 m.

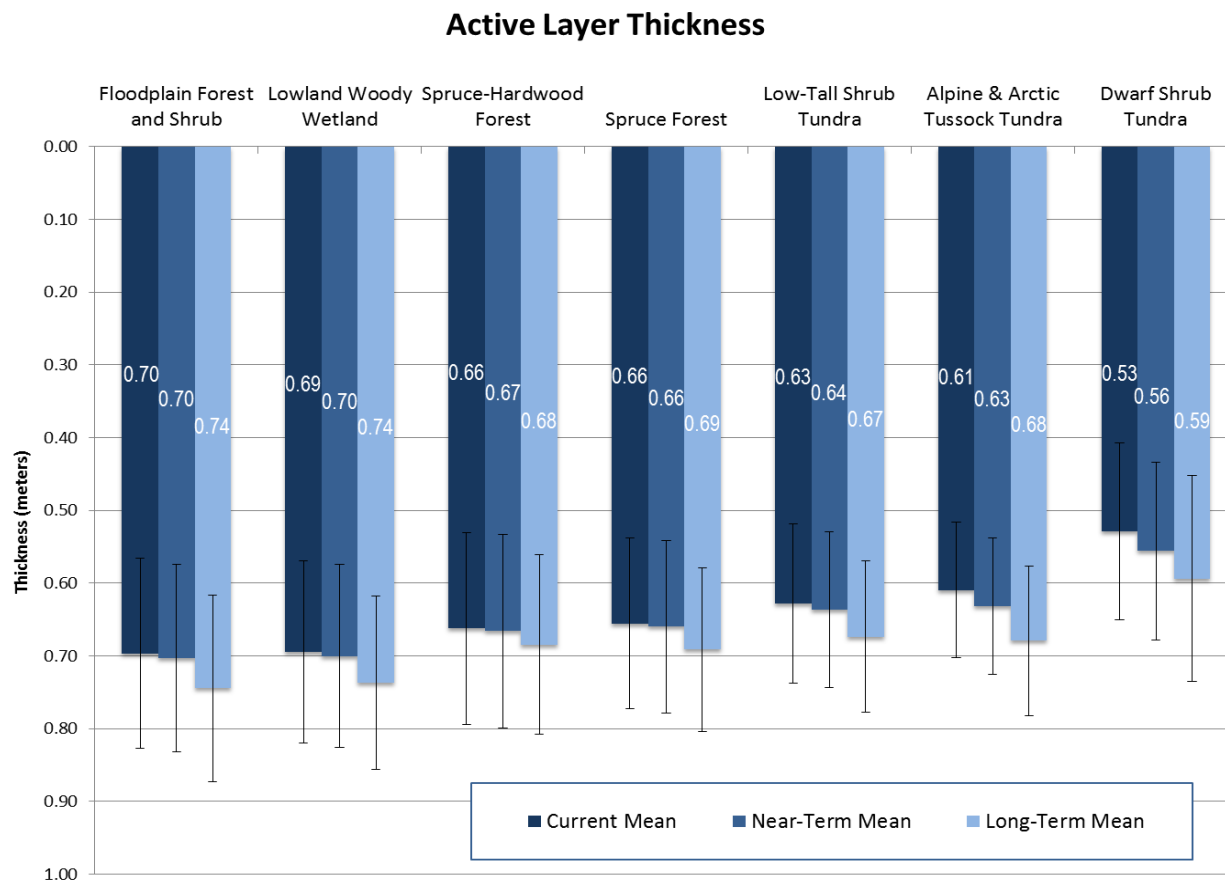


Figure G-13. Average depth of active layer by CE for areas with permafrost. Areas of permafrost loss not included.

We used the thermokarst predisposition model to illustrate the distribution of landscapes currently underlain by thermokarst-prone terrain (Figure G-14a) and combined that with the mean annual ground temperature model of areas projected to have a MAGT > 0 °C to highlight those regions most likely to be impacted by thermokarst as permafrost thaws between the current condition and long-term future (Figure G-14b). We intersected the thermokarst model with the distribution of each CE to illustrate the proportion of each CE that currently occurs on thermokarst-prone terrain (Figure G-14c). Habitats with the greatest proportion of highly thermokarst-prone terrain include lowland woody wetland (60%) and tussock tundra (45%), while those with the lowest proportion include floodplain forest and shrub (23%) and alpine dwarf shrub tundra (12%).

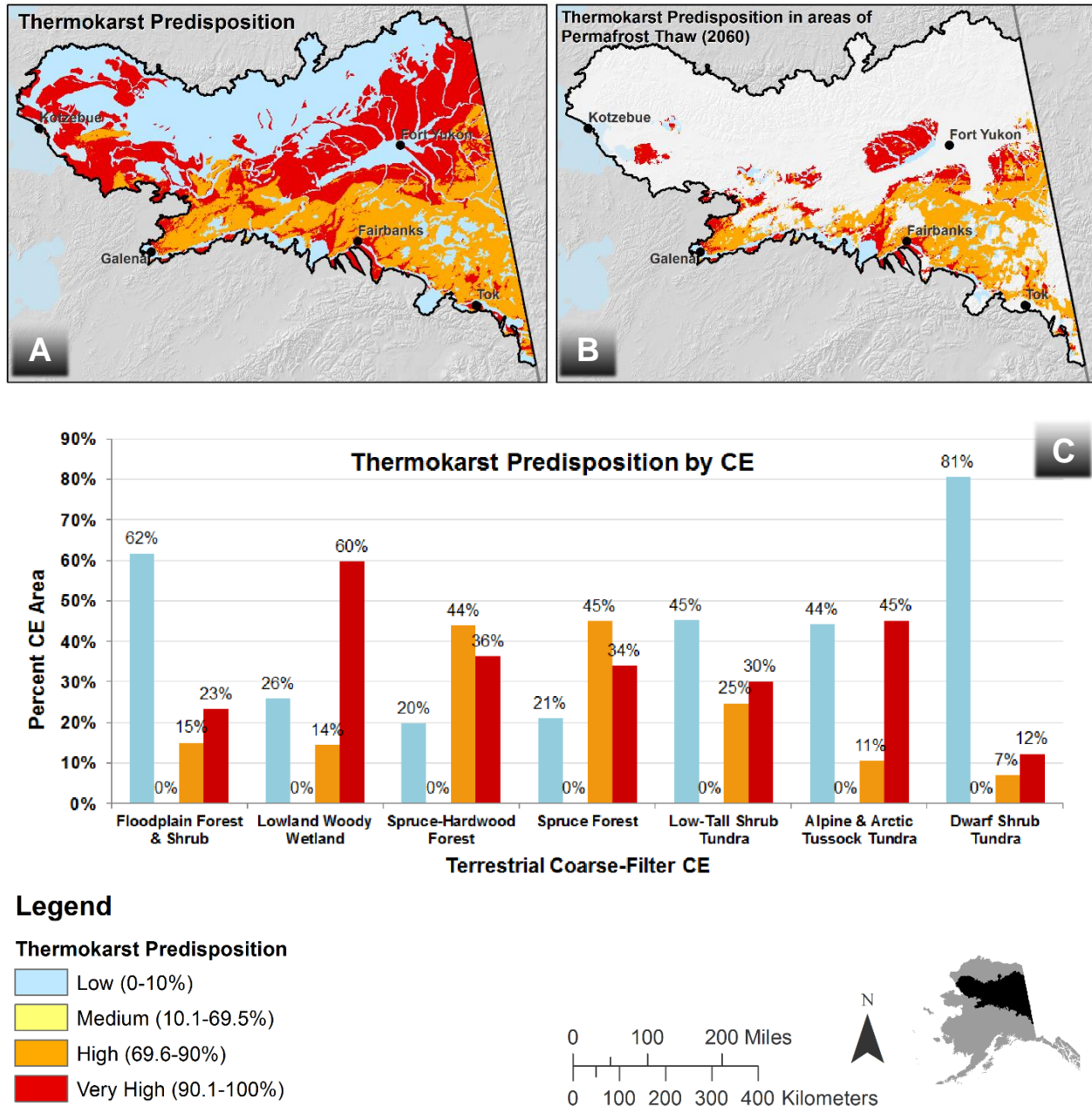


Figure G-14. Thermokarst predisposition model (A) and thermokarst predisposition in those areas projected to undergo permafrost thaw by the 2060s (B). Percent area of each CE that is predisposed to thermokarst (C), based on inset A.

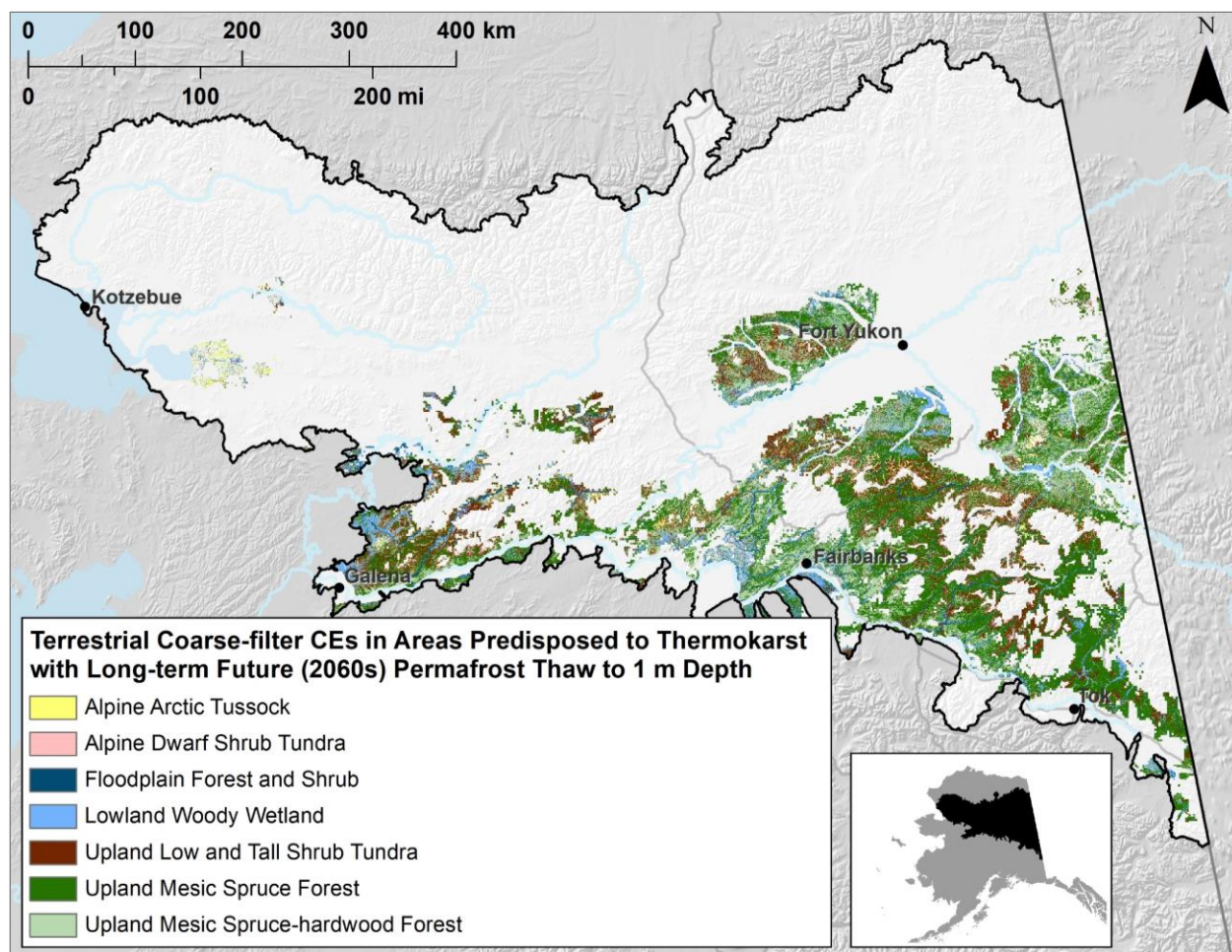


Figure G-15. Map of CE distributions for areas that are both predisposed to thermokarst and projected to lose permafrost by the 2060s.

Figure G-15 illustrates the distribution of CEs that occur on landscapes that are projected to lose permafrost by the 2060s and also are highly predisposed to thermokarst. This represents a conservative estimate of thermokarst prone habitat because it doesn't account for areas where permafrost is projected to remain, but the active layer has become deeper.

3.6 Fire and Vegetation Change

ALFRESCO Model

Fire and vegetation transitions were modeled using the Alaska Frame-based Ecosystem Code (ALFRESCO, Rupp et al. 2000, Rupp et al. 2002, Joly et al. 2012). The model assumptions reflect the hypothesis that fire regime and climate are the primary drivers of landscape-level changes in vegetation distribution in Arctic and boreal biomes. The model further assumes that vegetation composition and continuity serve as a major determinant of large, landscape-level fires. Climate projections, past fire history, and current vegetation patterns were used to model patterns of fire frequency across the landscape. The model combines fire, seed dispersal, and vegetation succession on a landscape at a spatial and temporal scale appropriate for investigating both transient and long-term effects of climate change.

Figure G-16 outlines the potential transitions between vegetation classes in ALFRESCO and the general drivers of those shifts. The transition arrows labeled “fire” can only occur post burn, while all other transitions may occur in the absence of fire. Most transitions are probabilistic, based on the variables that govern the model as a whole and each vegetation type in particular.

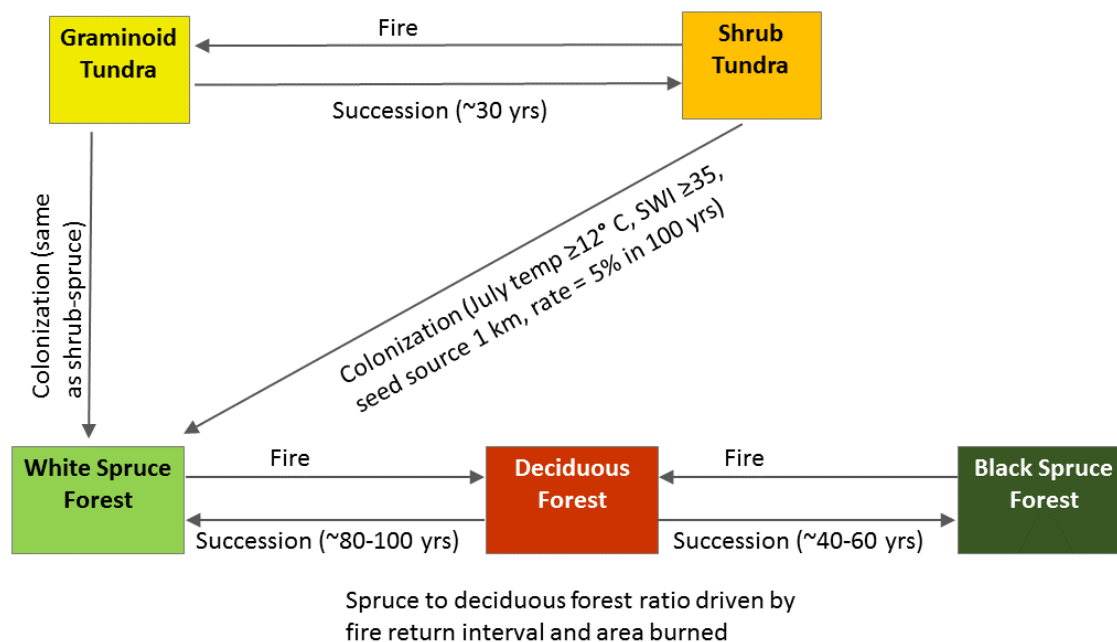


Figure G-16. Schematic of the ALFRESCO model showing potential vegetation transitions. Transitions that are not yet active in the model, such as thermokarst and drought, are not shown.

In this model, all deciduous forest is an early seral stage of white spruce forest or black spruce forest. When any spruce pixel burns, the default trajectory is for that pixel to revert to deciduous forest. The transition back to spruce is variable, but might typically occur at about 40 to 60 years for black spruce and 80 to 100 years for white spruce (Rupp et al. 2002).

Transitions from graminoid to shrub tundra are governed by multiple factors, including time since fire, mean July temperature, and SWI. Although tundra fire can promote shrub expansion (Racine et al. 2004), shrubbification can also occur without fire (Naito and Cairns 2015). ALFRESCO is calibrated such that post-fire, shrub tundra transitions to graminoid tundra. Approximately 30 years post-fire, graminoid tundra may transition to shrub tundra. If a fire occurred, there is a 5% chance of transition to shrub tundra (Racine et al. 2004). If a fire has not occurred, there is only a 1% chance of transition.

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

ALFRESCO Results

The model results include back-cast data to 1900 and modeled data out to 2100 (Figure G-17). The REA time steps, represented as vertical lines in the graph, capture only a small proportion of the change represented in the entire model run.

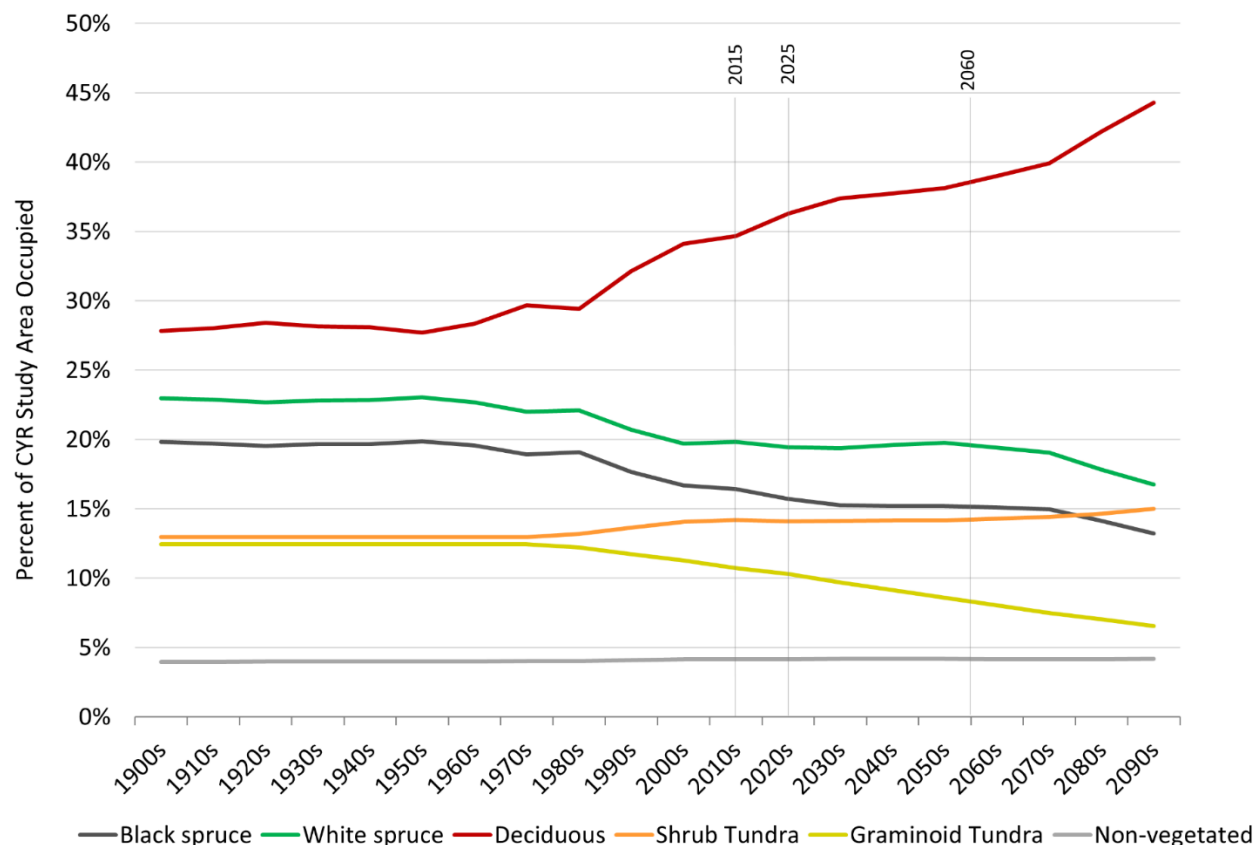


Figure G-17. Projected changes in vegetation as modeled in ALFRESCO from 1900 to 2100. The mid-points of the REA time steps for current (2015), near (2025), and long-term (2060) are indicated.

When modeled vegetation shifts are viewed across a 200-year time span, it is apparent that significant shifts started occurring in the latter decades of the twentieth century. These modeled shifts are corroborated by empirical evidence (Mann et al. 2012), and are expected to accelerate through the current century across the region. Changes include a sharp increase in deciduous forest and a modest increase in shrub tundra, with corresponding decreases in white spruce, black spruce, and graminoid tundra.

Central Yukon Study Area Current and Long-Term Vegetation

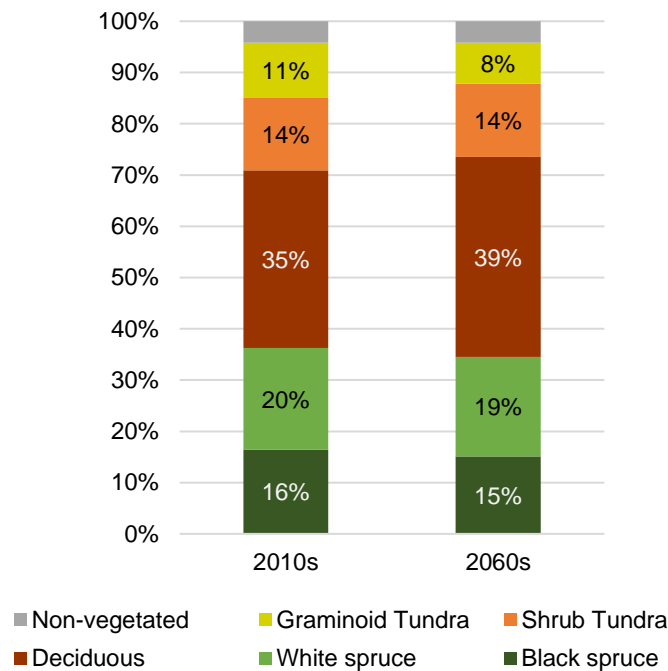


Figure G-18. ALFRESCO-modeled vegetation change averaged across the CYR study area for the current condition (2010s) and long-term future (2060s).

To display change across the CYR study area for the current and long-term future time steps identified in the REA, we extracted decadal means from the full model results. Across the 50-year time span of the REA, the changes in vegetation are far subtler than those reflected in the entire 200-year model run, but the direction of change is similar across all vegetation types. The dominant trends are a projected increase in deciduous forest and decreases in coniferous forest and graminoid tundra (Figure G-18).

Shrub tundra showed little change in the model when averaged across the entire area from the 2010s to the 2060s, but examining the trends by ecoregion shows differences across the CYR study area. Ecoregions of the CYR study area are shown in Figure G-19. Shrub cover increased in the Davidson Mountains, Kobuk Ridges and Valleys and Brooks Range, decreased in the Kotzebue Sound Lowlands and showed little change in the other ecoregions (Figure G-20, Table G-8).

Deciduous forest increased across all ecoregions in the model, black spruce decreased slightly across all ecoregions, and white spruce increased in two ecoregions (Davidson Mountains and Kotzebue Sound lowlands) and decreased in the remaining ecoregions (Figure G-20, Table G-8).

Graminoid tundra decreased across all ecoregions with a marked decrease in the Davidson Mountains and small decreases elsewhere in the ALFRESCO model (Figure G-20, Table G-8).

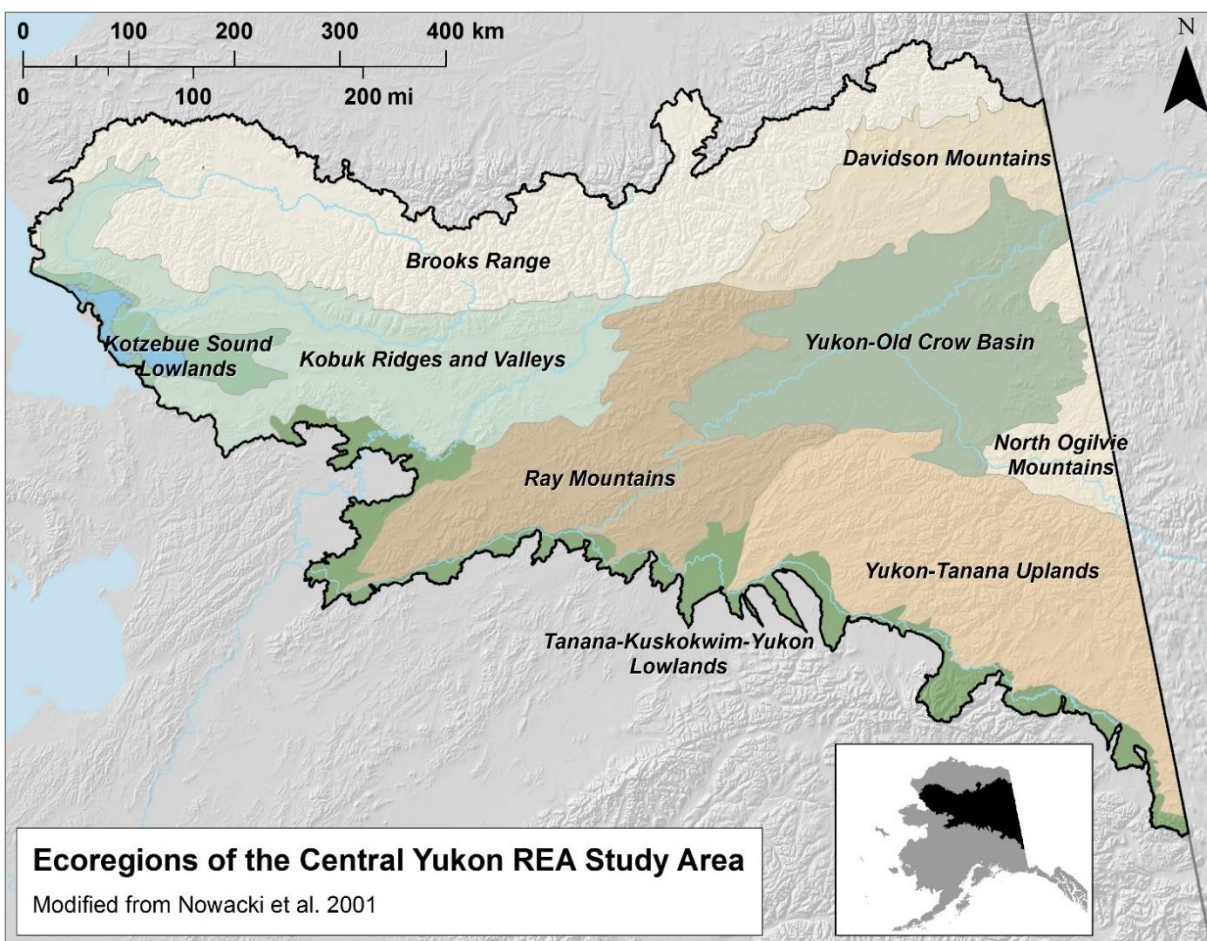


Figure G-19. Ecoregions of the CYR study area (modified from Nowacki et al. 2001).

Table G-8. Change in canopy cover for each vegetation type modeled in ALFRESCO by ecoregion from current condition to the long-term future (2060s) for the CYR study area.

Ecoregion	Percent Change in ALFRESCO Vegetation Type Per Ecoregion					
	Black Spruce	White Spruce	Deciduous Forest	Shrub Tundra	Graminoid Tundra	Non-vegetated
Kobuk Ridges and Valleys	-2	-2	+9	-3	-1	-1
Brooks Range Mountains	-1	-	+4	+1	-4	-
Davidson Mountains	-2	+2	+8	+5	-13	-
Ray Mountains	-2	-1	+5	-	-2	-
Yukon-Old Crow Basin	-1	-2	+3	-	-1	-
North Ogilvie Mountains	-1	-	+2	-	-1	-
Kotzebue Sound Lowlands	-	+7	+3	-9	-1	-
Tanana-Kuskokwim-Yukon Lowlands	-1	-2	+3	-	-	-
Yukon-Tanana Uplands	-1	-2	+4	+1	-1	-

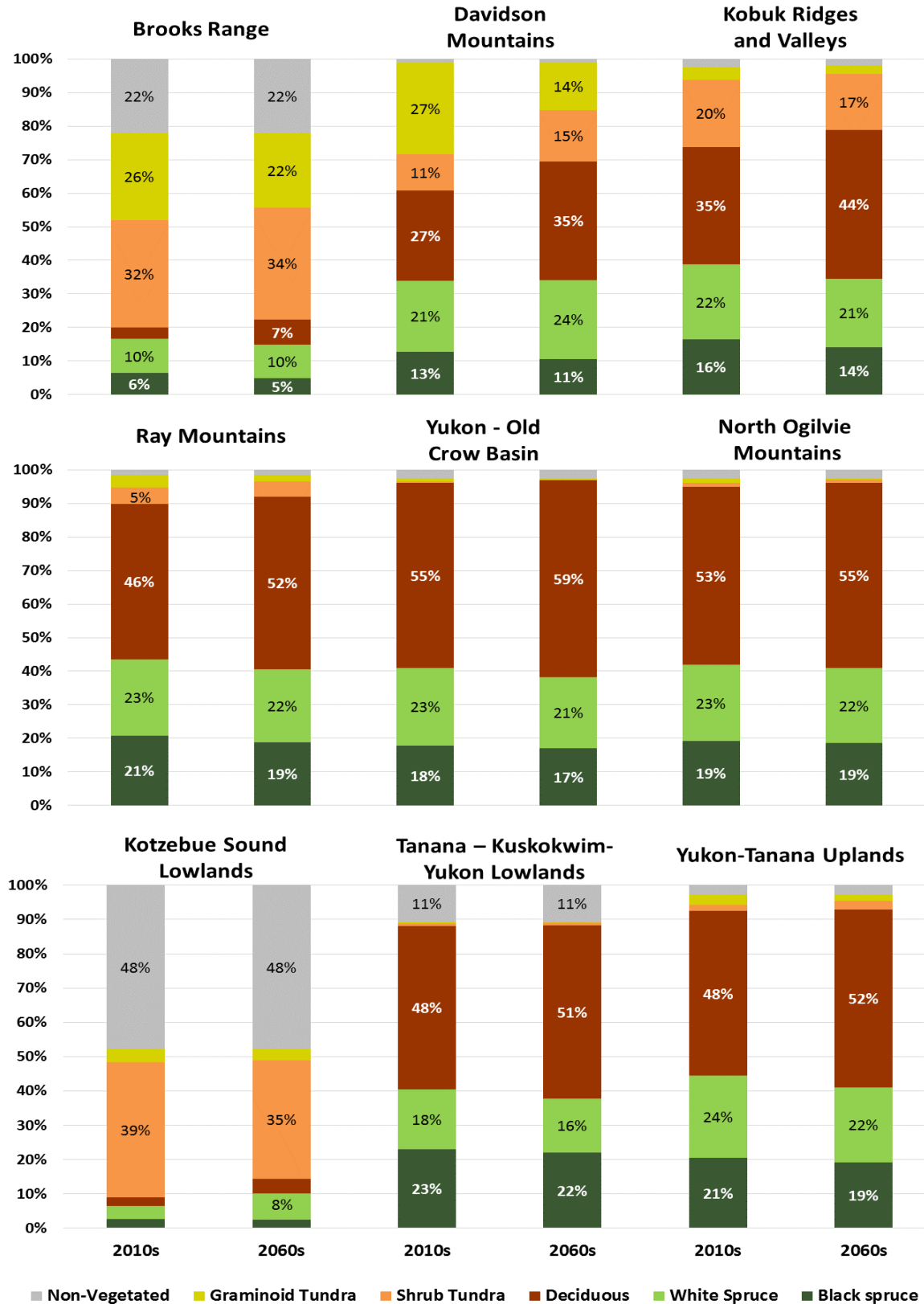


Figure G-20. Canopy cover for each vegetation type modeled in ALFRESCO for the current condition (2010s) and long-term future (2060s) across the CYR study area.

In order to interpret the impacts of the ALFRESCO projections on CE habitat, we intersected the CE distribution maps with the ALFRESCO base maps and calculated the area of each CE occupied by the ALFRESCO classes (Figure G-21). Several important differences between the classifications were revealed in this exercise. There is a higher overall proportion of deciduous forest in the ALFRESCO map than in the CE distributions, or in the NLCD map from which the forested CEs were derived. Some of these discrepancies result from classification differences between NLCD and NALCMS, but an additional source of difference originates from the reclassification of the NALCMS shrub class to deciduous forest in ALFRESCO where growing season temperatures were at least 6.5 °C. As a result of these differences in shrub and deciduous forest classification, the low and tall shrub CE (which is based on the NLCD shrub/scrub class) does not correspond with the ALFRESCO shrub tundra class. In the alpine, much of the alpine dwarf shrub CE corresponds to graminoid tundra in ALFRESCO, and the tussock tundra CE is split among shrub tundra, deciduous forest, and graminoid tundra. Understanding the differences in the classification systems provides an important connection between the results and the ecological implications for CE habitat.

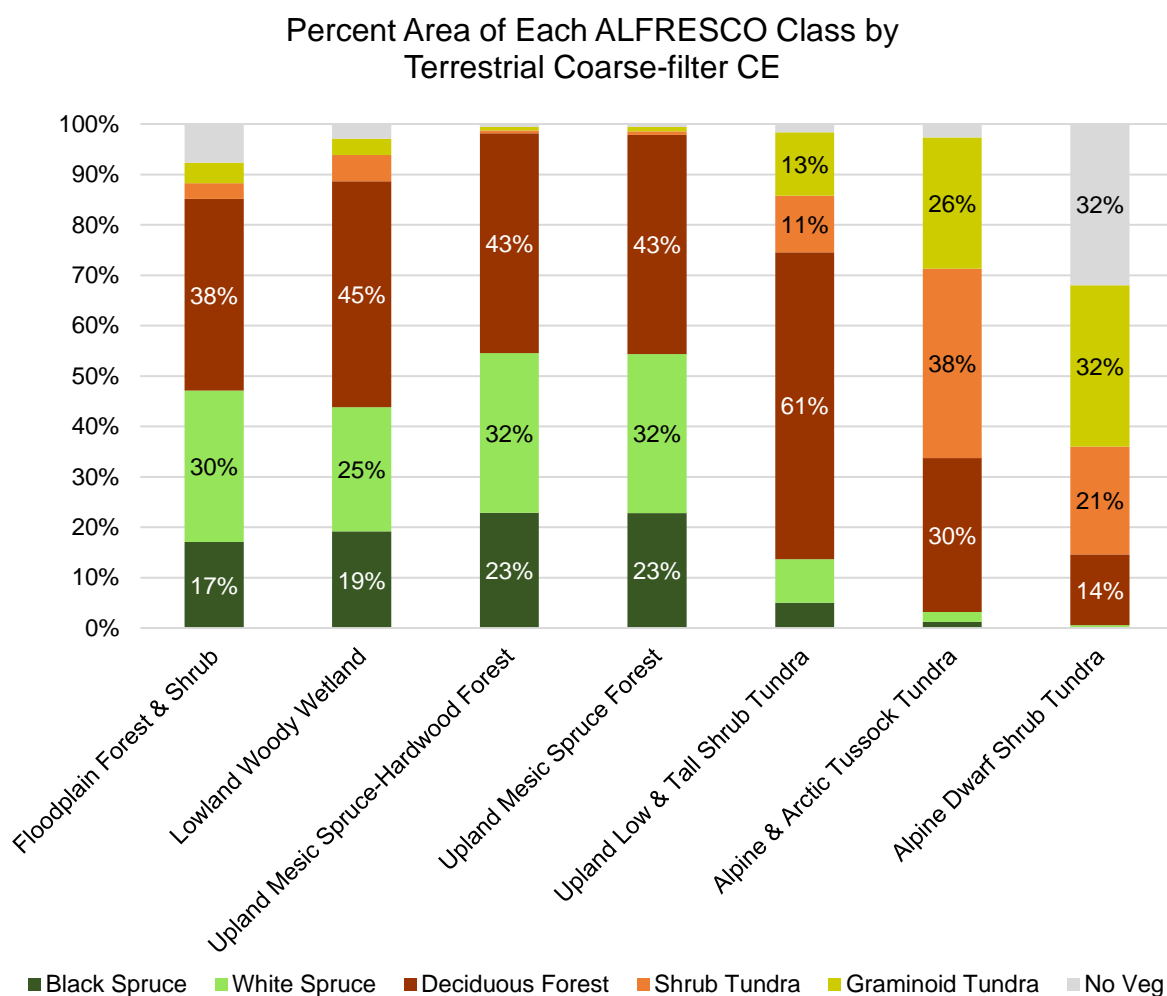


Figure G-21. Percent area of each ALFRESCO class by Terrestrial Coarse-filter CE.

3.7 Abiotic Change Agents Discussion (MQs B2 and F3)

Changes to temperature, precipitation, permafrost, and fire frequency and area burned are expected to alter the distribution and abundance of vegetation types across the CYR study area. Many of these changes have been documented in recent decades and are expected to continue through the next 50 years (the time span of the REA). In addition to shifts in vegetation pattern, new successional trajectories may emerge in the wake of increased fire and permafrost loss.

Two management questions are addressed in this section regarding the response of CE habitat to climate change. Vegetation response is linked to multiple factors, and changes to shrub and treeline are closely linked to changes in temperature, fire, and permafrost. We present the MQs independently but there is considerable overlap in the response to these questions.

Management Question B2

MQ B2: What are the expected associated changes to dominant vegetation communities and CE habitat in relation to altered permafrost distribution, active layer depth, precipitation regime, and evapotranspiration?

We addressed this MQ as part of the core analysis according to the process model shown in Figure G-2 (see Methods of this document).

Increasing temperatures across the region will cause a lengthening of the growing season and an increase in heat accumulation (measured as summer warmth index) during summer months. These changes could have profound effects on phenology, plant growth, water availability, and species distributions. July temperature isotherms and SWI have been used to help define vegetation distribution and potential for vegetation change across the boreal and Arctic biomes (Walker 2000, Walker et al. 2006, Larsen 1980). The northern limit of the boreal forest occurs approximately at the 12 °C mean July isotherm and a SWI of 35 °C mo (Walker 2000), and strong linkages have been described between SWI and treeline advance (Breen 2014). The southern boundary for the boreal forest occurs at approximately the 18 °C July isotherm (Larsen 1980). Increases in temperature and SWI have also been linked to increased NDVI and shrubbiness in Arctic and alpine habitats (Epstein et al. 2008, Raynolds et al. 2008). In contrast, increases in SWI in warm and dry Interior boreal forests correlated with decreasing NDVI, perhaps due to drought stress (Verbyla 2008).

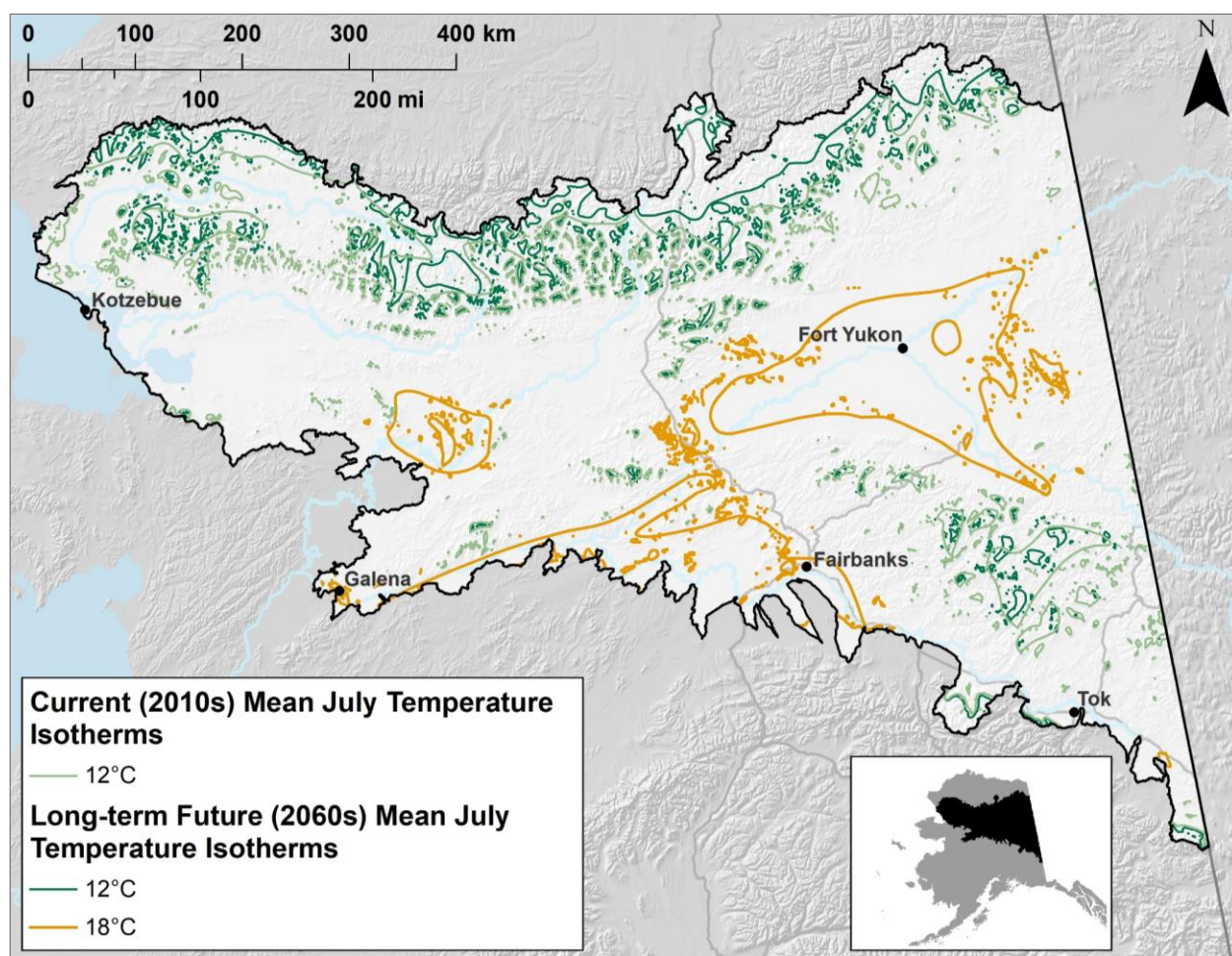


Figure G-22. July isotherms of 12 °C and 18 °C, the projected northern and southern limit of the boreal forest, for the current condition (2010s) and long-term future (2060s).

Figure G-22 illustrates the shift in July mean temperature between the 2010s and 2060s. The 12 °C isotherm shifts upward in elevation, but the change in area is relatively small when contrasted with the shift in the 18 °C isotherm at the southern boundary. In the 2010s, mean July temperatures are below 18 °C across all of Alaska, so there is no current July isotherm for the southern boundary, but by the 2060s, much of the lowland area around the Yukon and Tanana basins has reached and surpassed this temperature threshold. July isotherms are just one of many factors used to describe vegetation distribution, but they serve as a useful visual tool to express the potential for vegetation change at the limits of the boreal forest. While treeline is expected to continue to migrate upward and northward, the Brooks Range Mountains impose a major physiographic barrier to the expansion of boreal forest to the north because of the influence of elevation on climate (Figure G-22). At the southern edge of the boreal forest boundary, however, the temperature shifts across the boreal lowlands between the 2010s and 2060s will impact large regions of lowland habitat. Time lags for permafrost and vegetation change, and climate feedbacks from vegetation shifts may influence the rate of change in these ecosystems. For example, a shift from coniferous to deciduous vegetation will decrease absorbed solar radiation because the albedo of deciduous forests is about twice that of coniferous forest

(Baldocchi et al. 2000, Liu et al. 2005), but an earlier snow-free date would increase absorbed solar radiation and decrease surface albedo for all vegetation types. Additionally, the speed at which different plant communities respond to changes in climate is variable. The velocity of tundra retreat and shrub advance in montane habitats in Southcentral Alaska closely matches the change in climate, while the advance of forest is approximately 2.5 times slower; the high biotic inertia in forests are hypothesized to be due to competition with existing shrubs or more complex climate controls on treeline (Dial et al. 2016).

A shift from a landscape dominated by extensive stands of black spruce to a landscape of mixed deciduous and coniferous forest could change fire dynamics across the region. Deciduous stands are less flammable than coniferous stands and, therefore, can reduce the overall landscape flammability (Johnstone et al. 2010), but a longer fire season and more lightning strikes will increase the chance of ignition. The ALFRESCO model predicts that increasing temperature will overwhelm the reduced flammability afforded by deciduous cover types, and also predicts that during extreme fire seasons, such as those that occurred in 2004 and 2005, fires will be able to burn spruce and deciduous stands at similar frequencies (Kasischke et al. 2010, Mann et al. 2012). As a consequence of increased burning and reduced area of mature spruce forest, a new landscape pattern could emerge characterized by a patchier distribution of deciduous forests and younger stages of spruce. This new pattern may reach an equilibrium stage where the patch dynamics may self-perpetuate (Rupp and Springsteen 2009b).

Precipitation during the growing season (May–August) is projected to rise; however, this increase is unlikely to be enough to offset an increase in evapotranspiration caused by warmer temperatures and a longer growing season. The increase in precipitation is not projected to be distributed evenly across the CYR study area. Forested and lowland CEs are expected to see less increase than those habitats occurring above treeline, increasing the potential for drought stress in forested ecosystems. The increasing dominance of deciduous forest on the boreal landscape will further increase evaporative demand because evapotranspiration is 1.5–1.8 times greater in deciduous forests than coniferous forest (Chapin, III et al. 2000, Liu et al. 2005). Habitats in the highly continental portion of the CYR study area, which coincides roughly with the Yukon-Old Crow ecoregion, are expected to be the most impacted. This ecoregion currently has the lowest summer rainfall and the highest summer temperatures and it is projected to see greater July temperature increases and some of the lowest increases in summer precipitation (Figure G-6 and Figure G-7). Drought stress and wetland drying may become more common in this region.

Changes in potential evapotranspiration (PET) were not specifically evaluated at part of this analysis. An earlier assessment conducted by SNAP researchers (Rupp and Springsteen 2009a) evaluated PET for the Eastern Interior Management Area which coincides with the eastern central portion of the CYR study area. They reported that the typical water deficit in June, at the peak of the growing season, will become even greater in the future due to significant increases in PET without comparable increases in precipitation. The PET model used for this earlier assessment was a temperature-driven model; however, subsequent studies have demonstrated that PET does not always track temperature and have questioned the use of temperature-based PET estimates (McAfee 2013). Regional differences in cloud cover, relative humidity, and wind speed may be equally important drivers of PET. (See MQ B1 in Section C. Abiotic Change Agents for more information about the uncertainty of the PET models.)

Loss of permafrost and an increase in the depth of the active layer where permafrost remains intact will alter hydrology, water storage, and vegetation composition. Landscape position, soil type, and ice content all influence vegetation response to changes in permafrost conditions.

Forested and lowland habitats currently have deeper active layers and are projected to lose more permafrost than upper elevation habitats. CEs occurring in these habitats are projected to lose 37%–46% of their underlying permafrost by the 2060s (Table G-7). The underlying soil texture and ice content of the permafrost mediate surface subsidence and changes to hydrology after permafrost loss or degradation (Jorgenson et al. 2013). For example, in gravelly-sandy lowlands in Yukon Flats, permafrost degradation led to lake drainage and loss of surface water. Whereas, in peaty-silty lowlands of the Innoko Flats, permafrost collapse led to the development of thermokarst pits and succession to wetland vegetation types (Jorgenson et al. 2013). Similarly, in lowland forests of the Tanana Flats, degradation of ice-rich permafrost plateaus supporting birch forest resulted in the development of thermokarst pits in which wetland vegetation developed (Jorgenson et al. 2001). Thermokarst predisposition can provide an indication of the likelihood that permafrost degradation will lead to thermokarst initiation and spread. Terrain that is highly predisposed to thermokarst is typically underlain by silty or peaty soils with ice-rich permafrost, and, therefore, it follows that lowland woody wetlands have the largest proportion of terrain very highly predisposed to thermokarst (60%), while floodplain forest and shrub has the lowest proportion (23%) of the forested and lowland CEs. Upland forest CEs (mesic spruce and mesic spruce-hardwood) are projected to lose permafrost across a substantial amount of their distributions by the 2060s, but because the active layer is already relatively thick (66 cm), and these upland habitats are typically well-drained, it is unclear what the impact of changing permafrost conditions will be on these sites. Loss of permafrost isn't likely to improve rooting depth or site productivity, but loss of the impermeable layer could increase the chances of drought stress during the growing season.

Above treeline and in alpine habitats, permafrost loss will be less than in lower elevations, but the increase in the depth of the active layer will be greater in upper elevations than in lower elevations. Loss of permafrost and increase in active layer in low and tall shrublands and tussock tundra CEs will increase the depth of the rooting zone and provide trees and shrubs a competitive advantage over graminoids and non-vascular plants (Chapin, III et al. 1995, Lloyd et al. 2003, Walker et al. 2006). Increases in shrub abundance have already been detected in the sub-Arctic and Arctic (Sturm et al. 2001, Joly et al. 2007, Forbes et al. 2010). By definition, tussock tundra is underlain by permafrost. By the 2060s, 9% of tussock tundra habitat is projected to lose permafrost (Table G-7), and in areas where permafrost remains intact, the active layer depth is projected to increase by 7 cm (Figure G-13). Where the underlying permafrost thaws, transitions to taller shrublands and forest is likely to occur.

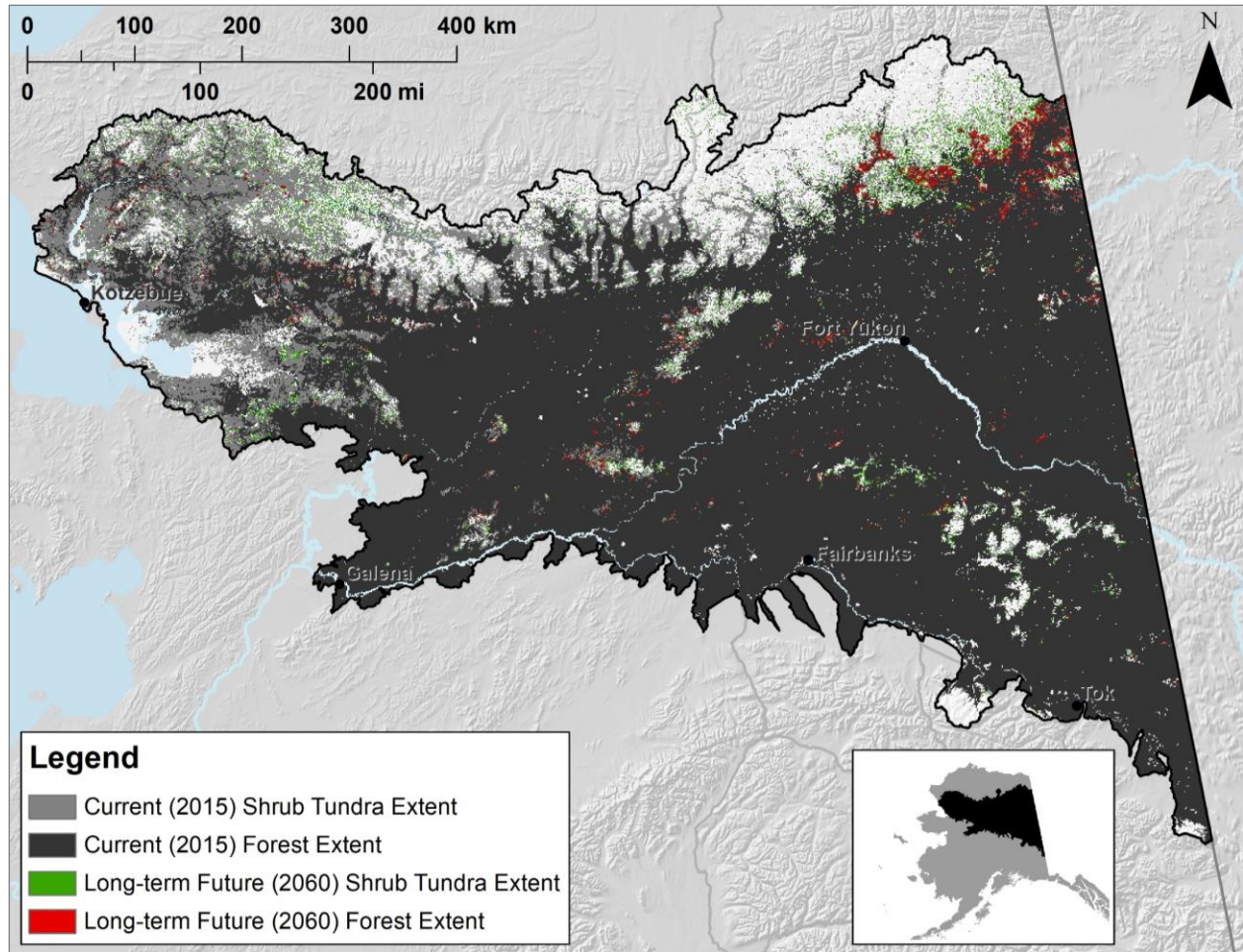


Figure G-23. Shrub and treeline expansion between the current condition (2010s) and long-term future (2060s) based on a single “best replicate” ALFRESCO run.

Management Question F3

MQ F3: How are major vegetation successional pathways likely to change in response to climate change, with special emphasis on increased shrub cover and treeline changes?

In the response to MQ F3 below, we present an overview of the changes to all CE habitat, but additional information about climate change and succession is presented in the individual CE accounts. Further detail about the changing fire regime can be found in Section C. Abiotic Change Agents, MQ A1. We addressed this core analysis MQ according to the process model shown in Figure G-3 in the Methods section.

Warming temperatures are increasing fire frequency and area burned, and this change is resulting in a transition from older coniferous forest vegetation (mainly black spruce and white spruce) to earlier-seral deciduous vegetation including birch, aspen, and willow. In 2011, evergreen forest comprised 22% of the CYR study area, which accounted for 56% of the forest area exclusive of woody wetlands (Homer et al. 2015). Retrospective modeling has suggested that evergreen forest was even more abundant between 1920 and 1990, comprising two-thirds of all forested stands (Mann et al. 2012).

Vegetation transitions modeled using ALFRESCO show an increase in the proportion of deciduous forest beginning in the latter decades of the twentieth century and a corresponding decrease in the proportion of white and black spruce. These modeled shifts are expected to continue across the region through the current century. The impacts of increased fire and warmer temperatures on successional trajectories for forested CEs are described below:

Upland mesic spruce-hardwood forest

The current post-fire successional pathway for spruce-hardwood forests typically progresses through a short herbaceous stage followed by a shrub/sapling stage, followed by a forest dominated by broadleaved deciduous trees often with spruce in the understory. Broadleaf dominance can persist for 100–200 years (Fastie et al. 2003, Kurkowski et al. 2008). In the absence of fire, spruce gradually emerges from the deciduous canopy. Under warmer climate conditions with a shortened fire interval, fire may return before spruce can gain canopy dominance, resulting in long-term dominance by deciduous species on some sites (Kurkowski et al. 2008).

ALFRESCO predicts a shortened fire return interval and an increase in area burned driven by climate warming. The altered fire regime is projected to cause a shift toward deciduous vegetation classes at the expense of coniferous forest types. In spite of this shift toward less flammable vegetation types, the model predicts more frequent fires and an overall increase in area burned annually. This suggests that the magnitude of modeled climatic changes, specifically increasing summer temperatures, overwhelms the potential negative feedback between increased area of less flammable deciduous vegetation and annual area burned (Mann et al. 2012). Because there are substantial discrepancies between the area of ALFRESCO deciduous forest class and the spruce-hardwood CE distribution (which is based on NLCD mixed and deciduous classes) the ALFRESCO results can only be compared qualitatively to the mapped CE distribution.

With ongoing increases in summer temperatures, an expansion of xeric forest communities like dry aspen woodlands that currently occupy south-facing bluffs has been predicted by several researchers (Bonan et al. 1990, Starfield and Chapin 1996). In a future scenario with a warmer boreal climate, the mixedwood forests of Southcentral Canada (Hogg and Hurdle 1995, Cumming 2001, Schneider et al. 2009) may provide an analog for forests of Interior Alaska (Mann et al. 2012), particularly in the highly continental portion of the CYR study area, which is projected to see less increase in summer precipitation in lower elevations than the rest of the region.

Floodplain forest and shrub

Floodplain forests are generally considered less flammable than upland forests because of an abundance of low flammability vegetation such as alder, willow, and poplar, and their proximity to rivers, which can act as fire breaks. Furthermore, some of the oldest white spruce stands in the boreal forest occur on floodplains (Chapin, III et al. 2006, Juday and Zasada 1984). However, paleoecological records from the Tanana River floodplain showed evidence of repeated fire and stand replacement within the floodplain, suggesting that these forests may ignite and burn at the same rate as upland forests (Mann et al. 1995). In a future scenario with a warmer boreal climate, it is likely that both floodplain forests and upland forests will burn more frequently.

Upland mesic spruce forest (white spruce)

Because the range of white spruce extends beyond that of black spruce, white spruce forests dominate treeline sites north of the Alaska Range and west to the limit of conifer growth. Altered climate conditions and fire regimes are expected to promote both expansion of spruce forest into tundra and conversion of spruce forest to deciduous forest. Numerous studies have predicted a widespread expansion of treeline throughout the boreal (Suarez et al. 1999, Lloyd and Fastie 2003), our ALFRESCO results specifically predict colonization of tundra by white spruce forests in the Davidson Mountains and Kotzebue Sound Lowlands (Figure G-23). In these regions the modeled SWI and July isotherm are predicted to exceed the Arctic treeline threshold values of 35 °C mos and 12 °C by the 2060s. However, increases in fire frequency and area burned are also expected to catalyze a conversion of spruce forest to deciduous forest (Mann et al. 2012, Kelly et al. 2013). Modeled results show that overall losses of white spruce forest to deciduous forest by the 2060s are likely to outweigh the expansion white spruce into tundra. However, because ALFRESCO does not allow self-replacement of conifers as a transition after disturbance, treeline spruce is reset to deciduous forest after fire. In the absence of a deciduous seed source, self-replacement by spruce and resprouting of woody plants from below ground tissues may be a more likely response to fire in treeline spruce stands than conversion to deciduous forest.

A shortened fire regime will alter understory composition even in the self-replacement successional model. *Cladina* spp. and other ecologically important lichens are associated with late successional stages of boreal forest development (Klein 1982), and require long periods of recovery following removal by fire (Viereck and Schandelmeier 1980, Jandt et al. 2008). Lichens rely on well-developed organic layers for protection and moisture retention, and mineral soil exposure and nutrient enrichment facilitates vascular species encroachment (Jandt et al. 2008). Thus, the lichens associated with late seral spruce forests are also likely to decline with increased fire frequency, organic layer thinning, and increased active layer depth.

Upland mesic spruce forest (black spruce)

Mesic to moist black spruce forests occur on cold well-drained sites and on north-facing slopes to treeline. Sites may have abundant moss cover in the ground layer, but they typically have shallower organic layers than peatland black spruce sites that occur in the lowlands. Larger late-season fires and deeper burning of organic layers leave mesic black spruce forests particularly vulnerable to the predicted changes in climate and fire regime. Post-fire succession in mesic black spruce forests has been widely documented, and fires intense enough to kill overstory trees have historically occurred every 25 to 130 years (Yarie 1983, Heinselman 1981, Viereck et al. 1983, Viereck et al. 1986). After fires of sufficient severity, exposed mineral soil often allows deciduous species to dominate post-fire succession (Johnstone et al. 2010). Birch dominates on mesic sites, but aspen is more common on drier sites (Foote 1983, Chapin, III et al. 2006). Because deciduous trees can maintain dominance for over 100 years, a shortened fire return interval may preclude black spruce from regaining canopy dominance, contributing to the predicted increase in deciduous forest throughout the CYR study area. The area of late season burns on well-drained black spruce sites has already increased, removing more of the organic layer and thereby facilitating recruitment of deciduous seedlings (Kasischke et al. 2010).

On sites with deeper organic layers and moist soils, such as north-facing slopes, self-replacement of black spruce after fire may be the predominant successional pathway. Low severity fires remove less of the organic layer, which favors recolonization by black spruce seedlings (Johnstone et al. 2010). Semi-serotinous cones attached to fire-killed trees provide a post-fire seed supply.

A shortened fire return interval however, may lead to reduced black spruce seed production, because black spruce trees will have less time to reach the cone-bearing stage before the next fire (Johnstone 2006).

Lowland woody wetlands

Black spruce and sedge-shrub-peatlands occur throughout the CYR study area on flat to gently sloping valley bottoms, abandoned floodplains, and other lowland terrain. Soils are poorly drained, acidic, nutrient poor, and typically have a well-developed peat layer. According to the thermokarst predisposition model, these habitats are the most highly prone to thermokarst, with 60% of CE area in the very highly predisposed category (Figure G-14). Additionally, the amount of area within this CE that is free of permafrost ($> 0^{\circ}\text{C}$ at 1-m depth) is projected to increase from 4% to 48% by the 2060s (Figure G-12). This change in permafrost conditions could impact these wetlands in several ways. Permafrost degradation and thermokarst has increased in lowland forests in the region, and this trend is expected to continue (Jorgenson et al. 2001, Jorgenson et al. 2013). When forested permafrost plateaus supported by ice-rich permafrost collapse, wetland vegetation eventually fills in the collapse scar. Under stable climate conditions, the permafrost plateau would eventually reform, elevating the surface above the water table; however, with degrading permafrost conditions, changes to the underlying hydrology could alter the successional pathways. If permafrost degradation leads to more connected drainage networks, then wetland drying could become more common.

Because peatland soils tend to retain moisture, fire in peatland forests typically does not consume the entire surface organic layer. Deep organic soil horizons impose an ecological inertia to conversion to deciduous forest after fire because black spruce tends to outcompete other tree species regenerating on these peaty sites. Only under the most severe drought conditions will the peat layer become sufficiently dry to be consumed by fire. When severe fires do occur on these sites, altered soil conditions and exposed mineral soil may allow deciduous broadleaved trees to replace black spruce as the dominant species (Johnstone and Kasischke 2005, Johnstone et al. 2010, Kasischke et al. 2010). With an increase in late-season burns, there will be an increased chance of severe fires consuming the organic mat and changing the successional trajectory of wetland forests.

Low and tall shrub tundra

Low and tall shrub vegetation dominates the landscape above treeline and below alpine dwarf shrub on sites with deep active layers and well drained soils, such as riparian zones and side slopes. Warmer temperatures, altered permafrost conditions, and a shortened fire interval are likely to effect the distribution of shrub tundra throughout the CYR study area.

By the 2060s, 24% of this CE is projected to be free of permafrost (Table G-7), and, where permafrost remains intact, the average active layer depth is projected to increase from 63 to 67

cm (Figure G-13). These changes in soil conditions will lead to greater depth of the rooting zone which will in turn promote an increase in shrub height and canopy cover, and may facilitate the advance of treeline given a seed source and favorable conditions for conifer establishment and growth. This advance in treeline into tundra habitats has been well documented (Okano and Bret-Harte 2015, Ropars and Boudreau 2012).

Increased fire will further promote permafrost degradation and also provide seedbed in which conifers and deciduous species can establish. ALFRESCO results predict that shrub tundra will increase slightly across the CYR study area, but the changes are not distributed evenly across the landscape. Mountainous ecoregions including the Davidson Mountains and Brooks Range are projected see a greater increase in shrub cover than other regions as shrubs advance into alpine tundra (Table G-8, Figure G-20). In other ecoregions, the modeled shift from graminoid to shrub tundra is followed by a shift to white spruce forest, and, in the event of fire, spruce is replaced by deciduous forest.

Because there are large discrepancies between the definition of shrub tundra in the CE distribution (based on the NLCD shrub/scrub class) and the ALFRESCO input map (Figure G-21), the spatial distributions cannot be compared. However, the shrub and treeline projections produced using a single ALFRESCO “best replicate” (Figure G-23) support the expected trend of white spruce encroaching into shrub tundra at treeline and shrub tundra expanding into higher elevation alpine sites.

Alpine and Arctic tussock tundra

Tussock tundra vegetation occurs above (or beyond) treeline on gently sloping terrain underlain by permafrost. Within the CYR study area, it is common on the southern slopes of the Brooks Range, in the Noatak Basin, and in low elevation terrain near the western treeline. Soils are typically acidic and poorly drained, and permafrost is usually present 30 to 50 cm below the surface at maximum thaw (Viereck et al. 1992). The combined effects of warmer temperatures, increased winter precipitation, altered permafrost conditions, and a shortened fire interval will likely impact the composition and structure of tussock tundra within the CYR study area.

By the 2060s, 9% of this CE is projected to be free of permafrost (Table G-7), and, where permafrost remains intact, the average active layer depth is projected to increase from 61 to 68 cm (Figure G-13). The increased the depth of the rooting zone will provide woody plants a competitive advantage over graminoids and non-vascular plants (Lloyd et al. 2003). Experimental warming in Arctic tussock tundra sites demonstrated increased height and cover of deciduous shrubs and graminoids and decreased cover of mosses and lichens (Walker et al. 2006). Shrubs may inhibit lichens through shading the understory and also by trapping snow and increasing leaf litter (Joly et al. 2009, Cabrajic et al. 2010). Increases in shrub abundance on the landscape have already been observed in the sub-Arctic and Arctic (Sturm et al. 2001, Joly et al. 2007, Forbes et al. 2010).

Silty soils and gently sloping terrain characteristic of this type create conditions in which thermokarst can occur after permafrost degradation. According to the thermokarst predisposition model, 45% of the CE area is categorized as highly prone to thermokarst (Figure G-14). Thermokarst slumps provide mineral substrate and microsites in which seedlings can become

established. Fire increases the rate of permafrost degradation and thaw and facilitates the establishment of trees and shrubs in tundra by creating mineral seedbed (Rupp et al. 2000, Sturm et al. 2001, Joly et al. 2009, Forbes et al. 2010, Beck et al. 2011, Joly et al. 2012). ALFRESCO does not explicitly model changes in tussock tundra, but the general trends of shrub and treeline expansion predicted to occur by the 2060s (Figure G-23) can be extrapolated to this CE. In the ALFRESCO input map, however, most of the area represented by the tussock tundra CE is classified as woody vegetation (Figure G-21), and thus, infilling of shrubs within the CE is likely under-represented in the model.

Tussock tundra is projected to see substantial increases annual precipitation by the 2060s. Growing season increases may be offset by increasing temperatures and evaporative demand, but increased winter precipitation will likely result in a deeper snowpack, providing increased thermal insulation of the soil and protecting woody plants from desiccating winter winds. Snow depths correlate closely with shrub canopy height and stem diameter, where shrub growth promotes snow retention, and deeper snowpack further promotes shrub growth (Sturm et al. 2001).

In summary, warming temperatures, increased fire frequency, and loss of permafrost will likely result in a loss of tussock tundra habitat in the future. Tussock tundra could become shrubbier, transition to shrub tundra, or white spruce may encroach at treeline. Sites with a shortened fire interval will have reduced cover of non-vascular species, particularly old-growth lichens including *Cladina rangiferina* and *Cladina stellaris* (Swanson 1996, Holt et al. 2008, Jandt et al. 2008, Klein and Shulski 2009, Joly et al. 2010, Collins et al. 2011).

Alpine dwarf shrub tundra

Alpine dwarf shrub tundra is widespread above treeline on ridges, summits, side slopes, and high elevation valleys throughout the CYR study area. In mountainous regions, dwarf shrub tundra represents the highest elevation zone of continuous vegetation. Under stable climate conditions, this type likely represents a topoedaphic climax. However, projected climate change, specifically warmer temperatures, longer growing season, and more precipitation, will facilitate vegetation transitions such as shrub expansion and treeline migration into higher elevations. Several authors have reported expansion of treeline across the boreal system (Suarez et al. 1999, Lloyd and Fastie 2003, Lloyd 2005), but these studies focus on the tundra ecotone near treeline, not specifically alpine dwarf shrub tundra. By the 2060s, the threshold values for Arctic treeline (SWI 35 °C mo and 12 °C mean July isotherm) will have been met and surpassed at the lower boundary of the alpine dwarf shrub CE, suggesting that establishment of trees and deciduous shrubs is likely in the alpine environment.

The expansion of deciduous shrubs into tundra has been linked to greater snow retention, higher winter soil temperatures, altered surface water hydrology during melt, and increased fire (Higuera et al. 2008, Liston et al. 2002, Sturm et al. 2001, Wahren et al. 2005, Tape et al. 2006).

The ALFRESCO model predicts an increase in shrub tundra and a decrease in graminoid tundra in Brooks Range and Davidson Mountain ecoregions (Figure G-20). Much of the alpine dwarf shrub CE is included in the ALFRESCO graminoid class (Figure G-21) and thus, these predicted changes can be interpreted as shrub expansion into alpine tundra in these ecoregions.

At the upper limits of the CE, warmer temperatures and a longer growing season could lead to the upward expansion of dwarf shrub tundra into previously unvegetated sites; however, we are not aware of any studies that have documented this upward migration of alpine tundra, and transitions into unvegetated terrain it is not included in the ALFRESCO model.

Permafrost is expected to remain continuous over most of the CE; however, active layer thickness is projected to increase, which will provide increased rooting depth and may allow for increased productivity. Rocky residual and colluvial soils that dominate the CE distribution are thaw-stable and are not expected to exhibit significant geomorphic change under a warmer climate regime (Martin et al. 2009).

3.8 Insect- and Disease-Related Forest Damage

The impacted proportions of upland mesic spruce–hardwood forest and floodplain forest and shrub were the highest of any CE: each was at least two times greater than the impacted proportion of upland mesic spruce forest, lowland woody wetland, or upland low and tall shrub (Figure G-24). This trend corresponded with the majority damage types: quaking aspen defoliation and willow defoliation caused by aspen leaf miner and willow leafblotch miner respectively. Quaking aspen and willow defoliation were observed in some areas where quaking aspen and/or willow were present but not dominant or co-dominant (e.g., areas classified as upland mesic spruce forest). Upland mesic spruce forest was damaged at a rate less than would be expected purely based on the proportion of the study area that it covered compared to either upland mesic spruce–hardwood forest or floodplain forest and shrub. As a result, the impacted proportion of upland mesic spruce forest was half that of either upland mesic spruce–hardwood forest or floodplain forest and shrub, despite the largest area of observed forest damage being located within upland mesic spruce forest.

Upland low and tall shrub was damaged at a rate much less than would be expected purely based on the proportion of the study area that it covers. The impacted proportion of upland low and tall shrub tundra was the lowest of the impacted proportions of the five tree- and shrub-dominated CEs. The least area of observed damage occurred in lowland woody wetland, but the impacted proportion of lowland woody wetland was still two times greater the impacted proportion of upland low and tall shrub tundra.

Most of the observed forest damage within upland low and tall shrub was aspen defoliation, which was not expected based on the definition of upland low and tall shrub. Several factors likely compounded to cause this result:

- 1.) the NLCD forested classes required presence of trees over 5 meters so some low spruce, mixed, and deciduous forests were likely mapped as shrub/scrub;
- 2.) the NLCD likely contained some areas of deciduous forest that were misclassified as shrub/scrub because differences between deciduous forest and tall shrub can be very subtle in source imagery; and
- 3.) low spatial accuracy of forest damage polygons caused overlap with vegetation classes other than those where the damage was actually observed.

Misclassification of the host tree during the aerial insect and disease damage surveys, however, is not as likely a cause. Aspen defoliation caused by aspen leaf miner is easily recognizable from the air because leaf cuticles remain intact, giving infested hosts a silver-gray color (Reich et al. 2013). Aspen defoliation aside, little forest damage was observed in upland low and tall shrub (this was also the least surveyed of the five tree- and shrub-dominated CEs).

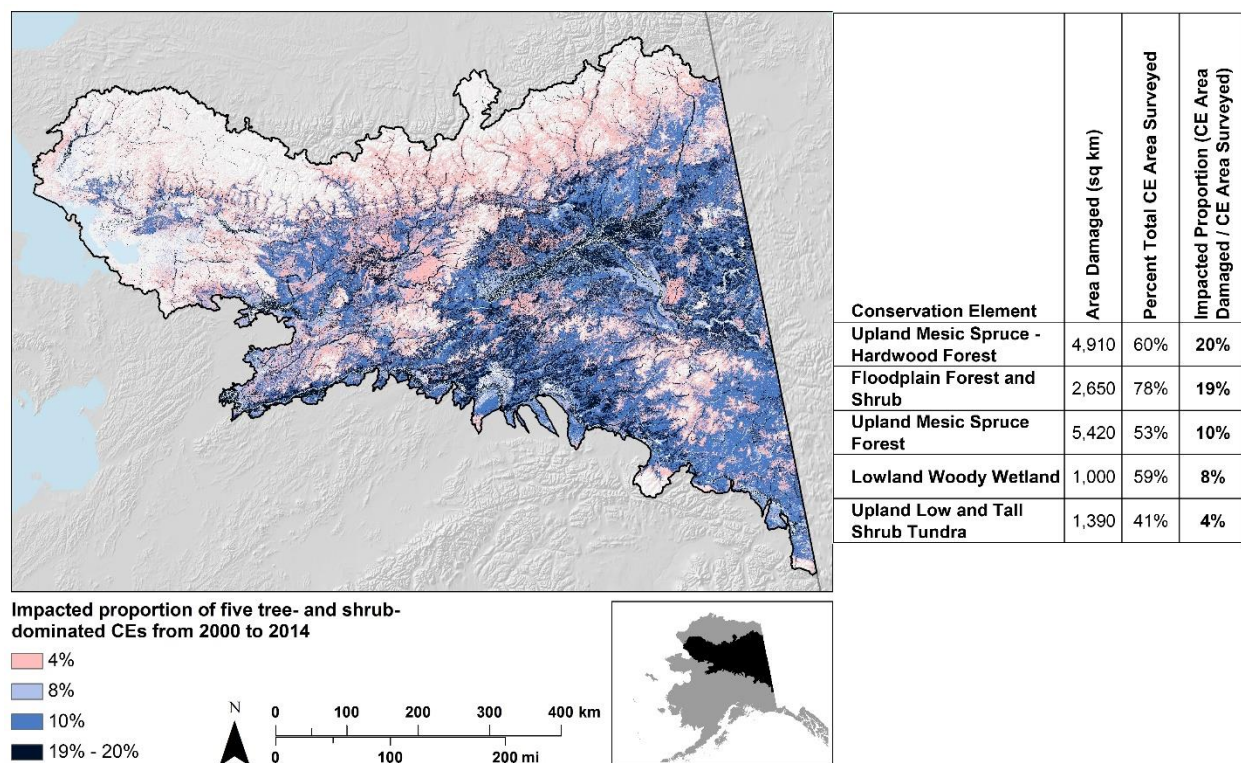


Figure G-24. Insect- and disease-impacted proportion of five tree- and shrub-dominated CEs from 2000 to 2014 in the CYR study area.

Spruce mortality contributed only 4% of observed forest damage from 2000 to 2014. The impacts of spruce mortality on CEs were specifically considered for this assessment because spruce mortality has high potential to cause ecosystem change and provides fuels for wildfire. Additionally, area of spruce mortality may increase in the future (Sherriff et al. 2011). Spruce mortality may have the greatest management implications of all forest damage types in the future because increases in spruce mortality could increase costs associated with fuels reductions and fire control.

The impacted proportion of floodplain forest and shrub was approximately five times greater than the impacted proportion of either lowland woody wetland or upland mesic spruce–hardwood forest (Figure G-25). Additionally, the largest area of spruce mortality was observed in floodplain forest and shrub. Spruce mortality occurred in upland mesic spruce–hardwood forest and upland mesic spruce forest at rates lower than would be expected based on the area occupied by those CEs. The association of spruce mortality with floodplain forest and shrub corresponded with the trend that much of observed forest damage was concentrated along major riparian corridors. The

impacted proportion of upland low and tall shrub tundra was lowest of all tree- and shrub-dominated CEs.

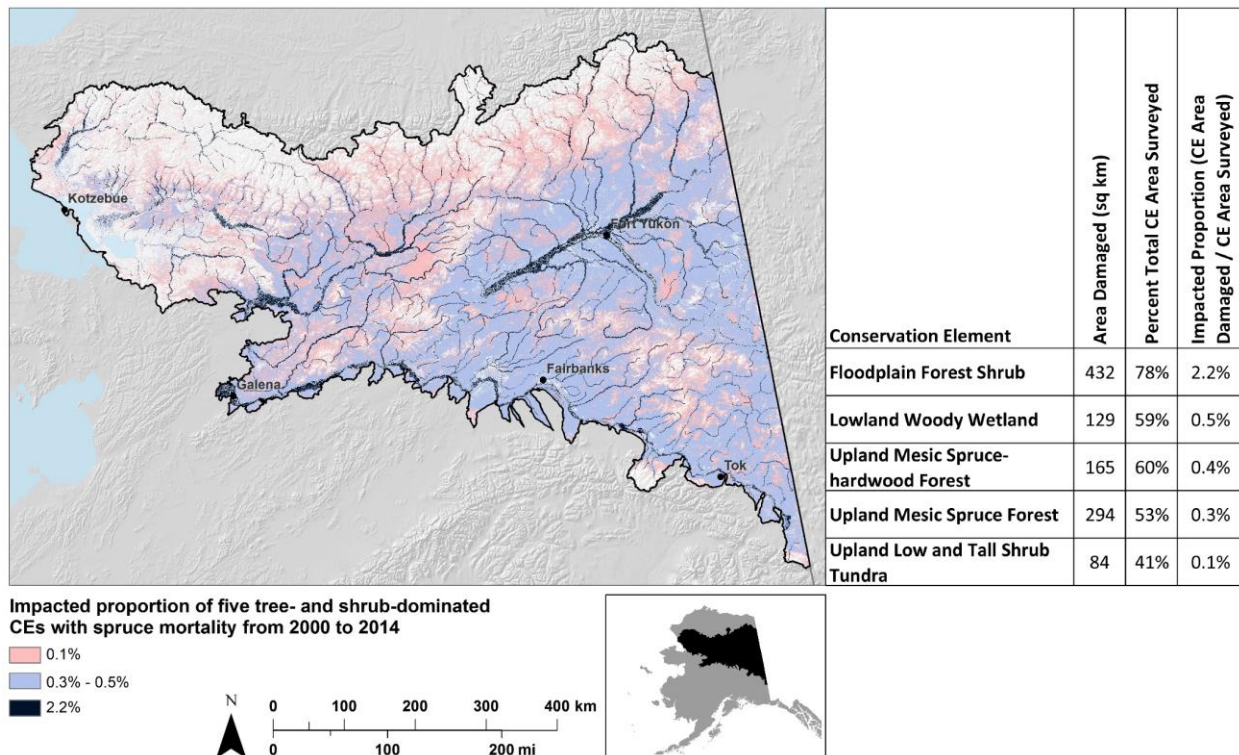


Figure G-25. Insect- and disease-impacted proportion of five tree- and shrub-dominated CEs with spruce mortality from 2000 to 2014 in the CYR study area.

3.9 Invasive Species

Non-native plants are largely restricted to areas of human habitation, roadsides, and ground disturbance, both in urban areas, villages, and in a few cases, around remote cabins and trails. Numerous species that are perceived to be ecologically damaging, such as *Melilotus albus* and *Vicia cracca*, are abundant in disturbed sites within the study area.

Ecological impacts of invasive plants to Terrestrial Coarse-filter CEs is likely to be minor. We do not anticipate extensive establishment of invasive plants in the upland CEs. However, *Vicia cracca* is well-known to establish in and adjacent to mesic spruce-hardwood forests and this Coarse-filter is also susceptible to the establishment of *Caragana arborescens*, as evidenced by expanding infestations in mixed aspen-white spruce forests in and around Fairbanks. As *Caragana arborescens* can form very dense coppices in its introduced and native range, current and future expansion of this shrub could be problematic (Carlson et al. 2008). The two lowland Coarse-filter CEs are more likely to experience measurable impacts from non-native species. Floodplains in Alaska have a large diversity of non-native plant species established, including species perceived to have greater ecological impacts, such as *Melilotus albus*, *Hordeum jubatum*, and *Prunus padus*. Once invasive plant populations establish in river systems, abundant exposed surfaces combined with frequent disturbance facilitate rapid expansion. On early successional

floodplains *Melilotus albus* can displace native vegetation potentially reducing the abundance of important habitat for moose and hares.

Prunus padus could become increasingly problematic in mixed lowland forests in this region, as it is becoming a dominant tree in semi-natural forests around Anchorage. Additionally, alder-dominated riparian habitats are susceptible to the defoliating green alder sawfly (*Monsoma pulveratum*). While only minor damage has been recorded in the Interior due to this species, higher population sizes fueled by warmer and longer summers and time for population growth, could result in defoliation and mortality similar to that observed in Southcentral Alaska. Expansion of wetland-associated invasive species, such as *Phalaris arundinacea*, is not particularly likely in the peatland-dominated lowland woody wetlands; however, this establishment of this species in more nutrient-rich areas within the lowland woody wetlands does seem possible.

The frequency, extent, and severity of wildfire may influence probabilities of future invasions within the study area. We suggest that watersheds with known infestations or high predicted invasion vulnerability that are also predicted to have high frequency of wildfire are more susceptible to establishment of problematic species off of the human footprint. However, regional differences in soil and vegetation composition were shown to be more important in invasive plant establishment than the severity of the burns or soil moisture (Spellman et al. 2014) and areas subjected to wildfire in remote areas of the Interior rarely have non-native plants at present (Greenstein and Heitz 2013).

3.10 Status Assessment

As mentioned in Section F. Landscape and Ecological Integrity, the Landscape Condition Model (LCM) used two parameters—site impact and decay distance—to assess landscape-scale impacts of human modification. For each land use type, a GIS model then generated a landscape condition raster based on that type's parameters, and all of these land use rasters were mosaicked for the CYR study area. Thus, the LCM allows us to spatially summarize the intensity and breadth of numerous human modifications across the entire CYR study area simultaneously.

Under the current condition, primary impacts on landscape condition are attributable to existing infrastructure in developed areas and the Dalton Highway, which bisects the CYR study area. The Parks and Alaska highways, which run along the southern border of the CYR study area, and the more interior Steese and Taylor highways also impact current landscape condition. In the near-term (2025), changes to landscape condition are predicted to be fairly minimal, though small-scale mining operations and infrastructure developments are expected. In the long-term (2060), however, the footprint of the Ambler mining district—including both construction of the Ambler road and development of Ambler district mining claims—is expected to lower landscape condition (Table G-9). The currently proposed road to Nome was also included in the LCM analysis and is projected to negatively impact the landscape. Additional placer and hard rock mines and North Star borough residential development are also predicted to lower landscape condition by the long-term future.

Table G-9. Landscape condition by CE for the current condition, near-term future, and long-term future.

Conservation Element	Time Step	Landscape Condition				
		Very Low	Low	Medium	High	Very High
Floodplain Forest Shrub	Current	1%	1%	1%	2%	94%
	Near	1%	1%	1%	2%	94%
	Long	1%	2%	2%	3%	92%
Lowland Woody Wetland	Current	1%	1%	1%	2%	95%
	Near	1%	1%	1%	2%	95%
	Long	1%	2%	2%	2%	93%
Upland Mesic Spruce Hardwood Forest	Current	1%	2%	2%	2%	94%
	Near	1%	2%	2%	2%	93%
	Long	1%	2%	2%	3%	91%
Upland Mesic Spruce Forest	Current	1%	2%	2%	2%	93%
	Near	1%	2%	2%	2%	93%
	Long	1%	2%	2%	3%	91%
Upland Low Tall Shrub Tundra	Current	0%	1%	1%	1%	97%
	Near	0%	1%	1%	1%	97%
	Long	1%	1%	1%	2%	95%
Alpine Arctic Tussock Tundra	Current	0%	0%	0%	1%	98%
	Near	0%	0%	0%	1%	98%
	Long	0%	1%	1%	1%	97%
Alpine Dwarf Shrub Tundra	Current	0%	0%	1%	1%	98%
	Near	0%	0%	1%	1%	98%
	Long	1%	1%	1%	1%	97%

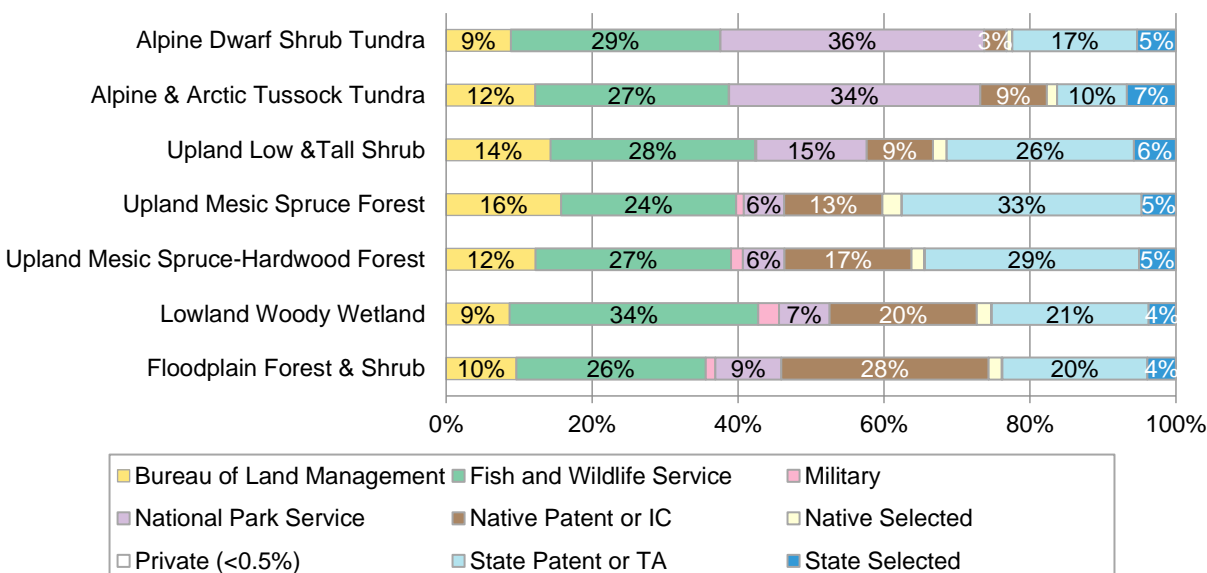
3.11 Relative Management Responsibility

Understanding the ownership distribution across the region can increase the effectiveness of public lands managed for habitats that span political boundaries. For example, National Park Service is responsible for managing a greater relative proportion of tundra habitats with 36% of alpine dwarf shrub tundra and 34% of Arctic and alpine tussock tundra under NPS management. Upland forest ownership is dominated by State or Fish and Wildlife Service with 27% of spruce-hardwood forest under USFWS and 34% under State (or State Selected), and 24% of spruce forest under USFWS and 38% under State (Table G-10, Figure G-26).

Table G-10. Total area of each CE associated with land ownership status.

Terrestrial Coarse-filter CE	BLM (km ²)	USFWS (km ²)	Military (km ²)	NPS (km ²)	Native Patent or IC (km ²)	Native Selected (km ²)	Private (km ²)	State Patent or TA (km ²)	State Selected (km ²)	TOTAL AREA (km ²)
Alpine & Arctic Tussock Tundra	3,937	8,543	8	11,087	2,935	463	2	3,077	2,162	32,214
Alpine Dwarf Shrub Tundra	2,962	9,563	21	12,054	1,028	262	2	5,708	1,778	33,377
Floodplain Forest & Shrub	1,889	5,095	260	1,777	5,578	356	16	3,902	771	19,644
Lowland Woody Wetland	2,253	8,817	733	1,788	5,224	502	22	5,562	971	25,873
Upland Low & Tall Shrub Tundra	12,063	23,599	146	12,723	7,650	1,579	6	21,602	4,853	84,222
Upland Mesic Spruce Forest	15,440	23,519	1,009	5,441	1,3177	2,596	45	32,178	4,612	98,017
Upland Mesic Spruce-Hardwood Forest	5,062	11,070	661	2,362	7,191	692	63	12,113	2,091	41,306

Relative Management Responsibility by CE


Figure G-26. Relative management responsibility for each Terrestrial Coarse-filter CE.

3.12 Limitations and Data Gaps

Landcover Datasets and CE Distributions

Limitations of the floodplain layer: our model of the forest floodplain and shrub CE would have benefitted from a full-coverage boreal floodplain layer. This would have allowed for a consistent method of CE development, rather than using NHD flowlines, which, though buffered according to stream order, do not directly correspond to floodplain boundaries. Floodplain models based on IfSAR elevation data would provide a more accurate depiction of floodplain boundaries; however, IfSAR coverage is currently incomplete across the CYR study area.

Limitations in the NLCD forest classification: the forest classes in NLCD are defined by trees at least 5-m tall with at least 20% canopy cover, and thus, short-statured trees and woodland classes (< 20% tree cover) may be included within the NLCD shrub/scrub class. However, because NLCD uses a consistent forest classification across the region and has a published accuracy assessment (Selkowitz and Stehman 2011), we felt that this inherent limitation in the classification was outweighed by other benefits of the NLCD. Furthermore, the NLCD provides a woody wetland class which furnishes important habitat detail unavailable in AKVM.

Limitations in the NLCD shrub and herbaceous classes: we used the AKVM to define the alpine dwarf shrub tundra CE and alpine and Arctic tussock tundra CE because the NLCD classification of non-forested vegetation does not accurately reflect the tundra and alpine vegetation classes of Alaska. Specifically, the NLCD class that captures tussock tundra, sedge graminoid, is defined by $\geq 85\%$ sedge canopy cover. This resulted in drastic under-mapping of tussock tundra vegetation with much of the tussock tundra area included in the shrub/scrub or dwarf shrub classes. It also appears that the dwarf shrub tundra class is over-mapped in NLCD.

Limitations of the AKVM: the AKVM is a mosaic of various source maps, some of which are based on old LandSat imagery, and many maps are out-of-date due to the frequent fire return interval of the region. Areas that were recently burned at the time of mapping are classified simply as “burn scar,” which is no longer an accurate depiction of the burned area. Maps produced by BLM-Ducks Unlimited for specific project areas have published accuracy assessments, but many source maps have no associated accuracy. Additionally, the classification systems of the various maps used in the AKVM were not consistent across the region, so information is lost when cross-walked to common classes across a broad area. Finally, the AKVM does not differentiate wetland forests from non-wetlands.

ALFRESCO

Area and distribution of deciduous forest and shrub classes differ between the ALFRESCO map and the NLCD, rendering comparison of modeled changes to landcover classes or CEs difficult.

ALFRESCO's climate-to-area burned relationship is based on present conditions. As climate and vegetation cover change, the relationship between climate and burning that the model uses may no longer hold true (e.g., negative feedbacks from changes in albedo).

Not all transitions are active in the ALFRESCO model: Wetland transitions and thermokarst are not active, but may be incorporated as part of the Integrated Ecosystem Model. Drought-driven

transitions are not active, and transitions involving non-vegetated portions of the landscape are not active (i.e., migration of vegetation upward in elevation into previously non-vegetated zones).

Spruce is always reset to deciduous forest after fire, so the self-replacement model that may be more common in some black spruce stands and in white spruce stands near treeline is not represented.

Data Gaps for MQs B2 and F3

Data gaps and limitations of the layers used to develop the CE distributions are described in the Methods section of this chapter.

See Section C. Abiotic Change Agents for data gaps and limitations pertaining to the SNAP climate models, the GIPL ground temperature model, and the ALFRESCO model.

How reliable are these predictions?

See Section C. Abiotic Change Agents for information about the reliability of the SNAP climate models and the ALFRESCO model.

Are there other data/models which provide information that is different than the output presented?

Information about the various landcover maps available for the region that are suitable for developing CE distributions is presented in the Methods section of this chapter.

The climate models, ground temperature models, and ALFRESCO model used in this analysis are the only models available for predicting change in temperature, precipitation, permafrost, and vegetation for the study area.

3.13 Literature Cited

- Baldocchi D., F. M. Kelliher, T. A. Black, and P. G. Jarvis. 2000. Climate and vegetation controls on boreal zone energy exchange. *Global Change Biology* 6:69–83.
- Beck, P. S. A., G. P. Juday, C. Alix, V. A. Barber, S. E. Winslow, E. E. Sousa, P. Heiser, J. D. Herriges, and S. J. Goetz. 2011. Changes in forest productivity across Alaska consistent with biome shift. *Ecology Letters* 14:373–379.
- Bonan, G. B., H. H. Shugart, and D. L. Urban. 1990. The sensitivity of some high-latitude boreal forests to climatic parameters. *Climatic Change* 16:9–29.
- Breen, A. L. 2014. Balsam poplar (*Populus balsamifera* L.) communities on the Arctic Slope of Alaska. *Phytocoenologia* 44:1–17.
- Cabracic, A. V. J., J. Moen, and K. Palmqvist. 2010. Predicting growth of mat-forming lichens on a landscape scale: comparing models with different complexities. *Ecography* 33:949–960.
- Carlson, M., I. Lapina, M. Shephard, J. Conn, R. Densmore, P. Spencer, J. Heys, J. Riley, and J. Nielsen. 2008. Invasiveness ranking system for non-native plants of Alaska. USDA Forest Service, R10-TP-143. 218 pp.
- Chapin, III, F. S., A. D. McGuire, J. Randerson, R. Pielke, D. Baldocchi, S. E. Hobbie, N. Roulet, W. Eugster, E. Kasiskche, E. B. Rastetter, S. A. Zimov, and S. W. Running. 2000. Arctic and boreal ecosystems of western North America as components of the climate system. *Global Change Biology* 6:211–223.
- Chapin, III, F. S., M. W. Oswood, K. Van Cleve, L. A. Viereck, and D. Verbyla. 2006. Alaska's changing boreal forest. Oxford University Press, New York.
- Chapin, III, F. S., G. R. Shaver, A. E. Giblin, K. J. Nadelhoffer, and J. A. Laundre. 1995. Responses of Arctic tundra to experimental and observed changes in climate. *Ecology* 76:694–711.
- Chapin, III, F. S., M. Sturm, M. C. Serreze, J. P. McFadden, J. R. Key, A. H. Lloyd, A. D. McGuire, T. S. Rupp, A. H. Lynch, J. P. Schimel, J. Beringer, W. L. Chapman, H. E. Epstein, E. S. Euskirchen, L. D. Hinzman, G. Jia, C.-L. Ping, K. D. Tape, C. D. C. Thompson, D. A. Walker, and J. M. Welker. 2005. Role of land-surface changes in Arctic summer warming. *Science* 310:657–660.
- Collins, W. B., B. W. Dale, L. G. Adams, D. E. McElwain, and K. Joly. 2011. Fire, grazing history, lichen abundance, and winter distribution of caribou in Alaska's taiga. *The Journal of Wildlife Management* 75:369–377.
- Cumming, S. G. 2001. A parametric model of the fire-size distribution. *Canadian Journal of Forest Research* 31:1297–1303.
- Dial, R. J., T. S. Smeltz, P. F. Sullivan, C. L. Rinas, K. Timm, J. E. Geck, S. C. Tobin, T. S. Golden, and E. C. Berg. 2016. Shrubline but not treeline advance matches climate velocity in montane ecosystems of Southcentral Alaska. *Global Change Biology* 22:1841–1856.
- Epstein, H. E., D. A. Walker, M. K. Reynolds, G. J. Jia, and A. M. Kelley. 2008. Phytomass patterns across a temperature gradient of the North American Arctic tundra. *Journal of Geophysical Research-Biogeosciences* 113(G3).
- Fastie, C. L., A. H. Lloyd, and P. Doak. 2003. Fire history and postfire forest development in an upland watershed of Interior Alaska. *Journal of Geophysical Research Atmospheres* 107:FFR 6-1 – FFR 6-13. DOI:10.1029/2001JD000570.
- Foote, M. J. 1983. Classification, description, and dynamics of plant communities after fire in the taiga of Interior Alaska. Research Paper PNW-307. Portland, Oregon: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 108 pp.
- Forbes, B. C., M. M. Fauria, and P. Zetterberg. 2010. Russian Arctic warming and 'greening' are closely tracked by tundra shrub willows. *Global Change Biology* 16:1542–1554.

- Greenstein, C., and B. Heitz. 2013. Non-native plant surveys on public lands affected by forest fires 2009-2010. Prepared for: the Bureau of Land Management – Alaska State Office. Alaska Natural Heritage Program, University of Alaska Anchorage, Alaska. 54 pp.
- Heinselman, M. L. 1981. Fire and succession in the conifer forests of northern North America. Chapter 23 in West, D. C., H. H. Shugart, and D. B. Botkin, eds. *Forest succession: concepts and application*. Springer-Verlag, New York.
- Higuera, P. E., L. B. Brubaker, P. M. Anderson, T. A. Brown, A. T. Kennedy, and F. S. Hu. 2008. Frequent fires in ancient shrub tundra: implications of paleorecords for Arctic environmental change. *PLoS One* 3:e1744.
- Hinzman, L. D., N. D. Bettes, W. R. Bolton, F. S. Chapin, III, M. B. Dyurgerov, C. L. Fastie, B. Griffith, R. D. Hollister, A. Hope, H. P. Huntington, A. M. Jensen, G. J. Jia, T. Jorgenson, D. L. Kane, D. R. Klein, G. Kofinas, A. H. Lynch, A. H. Lloyd, A. D. McGuire, F. E. Nelson, M. Nolan, W. C. Oechel, T. E. Osterkamp, C. H. Racine, V. E. Romanovsky, R. S. Stone, D. A. Stow, M. Sturm, C. E. Tweedie, G. L. Vourlitis, M. D. Walker, D. A. Walker, P. J. Webber, J. M. Welker, K. S. Winker, and K. Yoshikawa. 2005. Evidence and implications of recent climate change in northern Alaska and other Arctic regions. *Climatic Change* 72:251-298.
- Hogg, E. H., and P. A. Hurdle. 1995. The aspen parkland in western Canada: a dry-climate analogue for the future boreal forest? *Water, Air, and Soil Pollution* 82:391-400.
- Holt, E. A., B. McCune, and P. Neitlich. 2008. Grazing and fire impacts on macrolichen communities of the Seward Peninsula, Alaska, U.S.A. *The Bryologist* 111:68–83.
- Homer, C. G., J. A. Dewitz, L. Yang, S. Jin, P. Danielson, G. Xian, J. Coulston, N. D. Herold, J. D. Wickham, and K. Megown. 2015. Completion of the 2011 National Land Cover Database for the conterminous United States-representing a decade of land cover change information. *Photogrammetric Engineering and Remote Sensing* 81:345-354. Available: <http://www.mrlc.gov>
- Jandt, 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 disturbance factors. *Arctic, Antarctic, and Alpine Research* 40:89–95.
- Johnstone, J. F. 2006. Response of boreal plant communities to variations in previous fire-free interval. *International Journal of Wildland Fire* 15:497–508.
- Johnstone, J. F., T. N. Hollingsworth, F. S. Chapin, III, and M. C. Mack. 2010. Changes in fire regime break the 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 postfire regeneration in a recently burned black spruce forest. *Canadian Journal of Forest Research* 35:2151–2163.
- Joly, K., P. Bente, and J. Dau. 2007. Response of overwintering caribou to burned habitat in northwest Alaska. *Arctic* 60:401–410.
- 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., P. Duffy, and T. S. Rupp. 2012. Simulating the effects of climate change on fire regimes in Arctic biomes: implications for caribou and moose habitat. *Ecosphere* 3:1-18.
- Joly, K., R. R. Jandt, and D. R. Klein. 2009. Decrease of lichens in Arctic ecosystems: role of wildfire, caribou and reindeer, competition, and climate change. *Polar Research* 28:433–442.
- Jorgenson, M. T., J. Harden, M. Kanevskiy, J. O'Donnell, K. Wickland, S. Ewing, K. Manies, Q. Zhuang, Y. Shur, R. Striegl, and J. Koch. 2013. Reorganization of vegetation, hydrology and soil carbon after permafrost degradation across heterogeneous boreal landscapes. *Environmental Research Letters* 8:035017. Available: <http://iopscience.iop.org/1748-9326/8/3/035017>

- Jorgenson, M. T., C. Racine, J. Walters, and T. E. Osterkamp. 2001. Permafrost degradation and ecological changes associated with a warming climate in Central Alaska. *Climatic Change* 48:551–579.
- Juday, G. P., and J. C. Zasada. 1984. Structure and development of an old-growth white spruce forest on an Interior Alaska floodplain. Pages 227-234 *in* Fish and wildlife relationships in old-growth forests: proceedings of a symposium, Juneau, Alaska, April 12-15, 1982. American Institute of Fishery Research Biologists, Morehead City, North Carolina, USA.
- Kasischke, E. S., D. L. Verbyla, T. S. Rupp, A. D. McGuire, K. A. Murphy, R. Jandt, J. L. Barnes, E. E. Hoy, P. A. Duffy, M. Calef, and M. R. Turetsky. 2010. Alaska's changing fire regime—implications for the vulnerability of its boreal forests. *Canadian Journal of Forest Research* 40:1313–1324.
- Kelly, R., M. L. Chipman, P. E. Higuera, I. Stefanova, L. B. Brubaker, and F. S. Hu. 2013. Recent burning of boreal forests exceeds fire regime limits of the past 10,000 years. *PNAS* 110:13055-13060.
- Klein, D. R. 1982. Fire, lichens, and caribou. *Journal of Range Management* 35:390–395.
- Klein, D. R., and M. Shulski. 2009. Lichen recovery following heavy grazing by reindeer delayed by climate warming. *AMBIO: A Journal of the Human Environment* 38:11-16.
- Kurkowski, T. A., D. H. Mann, T. S. Rupp, and D. L. Verbyla. 2008. Relative importance of different secondary successional pathways in an Alaskan boreal forest. *Canadian Journal of Forest Research* 38:1911–1923.
- Larsen, J. A. 1980. The boreal ecosystem. Academic Press, New York, New York, USA.
- Liston, G. E., J. P. McFadden, M. Sturm, and R. A. Pielke. 2002. Modelled changes in Arctic tundra snow, energy and moisture fluxes due to increased shrubs. *Global Change Biology* 8:17–32.
- Liu, H. P., J. T. Randerson, J. Lindfors, and F. S. Chapin, III. 2005. Changes in the surface energy budget after fire in boreal ecosystems of Interior Alaska: an annual perspective. *Journal of Geophysical Research Atmospheres* 110:D13101. DOI:10.1029/2004JD005158.
- Lloyd, A. H. 2005. Ecological histories from Alaskan treeline sites provide insight into future change. *Ecology* 86:1687–1695.
- Lloyd, A. H., and C. Fastie. 2003. Recent changes in treeline forest distribution and structure in Interior Alaska. *Ecoscience* 10:176–185.
- Lloyd, A. H., K. Yoshikawa, C. L. Fastie, L. Hinzman, and M. Fraver. 2003. Effects of permafrost degradation on woody vegetation at Arctic treeline on the Seward Peninsula, Alaska. *Permafrost and Periglacial Processes* 14:93–101.
- Mann, D. H., C. L. Fastie, E. L. Rowland, and N. H. Bigelow. 1995. Spruce succession, disturbance, and geomorphology on the Tanana River floodplain, Alaska. *Ecoscience* 2:184–199.
- Mann, D. H., T. S. Rupp, M. A. Olson, and P. A. Duffy. 2012. Is Alaska's boreal forest now crossing a major ecological threshold? *Arctic, Antarctic, and Alpine Research* 44:319–331.
- Martin, P. D., J. L. Jenkins, F. J. Adams, M. T. Jorgenson, A. C. Matz, D. C. Payer, P. E. Reynolds, A. C. Tidwell, and J. R. Zelenak. 2009. Wildlife response to environmental Arctic change: predicting future habitats of Arctic Alaska. Report of the Wildlife Response to Environmental Arctic Change (WildREACH): Predicting Future Habitats of Arctic Alaska Workshop, 17-18 November 2008. Fairbanks, Alaska: U.S. Fish and Wildlife Service. 138 pp.
- McAfee, S. A. 2013. Methodological differences in projected potential evapotranspiration. *Climatic Change* 120:915–930.
- Naito, A. T., and D. M. Cairns. 2015. Patterns of shrub expansion in Alaskan Arctic river corridors suggest phase transition. *Ecology and Evolution* 5:87–101.
- Nation American Land Change Monitoring System (NALCMS). 2005. North American land cover at 250-m spatial resolution. Produced by Natural Resources Canada/Canadian Center for Remote Sensing (NRCan/CCRS), United States Geological Survey (USGS). Available: <http://landcover.usgs.gov/NALCMSs.php>

- National Hydrography Dataset (NHD). 2015. United States Geological Survey. Available: <http://nhd.usgs.gov/data.html>
- Nowacki, G., P. Spencer, M. Fleming, T. Brock, and T. Jorgenson. 2001. Ecoregions of Alaska: 2001. U.S. Geological Survey Open-File Report 02-297 (map).
- Okano, K., and M. S. Bret-Harte. 2015. Warming and neighbor removal affect white spruce seedling growth differently above and below treeline. *Springerplus* 4:79. doi:10.1186/s40064-015-0833-x.
- Racine, C. H., R. R. Jandt, C. R. Meyers, and J. Dennis. 2004. Tundra fire and vegetation change along a hillslope on the Seward Peninsula, Alaska, U.S.A. *Arctic, Antarctic, and Alpine Research* 36:1–10.
- Raynolds, M. K., J. C. Comiso, D. A. Walker, and D. Verbyla. 2008. Relationship between satellite-derived land surface temperatures, Arctic vegetation types, and NDVI. *Remote Sensing of Environment* 112:1884–1894.
- Reich, R., J. Lundquist, and V. Bravo. 2013. Characterizing spatial distributions of insect pests across Alaskan forested landscape: a case study using aspen leaf miner (*Phyllocnistis populiella* Chambers). *Journal of Sustainable Forestry* 32:527–548.
- Ropars, P., and S. Boudreau. 2012. Shrub expansion at the forest-tundra ecotone: spatial heterogeneity linked to local topography. *Environmental Research Letters* 7:015501.
- Rupp, T. S., and A. Springsteen. 2009a. Projected climate change scenarios for the Bureau of Land Management Eastern Interior Management Area, Alaska, 2001–2099. Available: https://www.snap.uaf.edu/sites/default/files/EIAK_cc_report.pdf
- Rupp, T. S., and A. Springsteen. 2009b. Summary report for eastern Interior Alaska: projected vegetation and fire regime response to future climate change in Alaska. Available: https://www.snap.uaf.edu/sites/default/files/ALFRESCO_summary_EIAK.pdf
- Rupp, T. S., A. M. Starfield, and F. S. Chapin. 2000. A frame-based spatially explicit model of sub-Arctic vegetation response to climatic change: comparison with a point model. *Landscape Ecology* 15:383–400.
- Rupp, T. S., A. M. Starfield, F. S. Chapin, and P. Duffy. 2002. Modeling the impact of black spruce on the fire regime of Alaskan boreal forest. *Climatic Change* 55:213–233.
- Scheffer, M., M. Hirota, M. Holmgren, E. H. V. Nes, and F. S. Chapin. 2012. Thresholds for boreal biome transitions. *Proceedings of the National Academy of Sciences of the United States of America* 109:21384–21389.
- Schneider, R. R., A. Hamann, D. Farr, X. Wang, and S. Boutin. 2009. Potential effects of climate change on ecosystem distribution in Alberta. *Canadian Journal of Forest Research* 39:1001–1010.
- Selkowitz, D. J., and S. V. Stehman. 2011. Thematic accuracy of the National Land Cover Database (NLCD) 2001 land cover for Alaska. *Remote Sensing of Environment* 115:1401–1407.
- Sherriff, R., E. Berg, and A. Miller. 2011. Climate variability and spruce beetle (*Dendroctonus rufipennis*) outbreaks in Southcentral and Southwest Alaska. *Ecology* 92:1459–1470.
- Spellman, K. V., T. Hollingsworth, and C. P. H. Mulder. 2014. Susceptibility of burned black spruce (*Picea mariana*) forests to non-native plant invasions in Interior Alaska. *Biological Invasions* 16:1879–1895.
- Starfield, A. M., and F. S. Chapin, III. 1996. Model of transient changes in Arctic and boreal vegetation in response to climate and land use change. *Ecological Applications* 6:842–864.
- Sturm, M., C. Racine, and K. Tape. 2001. Increasing shrub abundance in the Arctic. *Nature* 411:546–547.
- Suarez, F., D. Binkley, M. W. Kaye, and R. Stottlemeyer. 1999. Expansion of forest stands into the tundra in Noatak National Preserve, northwest Alaska. *Ecoscience* 6:465–470.
- Swanson, D. K. 1996. Fruticose lichen distribution in the Kobuk Preserve Unit, Gates of the Arctic National Park. USDI NPS Tech. Rept. AFA RNRINRTR-96/28. Anchorage, Alaska.
- Tape, K., M. Sturm, and C. Racine. 2006. The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. *Global Change Biology* 12:686–702.
- Verbyla, D. 2008. The greening and browning of Alaska based on 1982–2003 satellite data. *Global Ecology and Biogeography* 17:547–555. DOI:10.1111/j.1466-8238.2008.00396.x.

- Viereck, L. A., C. T. Dyrness, A. R. Batten, and K. J. Wenzlick. 1992. The Alaska vegetation classification. Portland, Oregon, USA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 278 pp.
- Viereck, L. A., C. T. Dyrness, K. Van Cleve, and M. J. Foote. 1983. Vegetation, soils, and forest productivity in selected forest types in Interior Alaska. *Canadian Journal of Forest Research* 13:703–720.
- Viereck, L. A., and L. A. Schandelmeier. 1980. Effects of fire in Alaska and adjacent Canada a literature review. Bureau of Land Management Alaska Tech. Rep. 6.
- Viereck, L. A., K. Van Cleve, and C. T. Dyrness. 1986. Forest ecosystems in the Alaska taiga. Pages 22-43 *in* Van Cleve, K., F. S. Chapin, III, P. W. Flanagan, L. A. Viereck, and C. T. Dyrness, eds. *Forest ecosystems in the Alaskan taiga: a synthesis of structure and function*. New York: Springer-Verlag.
- Wahren, C. H., M. D. Walker, and M. S. Bret-Harte. 2005. Vegetation responses in Alaskan Arctic tundra after 8 years of a summer warming and winter snow manipulation experiment. *Global Change Biology* 11:537–552.
- Walker, D. A. 2000. Hierarchical subdivision of Arctic tundra based on vegetation response to climate, parent material and topography. *Global Change Biology* 6:19–34.
- Walker, M. D., C. H. Wahren, R. D. Hollister, G. H. Henry, L. E. Ahlquist, J. M. Alatalo, M. S. Bret-Harte, M. P. Calef, T. V. Callaghan, A. B. Carroll, and H. E. Epstein. 2006. Plant community responses to experimental warming across the tundra biome. *Proceedings of the National Academy of Sciences* 103:1342–1346.
- Winton, M. 2006. Amplified Arctic climate change: what does surface albedo feedback have to do with it? *Geophysical Research Letters* 33:L03701. DOI:10.1029/2005GL025244.
- Yarie, J. 1983. Forest community classification of the Porcupine River drainage, Interior Alaska, and its application to forest management. USDA Forest Service GTR PNW-154.

4. Floodplain Forest and Shrub

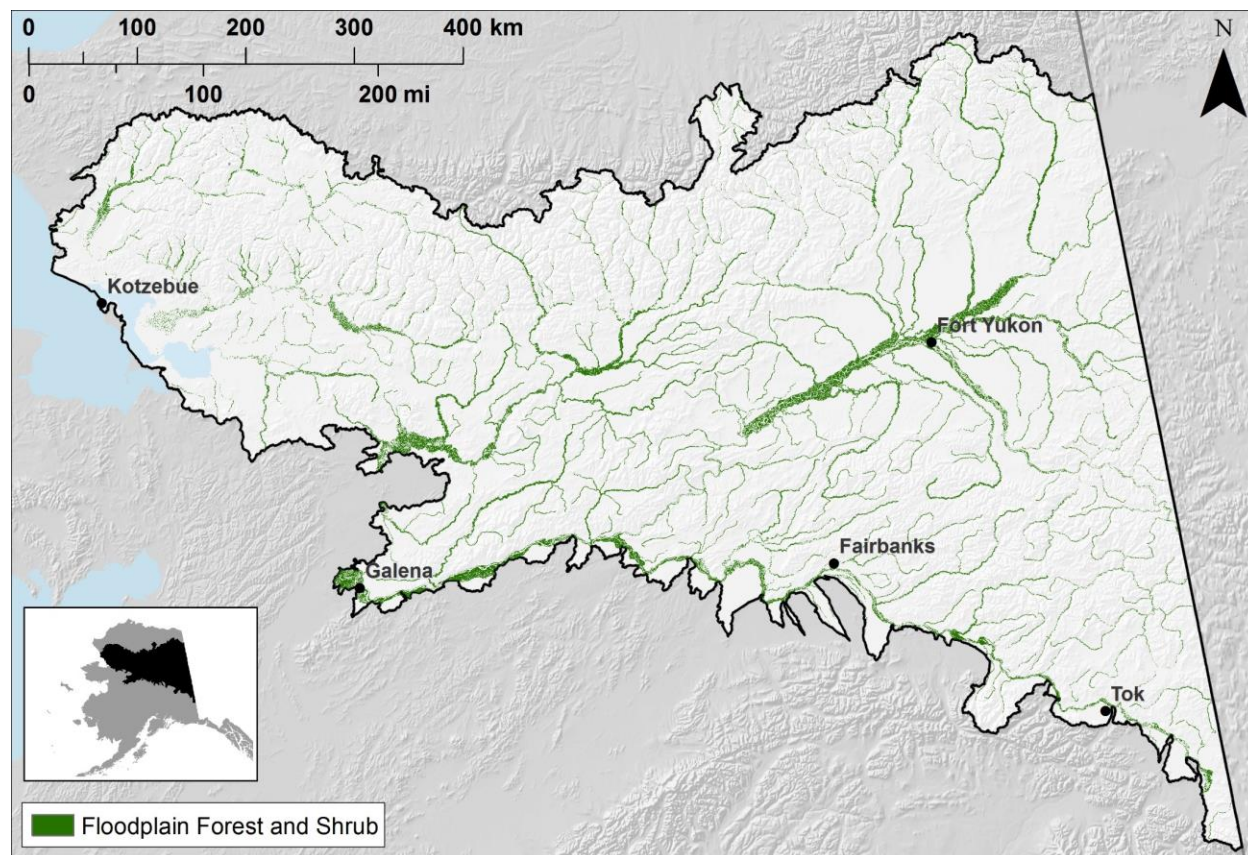


Figure G-27. Distribution map of the floodplain forest and shrub CE.

4.1 Introduction

The floodplain forest and shrub CE occurs on floodplains throughout the boreal region of Alaska (Figure G-27). Frequent river channel migration, flooding, deposition, and other fluvial processes constitute the major disturbances in this CE. The flooding regime is characterized by large spring floods fed by snow melt or summer floods caused by extreme rain events sometimes in combination with glacial melt. Spring flooding is often accompanied by the formation



Figure G-28. Lowland boreal floodplain. Photo by Mike Flemming.

of ice jams which can cause a rapid rise in water levels and lead to widespread ice scouring across the floodplain. The width of the active floodplain varies from several kilometers in broad lowlands to narrow channels in constrained mountainous terrain. Lowland floodplains have a wide range of deposit types, while montane floodplains typically have well-drained sand or cobble substrates deposited by high energy flooding. Permafrost is usually absent or deeper than 1 m in active lowland and montane floodplains (Boggs and Boucher 2008, Jorgenson and Meidinger 2015).

Vegetation

Floodplain vegetation is composed of a mix of successional stages linked to frequency of flooding and proximity to the river channel (Figure G-28). *Populus balsamifera* is the dominant deciduous tree while *Picea glauca* may be codominant in mid-seral stages and becomes dominant in late-seral stages. The shrub canopy is often dominated by alder or willow. The most common willow on active floodplains is *Salix alaxensis*. Other common willows include *S. arbusculoides*, *S. interior*, *S. lasiandra*, and *S. pulchra*. *Alnus incana* ssp. *tenuifolia* and *Alnus viridis* ssp. *fruticosa* are the dominant alder species in the CYR study area, though *A. viridis* ssp. *sinuata* is restricted along the southern margin of the CYR study area. Common shrubs in later seral stages include *Rosa acicularis* and *Viburnum edule*. Shrub composition on very well-drained, coarse deposits includes *Shepherdia canadensis*, *Elaeagnus commutata*, and *Dryas drummondii*. The composition of the herbaceous layer is diverse and varies by substrate type and seral stage. Common herbaceous species may include *Calamagrostis canadensis*, *Festuca rubra*, *Bromus pumpellianus*, *Elymus alaskanus* ssp. *alaskanus*, *Lupinus arcticus*, *Astragalus* spp., *Eurybia sibirica*, *Equisetum arvense*, *Chamerion latifolium*, *Hedysarum alpinum*, *Mertensia paniculata*, and *Rubus arcticus*. *Hylocomium splendens* is the dominant moss in late-seral stands (Vioreck 1966, Thilenius 1990, Scott 1974, Hollingsworth et al. 2010).

Classification Synonymy

This CE is similar to NVC G548 Western Boreal Floodplain Forest (excluding the sub-boreal distribution; FGDC 2008) and is equivalent to CBVM Yukon Floodplain Spruce-Poplar Forests and Scrub (Jorgensen and Meidinger 2015). The Vioreck classification (Vioreck et al. 1992) contains several classes that typically occur on boreal floodplains: IA1j (in part), IB1c, IB2c, and IC21.

Vegetation Succession

The primary disturbance in this ecosystem is flooding, which can be caused by snowmelt, precipitation, ice jams, and glacial runoff. Rivers of glacial origin, such as the Tanana and Yukon, typically carry a heavy sediment load which is deposited and reclaimed by the river as channels shift laterally across the floodplain. Successive flooding and deposition events gradually raise the elevation of the floodplain terrace above the channel. The frequency of overbank flooding and deposition declines as height and distance from the active channel increase (Chapin, III et al. 2006).

The general pattern of floodplain succession on large rivers such as the Tanana starts with newly deposited alluvial surfaces. *Salix* spp. are the first to establish, followed by either *Populus balsamifera* or *Alnus* spp. *Picea glauca* eventually gains canopy dominance in the absence of disturbance (Drury 1956, Vioreck 1970, Van Cleve et al. 1983, Vioreck et al. 1993,

Mann et al. 1995, Yarie et al. 1998, Hollingsworth et al. 2010). Wetland development occurs in abandoned channels and on fine, poorly drained deposits, however wetlands and wetland succession are not included in the definition of this CE.

The initial seral stage is dominated by *Salix* spp. which readily colonizes new alluvial deposits. Within 5 years, *Populus balsamifera* seedlings, *Equisetum* spp., *Calamagrostis canadensis*, *Chamerion latifolium*, *Hedysarum* spp., and *Lupinus arcticus* become common (Walker et al. 1986, Viereck et al. 1993, Boggs and Sturdy 2005). *Salix* spp. typically dominate the shrub canopy for at least the first 20 years post-flooding (Viereck et al. 1993). Most early colonizers are deep rooted species that stabilize the soils. Moose and hares intensively use this stage of succession because of the abundance of forage species, particularly *Salix* spp. (Kielland and Bryant 1998). Intensive browsing of broad-leaved species during this stage can accelerate succession to coniferous seral stages by reducing competition (Butler et al. 2007).

Alnus spp. often establish during the shrub stage (~20 years post-flooding), but the pattern and distribution of *Alnus* spp. is more variable than that of *Salix* spp. In general, *Alnus incana* ssp. *tenuifolia* establishes on fine-textured sediments and *Alnus viridis* dominates gravelly substrates (Chapin, III et al. 2006). Nitrogen accumulation is largely facilitated by *Alnus* spp., which have symbiotic actinorrhizal bacteria that fix nitrogen (Uliassi et al. 2000). A lack of nitrogen in the early stages of floodplain succession may strongly limit growth and productivity (Walker et al. 1986, Yarie 1993). *Salix* spp. are gradually eliminated as they are shaded by *Alnus* spp. and browsed by moose and hare (McAvinchey 1991, Viereck et al. 1993). *Populus balsamifera* populations are reduced for the same reasons.

Over the next 10–20 years (~40 years post flooding), *Populus balsamifera* starts to dominate, overtopping the shrub thickets (Viereck et al. 1983, Boggs and Sturdy 2005). *Picea glauca* recruitment is greatest during this seral stage particularly when high seed production follows a year of alluvial deposition (Yarie et al. 1998, Adams 1999). *Betula neoalaskana* forests may also develop on some sites (Boggs and Sturdy 2005). Because of the high canopy cover of deciduous woody species, leaf litter is abundant on the forest floor and mosses are sparse. Where beavers are common, they can affect forest succession and competition by felling *Populus balsamifera* trees and creating canopy openings (Oechel and Van Cleve 1986). Beaver dams can also alter the flooding regime in some locations.

Picea glauca grows rapidly during this stage and eventually becomes codominant with the deciduous canopy. *Populus balsamifera* is relatively short-lived species (100–150 years) and once the canopy establishes, new recruitment is rare (Viereck et al. 1983, Walker et al. 1986). *Picea glauca* eventually grows above the shade-intolerant *Populus balsamifera* and gains dominance in the canopy (~100 years post-flooding). Initially, stands of *Picea glauca* are relatively evenly aged because many of the trees are recruited as a single cohort during the *Populus balsamifera* stage of succession. However, older stands eventually develop an uneven age distribution because of variable recruitment during the *Picea glauca* stage of succession. *Alnus* spp. may still dominate the understory shrub canopy. Other common understory shrubs in this late-seral successional stage include *Rosa acicularis* and *Viburnum edule*. Feather mosses, including *Hylocomium splendens* and *Pleurozium schreberi*, often dominate the forest floor.

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 layer on the forest floor which further insulates the soil. In the absence of flooding or fire, *Picea glauca* forests can persist for over 300 years as the late-seral climax (Mann et al. 1995, Chapin, III et al. 2006).

4.2 Conceptual Model

The conceptual model below is based on literature review and describes the relationships among the various CAs and natural drivers for floodplain forest and shrub CE. Bold arrows indicate interactions with high ecological relevance and potential management implications, and for which spatial datasets can be intersected with the CE distribution. The primary CAs selected for this CE include climate change, fire, and development (Figure G-29).

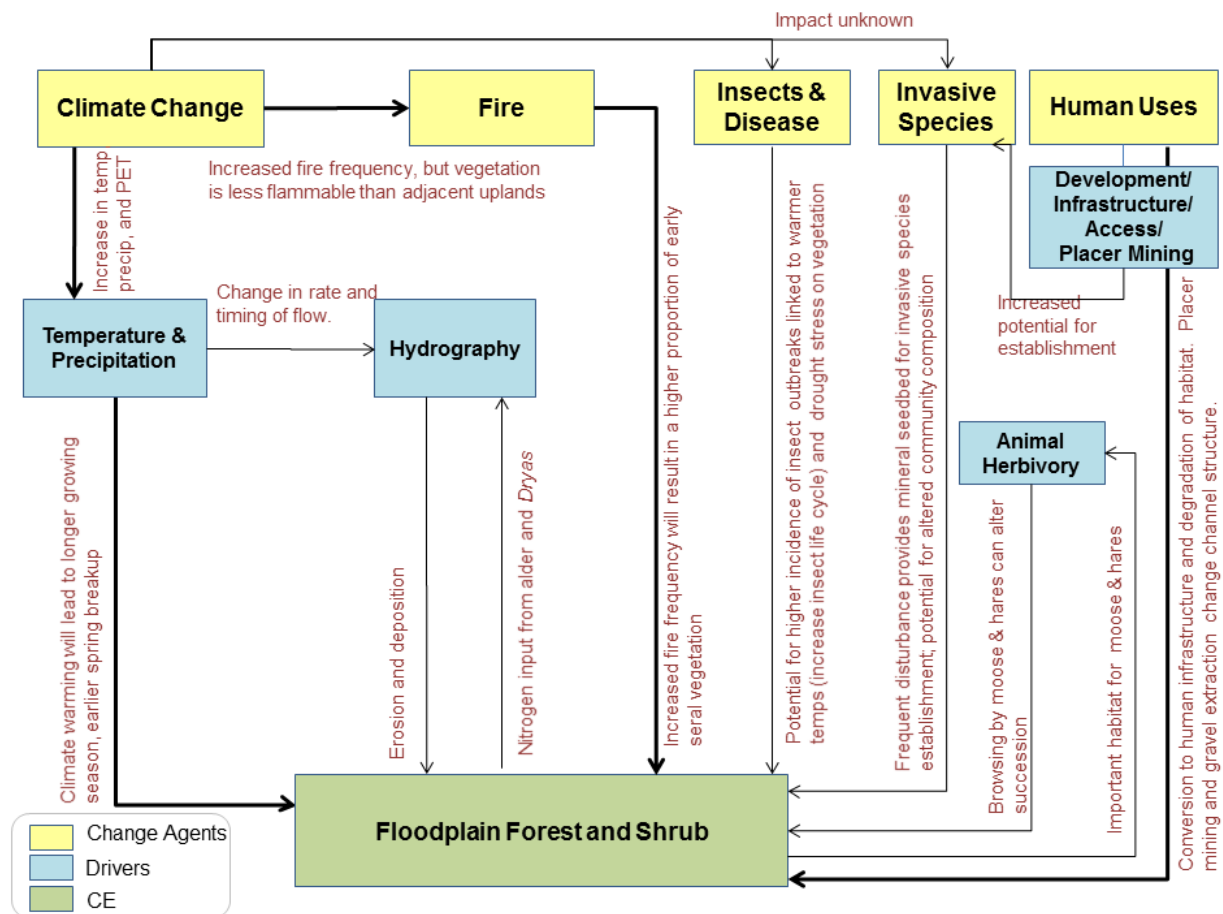


Figure G-29. Conceptual model of the floodplain forest and shrub CE.

4.3 Abiotic Change Agents Analysis

Length of Growing Season and Summer Warmth Index

The length of growing season for the floodplain forest and shrub CE is projected to increase by 8.8 days between the current condition to the long-term future (from 160.6 to 169.4 days), and

the Summer Warmth Index (annual sum of mean monthly temperatures that are above freezing) is projected to increase from 55 to 61 °C mo for the same time frame. Figure G-30 shows the distribution of summer heating measured by SWI across the lowland CE for the current condition and long-term future. Because each of the lowland CE occupies a relatively small fraction of the CYR study area, the patterns of SWI distribution for the individual CE were difficult to discern at the scale of the REA, and therefore, we combined the distributions to improve the visibility of the trends in SWI.

Floodplain Forest & Shrub and Lowland Woody Wetland

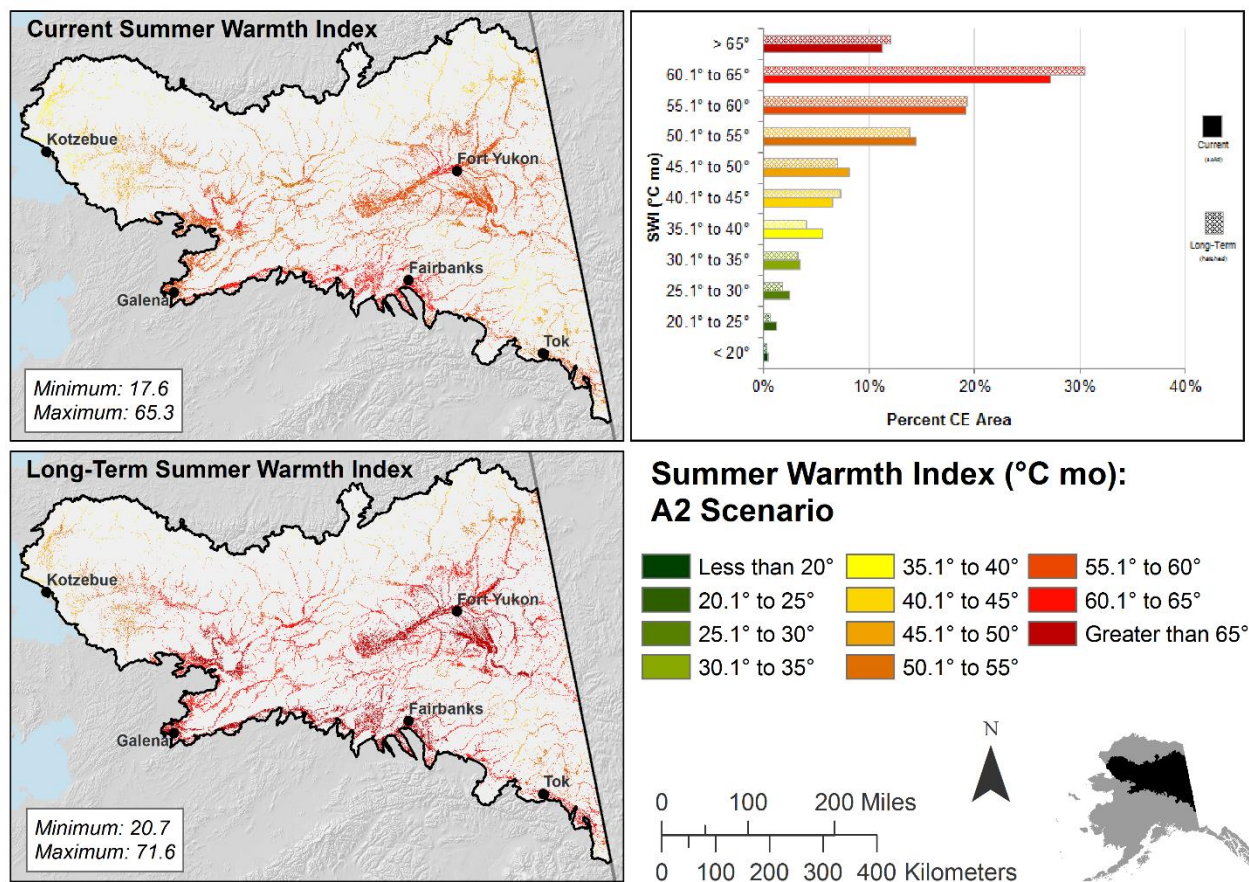


Figure G-30. Summer Warmth Index for lowland Coarse-filter CEs (floodplain forest and shrub, and lowland woody wetland) for the current condition and the long-term future.

Temperature and Precipitation

Mean annual temperature for floodplain forest and shrub is projected to increase by 2.0 °C between the current and long-term future, while mean January temperature is expected to increase by 3.8 °C and mean July temperature is expected to increase by 1.5 °C (Table G-11).

Table G-11. Temperature summary for floodplain forest and shrub.

Floodplain Forest and Shrub	Mean July Temperature (°C)				Mean January Temperature (°C)				Mean Annual Temperature (°C)			
	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change
	15.7	16.0	17.3	+1.5	-22.5	-21.8	-19.0	+3.5	-4.1	-3.9	-2.1	+2.0

Mean annual precipitation is projected to increase by 42 mm between current condition and long-term future, with precipitation during the summer months increasing by 12 mm and winter months increasing by 14 mm (Table G-12).

Table G-12. Precipitation summary for floodplain forest and shrub.

Floodplain Forest and Shrub	Precipitation (mm)														
	Summer					Winter					Mean Annual				
	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change
	154	157	164	+10	+6	59	66	69	+10	+17	351	366	394	+43	+12

Fire and Vegetation Change

Floodplain vegetation was not specifically addressed in the ALFRESCO model. Presumably, results would be similar to the upland spruce-hardwood CE, with a fire-driven increase in deciduous species and a decrease coniferous forest. Given the lower flammability of floodplain vegetation and the presence of rivers acting as fuel breaks, the climate-driven vegetation shifts would likely be less in the floodplain than in the upland.

Permafrost

Because the ground temperature model was developed at a 2-km resolution and floodplains tend to be narrow linear features, the intersection of the model with the CE distribution does not provide a realistic estimate of changes likely to occur within the boundaries of the floodplain, rather it gives a general picture of the permafrost trends affecting lowland forests in the region where the floodplains occur. According to ground temperature models developed by GIPL, 98% of the floodplain forest and shrub CE is underlain by permafrost in current conditions, but this is projected to decrease to 61% of the CE area by the long-term future (Table G-7). However, it is likely that this intersection overestimates the proportion of the CE underlain by permafrost, because permafrost is often deeper than 1 m or absent on active floodplains (Jorgenson et al. 2001).

According to the GIPL model, active layer thickness is currently estimated at 0.70-m thick across the portion of the CE currently underlain by permafrost, and this is projected to increase to 0.74 m where permafrost remains intact in the long-term future (Figure G-13). Again, it is likely that actual depth of active layer is much deeper on the floodplain than is represented by the model.

The thermokarst predisposition model takes into account ice content of the soil and surficial deposit, and as such, it may provide a more realistic view of permafrost conditions underlying floodplain forests than the ground temperature model. According to the thermokarst predisposition model, 23% of the floodplain forest and shrub CE occurs on landscapes that are very highly predisposed to thermokarst (Figure G-14).

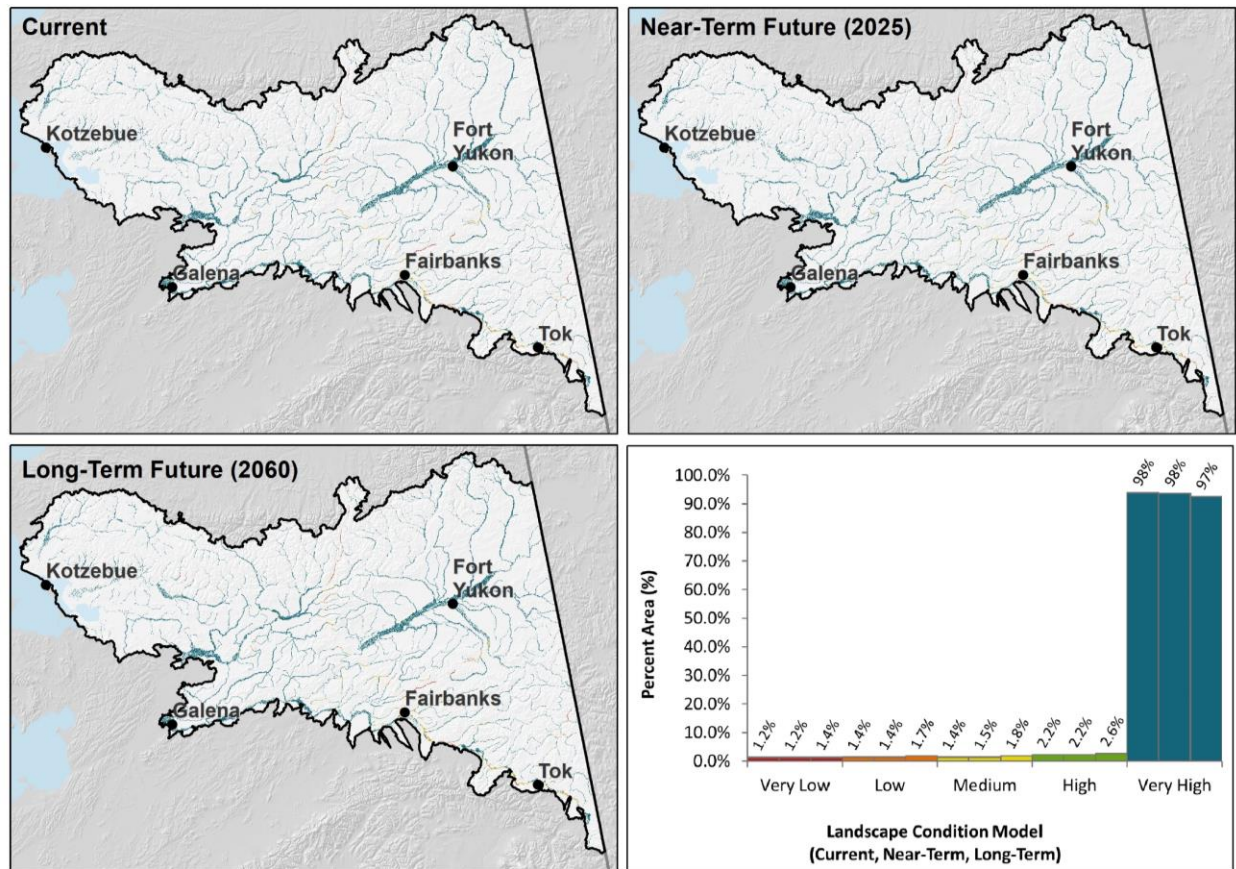
Abiotic Change Agents Discussion

Floodplain forests are generally considered less flammable than upland forests because of an abundance of low flammability vegetation such as alder, willow, and poplar, and their proximity to rivers, which can act as fire breaks. Furthermore, some of the oldest white spruce stands in the boreal forest occur on floodplains (Chapin, III et al. 2006, Juday and Zasada 1984). However, paleoecological records from the Tanana River floodplain show evidence of repeated fire and stand replacement within the floodplain, suggesting that these forests may ignite and burn at the same rate as upland forests (Mann et al. 1995). In a future scenario with a warmer boreal climate, it is likely that both floodplain forests and upland forests will burn more frequently.

Increasing temperatures and longer growing seasons may also alter disturbance dynamics in floodplain forests, promoting earlier spring breakup. Specifically, changes in precipitation and temperature may alter the timing and rate of peak river flow and, thereby, affect related disturbance events, such as ice scouring and large-scale silt deposition, which provide important substrate for the regeneration of *Salix* spp. and *Populus balsamifera* (Walker et al. 1986, Van Cleve et al. 1993). Thus, changes to the timing and severity of non-fire disturbance (i.e., flooding) could also have a major impact on the structure and distribution of floodplain vegetation.

Overall effects of permafrost degradation on this CE are expected to be low. Floodplains are typically underlain by well-drained alluvial deposits, and where permafrost is present, it tends to have low ice content. Permafrost loss in gravelly soils with low ice content does not lead to surface subsidence (Jorgenson et al. 2010) and is not expected to greatly impact floodplain vegetation. The floodplain forest and shrub CE has the lowest proportion of terrain highly predisposed to thermokarst (23%) of all the forested and lowland CEs.

4.4 Current Status and Future Landscape Condition



Current, near-term, and long-term landscape condition within the distribution of floodplain forest and shrub

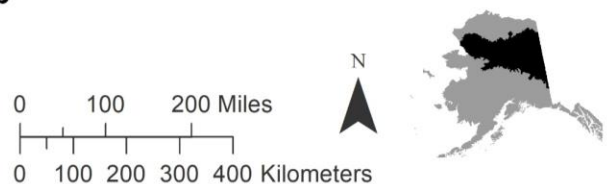


Figure G-31. Current, near-term, and long-term status of floodplain forest and shrub in the CYR study area.

The overall status of the floodplain forest and shrub CE was assessed by intersecting the Landscape Condition Model (LCM) with the CE distribution model for the current condition, near-term, and long-term future. The LCM is a way to measure the impact of the human footprint on a landscape. In the current condition, the impact on the highway system, alternative transport corridors (e.g., the Yukon and Tanana rivers), and small but impact-intense regions of placer mining, all account for the impacts to the current and near-term future landscape condition. In the long-term future, the area in the “very high” condition class is projected to decrease to 92% (Figure G-31). This 2% decrease reflects the addition and expansion of placer mining operations, the continued use of river roads, and the construction of the Ambler mining district access road, which will involve numerous river crossings. Gravel extraction and infrastructure development both degrade floodplain habitat and can facilitate the introduction of invasive species.

4.5 Invasive Species

Invasive plant species are relatively common on road corridors in Interior Alaska, and where rivers and roads intersect, invasive species can establish and expand along the floodplain. Invasive plants favor disturbed sites, and frequent disturbance on floodplains provides ample seedbed on which these plants can become established and spread. A number of populations of highly invasive plants have been documented on Interior 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 and reduce habitat quality for moose and hares.

4.6 Literature Cited

- Adams, P. 1999. The dynamics of white spruce populations on a boreal river floodplain. Ph.D. Dissertation, Duke University, Durham, North Carolina.
- AKEPIC. 2012. Alaska Exotic Plant Information Clearinghouse Database. Alaska Natural Heritage Program, University of Alaska Anchorage.
- Boggs, K., and T. V. Boucher. 2008. Draft ecological systems descriptions for Alaska. *In* NatureServe. International Ecological Classification Standard: Terrestrial Ecological Classifications.
- 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. 190 pp.
- Butler, L. G., K. Kielland, T. S. Rupp, and T. A. Hanley. 2007. Interactive controls of herbivory and fluvial dynamics over vegetation patterns along the Tanana River, Interior Alaska. *Journal of Biogeography* 34:1622–1631.
- Chapin, III, F. S., M. W. Oswood, K. Van Cleve, L. A. Viereck, and D. Verbyla. 2006. Alaska's changing boreal forest. Oxford University Press. New York.
- Drury, W. H. 1956. Bog flats and physiographic processes in the upper Kuskokwim River region, Alaska. *Contributions from the Gray Herbarium of Harvard University*, no. 178. 130 pp.
- FGDC. 2008. National vegetation classification standard, version 2. Federal Geographic Data Committee-Vegetation Subcommittee. FGDC-STD-005-2008 (Version 2).
- 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.
- Hollingsworth, T. N., A. H. Lloyd, D. R. Nossov, R. W. Ruess, B. A. Charlton, and K. Kielland. 2010. Twenty-five years of vegetation change along a putative successional chronosequence on the Tanana River, Alaska. *Canadian Journal of Forest Research* 40:1273–1287. 10.1139/X10-094.
- Jorgensen, T., and D. Meidinger. 2015. The Alaska Yukon region of the circumboreal vegetation map (CBVM). *Conservation of Arctic Flora and Fauna (CAFF)*.
- Jorgenson, M. T., C. Racine, J. Walters, and T. E. Osterkamp. 2001. Permafrost degradation and ecological changes associated with a warming climate in Central Alaska. *Climatic Change* 48:551–579.
- Jorgenson, M. T., V. Romanovsky, J. Harden, Y. Shur, J. O'Donnell, E. A. G. Schuur, M. Kanevskiy, and S. Marchenko. 2010. Resilience and vulnerability of permafrost to climate change. *Canadian Journal of Forest Research* 40:1219–1236.
- Juday, G. P., and J. C. Zasada. 1984. Structure and development of an old-growth white spruce forest on an Interior Alaska floodplain. Pages 227–234 *in* Meehan, W. R., T. R. Merrell, and T. A. Hanley, eds. Fish and wildlife relationships in old-growth forests. Proceedings of a symposium; 1982 April 12–15; Juneau, Alaska. Morehead City, North Carolina: American Institute of Fishery Research Biologists.
- Kielland, K., and J. Bryant. 1998. Moose herbivory in taiga: effects on biogeochemistry and vegetation dynamics in primary succession. *Oikos* 82:377–383.
- Mann, D. H., C. L. Fastie, E. L. Rowland, and N. H. Bigelow. 1995. Spruce succession, disturbance, and geomorphology on the Tanana River floodplain, Alaska. *Ecoscience* 2:184–199.
- 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.
- Oechel, W., and K. Van Cleve. 1986. The role of bryophytes in the Alaskan taiga. Pages 121–137 *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.

- Scott, R. W. 1974. Successional patterns on moraines and outwash of the Frederika Glacier, Alaska. Pages 319-329 in Bushnell, V. C., and M. G. Marcus, eds. Icefield ranges research project scientific results. New York: American Geographical Society, Vol. 4.
- 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.
- Thilenius, J. F. 1990. Woody plant succession on earthquake-uplifted coastal wetlands of the Copper River Delta, Alaska. *Forest Ecology and Management* 33/34:439-462.
- 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. A. Viereck, and C. Dyrness. 1983. Productivity and nutrient cycling in taiga forest ecosystems. *Canadian Journal of Forest Research* 13:747–766.
- Viereck, L. A. 1966. Plant succession and soil development on gravel outwash on the Muldrow Glacier, Alaska. *Ecological Monographs* 36:181–199.
- 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., C. T. Dyrness, A. R. Batten, and K. J. Wenzlick. 1992. The Alaska vegetation classification. Portland, Oregon, USA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 278 pp.
- 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. A., C. T. Dyrness, K. Van Cleve, and M. J. Foote. 1983. Vegetation, soils, and forest productivity in selected forest types in Interior Alaska. *Canadian Journal of Forest Research* 13:703–720.
- 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.
- 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. A. Viereck, K. Van Cleve, and P. Adams. 1998. Flooding and ecosystem dynamics along the Tanana River. *BioScience* 48:690–695.

5. Lowland Woody Wetland

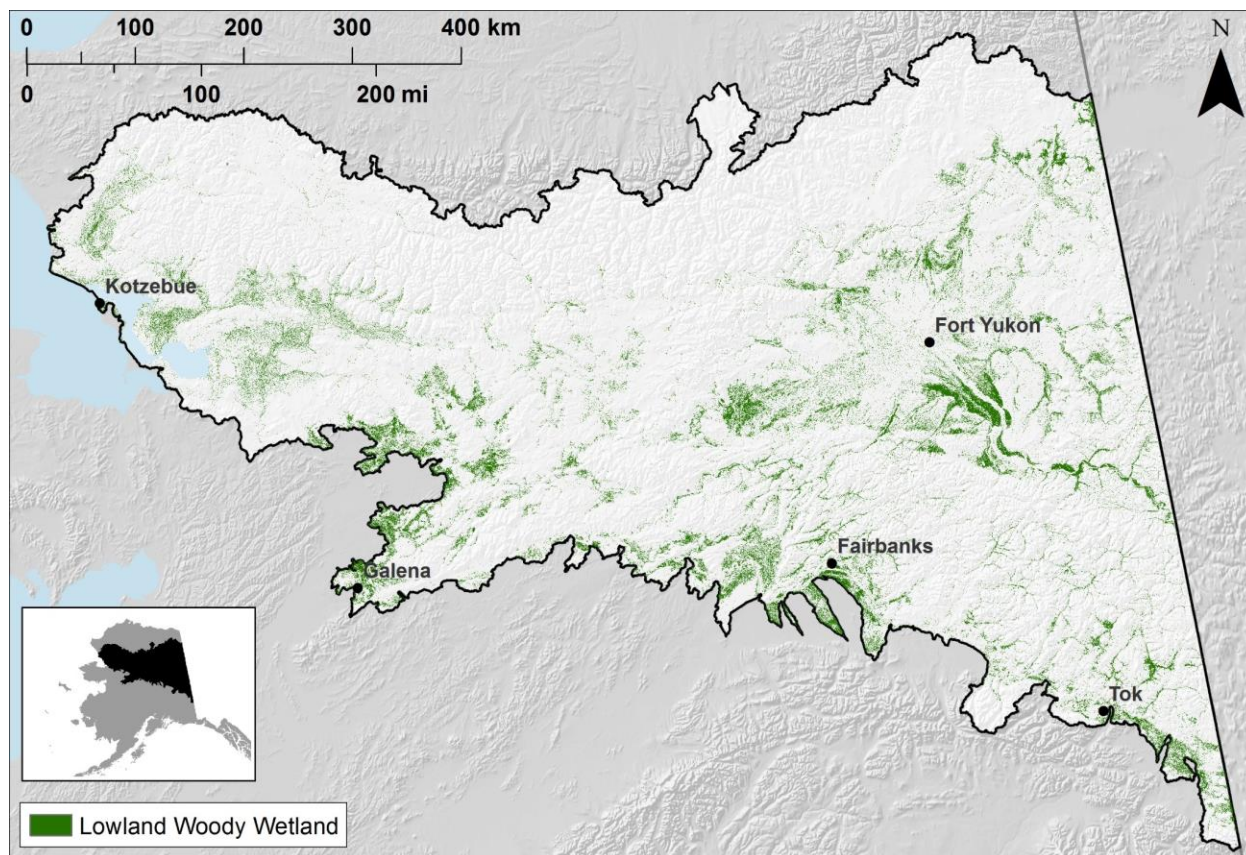


Figure G-32. Distribution map of the lowland woody wetland CE.

5.1 Introduction

The lowland woody wetland CE occurs throughout the boreal regions of Alaska on flat to gently sloping valley bottoms, abandoned floodplains, and other lowland terrain (Figure G-32, Figure G-33). Soils are poorly drained, acidic, nutrient-poor, and often have a well-developed peat layer. Permafrost is discontinuous with extensive thermokarst (Jorgensen and Meidinger 2015).



Figure G-33. Lowland woody wetland, showing a mixture of stunted black spruce and non-forested peatlands.

Vegetation

This CE is characterized by coniferous wetlands and associated sedge-shrub bogs and fens forming a mosaic of forested and non-forested wetland types (Figure G-33). *Picea mariana* is the dominant conifer, though *Larix laricina* may be locally common, especially on less acidic sites. The tree canopy is typically 10–30%, and trees are stunted and slow-growing. The shrub canopy is composed of low and dwarf shrubs including *Rhododendron groenlandicum*, *Rhododendron tomentosum*, *Andromeda polifolia*, *Betula nana*, *B. glandulosa*, *Empetrum nigrum*, *Vaccinium vitis-idaea*, *V. uliginosum*, *Dasiphora fruticosa*, and *Chamaedaphne calyculata*. Sedges and cottongrass are often abundant in the understory and include *Carex bigelowii*, *C. pluriflora*, *Eriophorum vaginatum*, *E. angustifolium*. Other common herbaceous species are *Rubus chamaemorus*, *Calamagrostis canadensis*, and *Equisetum* spp. The moss layer is continuous and typically includes *Sphagnum* spp., *Hylocomium splendens*, and *Pleurozium schreberi*. Lichens, such as *Cladina* spp., are common in older stands (Jorgenson et al. 2001b, Jorgenson et al. 2001c, Boggs and Sturdy 2005, Boggs and Boucher 2008).

Classification synonymy

This CE is similar in concept to the CBVM classes Alaska-Yukon Wet Black Spruce Woodlands and Scrub Coniferous Forest and Yukon Sphagnum Bogs and Herbaceous Fens (Jorgensen and Meidinger 2015), NVC Group 360 Western North American Boreal Acidic Bog and Fen and Group 546 West-Central Boreal Black Spruce-Tamarack Acidic Bog and Swamp (FGDC 2008), and the Alaska Vegetation Classification IA3d Black Spruce, IA2h Black Spruce-Tamarack, IIC2b Mixed Shrub-sedge Tussock Bog and IIC2d Shrub Birch Ericaceous Shrub Bog (Vioreck et al. 1992).

Vegetation Succession

Two potential successional sequences are described below: 1) peatland succession after thermokarst and paludification, and 2) fire succession in black spruce tussock woodlands.

Black Spruce Peatlands: In landscapes underlain by permafrost, peatland succession often begins in wetlands formed by thermokarst. Permafrost degradation leading to collapse scars and thaw ponds is a common in boreal Alaska, and studies from the Tanana Flats show areas of widespread degradation (Racine et al. 1998, Jorgenson et al. 2001a, Jorgenson et al. 2013). Thaw ponds form when ice-rich permafrost degrades and collapses forming a basin. Aquatic plants rapidly colonize the pond. Over time, marsh plants and sphagnum moss invade, creating peatland conditions. If a collapse scar is isolated, succession follows a bog development model, whereas in an open hydrologic setting, succession follows a fen development model. Pond systems may become connected as adjacent permafrost thaws. Succession to peatlands can also occur through paludification of previously forested landscapes. Restricted drainage from permafrost development (on inactive alluvial terraces, for example) can lead to the establishment of *Sphagnum* spp. or other peat-forming mosses or sedges. Over time, peatland plants can dominate the site. Fire is common in black spruce peatlands; however, moist surface fuels and standing water limit fire spread and a wet soil profile limits the depth of burn into the organic horizon.

Black Spruce Tussock: Fire is the primary disturbance mechanism in black spruce tussock woodlands. The fuel layer is dense and continuous, leading to large, fast-spreading fires (Duchesne and Hawkes 2000, Racine et al. 1987). Owing to the wet soil profile, fire severity in

this forest type is typically low (Wein 1971). Patches of higher severity occur where organic layers are removed. Fire in black spruce tussock woodlands generally kills the overstory trees, and removes the aerial parts of graminoids and shrubs. Post-fire succession begins with vigorous resprouting of tussocks from meristematic tissue while shrubs resprout more slowly from rootstocks. A shrub-tussock canopy can persist for several decades before black spruce regain canopy dominance.

5.2 Conceptual Model

The conceptual model below is based on literature review and describes the relationships among CAs and natural drivers for the lowland woody wetland CE. The boxes in each diagram indicate CEs, CAs, and drivers. Arrows indicate regionally important interactions known to occur in the CYR study area. Text positioned next to arrows indicates the most likely relationships between constituents. Bold arrows indicate interactions with high ecological relevance and potential management implications, and for which spatial datasets can be intersected with the CE distribution. The primary CAs selected for this CE include climate change, permafrost, fire, and development (Figure G-34).

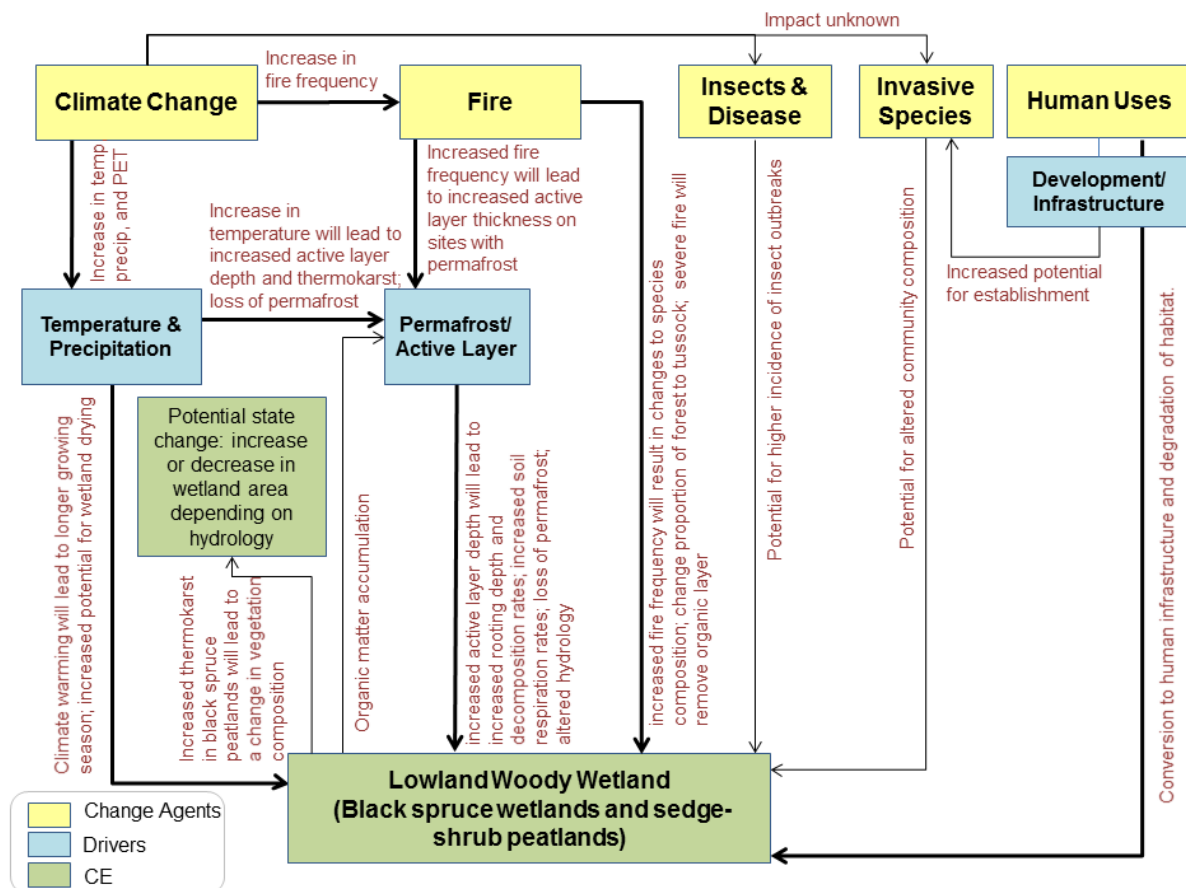


Figure G-34. Conceptual model for lowland woody wetland CE.

5.3 Abiotic Change Agents Analysis

Length of Growing Season and Summer Warmth Index

The length of growing season for lowland woody wetlands is projected to increase by 8.7 days between the current condition to the long-term future (from 161.7 to 170.4 days), and the SWI (annual sum of mean monthly temperatures that are above freezing) is projected to increase from 55 to 62 °C mo for the same time frame (Figure G-8, Figure G-30).

Temperature and Precipitation

Mean annual temperature for lowland woody wetlands is projected to increase by 2.0 °C between the current condition and the long-term future, while mean January temperature is expected to increase by 3.8 °C and mean July temperature is expected to increase by 1.5 °C (Table G-13).

Table G-13. Temperature summary for lowland woody wetland.

Lowland Woody Wetland	Mean July Temperature (°C)				Mean January Temperature (°C)				Mean Annual Temperature (°C)			
	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change
	16.1	16.1	17.6	+1.5	-21.8	-21.7	-18.3	+3.5	-3.8	-3.6	-1.6	+2.3

Mean annual precipitation is projected to increase by 39 mm between current and long-term future, with precipitation during the summer months increasing by 12 mm and winter months increasing by 13 mm (Table G-14).

Table G-14. Precipitation summary for lowland woody wetland.

Lowland Woody Wetland	Precipitation (mm)														
	Summer					Winter					Mean Annual				
	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change
	151	154	160	+9	+6	55	62	64	+9	+16	336	351	376	+40	+12

Fire and Vegetation Change

ALFRESCO currently predicts a decrease in black spruce forests, but the transitions critical to this CE—thermokarst and drought—are not yet active in the model.

Permafrost

According to ground temperature models developed by GIPL, 96% of the lowland woody wetland CE is underlain by permafrost under current conditions, and this is projected to decrease to 52% of the CE area by the long-term future (Table G-7).

Active layer thickness is currently estimated at 0.69-m thick across the portion of the CE currently underlain by permafrost, and this is projected to increase to 0.74 m where permafrost remains intact in the long-term future (Figure G-13).

According to the thermokarst predisposition model, 60% of the lowland woody wetland CE occurs on landscapes that are very highly predisposed to thermokarst (Figure G-14).

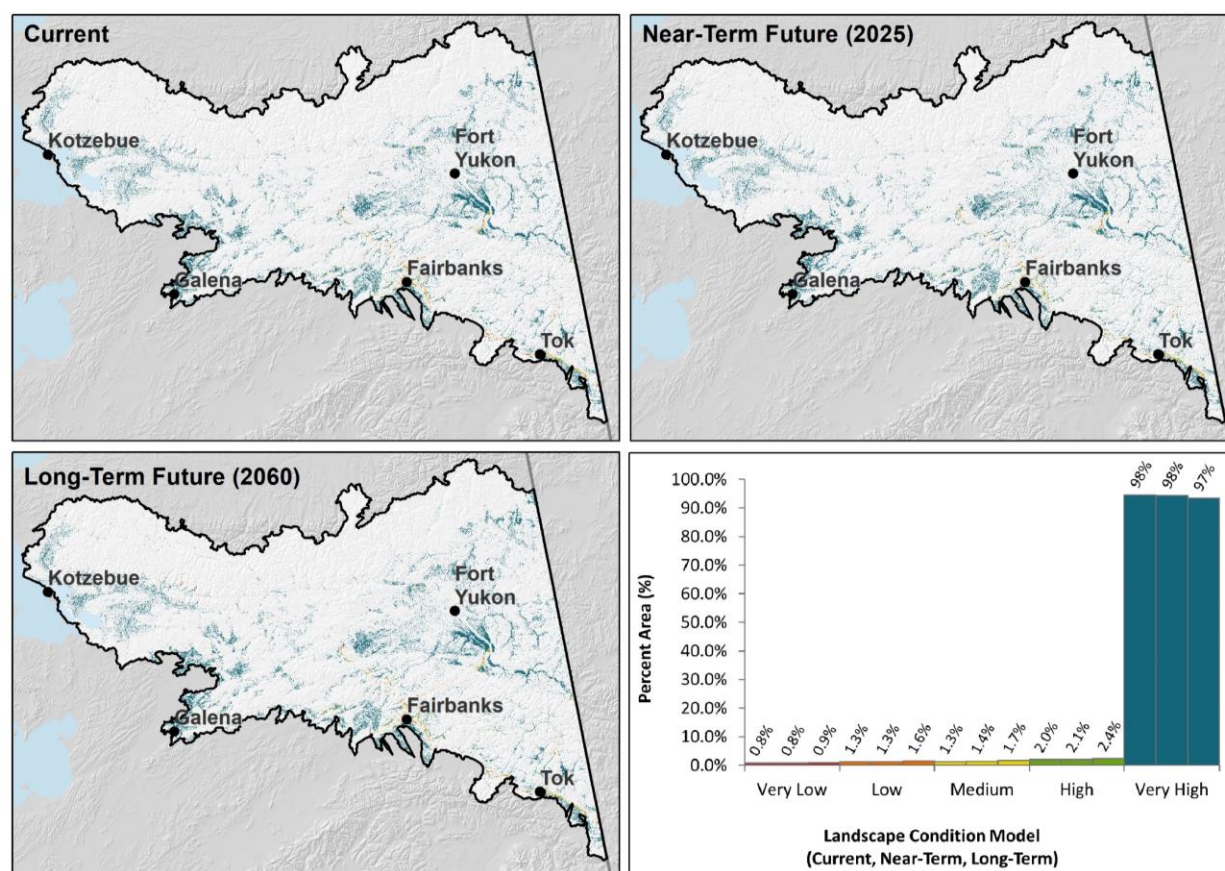
Abiotic Change Agents Discussion

As temperatures and growing season lengths increase, fire frequency and intensity are projected to increase. While shifts to deciduous dominance are predicted for drier upland spruce and spruce-hardwood forests, lowland spruce forests are expected to be more resistant to vegetation shifts due to their hydrology and species composition. Specifically, lowland forests tend to occur on poorly drained sites and often have a thick sphagnum layer. Sphagnum's efficient moisture retention properties make it resistant to combustion (Shetler et al. 2008) and the organic layer on sphagnum-rich sites is, thus, more resistant to deep burning (Kasischke et al. 2010). Shortened fire return intervals may prevent black spruce stands from reaching sexual maturity or even canopy dominance between burns (Johnstone 2006, Johnstone et al. 2010). Deciduous species are rare in these lowland communities, though, and without a seed source or mineral seedbed, widespread transition to deciduous-dominated forest is less likely than in upland forests.

Lowland woodlands and forests will be particularly vulnerable to permafrost degradation and thermokarst in coming decades. In lowland birch forests in the Tanana Flats, the loss of ice-rich permafrost has already resulted in the conversion of forests to wetlands (Jorgenson et al. 2001a, Jorgenson and Osterkamp 2005). Though initially small and localized, thermokarst wetlands can undergo lateral expansion, both slowly as a result of surface water-induced warming and more drastically as a result of fire feedbacks (Jorgenson and Osterkamp 2005, Myers-Smith et al. 2008, Jorgenson et al. 2010). However, permafrost degradation can also result in wetland drainage where hydrologic connectivity is increased through the formation of channels through the degrading permafrost or soil permeability is increased after the ice layer disappears (Jorgenson et al. 2001a, Jorgenson et al. 2013). These divergent thermokarst responses are largely influenced by soil texture and ice content, such that gravelly-sandy lowlands often undergo lake and wetland drainage, while peaty-silty lowlands generally develop thermokarst pits and form new wetlands (Jorgenson et al. 2013). Vegetation and surface water also generate feedback cycles, such that permafrost under late-successional forests is insulated against warming, while permafrost beneath standing water may degrade even if temperatures decrease (Jorgenson et al. 2010). The lowland woody wetland CE is, thus, likely to experience increases in thermokarst followed by vegetation transitions that may represent new successional trajectories resulting in either wetter or drier conditions depending on soil and ice characteristics.

Increases in summer surface temperatures without concomitant increases in growing season precipitation (Keyser et al. 2000) are expected to increase evapotranspiration rates, resulting in overall drier conditions even in these wetland settings. Our climate models suggest that precipitation on lowland CEs will increase the least, potentially subjecting the lowland woody wetland CE to moisture stress (Myers-Smith et al. 2008). Under drier conditions, black spruce tussock communities, which lack the protection afforded by thick peat layers, may be more vulnerable to the deciduous encroachment associated with increasing fire frequency. The combined effects of permafrost degradation, drought, and fire could even leave peatlands vulnerable to vegetation shifts (Turetsky et al. 2010, Kettridge et al. 2015).

5.4 Current Status and Future Landscape Condition



Current, near-term, and long-term landscape condition within the distribution of lowland woody wetland



Figure G-35. Current, near-term, and long-term status of lowland woody wetland in the CYR study area.

The overall status of the lowland woody wetland CE was assessed by intersecting the LCM with the CE distribution model for the current condition, near-term, and long-term future. The LCM is a way to measure the impact of the human footprint on a landscape. In the current condition, impacts on the lowland woody wetland CE are very low, with 95% of the area in the “very high” condition class; this proportion is expected to remain unchanged for the near-term future. The Alaska and Steese highways, use of alternative transport corridors (e.g., the Yukon and Tanana rivers), and the infrastructure near Fairbanks, account for most of the impacts to the current and near-term future landscape condition. In the long-term future, the area in the “very high” condition class is projected to drop to 93% as a result of addition and expansion of mining operations and the continued use of river roads, and, to a lesser degree, impacts from the Ambler and Nome roads, as well as expansion of North Slope Borough infrastructure (Figure G-35).

5.5 Literature Cited

- Boggs, K., and T. V. Boucher. 2008. Draft ecological systems descriptions for Alaska. In NatureServe. International Ecological Classification Standard: Terrestrial Ecological Classifications.
- 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. 190 pp.
- Duchesne, L. C., and B. C. Hawkes. 2000. Fire in northern ecosystems. Page 257 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. Ogden, Utah: USDA Forest Service, Rocky Mountain Research Station.
- FGDC. 2008. National vegetation classification standard, version 2. Federal Geographic Data Committee--Vegetation Subcommittee. FGDC-STD-005-2008 (Version 2).
- Johnstone, J. F. 2006. Response of boreal plant communities to variations in previous fire-free interval. *International Journal of Wildland Fire* 15:497–508.
- Johnstone, J. F., F. S. Chapin, III, T. N. Hollingsworth, M. C. Mack, V. Romanovsky, and M. Turetsky. 2010. Fire, climate change, and forest resilience in Interior Alaska. *Canadian Journal of Forest Research* 40:1302–1312.
- Jorgensen, T., and D. Meidinger. 2015. The Alaska Yukon region of the circumboreal vegetation map (CBVM). Conservation of Arctic Flora and Fauna (CAFF).
- Jorgenson, M. T., J. Harden, M. Kanevskiy, J. O'Donnell, K. Wickland, S. Ewing, K. Manies, Q. Zhuang, Y. Shur, R. Striegl, and J. Koch. 2013. Reorganization of vegetation, hydrology and soil carbon after permafrost degradation across heterogeneous boreal landscapes. *Environmental Research Letters* 8: 035017. Available: <http://iopscience.iop.org/1748-9326/8/3/035017>
- Jorgenson, M. T., and T. E. Osterkamp. 2005. Response of boreal ecosystems to varying modes of permafrost degradation. *Canadian Journal of Forest Research* 35:2100–2111.
- Jorgenson, M. T., C. H. Racine, J. C. Walters, and T. E. Osterkamp. 2001a. Permafrost degradation and ecological changes associated with a warming climate in Central Alaska. *Climatic Change* 48:551–579.
- Jorgenson, M. T., V. Romanovsky, J. Harden, Y. Shur, J. O'Donnell, E. A. G. Schuur, M. Kanevskiy, and S. Marchenko. 2010. Resilience and vulnerability of permafrost to climate change. *Canadian Journal of Forest Research* 40:1219–1236.
- Jorgenson, M. T., J. E. Roth, M. K. Reynolds, M. D. Smith, W. Lentz, A. L. Zusi-Cobb, and C. H. Racine. 2001c. An ecological land survey for Fort Wainwright, Alaska. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. CRREL TR-99-9. 92 pp.
- Jorgenson, M. T., J. E. Roth, M. D. Smith, S. Schlentner, W. Lentz, and E. R. Pullman. 2001b. An ecological land survey for Fort Greely, Alaska. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. ERDC/CRREL TR-01-04. 85 pp.
- Kasischke, E. S., D. L. Verbyla, T. S. Rupp, A. D. McGuire, K. A. Murphy, R. Jandt, J. L. Barnes, E. E. Hoy, P. A. Duffy, M. Calef, and M. R. Turetsky. 2010. Alaska's changing fire regime—implications for the vulnerability of its boreal forests. *Canadian Journal of Forest Research* 40:1313–1324.
- Kettridge, N., M. R. Turetsky, J. H. Sherwood, D. K. Thompson, C. A. Miller, B. W. Benscoter, M. D. Flannigan, B. M. Wotton, and J. M. Waddington. 2015. Moderate drop in water table increases peatland vulnerability to post-fire regime shift. *Scientific Reports* 5:doi:10.1038/srep08063.
- Keyser, A. R., J. S. Kimball, R. R. Nemani, and S. W. Running. 2000. Simulating the effects of climate change on the carbon balance of North American high-latitude forests. *Global Change Biology* 6:185–195.

- Myers-Smith, I. H., J. W. Harden, M. Wilmking, C. C. Fuller, A. D. McGuire, and F. S. Chapin, III. 2008. Wetland succession in a permafrost collapse: interactions between fire and thermokarst. *Biogeosciences* 5:1273–1286.
- Racine, C. H., L. A. Johnson, and L. A. Viereck. 1987. Patterns of vegetation recovery after tundra fires in northwestern Alaska, USA. *Arctic and Alpine Research* 19:461–469.
- Racine, C. H., M. T. Jorgenson, and J. C. Walters. 1998. Thermokarst vegetation in lowland birch forests on the Tanana Flats, Interior Alaska, USA. In *Proceedings of the 7th International Conference on Permafrost* 55:927-934.
- Shetler, G., M. R. Turetsky, E. Kane, and E. Kasischke. 2008. Sphagnum mosses limit total carbon consumption during fire in Alaskan black spruce forests. *Canadian Journal of Forest Research* 38:2328–2336.
- Turetsky, M. R., M. C. Mack, T. N. Hollingsworth, and J. W. Harden. 2010. The role of mosses in ecosystem succession and function in Alaska's boreal forest. *Canadian Journal of Forest Research* 40:10.1139/X10-072.
- Viereck, L. A., C. T. Dyrness, A. R. Batten, and K. J. Wenzlick. 1992. The Alaska vegetation classification. Portland, Oregon, USA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 278 pp.
- Wein, R. W. 1971. Panel discussion. *In* Slaughter, C. W., R. J. Barney, and G. M. Hansen, eds. *Fire in the northern environment – a symposium*. Sponsors: Alaska Forest Fire Council and Society of American Foresters. Held at: The University of Alaska, Fairbanks. April 13-14, 1971. Published by: Pacific Northwest Forest and Range Experiment Station.

6. Upland Mesic Spruce-hardwood Forest

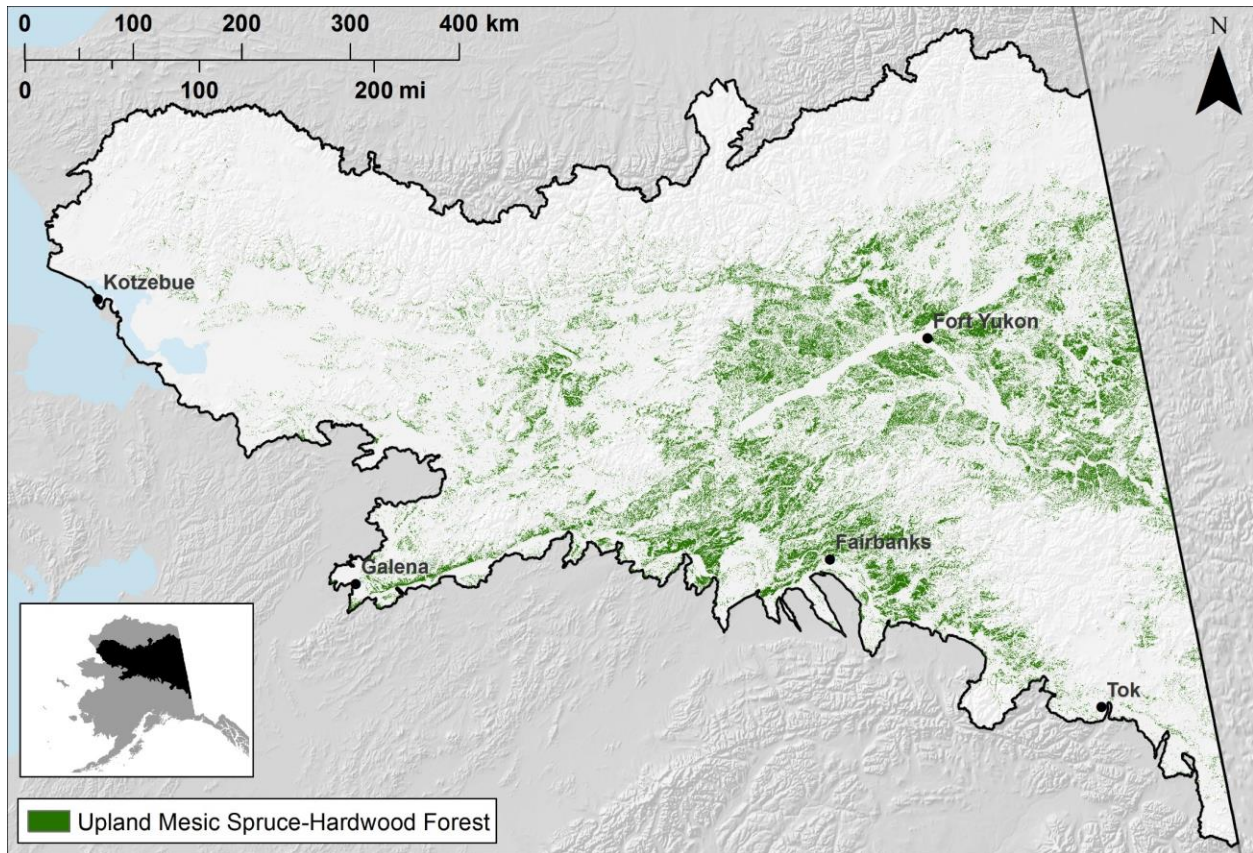


Figure G-36. Distribution map of the upland mesic spruce-hardwood forest CE.

6.1 Introduction

The upland mesic spruce-hardwood CE occurs from the southern slopes of the Brooks Range to Southcentral Alaska and west to the limit of tree growth (Figure G-36). Soils are well-drained and typically derived from glacial deposits, colluvium, ancient alluvium, or loess. This CE typically occurs on upland terrain to 750 m on all aspects but north. Permafrost is discontinuous in this CE (Jorgenson et al. 2008, Boggs and Boucher 2008, Jorgenson and Meidinger 2015).



Figure G-37. Upland mesic spruce-hardwood forest along the Yukon River. Photo by Mike Flemming.

Vegetation

Forests contain all post-fire seral stages including needle-leaved evergreen, broad-leaved deciduous or mixed (Figure G-37). Dominant canopy species include *Picea glauca*, *Betula neoalaskana*, and *Populus tremuloides*. Canopy cover typically ranges from 30%–80%. Mature stands are often open-canopied with a well-developed shrub layer. Common shrubs include *Alnus viridis* ssp. *fruticosa*, *Betula glandulosa*, *Rosa acicularis*, *Rhododendron tomentosum*, *Rhododendron groenlandicum*, *Salix glauca*, *Vaccinium vitis-idaea*, *Vaccinium uliginosum*, and *Linnaea borealis*. The herbaceous layer is sparse with low species diversity, but may include *Calamagrostis canadensis*, *Equisetum arvense*, *Equisetum sylvaticum*, *Gymnocarpium dryopteris*, *Pyrola* spp., and *Geocaulon lividum*. The most common moss is *Hylocomium splendens* (Viereck et al. 1992, Boggs and Sturdy 2005, Boggs and Boucher 2008).

Classification synonymy

The CE is equivalent in concept to NVC Group 579 Alaskan-Yukon Boreal Mesic White Spruce-Hardwood Forest (the mapped distribution may include G627 Alaskan-Yukon Boreal Moist White Spruce-Hardwood Forest, which occurs on moist, nutrient-rich sites but is uncommon in the northern boreal region; FGDC 2008), CBVM Vegetation level II Yukon Mixed Spruce-Birch-Aspen Forests (Jorgenson and Meidinger 2015), and Viereck classification IB1d/e/f, IB2a/b, IC1a/c/d, IC2a/b (Viereck et al. 1992).

Vegetation Succession

The disturbance regime is characterized by large, stand-replacing crown fires. Estimates of historic mean fire return intervals range 50–238 years (Rowe 1972, Heinselman 1981, Yarie 1981, Yarie 1983, Foote 1983, Duchesne and Hawkes 2000). Except in the case of severe fires, post-fire succession tends to return to the pre-disturbance forest type (Foote 1983). Pre-burn species colonize the site via rhizomes, root sprouts, and trunk sprouts, while pioneer species establish on newly exposed surfaces by seed. A typical successional sequence progresses from herbaceous, to shrub, then to hardwood/hardwood-spruce, and finally to spruce (Boggs and Boucher 2008). Individual seral stages are described below:

1. 0–4 years. Early-seral herbaceous forbs and grasses. A variety of herbaceous communities dominate in the years immediately following fire. The most common species are *Chamerion angustifolium* and *Calamagrostis canadensis*. Other herbaceous species can include *Equisetum sylvaticum*, *E. arvense*, *Geocaulon lividum*, *Mertensia paniculata*, and *Pyrola* spp. (Viereck et al. 1992). Shrubs and trees resprout from root stocks, but woody cover is low.
2. 5–29 years. Early-seral shrubs and saplings. Common shrub species include *Rosa acicularis*, *Viburnum edule*, *Betula nana*, *Rhododendron tomentosum*, *R. groenlandicum*, *Vaccinium vitis-idaea*, and *V. uliginosum* (Viereck et al. 1992). *Betula neoalaskana* and *Populus tremuloides* saplings are common on some sites.
3. 30–129 years. Mid-seral deciduous forest. This is predominantly a hardwood forest although conifers may be present and mixed with the hardwoods. Trees begin to shade out the shrub layer. The overstory dominants include *Betula neoalaskana* and *Populus tremuloides*. *Picea glauca* and *P. mariana* may be present. Common

understory species include *Rosa acicularis*, *Viburnum edule*, *Linnaea borealis*, *Chamerion angustifolium*, and *Geocaulon lividum*

4. 130+ years. Late-seral mature spruce forest. Hardwoods senesce. Accumulation of evergreen litter begins to change soil characteristics. *Picea glauca* dominates the overstory but *P. mariana* may be present. Common understory species include *Rosa acicularis*, *Viburnum edule*, *Vaccinium vitis-idaea*, *Linnaea borealis*, *Chamerion angustifolium*, and *Geocaulon lividum*.

6.2 Conceptual Model

The conceptual model below is based on literature review and describes the relationships among the various CAs and natural drivers for upland mesic spruce-hardwood Forest. Bold arrows indicate interactions with high ecological relevance and potential management implications, and for which spatial datasets can be intersected with the CE distribution. The primary CAs selected for this CE include climate change, permafrost, fire, and development (Figure G-38).

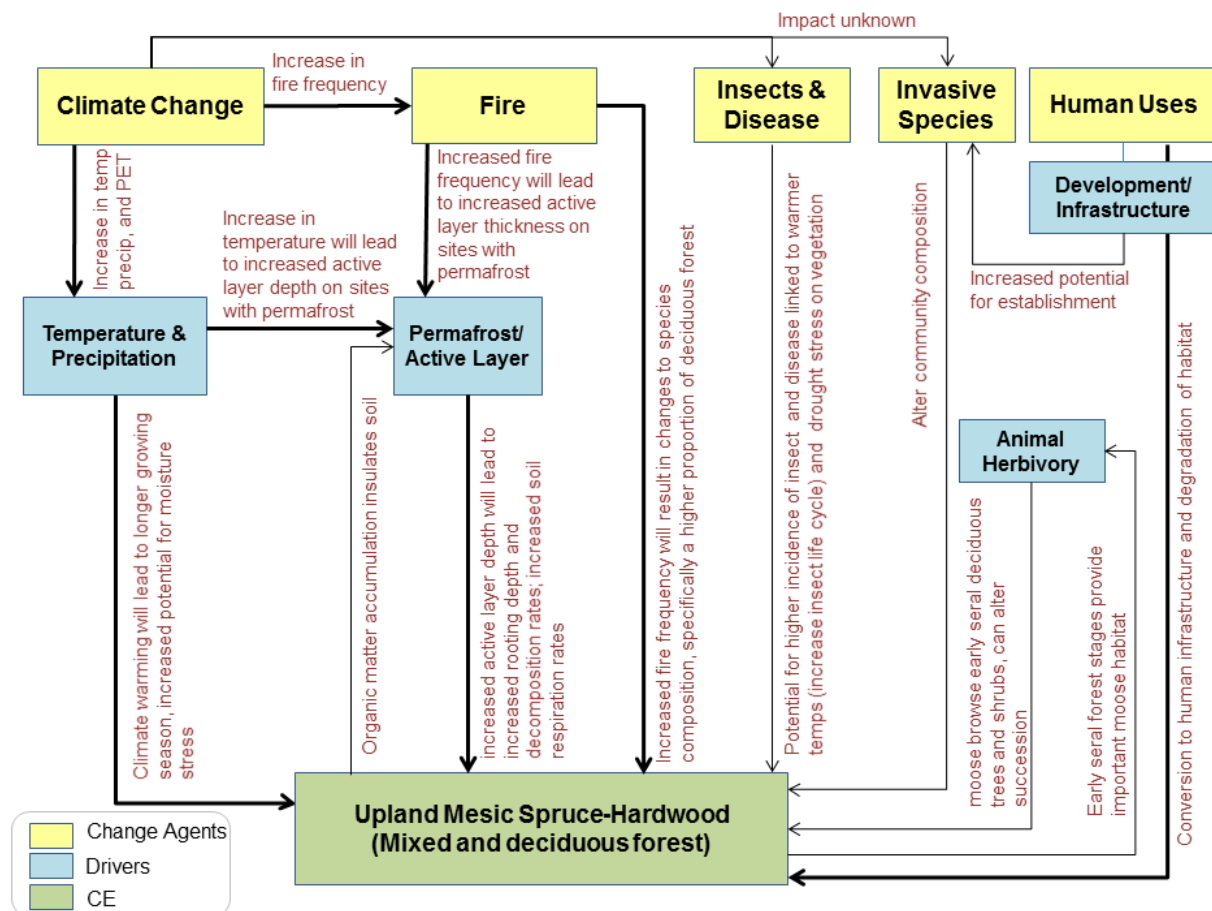


Figure G-38. Conceptual model for upland mesic spruce-hardwood forest.

6.3 Abiotic Change Agents Analysis

Length of Growing Season and Summer Warmth Index

The length of growing season for upland spruce-hardwood forests is projected to increase by 8.7 days between the current condition to the long-term future (from 163.9 to 172.6 days), and the Summer Warmth Index (annual sum of mean monthly temperatures that are above freezing) is projected to increase from 56 to 62 °C mo for the same time frame (Figure G-39).

Upland Mesic Spruce-Hardwood Forest

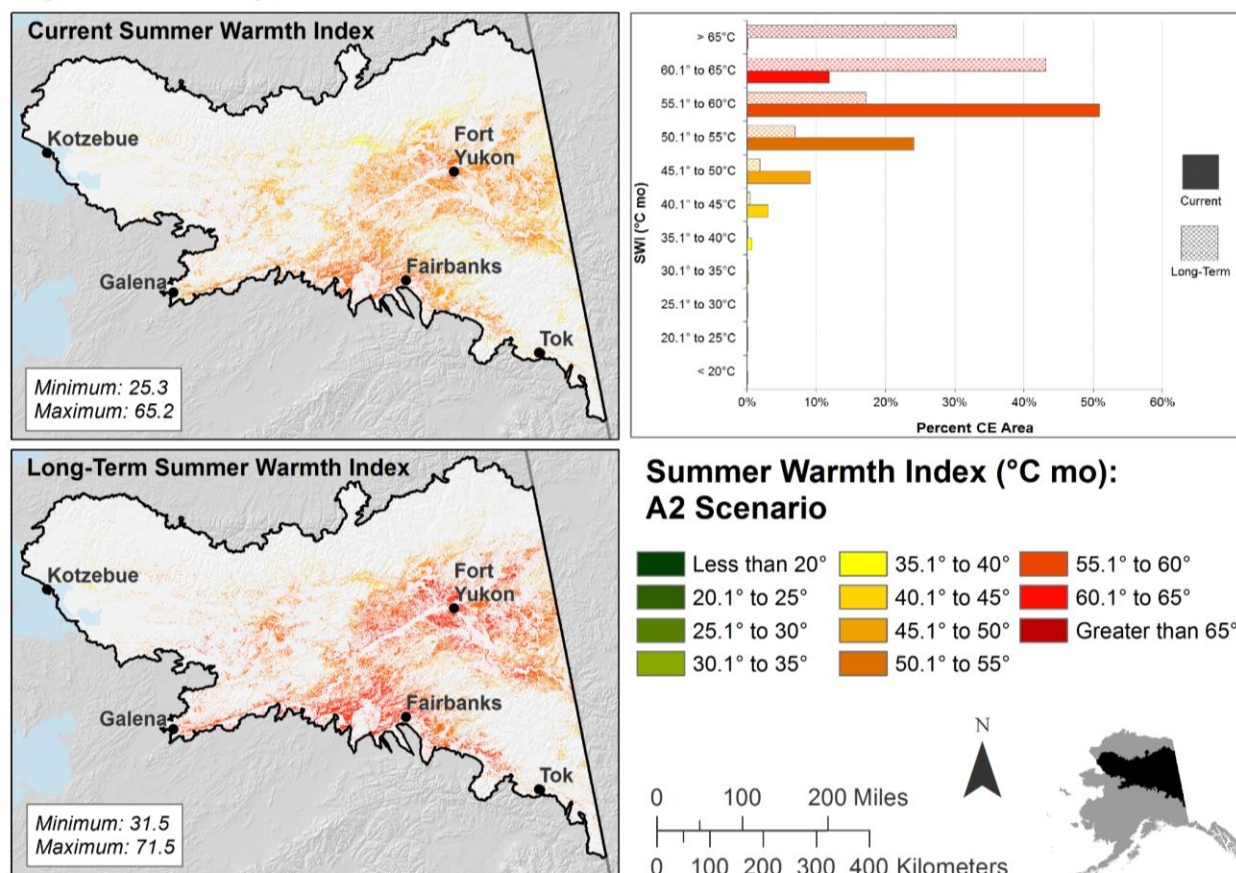


Figure G-39. Summer Warmth Index for upland mesic spruce hardwood forest for the current condition and long-term future.

Temperature and Precipitation

Mean annual temperature for upland mesic spruce-hardwood forests is projected to increase by 1.9 °C between the current condition and the long-term future, while mean January temperature is expected to increase by 3.9 °C and mean July temperature is expected to increase by 1.6 °C (Table G-15).

Table G-15. Temperature summary for upland mesic spruce-hardwood forests.

Upland Mesic Spruce-Hardwood Forest	Mean July Temperature (°C)				Mean January Temperature (°C)				Mean Annual Temperature (°C)			
	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change
	15.9	16.1	17.5	+1.5	-21.8	-20.1	-18.3	+3.5	-3.2	-3.0	-1.5	+1.7

Mean annual precipitation is projected to increase by 41 mm between the current condition and the long-term future, with precipitation during the summer months and winter months projected to increase by 12 and 15 mm, respectively (Table G-16).

Table G-16. Precipitation summary for upland mesic spruce-hardwood forests.

Upland Mesic Spruce-Hardwood Forest	Precipitation (mm)													
	Summer					Winter					Mean Annual			
	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	% Change
	164	168	174	+9	+6	59	65	69	+9	+16	362	378	403	+41

Fire and Vegetation Change

Averaged across the CYR study area, the proportion of deciduous forest relative to coniferous forest is projected to increase. Deciduous forest is projected to increase across all ecoregions, and black spruce is projected to decrease across all ecoregions, while the white spruce response varies by ecoregion (Figure G-20).

Permafrost

According to ground temperature models developed by GIPL, 96% of upland spruce-hardwood CE is underlain by permafrost under current conditions, and this is projected to decrease to 50% of the CE area by the long-term future (Table G-7).

Active layer thickness is currently estimated at 0.66-m thick across the portion of the CE currently underlain by permafrost, and this is projected to increase to 0.68 m where permafrost remains intact in the long-term future (Figure G-13).

According to the thermokarst predisposition model, 36% of the spruce-hardwood forest CE occurs on landscapes that are very highly predisposed to thermokarst (Figure G-14).

Abiotic Change Agents Discussion

Over the past several decades, temperatures and growing season length have increased in forests of Interior Alaska (Stafford et al. 2000, Soja et al. 2007, Mann et al. 2012). Our climate analyses suggest that this trend will continue, extending the growing season in upland spruce-hardwood forests by 8.7 days and increasing mean annual temperature by 1.5 °C by the 2060s.

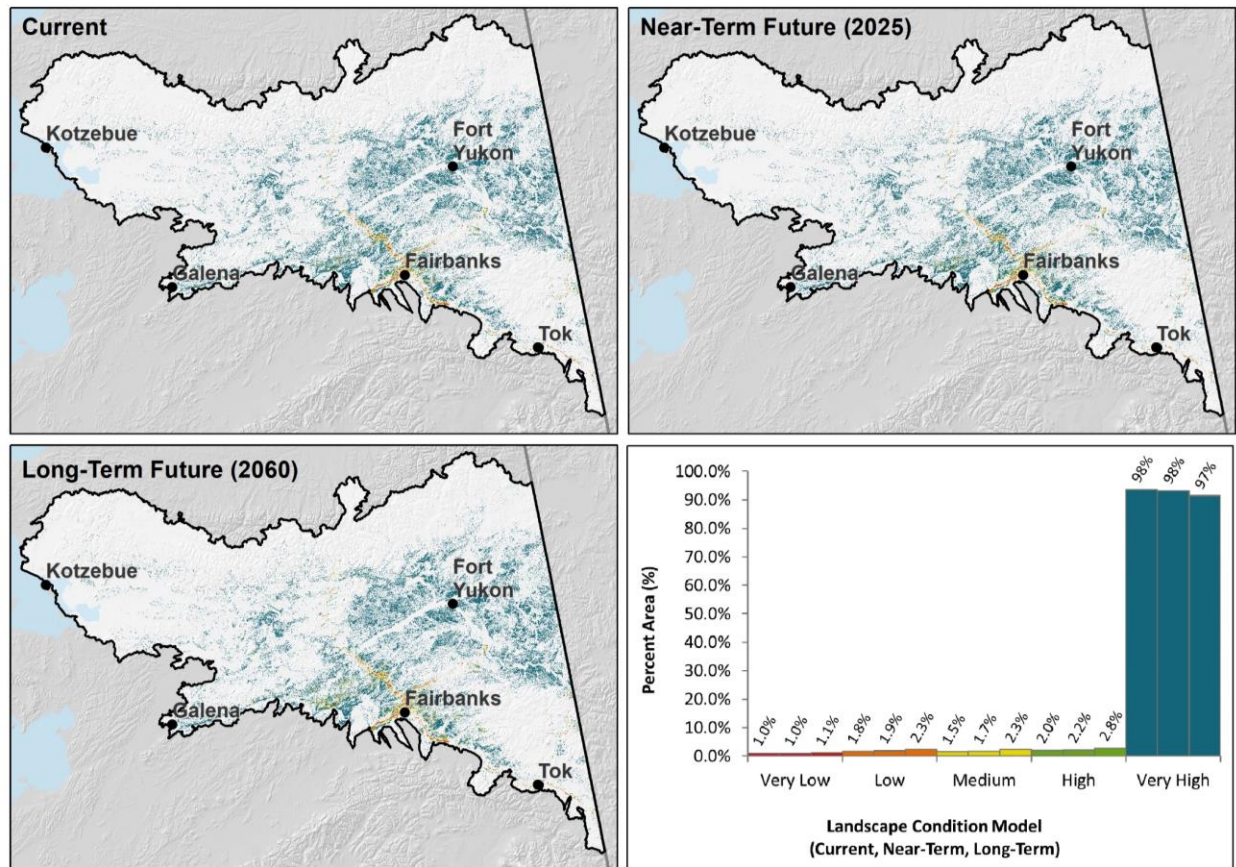
Climate warming is expected to promote fire frequency and severity via both warmer temperatures and more lightning-related ignitions resulting from increased convective activity associated with a warmer atmosphere (Soja et al. 2007). Predicted increases in precipitation could help offset the potential for increased fire activity; however, any increases in summer precipitation may be offset by increased evaporative demand, particularly at the peak of the growing season in June. It should also be noted that although the 5-model average predicts increasing precipitation in the region, to date, no increase in summer precipitation (May through August) has been realized for Interior Alaska (NOAA 2016). Similarly, long-term meteorological records from Alaska and northwest Canada showed that from 1950–2000 annual surface temperatures increased by approximately 2 °C, while growing season precipitation exhibited no apparent trend (Keyser et al. 2000).

Driven by warming summers, fire appears to already be increasing in frequency (Kelly et al. 2013) and severity (Genet et al. 2013), resulting in altered forest composition and processes (Wolken et al. 2011). Historical data, recent observations, and model simulations all suggest that increases in fire frequency may be mitigated, to some extent, by feedbacks between fire severity and forest composition (Johnstone et al. 2011, Mann et al. 2012, Kelly et al. 2013). Because deciduous vegetation is markedly less flammable than coniferous vegetation, a shift toward a higher proportion of deciduous vegetation can limit the spread of subsequent fires. Indeed, paleoclimatic data suggest that during the Medieval Climate Anomaly (MCA; ~1,000–5,000 ybp), warm and dry climatic conditions promoted an initial increase in fire frequency and severity, which in turn favored recruitment of deciduous species, ultimately resulting in a stable fire frequency during that period despite climatic conditions conducive to burning (Kelly et al. 2013). Modern increases in fire frequency and severity may already be causing a shift in the proportion of deciduous to coniferous forest in the boreal (Mann et al. 2012), but it remains unclear when or if these changes will feedback to stabilize area burned.

Warmer temperatures and extended growing seasons affect white spruce productivity and treeline advance, though the direction of response varies by region (Lloyd and Fastie 2003). For example, broad-scale geographic trends reveal increasing productivity at the tundra-forest ecotone but declining productivity in Interior Alaska (Beck et al. 2011). This regional divergence in productivity response was once thought to be a result of drought stress (Barber et al. 2000), or a growing season temperature threshold above which white spruce growth and productivity begin to decline (Baird et al. 2012). Recent evidence, however, suggests that neither temperature nor drought stress can explain the divergent growth pattern (Brownlee et al. 2016). Whatever the mechanism, widespread expansion of treeline throughout the boreal region is well-documented, however, it is expected to have a greater effect on spruce forests near treeline than on mid-elevation mixed forests.

Widespread loss of permafrost is also predicted for this CE, and active layer thickness is projected to increase by 2 cm where permafrost remains. Active layer depths for this CE, however, are already relatively thick—approximately 66 cm—and soils are generally well-drained to moderately well-drained, so the effects of permafrost loss are expected to be relatively small. Resultant increases in soil drainage could increase productivity on some sites, but may also allow for increased drought stress on south-facing or well-drained sites. We do not expect thermokarst or changes in active layer depth to substantially alter upland spruce-hardwood forests.

6.4 Current Status and Future Landscape Condition



Current, near-term, and long-term landscape condition within the distribution of upland mesic spruce-hardwood forest

Figure G-40. Current, near-term, and long-term status of upland mesic spruce-hardwood forest in the CYR study area.

The overall status of the upland mesic spruce hardwood forest CE was assessed by intersecting the LCM with the CE distribution model for the current condition, near-term, and long-term future. The LCM is a way to measure the impact of the human footprint on a landscape. In the current condition, impacts on the upland mesic spruce CE are very low, with 94% of the area in the “very high” condition class, and this proportion is expected to drop only by 1% for the near-term future. The highway system, alternative transport corridors (e.g., the Yukon and Tanana rivers), and small but impact-intense regions of placer mining account for most of the current and near-future impacts to this CE. In the long-term future, however, the proportion of the upland mesic spruce CE in the “very high” condition class is projected to fall to 91%, a loss of 3% (Figure G-40). Primary impacts in the long-term future are largely attributable to mining development, with additional

impacts from the Nome and Ambler roads, as well as expansion of alternative transportation infrastructure (e.g., river roads, trails, railroads). Development of infrastructure also increases the potential for establishment of invasive plant species.

6.5 Literature Cited

- Baird, R. A., D. Verbyla, and T. N. Hollingsworth. 2012. Browning of the landscape of Interior Alaska based on 1986-2009 Landsat sensor NDVI. *Canadian Journal of Forest Research* 42:1371–1382.
- Barber, V. A., G. P. Juday, and B. P. Finney. 2000. Reduced growth of Alaskan white spruce in the twentieth century from temperature-induced drought stress. *Letters to Nature* 405:668–673.
- Beck, P. S. A., G. P. Juday, C. Alix, V. A. Barber, S. E. Winslow, E. E. Sousa, P. Heiser, J. D. Herriges, and S. J. Goetz. 2011. Changes in forest productivity across Alaska consistent with biome shift. *Ecology Letters* 14:373–379.
- Boggs, K., and T. V. Boucher. 2008. Draft ecological systems descriptions for Alaska. In NatureServe. International Ecological Classification Standard: Terrestrial Ecological Classifications.
- 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. 190 pp.
- Brownlee, A. H., P. F. Sullivan, A. Z. Csank, B. Sveinbjörnsson, and S. B. Z. Ellison. 2016. Drought-induced stomatal closure probably cannot explain divergent white spruce growth in the Brooks Range, Alaska. *Ecology* 97:145–159.
- Duchesne, L. C., and B. C. Hawkes. 2000. Fire in northern ecosystems. Page 257 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. Ogden, Utah: USDA Forest Service, Rocky Mountain Research Station.
- FGDC. 2008. National vegetation classification standard, version 2. Federal Geographic Data Committee-Vegetation Subcommittee. FGDC-STD-005-2008 (Version 2).
- Foote, M. J. 1983. Classification, description, and dynamics of plant communities after fire in the taiga of Interior Alaska. Research Paper PNW-307. Portland, Oregon: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 108 pp.
- Genet, H., A. D. McGuire, K. Barrett, A. Breen, E. S. Euskirchen, J. F. Johnstone, E. S. Kasischke, A. M. Melvin, A. Bennett, M. C. Mack, and T. S. Rupp. 2013. Modeling the effects of fire severity and climate warming on active layer thickness and soil carbon storage of black spruce forests across the landscape in Interior Alaska. *Environmental Research Letters* 8:045016.
- Heinselman, M. L. 1981. Fire and succession in the conifer forests of northern North America. Chapter 23 in West, D. C., H. H. Shugart, and D. B. Botkin, eds. *Forest succession: concepts and application*. Springer-Verlag, New York.
- Johnstone, J. F., T. S. Rupp, T. S., M. Olson, and D. Verbyla. 2011. Modeling impacts of fire severity on successional trajectories and future fire behavior in Alaskan boreal forests. *Landscape Ecology* 26:487–500.
- Jorgenson, T., K. Yoshikawa, M. Kanevskyi, Y. Shur, V. Romanovsky, S. Marchenko, G. Grosse, J. Brown, and B. Jones. 2008. Permafrost characteristics of Alaska. Institute of Northern Engineering, University of Alaska Fairbanks, NICOP.
- Kelly, R., M. L. Chipman, P. E. Higuera, I. Stefanova, L. B. Brubaker, and F. S. Hu. 2013. Recent burning of boreal forests exceeds fire regime limits of the past 10,000 years. *PNAS* 110:13055-13060.
- Keyser, A. R., J. S. Kimball, R. R. Nemani, and S. W. Running. 2000. Simulating the effects of climate change on the carbon balance of North American high-latitude forests. *Global Change Biology* 6:185–195.
- Lloyd, A. H., and C. Fastie. 2003. Recent changes in treeline forest distribution and structure in Interior Alaska. *Ecoscience* 10:176–185.
- Mann, D. H., T. S. Rupp, M. A. Olson, and P. A. Duffy. 2012. Is Alaska's boreal forest now crossing a major ecological threshold? *Arctic, Antarctic, and Alpine Research* 44:319–331.

- National Centers for Environmental Information (NOAA). 2016. Climate at a glance. Climate Division 3, Central Interior. Available: <http://www.ncdc.noaa.gov/cag/>
- Rowe, J. S. 1972. Forest regions of Canada. Canadian Forest Service, Department of Environment. Ottawa. Information Canada Catalogue #FO 47-1300.
- Soja, A. J., N. M. Tchebakova, N. H. French, M. D. Flannigan, H. H. Shugart, B. J. Stocks, A. I. Sukhinin, E. I. Parfenova, F. S. Chapin, and P. W. Stackhouse. 2007. Climate-induced boreal forest change: predictions versus current observations. *Global and Planetary Change* 56:274–296.
- Stafford, J. M., G. Wendler, and J. Curtis. 2000. Temperature and precipitation of Alaska: 50 year trend analysis. *Theoretical Applications of Climatology* 67:33–44.
- Viereck, L. A., C. T. Dyrness, A. R. Batten, and K. J. Wenzlick. 1992. The Alaska vegetation classification. Portland, Oregon, USA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 278 pp.
- Volken, J. M., T. N. Hollingsworth, T. S. Rupp, F. S. Chapin, S. F. Trainor, T. M. Barrett, P. F. Sullivan, A. D. McGuire, E. S. Euskirchen, P. E. Hennon, and E. A. Beever. 2011. Evidence and implications of recent and projected climate change in Alaska's forest ecosystems. *Ecosphere* 2:1–35.
- Yarie, J. 1981. Forest fire cycles and life tables: a case study from Interior Alaska. *Canadian Journal of Forest Research* 11:554-562.
- Yarie, J. 1983. Forest community classification of the Porcupine River drainage, Interior Alaska, and its application to forest management. USDA Forest Service GTR PNW-154.

7. Upland Mesic Spruce Forest

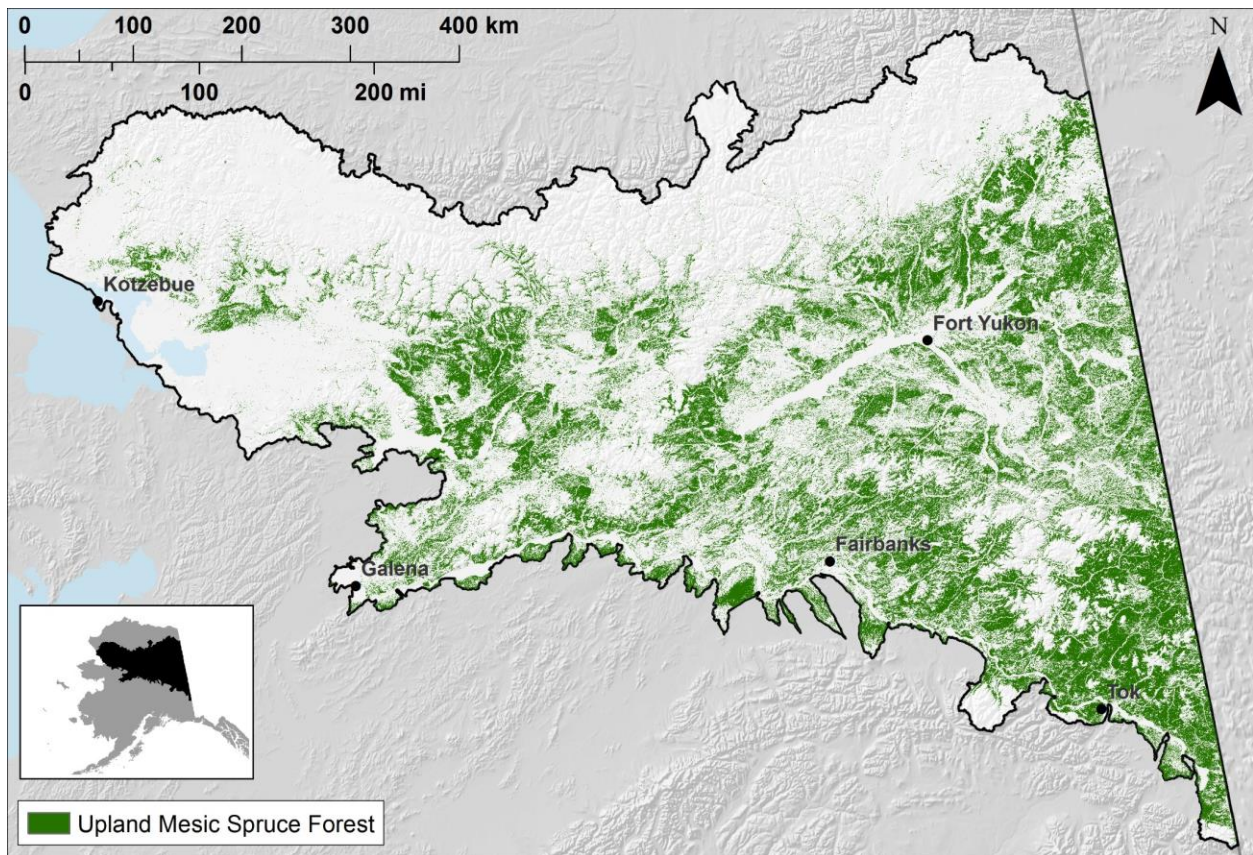


Figure G-41. Distribution map of the upland mesic spruce forest CE.

7.1 Introduction

The upland mesic spruce forest CE occurs throughout the boreal region of Alaska from the south slopes of the Brooks Range to the north slopes of the Alaska Range and west to the limit of conifer growth (Figure G-41). This CE often occurs near the limit of conifer growth, both near elevational treeline and near the western limit of coniferous forest (Figure G-42). The canopy is characterized by a woodland to open forest structure with a well-developed understory composed of low



Figure G-42. Upland mesic spruce forest in western Alaska. Photo by Mike Fleming

and dwarf shrubs. Because of mapping limitations, this CE includes both white and black spruce forests that occur on upland mesic slopes and inactive alluvial deposits. The range of *Picea glauca* extends beyond that of *Picea mariana*, and thus, *Picea glauca* is more likely to be the dominant tree near the limit of conifer growth. Soils are cold, gravelly, and well-drained with little to no peat development (Boggs and Boucher 2008). Permafrost is continuous to discontinuous.

Vegetation

In woodland forests near treeline, *Picea glauca* is generally the dominant conifer. Canopy cover is open to woodland in mature forests. Hardwoods do not make up a significant part of the canopy. The understory is typically a low shrub layer composed of *Betula nana*, *B. glandulosa*, *Vaccinium uliginosum*, *Rhododendron* spp., and *Salix pulchra*. Feathermoss, including *Hylocomium splendens* and *Pleurozium schreberi*, may be common in the ground layer. On drier or more exposed sites, *Cladina* spp. replace feathermosses as the dominant ground cover (Viereck 1979, Boggs and Boucher 2008).

On mesic sites dominated by *Picea mariana*, the canopy cover is generally open. Common understory species include *Alnus viridis* ssp. *fruticosa*, *Rhododendron groenlandicum*, *Rhododendron tomentosum*, *Vaccinium vitis-idaea*, *Empetrum nigrum*, *Rosa acicularis*, *Spiraea stevenii*, *Calamagrostis canadensis*, *Equisetum sylvaticum*, and *Cornus canadensis*. Common mosses include *Hylocomium splendens* and *Pleurozium schreberi*. Lichens, such as *Cladina* spp., may be abundant in later seral stages. Early successional stands may be dominated by *Betula neoalaskana* or *Populus tremuloides* (Foote 1983, Chapin, III et al. 2006, Boggs and Boucher 2008).

Classification Synonymy

This CE is similar in concept to CBVM Northern Alaska–Yukon Spruce Woodlands and Scrub, and CBVM Yukon Subalpine Spruce Woodlands and Scrub (Jorgenson and Meidinger 2015), NVC Macrogoup 179 North American Boreal Subalpine and Sub-Arctic Woodland and NVC Group 350 Alaskan-Yukon Boreal Mesic-Moist Black Spruce Forest, and Viereck IA1j/k (in part), IA2e/f/g, IA3c/e (Viereck et al. 1992).

Vegetation Succession

Potential successional pathways for both the white spruce and black spruce components of this type are described below:

Succession in white spruce treeline forests has not been well-documented. Post-fire succession likely begins with the resprouting of low shrubs from underground propagules followed by *Picea glauca* invading by seed from adjacent stands or surviving trees. *Betula neoalaskana* seeds may establish if a seed source is available and site conditions are favorable; however, the typical succession sequence for this type does not include a hardwood sere. The rate of succession depends on severity of fire and seed source, and some sites may be shrub-dominated for long periods without spruce invasion. Lichens, such as *Cladina* spp., recolonize the understory in the later stages of succession.

Post-fire succession in mesic black spruce forests has been widely documented. Crown fires or ground fires of enough intensity to kill overstory trees are the dominant disturbance influencing this type. Historic mean fire return intervals for black spruce forests in Interior Alaska have been

estimated at 25–130 years (Yarie 1983, Heinselman 1981, Viereck et al. 1983, Viereck et al. 1986).

Stages of succession in mesic black spruce forests can be characterized as follows:

1. Herbaceous grasses and forbs: 0–4 years post-fire herbaceous vegetation dominates the site. Common species include *Calamagrostis canadensis*, *Chamerion angustifolium* and *Equisetum* spp.
2. Shrub. 5–29 years post-fire, shrubs begin to dominate. Common species include *Salix* spp., *Betula nana*, *Ledum* spp., *Rosa acicularis*, *Vaccinium uliginosum*, *V. vitis-idaea*, and *Empetrum nigrum*. Both hardwood and spruce regeneration may be present, but on less severely burned sites where the organic layer remains intact, spruce regeneration is more common.
3. Mixed hardwood-spruce: 30–119 years after fire hardwoods and conifers overtop the shrub canopy. *Betula neoalaskana* is the dominant hardwood on mesic sites, but *Populus tremuloides* is more common on drier sites (Foote 1983, Chapin, III et al. 2006). Spruce may occur as an understory, subdominant and/or codominant component. As this stage advances, both spruce and feather moss become more important. If the regeneration in stage 2 was dominated by spruce, the mixed hardwood-spruce stage can be bypassed.
4. Spruce forest and woodland: 120+ years after fire, the system is characterized by open-canopied, old-growth *Picea mariana* (*Picea glauca* may be co-dominant on some sites). Spruce gains dominance over hardwoods (if previously present). Tree canopy at this stage is generally less than 60% and maybe less than 25% depending on site conditions. Occasional hardwoods may remain. The understory may include various combinations of tall shrubs, low shrubs, herbs, mosses, and lichens. If fire is absent for long periods, paludification may occur, resulting in an opening of the tree canopy to woodland conditions (Boggs and Boucher 2008).

7.2 Conceptual Model

The conceptual model below is based on literature review and describes the relationships among the various CAs and natural drivers for upland mesic spruce-hardwood forest. Bold arrows indicate interactions with high ecological relevance and potential management implications, and for which spatial datasets can be intersected with the CE distribution. The primary CAs selected for this CE include climate change, permafrost, fire, and development (Figure G-43).

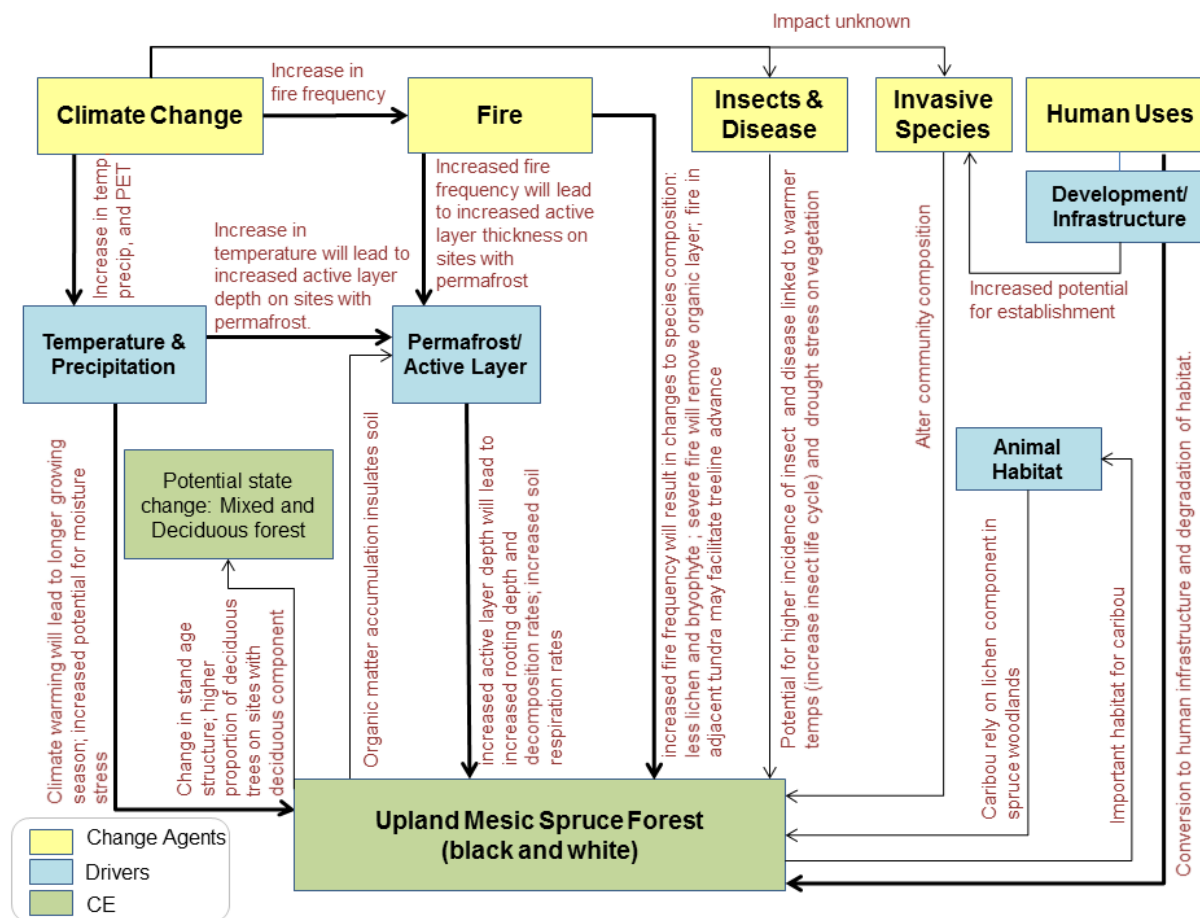


Figure G-43. Conceptual model for upland mesic spruce forest.

7.3 Abiotic Change Agents Analysis

Length of Growing Season and Summer Warmth Index

The length of growing season for upland spruce forests is projected to increase by 8.9 days between the current condition to the long-term future (from 162.4 to 171.3 days), and the mean SWI (annual sum of mean monthly temperatures that are above freezing) is projected to increase from 53 to 60 °C mos for the same time frame (Figure G-44).

Upland Mesic Spruce Forest

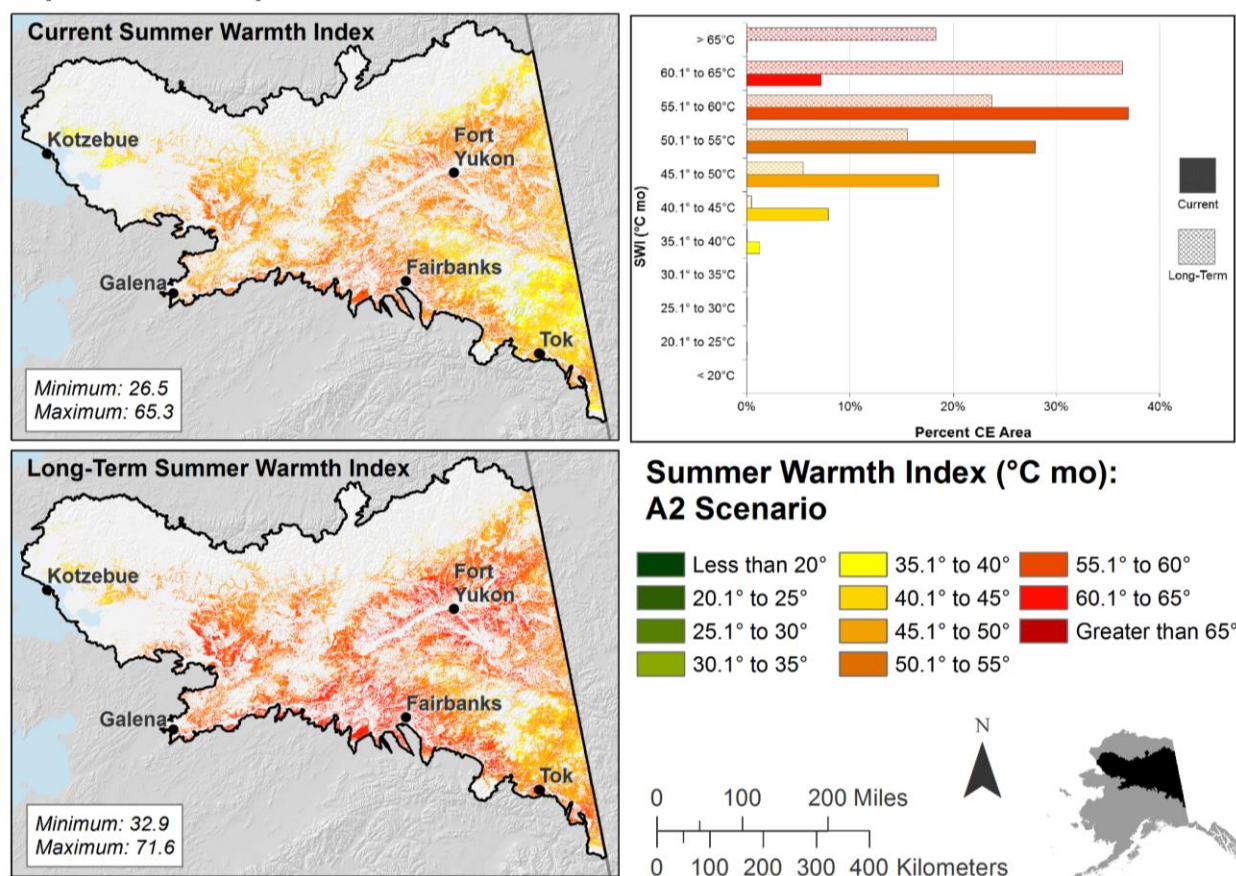


Figure G-44. Summer Warmth Index for upland mesic spruce forest for the current condition and long-term future.

Temperature and Precipitation

Mean annual temperature for upland spruce forests is projected to increase by 1.9 °C between the current condition and the long-term future, while mean January temperature is expected to increase by 3.8 °C and mean July temperature is expected to increase by 1.5 °C (Table G-17).

Table G-17. Temperature summary for upland spruce forests.

Upland Mesic Spruce Forests	Mean July Temperature (°C)				Mean January Temperature (°C)				Mean Annual Temperature (°C)			
	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change
	15.5	15.6	17.0	+1.5	-21.5	-20.4	-18.0	+3.5	-3.5	-3.3	-1.5	+1.9

Mean annual precipitation is projected to increase by 42 mm between the current condition and the long-term future, with precipitation during the summer months and winter months increasing by 12 and 14 mm, respectively (Table G-18).

Table G-18. Precipitation summary for upland spruce forests.

Upland Mesic Spruce Forest	Precipitation (mm)														
	Summer					Winter					Mean Annual				
	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change
	173	177	182	+9	+5	58	65	68	+9	+16	374	389	415	+42	+11

Fire and Vegetation Change

The ALFRESCO model shows white spruce colonization of tundra (Figure G-23) and increases in white spruce canopy cover in two ecoregions by 2060 (Davidson Mountains and Kotzebue Sound Lowlands), but the overall trend is for decreasing white spruce in the future. While white spruce distribution is expanding at treeline, the increase in fire frequency and area burned contributes to the conversion of spruce to deciduous forest. Within the ALFRESCO model, it appears that some of the gain in white spruce at treeline has been converted to deciduous forest.

Black spruce is decreasing across all ecoregions as a result of increased fire.

Permafrost

According to ground temperature models developed by GIPL, 96% of upland mesic spruce CE is underlain by permafrost under current conditions (2010s), and this is projected to decrease to 55% of the CE area by the 2060s (Table G-7).

Active layer thickness is currently estimated at 66 cm thick across the portion of the CE currently underlain by permafrost, and this is projected to increase to 69 cm where permafrost remains intact in the long-term future (Figure G-13).

According to the thermokarst predisposition model, 34% of the CE area occurs on terrain that is very highly predisposed to thermokarst (Figure G-14).

Abiotic Change Agents Discussion

Due to mapping limitations, the upland mesic spruce CE includes both white and black spruce forests that occur on upland slopes and inactive alluvial deposits. Increases in temperature and growing season length are expected to alter the distribution of spruce on the landscape. An increase in fire frequency and severity is predicted to shift forest composition toward deciduous forest at the expense of both black and white spruce. Substantial changes to permafrost extent—driven by both temperature increases and fire—are also predicted across the upland mesic spruce CE. Because of differences in community composition, site characteristics, and secondary successional processes between white spruce and black spruce forest types, we discuss separately the specific implications of these CAs on each forest type below.

White Spruce Treeline Forests

Because the range of *Picea glauca* extends beyond that of *P. mariana*, white spruce forests generally dominate at treeline sites north of the Alaska Range and west to the limit of conifer growth. Altered climate conditions and fire regimes are expected to promote both expansion of

spruce forest into tundra and to conversion of spruce forest to deciduous forest. Numerous studies have predicted a widespread expansion of treeline throughout the boreal (e.g., Suarez et al. 1999, Lloyd and Fastie 2003), and our ALFRESCO results specifically predict colonization of tundra by white spruce forests in the Davidson Mountains and Kotzebue Sound Lowlands. There, the modeled summer warmth indices and July isotherms are predicted to exceed the Arctic treeline threshold values of 35 °C mo and 12 °C, respectively (Beck et al. 2011). However, increases in fire frequency and area burned are also expected to catalyze a conversion of mesic spruce forest to deciduous forest (Mann et al. 2012, Kelly et al. 2013). Near treeline, however, deciduous species are less common and post-fire succession usually does not include a deciduous sere (Viereck 1979). Therefore, self-replacement by spruce and resprouting of woody plants from below-ground tissues may be a more likely response to fire than conversion to deciduous forest, particularly in the absence of a deciduous seed source. A shortened fire regime will alter understory composition even in the self-replacement successional model.

Ecologically important lichens associated with late successional stages of boreal forest development, such as *Cladina* spp., require long periods of recovery following removal by fire (Klein 1982, Viereck and Schandelmeier 1980, Jandt et al. 2008). These lichens rely on well-developed organic layers for protection and moisture retention, and mineral soil exposure and nutrient enrichment facilitates vascular species encroachment (Jandt et al. 2008). Thus, the lichens associated with late-seral spruce forests are also likely to decline with increased fire frequency, organic layer thinning, and increased active layer depth.

Our findings, in conjunction with a substantial body of existing literature, suggest a highly complex relationship between white spruce growth and climatic variables, characterized by non-linearity and variability across space and time, making prediction of decadal-scale responses difficult (D'Arrigo et al. 2004, Lloyd 2005, Lloyd et al. 2013). Such non-linear responses to climate warming were initially thought to arise from moisture stress (e.g., Barber et al. 2000, Wilmking and Juday 2005) but recent analysis suggests that neither drought nor temperature can sufficiently explain this phenomenon (Brownlee et al. 2016). Though the mechanisms of the white spruce growth-climate relationship are not fully understood, it is well-established that ideal growth conditions for white spruce (i.e., cool wet summers) are becoming increasingly rare in the Interior. In response, white spruce in drought-prone regions of the Interior are likely to undergo short-term productivity declines and a long-term contraction to the cooler, moister parts of its range (Lloyd et al. 2013). Though more western treeline white spruce forests may not be subjected to the same detrimental summer conditions as Interior forests, their continued expansion into the highly exposed and poorly drained tundra will likely be contingent upon the creation of well-drained microsites as a result of permafrost degradation (Suarez et al. 1999, Lloyd 2005).

Further adding to the complexity is the variable relationship between permafrost and white spruce. Predicted changes to climate and fire regimes are already catalyzing permafrost loss and increasing active layer depths. Specifically, shorter fire-return intervals and increased late-season burning reduce post-fire organic layer thickness, which in turn decreases albedo and increases the amount of heat flowing through the active layer into the permafrost (Yoshikawa et al. 2002). Our ground temperature models predict that the percent of the upland spruce CE underlain by permafrost will decrease from 96% to 55% by the 2060s, and that active layer depth will increase by 3 cm where permafrost remains intact. Depending on site hydrology, soil texture, and

landscape position, permafrost degradation can take many forms, and each has unique ecological consequences for the post-disturbance community type (Jorgenson and Osterkamp 2005). Predicting the net effect of permafrost degradation on upland white spruce forests is, thus, quite difficult. Permafrost loss and associated increases of active layer depth may promote the transition from spruce to deciduous forests by modifying abiotic site conditions in a way that favors deciduous species—specifically, by creating well-drained, nutrient-enriched sites. This trend will be particularly pronounced when combined with fire. Additionally, permafrost degradation may facilitate localized encroachment of white spruce into tussock tundra (Lloyd et al. 2003, Lloyd 2005). Though such treeline advances occur on relatively small, localized scales, fire can also promote lateral expansion of thermokarst features, such that widespread permafrost degradation and/or positive feedbacks between permafrost and fire may interact to affect larger-scale treeline advance.

Our ALFRESCO results show that overall losses of white spruce forest to deciduous forest by 2060 will outweigh the expansion of white spruce into tundra; however, the model does not include a self-replacement successional pathway for conifers after fire, and thus, treeline spruce forests are reset to deciduous forest after burning. Though deciduous seed sources are scarce at treeline, making such a seemingly unlikely transition, aspen has replaced spruce after fire as the dominant woody species at least in some sites (Lloyd and Fastie 2014). Post-fire succession in treeline white spruce forests is thought to proceed via an initial re-sprouting of shrubs followed by encroachment of white spruce, without an intermediate hardwood sere, post-fire succession in white spruce treeline forests is poorly studied. Thus far, no studies have successfully disentangled the complex interactions between climatic and non-climatic (e.g., fire, permafrost) variables on treeline advance. Some have even suggested that the presence and expansion of tall shrubs at treeline could act to limit treeline spruce establishment and thereby inhibit treeline expansion (Fastie and Lloyd 2014). From what we do know, white spruce growth exhibits non-linear relationships with a variety of abiotic factors, and post-fire responses among treeline communities are likely to vary by region and by site (Lloyd et al. 2013).

Mesic Black Spruce Forests

Upland mesic to moist black spruce forests generally occur on cold, moderately well-drained sites and on north-facing slopes to treeline. They typically have shallower organic layers than their lowland peatland counterparts, though moss cover may be high. Larger late-season fires and deeper burning of organic layers leave mesic black spruce forests particularly vulnerable to the predicted changes in climate and fire regime. Post-fire succession in mesic black spruce forests has been widely documented, and fires intense enough to kill overstory trees historically occur every 25–130 years (Heinselman 1981, Foote 1983, Yarie 1983, Viereck 1983, Viereck et al. 1986). Post-fire community composition is largely determined by the initial composition of recruited seedlings. After fire, forest composition either passes through a mixed deciduous-conifer stage before black spruce regains dominance, or, on moist sites with organic surface layers, composition returns to black spruce without passing through a mixed stage. This self-replacement successional pathway is common on moist sites subjected to low-severity fire, where the organic layer remains more or less intact.

The area of late season burns on well-drained black spruce sites has increased, removing more of the organic layer and exposing mineral soil, providing favorable conditions for the recruitment of deciduous seedlings (Kasischke et al. 2010, Johnstone et al. 2010b), and facilitating the shift toward forest composition dominated by deciduous species. Severe fires can disrupt the traditional post-fire successional trajectories that result in a return to the pre-disturbance forest type. More severe fires reduce surface organic layer depth creating seedbed conditions that favor the establishment of deciduous seedlings over coniferous seedlings (Johnstone et al. 2010a, Hollingsworth et al. 2013). Indeed, the proportion of coniferous to deciduous vegetation in mesic spruce forests may already be increasing (Johnstone et al. 2010a, Mann et al. 2012).

As fire frequency increases, black spruce seed sources may become less abundant because black spruce stands will have less time to reach maturity before the next fire. Forest type conversion to deciduous species or white spruce will further reduce black spruce seed supply (Johnstone 2006, Kurkowski et al. 2008). Some studies have already found evidence of white spruce recruitment exceeding that of black spruce on legacy black spruce sites (Wirth et al. 2008).

7.4 Current Status and Future Landscape Condition

The overall status of the upland mesic spruce forest CE was assessed by intersecting the LCM with the CE distribution model for the current condition, near-term, and long-term future. In the current condition, 93% of the floodplain forest and shrub area falls in the “very high” condition class, and this proportion is not projected to change in the near-term future. As in the upland mesic spruce-hardwood forest CE, the highway system, alternative transport corridors (e.g., the Yukon and Tanana rivers), and small but impact-intense regions of placer mining account for impacts to the current and near-term future landscape condition. However, in the long-term future, only 91% of this CE is predicted to fall within the “very high” condition class, owing to the projected development of the Ambler mining district and, to a lesser degree, its associated infrastructure. Development of this infrastructure and expansion of human habitation will impact this CE directly by removing habitat; however, development also causes indirect effects, including changes to the natural fire regime around infrastructure and houses through fire suppression and fuel treatments. Development of infrastructure also increases the potential for establishment of invasive plant species. The proposed road path can be seen in the 2060 panel of Figure G-45 as a thin band of green, yellow, and orange, and the proposed mining sites can be seen to its north as red dots.

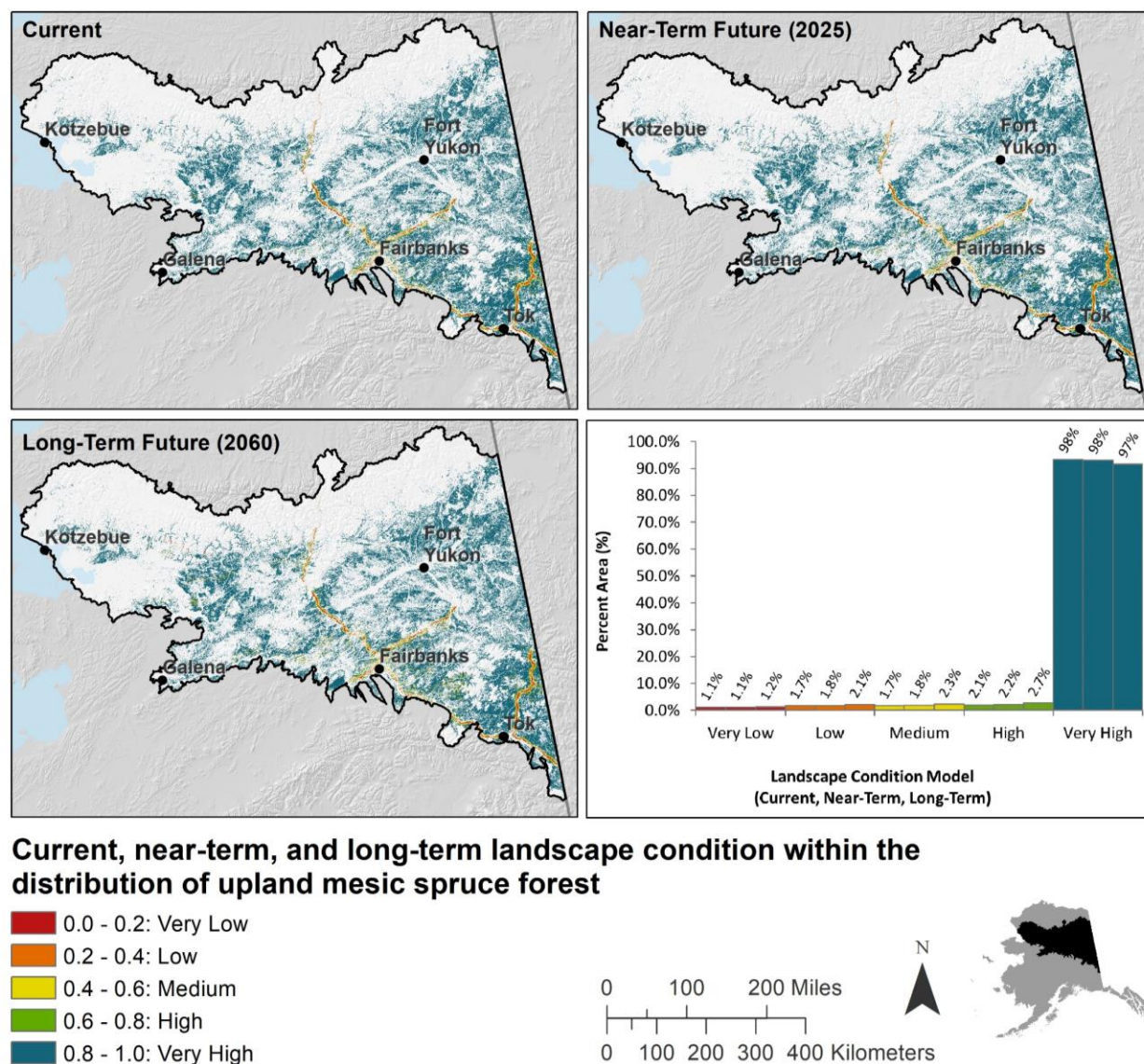


Figure G-45. Current, near-term, and long-term status of upland mesic spruce forest in the CYR study area.

7.5 Literature Cited

- Barber, V. A., G. P. Juday, and B. P. Finney. 2000. Reduced growth of Alaskan white spruce in the twentieth century from temperature-induced drought stress. *Letters to Nature* 405:668–673.
- Beck, P. S. A., G. P. Juday, C. Alix, V. A. Barber, S. E. Winslow, E. E. Sousa, P. Heiser, J. D. Herriges, and S. J. Goetz. 2011. Changes in forest productivity across Alaska consistent with biome shift. *Ecology Letters* 14:373–379.
- Boggs, K., and T. V. Boucher. 2008. Draft ecological systems descriptions for Alaska. In NatureServe. International Ecological Classification Standard: Terrestrial Ecological Classifications.
- Brownlee, A. H., P. F. Sullivan, A. Z. Csank, B. Sveinbjörnsson, and S. B. Z. Ellison. 2016. Drought-induced stomatal closure probably cannot explain divergent white spruce growth in the Brooks Range, Alaska. *Ecology* 97:145–159.
- Chapin, III, F. S., M. W. Oswood, K. Van Cleve, L. A. Viereck, and D. Verbyla. 2006. *Alaska's changing boreal forest*. Oxford University Press, New York.
- D'Arrigo, R. D., R. K. Kaufmann, N. Davi, G. C. Jacoby, C. Laskowski, R. B. Myneni, and P. Cherubini. 2004. Thresholds for warming-induced growth decline at elevational treeline in the Yukon Territory, Canada. *Global Biogeochemical Cycles* 18: 10.1029/2004GB002249.
- Fastie, G., and A. H. Lloyd. 2014. Effect of shrub cover on spruce seedling establishment at and above alpine treeline in the Alaska Range. In *AGU Fall Meeting Abstracts*. Vol. 1, p. 0682.
- Foote, M. J. 1983. Classification, description, and dynamics of plant communities after fire in the taiga of Interior Alaska. Research Paper PNW-307. Portland, Oregon: USDA Forest Service, Pacific Northwest Forest and Range Experiment Station. 108 pp.
- Heinselman, M. L. 1981. Fire and succession in the conifer forests of northern North America. Chapter 23 in West, D. C., H. H. Shugart, and D. B. Botkin, eds. *Forest succession: concepts and application*. Springer-Verlag, New York.
- Hollingsworth, T. N., J. F. Johnstone, E. L. Bernhardt, and F. S. Chapin, III. 2013. Fire severity filters regeneration traits to shape community assembly in Alaska's boreal forest. *PLoS One* 8:1–11.
- Jandt, 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 disturbance factors. *Arctic, Antarctic, and Alpine Research* 40:89–95.
- Johnstone, J. F. 2006. Response of boreal plant communities to variations in previous fire-free interval. *International Journal of Wildland Fire* 15:497–508.
- Johnstone, J. F., F. S. Chapin, III, T. N. Hollingsworth, M. C. Mack, V. Romanovsky, and M. Turetsky. 2010b. Fire, climate change, and forest resilience in Interior Alaska. *Canadian Journal of Forest Research* 40:1302–1312.
- Johnstone, J. F., T. N. Hollingsworth, F. S. Chapin, III, and M. C. Mack. 2010a. Changes in fire regime break the legacy lock on successional trajectories in Alaskan boreal forest. *Global Change Biology* 16:1281–1295.
- Jorgenson, M. T., and D. Meidinger. 2015. The Alaska Yukon region of the circumboreal vegetation map (CBVM). CAFF Strategies Series Report. Conservation of Arctic Flora and Fauna, Akureyri, Iceland.
- Jorgenson, M. T., and T. E. Osterkamp. 2005. Response of boreal ecosystems to varying modes of permafrost degradation. *Canadian Journal of Forest Research* 35:2100–2111.
- Kasischke, E. S., D. L. Verbyla, T. S. Rupp, A. D. McGuire, K. A. Murphy, R. Jandt, J. L. Barnes, E. E. Hoy, P. A. Duffy, M. Calef, and M. R. Turetsky. 2010. Alaska's changing fire regime—implications for the vulnerability of its boreal forests. *Canadian Journal of Forest Research* 40:1313–1324.
- Kelly, R., M. L. Chipman, P. E. Higuera, I. Stefanova, L. B. Brubaker, and F. S. Hu. 2013. Recent burning of boreal forests exceeds fire regime limits of the past 10,000 years. *PNAS* 110:13055–13060.
- Klein, D. R. 1982. Fire, lichens, and caribou. *Journal of Range Management* 35:390–395.

- Kurkowski, T. A., D. H. Mann, T. S. Rupp, and D. L. Verbyla. 2008. Relative importance of different secondary successional pathways in an Alaskan boreal forest. *Canadian Journal of Forest Research* 38:1911–1923.
- Lloyd, A. H. 2005. Ecological histories from Alaskan treeline sites provide insight into future change. *Ecology* 86:1687–1695.
- Lloyd, A. H., P. A. Duffy, and D. H. Mann. 2013. Nonlinear responses of white spruce growth to climate variability in Interior Alaska. *Canadian Journal of Forest Research* 43:331–343.
- Lloyd, A. H., and C. Fastie. 2003. Recent changes in treeline forest distribution and structure in Interior Alaska. *Ecoscience* 10:176–185.
- Lloyd, A. H., and C. L. Fastie. 2014. Patterns of twentieth century treeline advance in Alaska: insights from dendrochronology and permanent plot studies. *AGU Fall Meeting Abstracts*. Vol. 1.
- Lloyd, A. H., K. Yoshikawa, C. L. Fastie, L. Hinzman, and M. Fraver. 2003. Effects of permafrost degradation on woody vegetation at Arctic treeline on the Seward Peninsula, Alaska. *Permafrost and Periglacial Processes* 14:93–101.
- Mann, D. H., T. S. Rupp, M. A. Olson, and P. A. Duffy. 2012. Is Alaska's boreal forest now crossing a major ecological threshold? *Arctic, Antarctic, and Alpine Research* 44:319–331.
- Suarez, F., D. Binkley, M. W. Kaye, and R. Stottlemeyer. 1999. Expansion of forest stands into the tundra in Noatak National Preserve, northwest Alaska. *Ecoscience* 6:465–470.
- Viereck, L. A. 1979. Characteristics of treeline plant communities in Alaska. *Holarctic Ecology* 2:228–238.
- Viereck, L. A. 1983. The effects of fire in black spruce ecosystems of Alaska and northern Canada. Pages 210–220 in Wein, R. W., and D. A. MacLean, eds. *The role of fire in northern circumpolar ecosystems*. Wiley, New York.
- Viereck, L. A., K. Van Cleve, and C. T. Dyrness. 1986. Forest ecosystem distribution in the taiga environment. Pages 22–43 in Van Cleve, K., F.S. Chapin, III, P. W. Flanagan, L. A. Viereck, and C. T. Dyrness, eds. *Forest ecosystems in the Alaskan taiga*. Springer-Verlag, New York.
- Viereck, L. A., C. T. Dyrness, A. R. Batten, and K. J. Wenzlick. 1992. *The Alaska vegetation classification*. Pacific Northwest Research Station, U.S. Forest Service, Portland, Oregon. Gen. Tech. Rep. PNW-GTR286. 278 pp.
- Viereck, L. A., C. T. Dyrness, K. Van Cleve, and M. J. Foote. 1983. Vegetation, soils, and forest productivity in selected forest types in Interior Alaska. *Canadian Journal of Forest Research* 13:703–720.
- Viereck, L. A., K. Van Cleve, and C. T. Dyrness. 1986. Forest Ecosystems in the Alaska Taiga. Pages 22–43 in Van Cleve, K., F. S. Chapin, III, P. W. Flanagan, L. A. Viereck, and C. T. Dyrness, eds. *Forest ecosystems in the Alaskan taiga: a synthesis of structure and function*. New York: Springer-Verlag.
- Viereck, L. A., and L. A. Schandelmeier. 1980. Effects of fire in Alaska and adjacent Canada a literature review. Bureau of Land Management Alaska Tech. Rep. 6.
- Wilmking, M., and G. P. Juday. 2005. Longitudinal variation of radial growth at Alaska's northern treeline—recent changes and possible scenarios for the 21st century. *Global and Planetary Change* 47:282–300.
- Wirth, C., J. W. Lichstein, J. Dushoff, A. Chen, and F. S. Chapin, III. 2008. White spruce meets black spruce: dispersal, postfire establishment, and growth in a warming climate. *Ecological Monographs* 78:489–505.
- Yarie, J. 1983. Forest community classification of the Porcupine River drainage, Interior Alaska, and its application to forest management. USDA Forest Service GTR PNW-154.
- Yoshikawa, K., W. R. Bolton, V. E. Romanovsky, M. Fukuda, and L. D. Hinzman. 2002. Impacts of wildfire on the permafrost in the boreal forests of Interior Alaska. *Journal of Geophysical Research Atmospheres* 107: FFR 4-1–FFR 4-14.

8. Upland Low and Tall Shrub Tundra

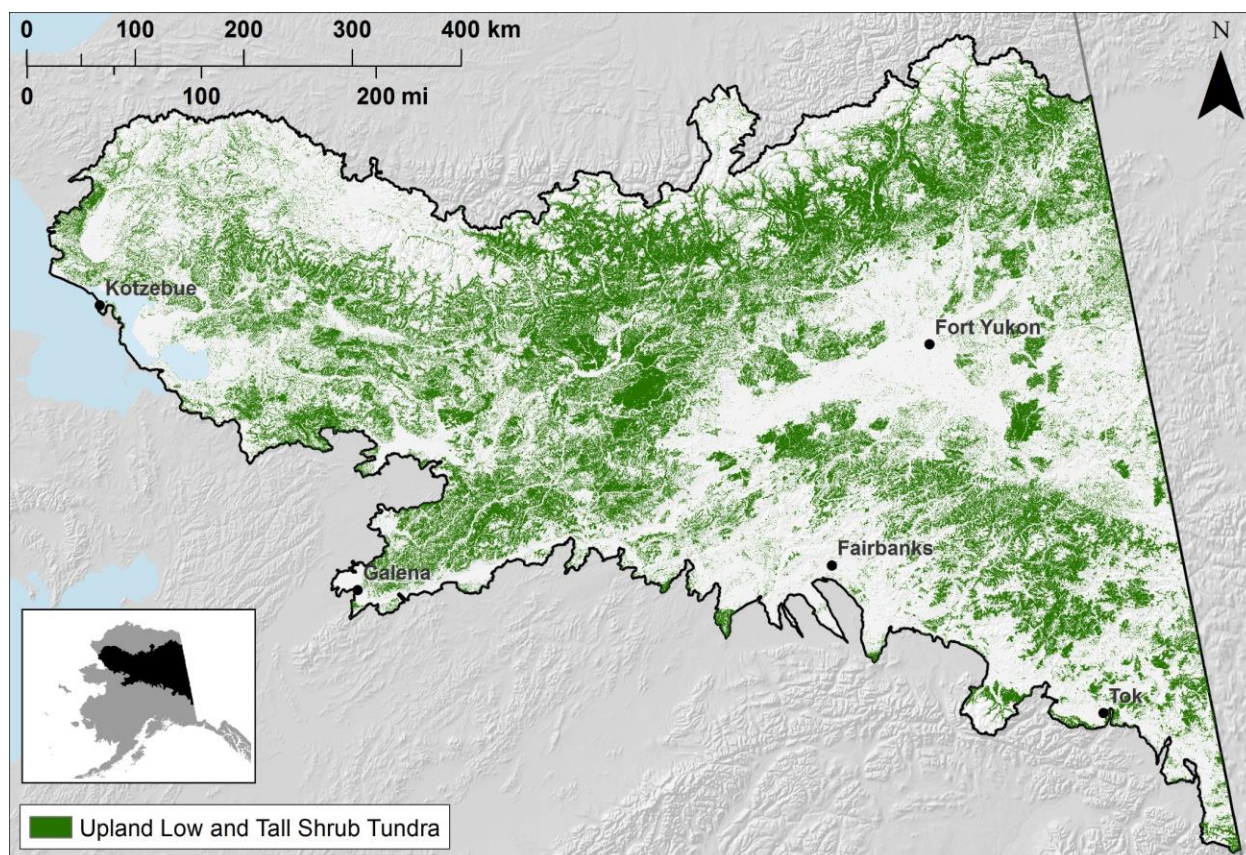


Figure G-46. Distribution map of the upland low and tall shrub tundra CE.

8.1 Introduction

The upland low and tall shrub tundra CE occurs throughout the boreal region (Figure G-46). Low shrub tundra dominated by scrub birch and low willows is abundant on slopes above treeline and below alpine tundra, while tall shrub thickets composed of alder and tall willows occur in patches on side slopes, drainages, and avalanche tracks (Figure G-47). Both shrubland types typically



Figure G-47. Low and tall shrub tundra near treeline. Photo by Mike Fleming.

occur on well-drained moist to mesic sites. Soils are mineral with a shallow organic layer (Viereck et al. 1992, Boggs and Boucher 2008). Permafrost is often present.

Vegetation

Low shrub tundra is often dominated by *Betula glandulosa* or *Betula nana* and *Salix pulchra*. Other common low shrubs include *Rhododendron groenlandicum*, *R. tomentosum*, *Vaccinium uliginosum*, and *Salix glauca*. Dwarf shrubs including *Vaccinium vitis-idaea* and *Empetrum nigrum* may be common below the low shrub layer. Herbaceous species are sparse and may include *Calamagrostis canadensis*, *Carex bigelowii*, *Rubus chamaemorus*, and *Chamerion angustifolium*. Feathermosses such as *Hylocomium splendens*, and *Pleurozium schreberi* and lichens such as *Cladina* spp. are common in the ground layer (Viereck 1979, Viereck et al. 1992, Boggs and Boucher 2008).

Tall shrub thickets are typically dominated by the deciduous shrub species *Alnus viridis* ssp. *fruticosa* or *Salix pulchra* or a combination of the two. Willows such as *Salix glauca*, *Salix richardsonii*, or *Salix bebbiana* may be present and occasionally dominate the canopy. Other shrub associates include *Vaccinium uliginosum*, *Empetrum nigrum*, *Betula nana* or *Betula glandulosa*, *Vaccinium vitis-idaea*, and *Ledum palustre* ssp. *decumbens*. Understory herbaceous species include *Calamagrostis canadensis*, *Equisetum arvense*, *Rubus arcticus*, *Chamerion angustifolium*, and *Sanguisorba canadensis*. In riparian zones, which make up a very small fraction of the overall CE area, *Salix alaxensis* is the dominant shrub (Viereck 1979, Viereck et al. 1992, Boggs and Boucher 2008).

Classification Synonymy

This CE is similar in concept to NVC G356 Western Boreal Scrub Birch Shrubland and G357 Western Boreal Mesic Alder-Willow Shrubland (FGDC 2008), and Viereck IIB1a/b/c/d/e, IIB2a/b/c/d, IIC1a/b/c, IIC2f (Viereck et al. 1992). This CE is similar to the scrub component of the CBVM Yukon Subalpine Spruce Woodlands and Scrub and Northern Alaska-Yukon Spruce Woodlands and Scrub (Jorgenson and Meidinger 2015).

Vegetation Succession

Shrub tundra dominated by ericaceous shrubs and scrub birch is highly flammable and tends to produce severe burns (Racine 1979), while shrublands dominated by alder and willow are less flammable. After fire, shrubs resprout from surviving underground tissue, and herbaceous species establish by seed and may dominate the site temporarily. A shrub community typically re-establishes on the site within five years. However, high severity fires that remove the organic surface layer may kill underground woody propagules. Adjacent vegetation influences the fire frequency; if the adjacent vegetation is highly flammable, then the shrub type will have a more frequent fire return. Fire can facilitate treeline migration and seedling establishment by providing mineral seedbed if a coniferous seed source is available (Racine et al. 2004). Conversely, severe fires can convert white spruce woodlands near treeline to low shrub if spruce trees and seeds are consumed in the fire (Pegau 1972). In the absence of fire, spruce trees can become established in shrub tundra near treeline and shrubs can expand upward in elevation into alpine zones given favorable climate conditions.

8.2 Conceptual Model

The conceptual model below is based on literature review and describes the relationships among the various CAs and natural drivers for upland low and tall shrub tundra. Bold arrows indicate interactions with high ecological relevance and potential management implications, and for which spatial datasets can be intersected with the CE distribution. The primary CAs selected for this CE include climate change, permafrost, fire, and development (Figure G-48).

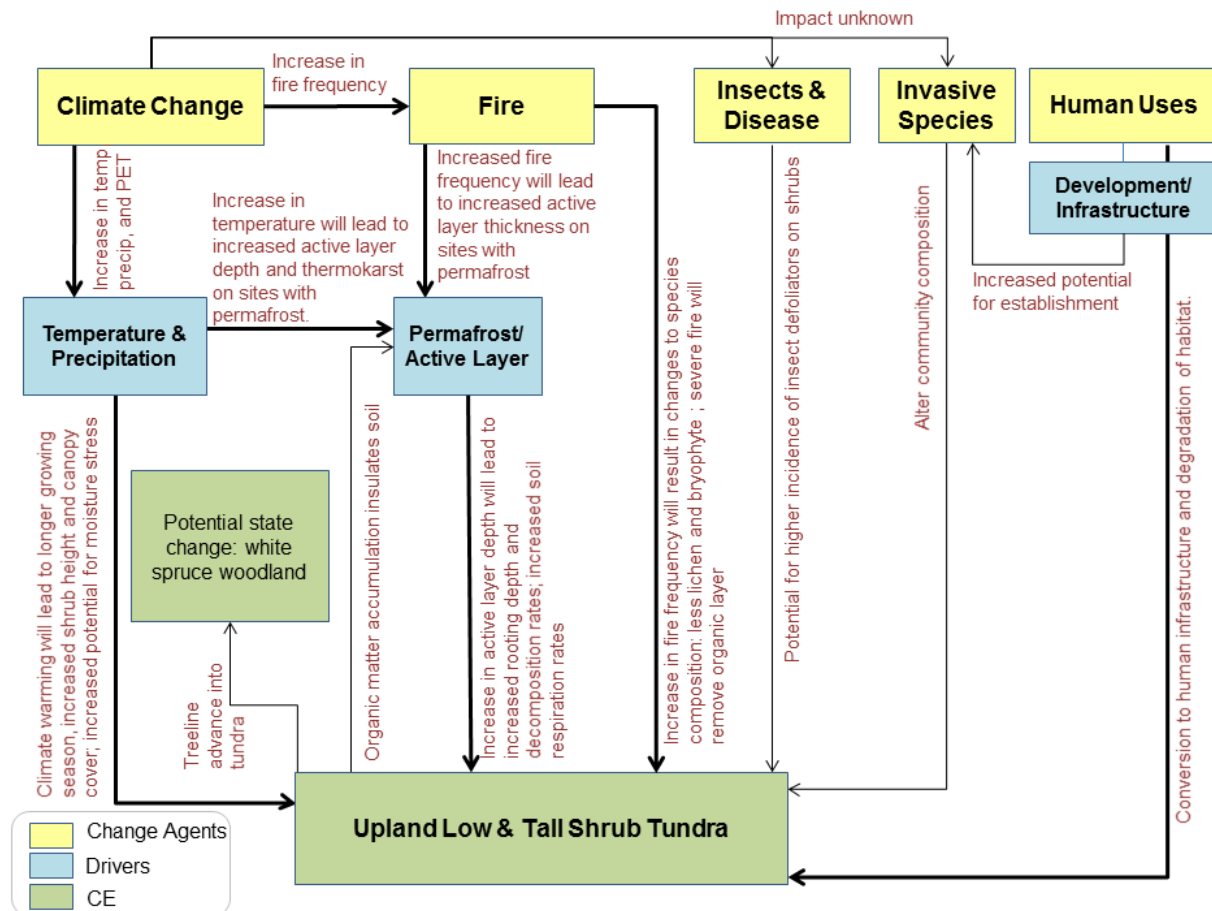


Figure G-48. Conceptual model for upland low and tall shrub tundra.

8.3 Abiotic Change Agents Analysis

Length of Growing Season and Summer Warmth Index

The length of growing season for low and tall shrub tundra is projected to increase by 9.6 days between the current condition to the long-term future (from 153.7 to 163.2 days), and the mean Summer Warmth Index (annual sum of mean monthly temperatures that are above freezing) is projected to increase from 47 to 54 °C mo for the same time frame (Figure G-49).

Upland Low and Tall Shrub Tundra

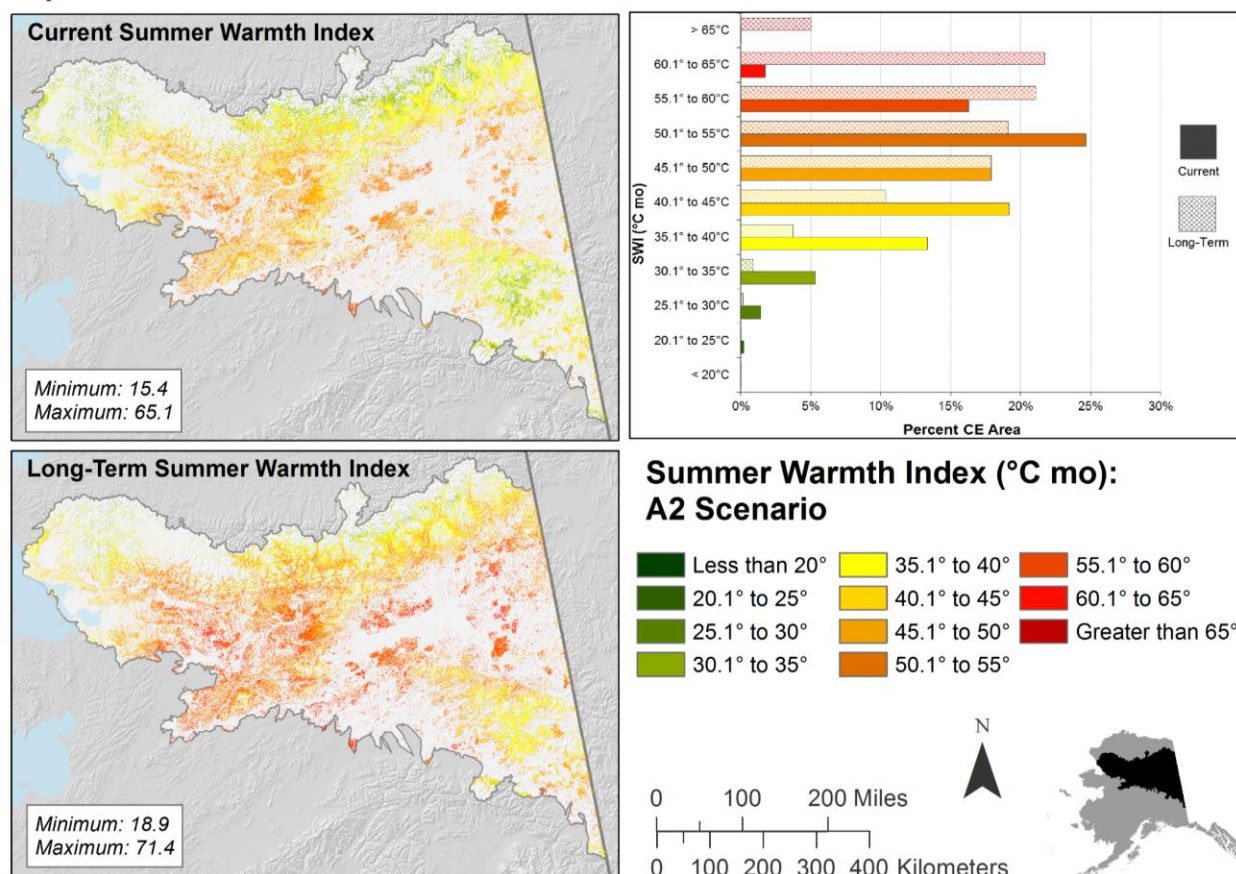


Figure G-49. Summer Warmth Index for upland low and tall shrub tundra for the current condition and long-term future.

Temperature and Precipitation

Mean annual temperature for upland low and tall shrub tundra is projected to increase by 2.0 °C between the current condition and the long-term future, while mean January temperature is expected to increase by 3.9 °C and mean July temperature is expected to increase by 1.5 °C (Table G-19).

Table G-19. Temperature summary for upland low and tall shrub tundra.

Upland Low and Tall Shrub Tundra	Mean July Temperature (°C)				Mean January Temperature (°C)				Mean Annual Temperature (°C)			
	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change
	14.2	14.5	15.8	+1.5	-21.7	-19.3	-18.1	+3.6	-4.1	-3.9	-2.8	+1.3

Mean annual precipitation is projected to increase by 52 mm between the current condition and the long-term future, with precipitation during the summer months and winter months increasing by 15 and 17 mm, respectively (Table G-20).

Table G-20. Precipitation summary for upland low and tall shrub tundra.

Upland Low and Tall Shrub Tundra	Precipitation (mm)														
	Summer					Winter					Mean Annual				
	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change
	189	192	201	+12	+7	69	76	81	+12	+18	424	442	477	+52	+12

Fire and Vegetation Change

ALFRESCO results predict that shrub tundra will increase slightly across the CYR study area, but the changes are not distributed evenly across the landscape. Mountainous ecoregions including the Davidson Mountains and Brooks Range are projected to see a greater increase in shrub cover than other regions as shrubs advance into alpine tundra (Table G-8, Figure G-23). In other ecoregions, the modeled shift from graminoid to shrub tundra is followed by a shift to white spruce forest, and, in the event of fire, spruce is replaced by deciduous forest in the ALFRESCO model, which does not include a spruce self-replacement option after fire.

Permafrost

According to ground temperature models developed by GIPL, 99% of the low and tall shrub tundra CE is underlain by permafrost under current conditions (2010s), and this is projected to decrease to 76% of the CE area by the 2060s (Table G-7, Figure G-12).

Active layer thickness is currently estimated at 63 cm thick across the portion of the CE currently underlain by permafrost, and this is projected to increase to 67 cm where permafrost remains intact in the long-term future (Figure G-13).

According to the thermokarst predisposition model, 30% of the low and tall shrub tundra occurs on landscapes that are highly or very highly predisposed to thermokarst (Figure G-14).

Abiotic Change Agents Discussion

Warmer temperatures, altered permafrost conditions, and a shortened fire interval are likely to affect the distribution of low and tall shrub tundra throughout the CYR study area. Near treeline, white spruce encroachment into shrub tundra is predicted, and at the ecotone between low shrub tundra and alpine dwarf shrub tundra, the expansion of low shrubs into higher elevation alpine tundra is predicted.

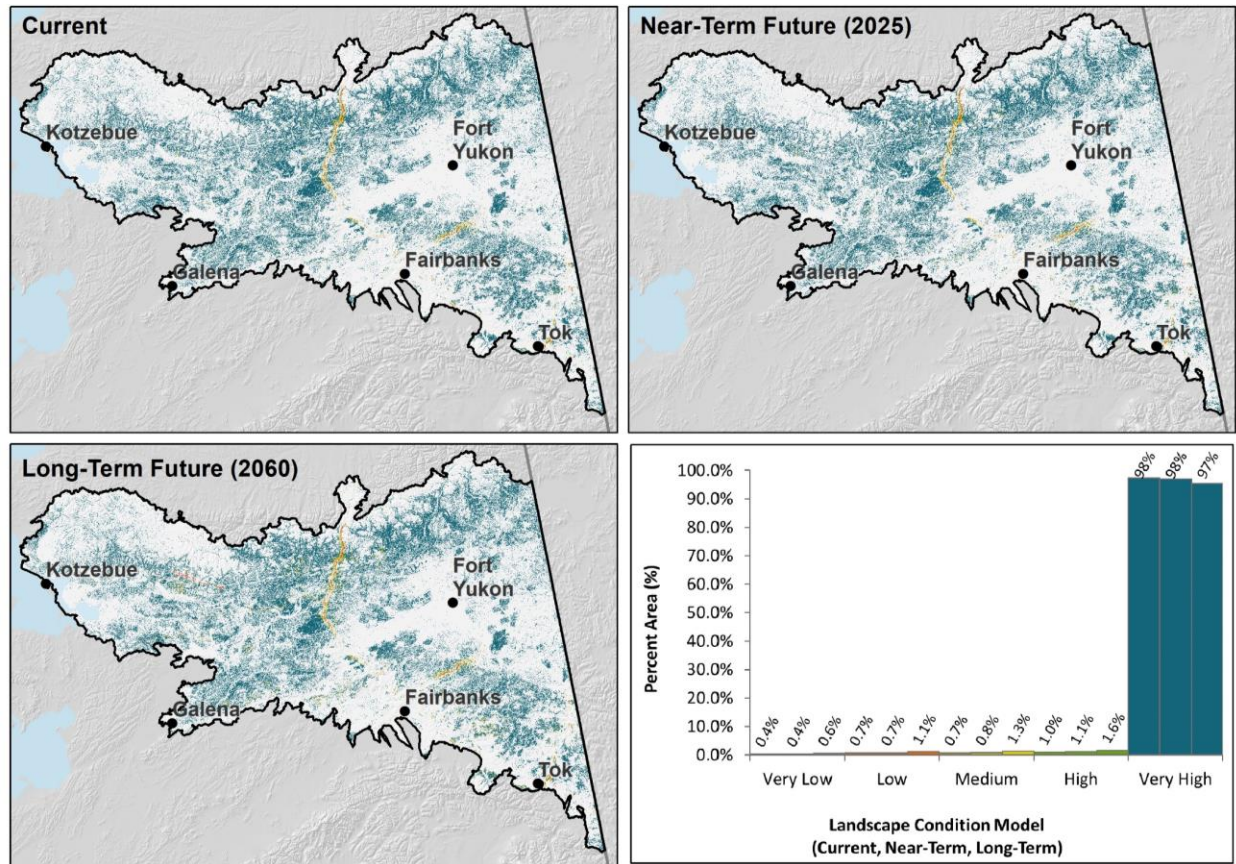
Loss of permafrost and increase in active layer thickness will lead to greater depth of the rooting zone, which will in turn promote an increase in shrub height and canopy cover. This may facilitate the advance of treeline into shrub tundra, given a seed source and favorable conditions for conifer establishment and growth. Experimental warming experiments have demonstrated a relationship between increasing temperature and increases in deciduous shrub height and cover, with greatest cover increases at alpine sites and greatest canopy height increases in low Arctic sites (Walker et al. 2006). Indeed, increases in shrub abundance (Sturm et al. 2001, Joly et al. 2007, Forbes et al. 2010) and advance in treeline into tundra habitats (Lloyd and Fastie 2003, Suarez et al. 1999, Okano and Bret-Harte 2015, Ropars and Boudreau 2012) have already been widely documented.

Some authors have suggested that the expansion of tall shrubs at treeline could act to limit treeline spruce establishment and thereby inhibit treeline expansion (Fastie and Lloyd 2014, Dial et al. 2016). Near surface permafrost may also be a limiting factor in spruce establishment at Arctic treeline (Lloyd 2005).

Increased fire frequency and extent will further promote permafrost degradation and also provide more abundant seedbeds in which conifers and deciduous species can establish. ALFRESCO results predict that shrub tundra will increase slightly across the CYR study area, but the changes are not distributed evenly across the landscape. Mountainous ecoregions including the Davidson Mountains and Brooks Range are projected see a greater increase in shrub cover than other regions as shrubs advance into alpine tundra (Table G-8, Figure G-23). In other ecoregions, the modeled shift from graminoid to shrub tundra is followed by a shift to white spruce forest, and, in the event of fire, spruce is replaced by deciduous forest (as the ALFRESCO model does not allow for spruce self-replacement after fire). Because there are large discrepancies in the definition of shrub tundra between the CE distribution map and the ALFRESCO input map (Figure G-21), the spatial distributions cannot be compared. However, the shrub and treeline projections produced using an ALFRESCO best replicate (Figure G-23) support the expected trend of white spruce encroaching into shrub tundra at treeline and shrub tundra expanding into higher elevation alpine sites.

While there may be time lags associated with shifting boundaries between ecotones (see Dial et al. 2016), positive feedbacks can produce more rapid localized results for both shrub and treeline advance. Specifically, the infilling of shrubs—the increase in height and canopy cover of existing shrubs—can increase snow retention, which in turn provides thermal insulation to the soil and protects shrubs from desiccating winter winds (Sturm et al. 2001). At Arctic treeline, Tape et al. (2006) noted the presence of dwarf birch and willow ‘halos’ around central alders, illustrating that small stands or even individual alders can produce microclimates that facilitate infilling. Similarly, krummholz trees beyond current treeline may catalyze increases in spruce density by providing seed sources and by creating microclimatic conditions conducive to spruce seedling survival (Lloyd and Fastie 2003).

8.4 Current Status and Future Landscape Condition



Current, near-term, and long-term landscape condition within the distribution of upland low and tall shrub tundra

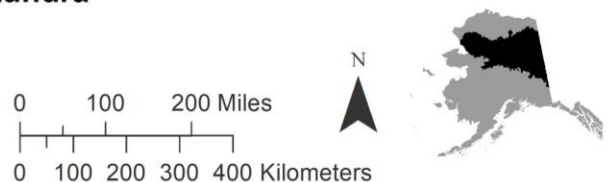


Figure G-50. Current, near-term and long-term status of upland low and tall shrub tundra in the CYR study area.

The overall status of the upland low and tall shrub tundra CE was assessed by intersecting the LCM with the CE distribution model for the current condition, near-term, and long-term future. The LCM is a way to measure the impact of the human footprint on a landscape. In the current condition, the impact on alpine and Arctic tussock tundra is minimal, with 97% of the area in the “very high” condition class, and this is not expected to change in the near future. In the current and near-term, the highway system, as well as alternative transportation impacts (e.g., the Yukon and Tanana rivers) account for the majority of the impact to landscape condition. By the long-term future (2060), however, the percentage of this CE in “very good” condition drops to 95% as a result of Ambler district mining development and the construction of the Ambler road (Figure G-50).

8.5 Literature Cited

- Boggs, K., and T. V. Boucher. 2008. Draft ecological systems descriptions for Alaska. *In* NatureServe. International Ecological Classification Standard: Terrestrial Ecological Classifications.
- Dial, R. J., T. S. Smeltz, P. F. Sullivan, C. L. Rinas, K. Timm, J. E. Geck, S. C. Tobin, T. S. Golden, and E. C. Berg. 2016. Shrubline but not treeline advance matches climate velocity in montane ecosystems of Southcentral Alaska. *Global Change Biology* 22:1841–1856.
- Fastie, G., and A. H. Lloyd. 2014. Effect of shrub cover on spruce seedling establishment at and above alpine treeline in the Alaska Range. *In* AGU Fall Meeting Abstracts. Vol. 1, p. 0682.
- FGDC. 2008. National vegetation classification standard, version 2. Federal Geographic Data Committee—Vegetation Subcommittee. FGDC-STD-005-2008 (Version 2).
- Forbes, B. C., M. M. Fauria, and P. Zetterberg. 2010. Russian Arctic warming and ‘greening’ are closely tracked by tundra shrub willows. *Global Change Biology* 16:1542–1554.
- Joly, K., P. Bente, and J. Dau. 2007. Response of overwintering caribou to burned habitat in northwest Alaska. *Arctic* 60:401–410.
- Jorgenson, M. T., and D. Meidinger. 2015. The Alaska Yukon region of the circumboreal vegetation map (CBVM). CAFF Strategies Series Report. Conservation of Arctic Flora and Fauna, Akureyri, Iceland.
- Lloyd, A. H. 2005. Ecological histories from Alaskan treeline sites provide insight into future change. *Ecology* 86:1687–1695.
- Lloyd, A. H., and C. Fastie. 2003. Recent changes in treeline forest distribution and structure in Interior Alaska. *Ecoscience* 10:176–185.
- Okano, K., and M. S. Bret-Harte. 2015. Warming and neighbor removal affect white spruce seedling growth differently above and below treeline. *Springerplus* 4:79. doi:10.1186/s40064-015-0833-x.
- Pegau, R. E. 1972. Caribou investigations-analysis of range. Pages 1-216 *in* Pegau, R. E., 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.
- Racine, C. H. 1979. Climate of the Chucki-Imuruk area. Pages 32-37 *in* Melchior, H. R. eds. Biological Survey of the Bering Land Bridge National Monument. Alaska Cooperative Park Studies Unit, University of Alaska Fairbanks, Fairbanks, Alaska.
- Racine, C. H., R. R. Jandt, C. R. Meyers, and J. Dennis. 2004. Tundra fire and vegetation change along a hillslope on the Seward Peninsula, Alaska, U.S.A. *Arctic, Antarctic, and Alpine Research* 36:1–10.
- Ropars, P., and S. Boudreau. 2012. Shrub expansion at the forest-tundra ecotone: spatial heterogeneity linked to local topography. *Environmental Research Letters* 7:015501.
- Sturm, M., C. Racine, and K. Tape. 2001. Increasing shrub abundance in the Arctic. *Nature* 411:546–547.
- Suarez, F., D. Binkley, M. W. Kaye, and R. Stottlemeyer. 1999. Expansion of forest stands into the tundra in Noatak National Preserve, northwest Alaska. *Ecoscience* 6:465-470.
- Tape, K., M. Sturm, and C. Racine. 2006. The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. *Global Change Biology* 12:686–702.
- Viereck, L. A. 1979. Characteristics of treeline plant communities in Alaska. *Holarctic Ecology* 2:228–238.
- Viereck, L. A., C. T. Dyrness, A. R. Batten, and K. J. Wenzlick. 1992. The Alaska vegetation classification. Pacific Northwest Research Station, U.S. Forest Service, Portland, Oregon. Gen. Tech. Rep. PNW-GTR286. 278 pp.
- Walker, M. D., C. H. Wahren, R. D. Hollister, G. H. Henry, L. E. Ahlquist, J. M. Alatalo, M. S. Bret-Harte, M. P. Calef, T. V. Callaghan, A. B. Carroll, and H. E. Epstein. 2006. Plant community responses to experimental warming across the tundra biome. *Proceedings of the National Academy of Sciences* 103:1342–1346.

9. Alpine and Arctic Tussock Tundra

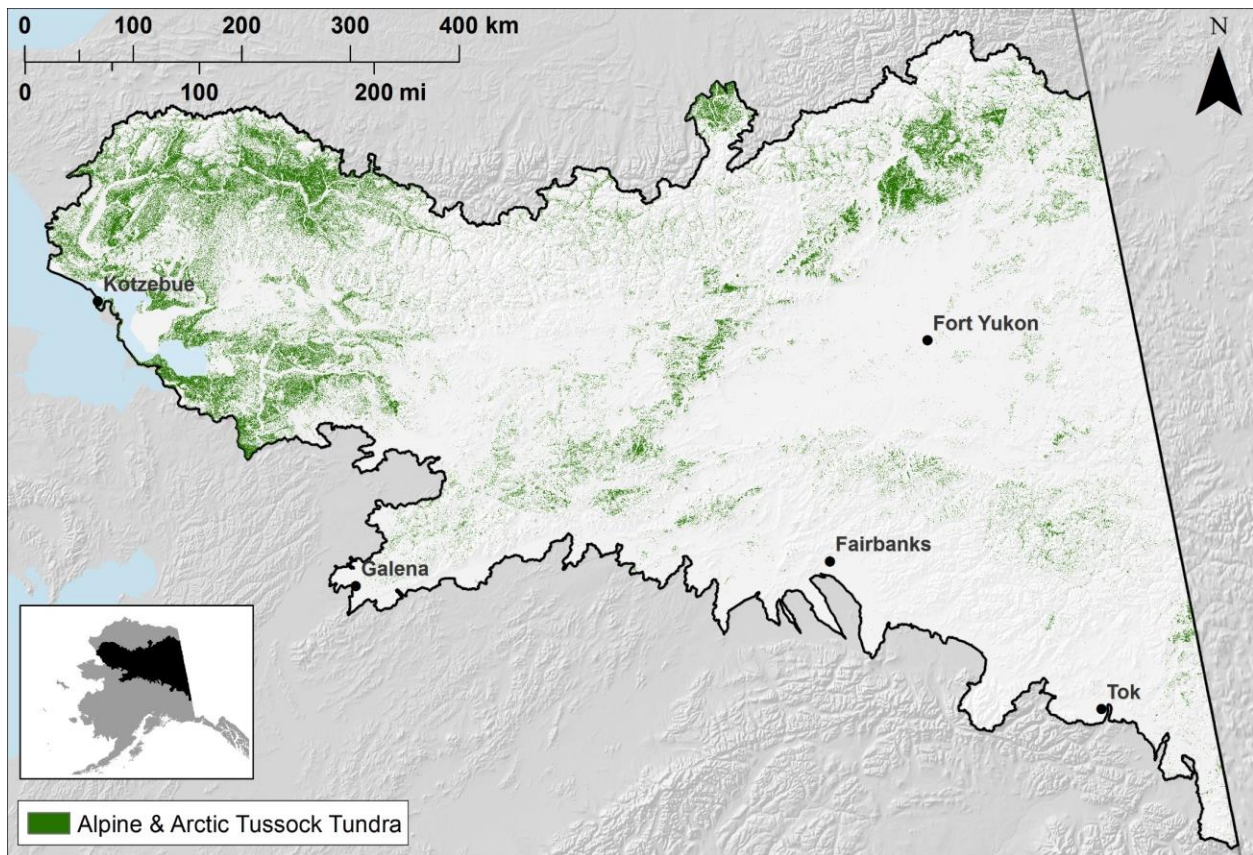


Figure G-51. Distribution map of the alpine and Arctic tussock tundra CE.

9.1 Introduction

Alpine and Arctic tussock tundra is defined by tussock-forming sedges often in combination with dwarf and low shrubs occurring in the boreal and Arctic regions of Alaska (Figure G-51). In the boreal region, it is common near and above treeline on gently sloping terrain, particularly on the southern slopes of the Brooks Range. This CE includes both shrub tussock and graminoid tussock vegetation communities (Figure G-52). Soils are generally acidic, poorly drained, gleyed, and often have a poorly decomposed surface organic horizon (10- to 40-cm thick). Permafrost is



Figure G-52. Alpine and Arctic tussock tundra in Yukon Charlie National Preserve.

usually present at depths of 30–50 cm, and frost scars are common (Viereck et al. 1992, Boggs and Boucher 2008).

Vegetation

Canopy cover of tussock-forming sedges is typically at least 30%; shrub cover is variable but is often at least 25% composed of low shrubs (0.2- to 1.5-m tall) and dwarf shrubs (< 0.2-m tall). The primary tussock-forming sedge is *Eriophorum vaginatum*, though *Carex bigelowii* ssp. *lugens* may be the dominant on some sites. The low shrubs *Betula nana* and *Rhododendron tomentosum*, the dwarf shrub *Vaccinium vitis-idaea*, and the forb *Rubus chamaemorus* are diagnostic species for the type. Other common shrubs include *Salix pulchra*, *V. uliginosum*, *Betula glandulosa*, *Empetrum nigrum*, and *Cassiope tetragona*. Forb diversity and abundance is low, but grasses such as *Calamagrostis* spp. and *Arctagrostis latifolia* may occur with low cover. Mosses including *Sphagnum* spp., *Aulacomnium* spp., and *Hylocomium splendens* may form a nearly continuous mat between tussocks; lichens such as *Cladina* spp. and *Flavocetraria* spp. may be common, but usually with low canopy cover.

Classification Synonymy

This CE includes Viereck classes IIC2a (mixed shrub-sedge tussock tundra) and IIIA2d (tussock tundra) (Viereck et al. 1992); and is synonymous with National Vegetation Classification Group G371 North American Arctic and sub-Arctic tussock tundra (FGDC 2008). The CE does not have an equivalent in the CBVM, though it may be contained within the woodlands and scrub classes.

Vegetation Succession

The fuel layer in sedge-shrub tussock tundra is dense and continuous and produces large, fast spreading fires (Duchesne and Hawkes 2000, Racine et al. 1987). Variations in topography and fuel moisture can create a patchy burn pattern of burn severity. In burned areas, fires typically consume all aerial woody and herbaceous plant material, but generally do not kill the meristematic tissue and roots; regeneration is vigorous via rhizomes, root sprouts, and tillering (*Eriophorum vaginatum*). Fire severity in sites with a wet soil profile tends to be low (Wein 1971). Subsidence and thermal erosion following fire is usually minimal in tundra ecosystems unless the organic layer is removed (Racine 1979, Walker 1996).

In the first year following a fire, *Eriophorum* (cottongrass) and *Carex* spp. (sedges) regrow via tillers and rhizomes, most vascular plants begin to recover, and shrubs sprout from rootstocks. Grasses, such as *Calamagrostis* and *Arctagrostis*, are locally important following fire. Total vascular plant cover may return to pre-fire levels within 6 to 10 years following fire, primarily due to rapid basal resprouting of *Eriophorum vaginatum* tussocks. *Betula nana*, *Salix* spp., and ericaceous shrubs also resprout, but their cover can remain well below pre-fire levels during the first 6 to 10 years after fire (Racine et al. 1987).

Production and biomass of vascular plants can recover to pre-fire levels within 10 years (Wein and Bliss 1973, Racine et al. 1987), bryophyte and lichen communities are largely destroyed by fires in tussock tundra and their recovery rate is much slower. Following fire, bryophytes including *Marchantia polymorpha* and *Ceratodon purpureus* rapidly colonize in the inter-tussock spaces. These species appear to reach a maximum cover within five years after fire and then decline as the vascular overstory develops. The time required for successional return to pre-fire bryophyte

species compositions (e.g., *Sphagnum* spp., *Aulacomnium* spp., *Dicranum* spp., and *Hylocomium splendens*) is largely unknown, but likely to require a minimum of 25 years (Racine et al. 1987).

For the first 15 years following fire, crustose lichens and *Cladonia* squamules are reported to occur with high frequency, but at low ($\leq 1\%$) cover (Jandt et al. 2008); 30–35 years post-fire, lichen cover in burned tundra was less than 5% (Holt et al. 2008, Jandt et al. 2008); 50–100 years after fire, *Cladina mitis*, *Cladina arbuscula* and other *Cladonia* spp. may reach peak abundance but are eventually replaced by late-successional species such as *Cladina stellaris* and *Cladina rangiferina* (Swanson 1996).

In the absence of fire, the peat-forming mosses, such as *Sphagnum* spp., become more abundant, and through the process of paludification, sites develop acidic organic soils (Walker et al. 1998).

9.2 Conceptual Model

The conceptual model below is based on literature review and describes the relationships among the various CAs and natural drivers for Arctic and alpine tussock tundra. Bold arrows indicate interactions with high ecological relevance and potential management implications, and for which spatial datasets can be intersected with the CE distribution. The primary CAs selected for this CE include climate change, permafrost, fire, and development (Figure G-53).

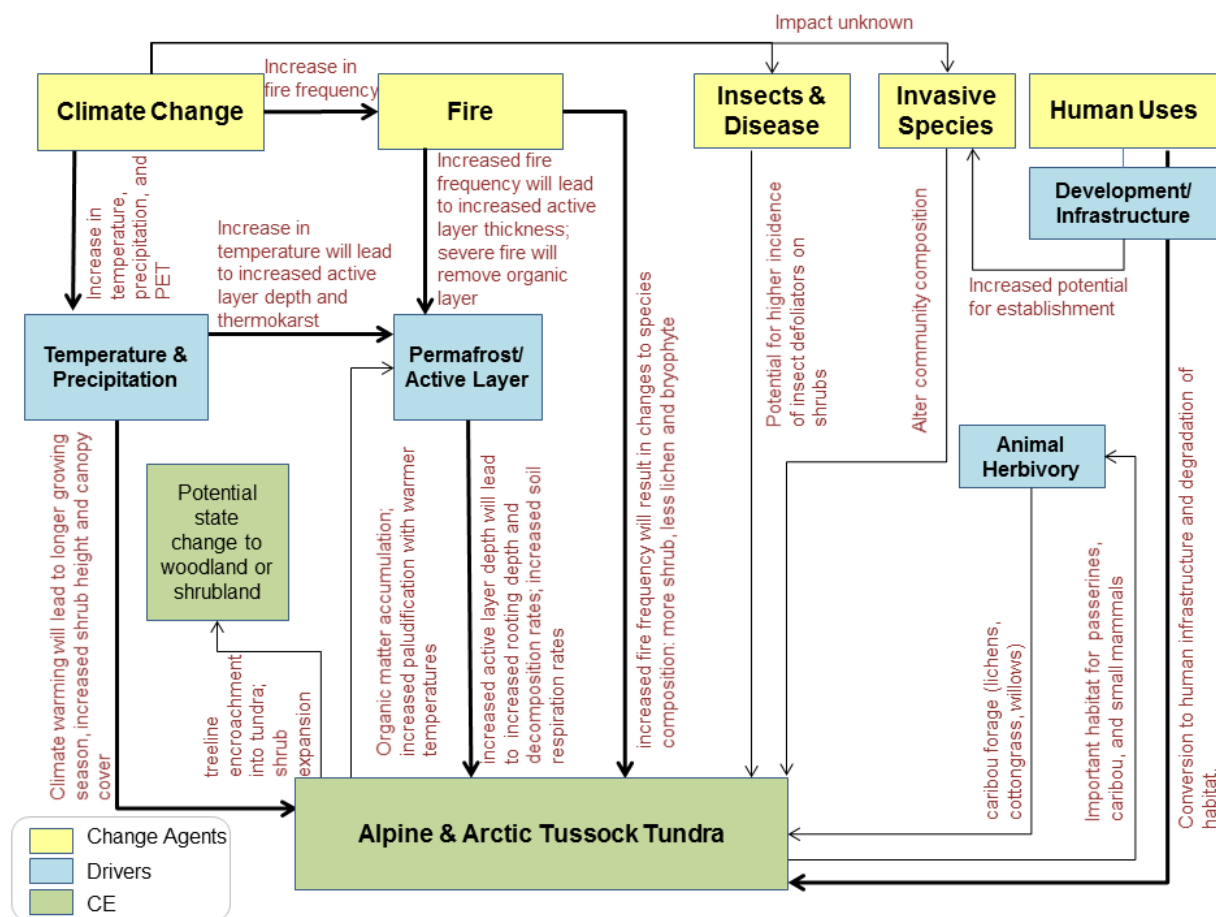


Figure G-53. Conceptual model for alpine and Arctic tussock tundra.

9.3 Abiotic Change Agents Analysis

Length of Growing Season and Summer Warmth Index

The length of growing season for tussock tundra is expected to increase by 9.8 days from the current 144.3 days to 154.2 days in the long-term future (Figure G-9), and the mean SWI (annual sum of mean monthly temperatures that are above freezing) is projected to increase from 42 °C to 48 °C for the same time frame (Figure G-54).

Alpine & Arctic Tussock Tundra and Alpine Dwarf Shrub Tundra

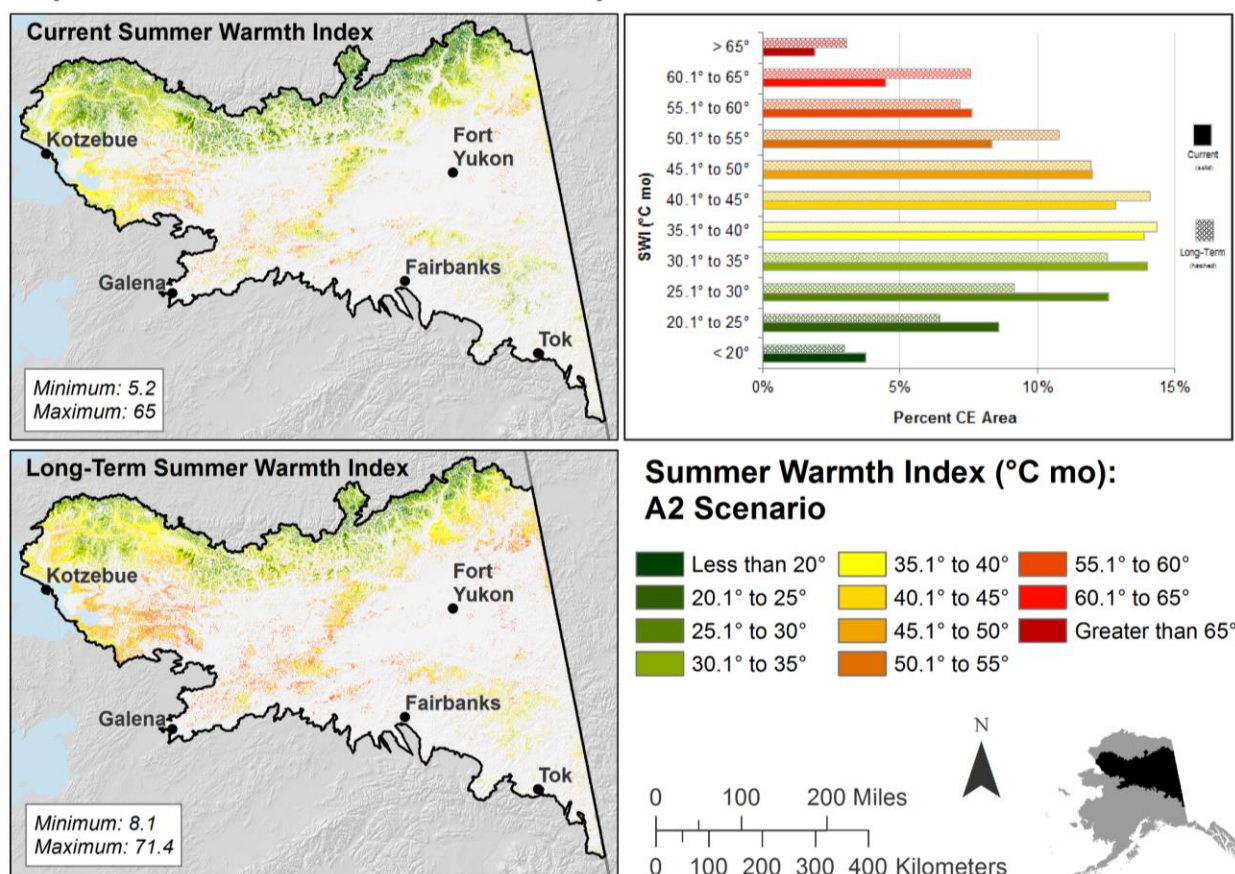


Figure G-54. Summer Warmth Index for alpine dwarf shrub tundra and alpine and Arctic tussock tundra for the current condition and long-term future.

Temperature and Precipitation

Mean annual temperature for tussock tundra is projected to increase by 2.1 °C between the current condition and the long-term future, while mean January temperature is expected to increase by 3.9 °C and mean July temperature is expected to increase by 1.5 °C (Table G-21).

Table G-21. Temperature summary for alpine and Arctic tussock tundra.

Alpine and Arctic Tussock Tundra	Mean July Temperature (°C)				Mean January Temperature (°C)				Mean Annual Temperature (°C)			
	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change
	13.9	13.8	15.4	+1.5	-21.5	-19.6	-17.8	+3.7	-5.2	-4.9	-3.4	+1.7

Mean annual precipitation is projected to increase by 54 mm between the current condition and the long-term future, with precipitation during the summer and winter months increasing by 14 and 16 mm, respectively (Table G-22).

Table G-22. Precipitation summary for alpine and Arctic tussock tundra.

Alpine and Arctic Tussock Tundra	Precipitation (mm)														
	Summer					Winter					Mean Annual				
	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change
	178	179	190	+12	+7	69	78	81	+12	+17	415	431	470	+55	+13

Fire and Vegetation Change

The ALFRESCO model does not explicitly model changes to tussock tundra. In the ALFRESCO input map, the area represented by the tussock tundra CE is classified as woody vegetation (68% combined shrub and deciduous) and only 26% is classified as graminoid tundra (Figure G-21). ALFRESCO projects a decrease in overall area of graminoid tundra but little change in the overall area of shrub tundra, but the changes to these vegetation types cannot be directly linked to changes in tussock tundra using the ALFRESCO model.

Permafrost and Active Layer

Permafrost is currently continuous under the tussock tundra CE and this is not projected to change in the near-term future; however, by the 2060s, 9% of the CE area is projected to lose permafrost or have permafrost deeper than 1 m (Table G-7). This change is concentrated in the western portion of the CE distribution where the elevation range of tussock tundra is lower than in the central region of the CYR study area (Figure G-12).

The average active layer depth under tussock tundra is currently modeled at 61 cm, and this depth is projected to increase to 63 cm in the near-term and 68 cm in the long-term future (Figure G-13).

Forty-five percent of this CE is categorized as very highly prone to thermokarst (Figure G-14, Figure G-15). High thermokarst potential is consistent with the silty soils characteristic of this type.

Abiotic Change Agents Discussion

The combined effects of warmer temperatures, increased winter precipitation, altered permafrost conditions, and increased fire will likely impact the composition and structure of tussock tundra within the CYR study area.

The increased depth of the rooting zone will provide woody plants a competitive advantage over graminoids and non-vascular plants (Lloyd and Fastie 2003). Experimental warming in Arctic tussock tundra sites has shown an increased height and cover of deciduous shrubs and graminoids and decreased cover of mosses and lichens (Walker et al. 2006). Shrubs may inhibit lichens by shading the understory and by trapping snow and increasing leaf litter (Joly et al. 2009, Cabrajic et al. 2010). Increases in shrub abundance on the landscape have already been observed in the sub-Arctic and Arctic biomes (Sturm et al. 2001, Joly et al. 2007, Forbes et al. 2010). In the Alaskan Arctic specifically, substantial evidence exists for the expansion of tall shrubs (i.e., alder and floodplain willows) over the last century via shrub growth, patch infilling,

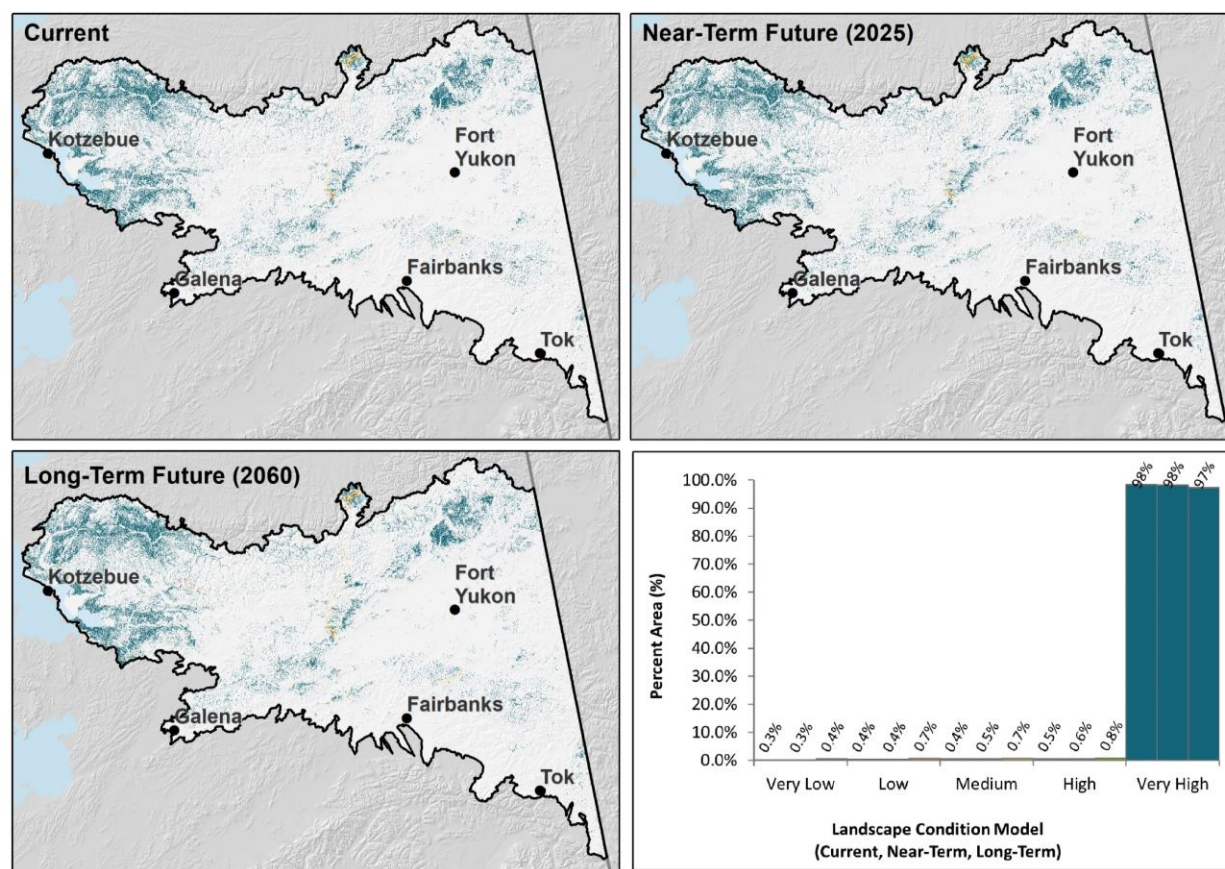
and establishment of new patches. Low shrubs such as low willows and dwarf birch, though harder to detect via satellite imagery, seem to be following a similar trajectory (Tape et al. 2006).

Fire increases the rate of permafrost degradation and thaw and facilitates the establishment of trees and shrubs in tundra by creating mineral seedbed (Rupp et al. 2000, Sturm et al. 2001, Joly et al. 2009, Forbes et al. 2010, Beck et al. 2011, Joly et al. 2012). ALFRESCO does not explicitly model changes in tussock tundra, but the general trends of shrub and treeline expansion predicted to occur by the 2060s (Figure G-22) can be extrapolated to this CE. In the ALFRESCO input map, however, most of the area represented by the tussock tundra CE is classified as woody vegetation (Figure G-21), and thus, infilling of shrubs within the CE is likely under-represented in the model.

Tussock tundra is projected to see substantial increases annual precipitation by the 2060s. Growing season increases may be offset by increasing temperatures and evaporative demand, but increased winter precipitation will likely result in a deeper snowpack, providing increased thermal insulation of the soil and protecting woody plants from desiccating winter winds. Snow depths correlate closely with shrub canopy height and stem diameter, where shrub growth promotes snow retention, and deeper snowpack further promotes shrub growth (Sturm et al. 2001).

In summary, warming temperatures, increased fire frequency, and loss of permafrost will likely result in a loss of tussock tundra habitat in the future. Tussock tundra could become shrubbier, transition to shrub tundra, or white spruce may encroach at treeline. Sites with a shortened fire interval will have reduced cover of non-vascular species, particularly old-growth lichens including *Cladina rangiferina* and *Cladina stellaris* (Swanson 1996, Holt et al. 2008, Jandt et al. 2008, Klein and Shulski 2009, Joly et al. 2010, Collins et al. 2011).

9.4 Current Status and Future Landscape Condition



Current, near-term, and long-term landscape condition within the distribution of alpine and arctic tussock tundra

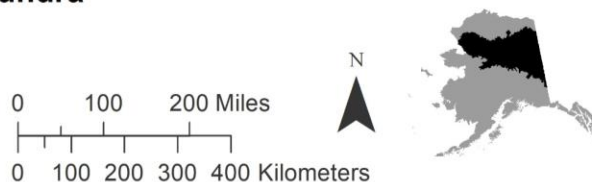


Figure G-55. Current, near-term, and long-term status of alpine and Arctic tussock tundra in the CYR study area.

The overall status of the alpine and Arctic tussock tundra CE was assessed by intersecting the LCM with the CE distribution model for the current condition, near-term, and long-term future. The LCM is a way to measure the impact of the human footprint on a landscape. In the current condition, the impact on alpine and Arctic tussock tundra is minimal, with 98% of the area in the “very high” condition class, and this is not expected to change in the near future. In the current and near-term, the Dalton Highway near Toolik Lake and Dietrich Airport accounts for the majority of the impact to landscape condition. In the long-term, development of the Ambler mining district and, to a lesser extent, construction of the Ambler road account for added impact, and the percentage area in the “very high” condition is expected to decrease to 97% (Figure G-55).

9.5 Literature Cited

- Beck, P. S. A., G. P. Juday, C. Alix, V. A. Barber, S. E. Winslow, E. E. Sousa, P. Heiser, J. D. Herriges, and S. J. Goetz. 2011. Changes in forest productivity across Alaska consistent with biome shift. *Ecology Letters* 14:373–379.
- Boggs, K., and T. V. Boucher. 2008. Draft ecological systems descriptions for Alaska. *In* NatureServe. International Ecological Classification Standard: Terrestrial Ecological Classifications.
- Cabrajic, A. V. J., J. Moen, and K. Palmqvist. 2010. Predicting growth of mat-forming lichens on a landscape scale: comparing models with different complexities. *Ecography* 33:949–960.
- Collins, W. B., B. W. Dale, L. G. Adams, D. E. Mcelwain, and K. Joly. 2011. Fire, grazing history, lichen abundance, and winter distribution of caribou in Alaska's taiga. *The Journal of Wildlife Management* 75:369–377.
- Duchesne, L. C., and B. C. Hawkes. 2000. Fire in northern ecosystems. Page 257 *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. Ogden, Utah: USDA Forest Service, Rocky Mountain Research Station.
- FGDC. 2008. National vegetation classification standard, version 2. Federal Geographic Data Committee-Vegetation Subcommittee. FGDC-STD-005-2008 (Version 2)
- Forbes, B. C., M. M. Fauria, and P. Zetterberg. 2010. Russian Arctic warming and 'greening' are closely tracked by tundra shrub willows. *Global Change Biology* 16:1542–1554.
- Holt, E. A., B. McCune, and P. Neitlich. 2008. Grazing and fire impacts on macrolichen communities of the Seward Peninsula, Alaska, U.S.A. *The Bryologist* 111:68–83.
- Jandt, 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 disturbance factors. *Arctic, Antarctic, and Alpine Research* 40:89–95.
- Joly, K., P. Bente, and J. Dau. 2007. Response of overwintering caribou to burned habitat in northwest Alaska. *Arctic* 60:401–410.
- 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., P. Duffy, and T. S. Rupp. 2012. Simulating the effects of climate change on fire regimes in Arctic biomes: implications for caribou and moose habitat. *Ecosphere* 3:1–18.
- Joly, K., R. R. Jandt, and D. R. Klein. 2009. Decrease of lichens in Arctic ecosystems: role of wildfire, caribou and reindeer, competition, and climate change. *Polar Research* 28:433–442.
- Klein, D. R., and M. Shulski. 2009. Lichen recovery following heavy grazing by reindeer delayed by climate warming. *AMBIO: A Journal of the Human Environment* 38:11–16.
- Lloyd, A. H., and C. Fastie. 2003. Recent changes in treeline forest distribution and structure in Interior Alaska. *Ecoscience* 10:176–185.
- Racine, C. H. 1979. Climate of the Chucki-Imuruk area. Pages 32–37 *in* Melchior, H. R. eds. *Biological Survey of the Bering Land Bridge National Monument*. Alaska Cooperative Park Studies Unit, University of Alaska Fairbanks, Fairbanks, Alaska.
- Racine, C. H., L. A. Johnson, and L. A. Viereck. 1987. Patterns of vegetation recovery after tundra fires in northwestern Alaska, USA. *Arctic and Alpine Research* 19:461–469.
- Rupp, T. S., A. M. Starfield, and F. S. Chapin. 2000. A frame-based spatially explicit model of sub-Arctic vegetation response to climatic change: comparison with a point model. *Landscape Ecology* 15:383–400.
- Sturm, M., C. Racine, and K. Tape. 2001. Increasing shrub abundance in the Arctic. *Nature* 411:546–547.
- Swanson, D. K. 1996. Fruticose lichen distribution in the Kobuk Preserve Unit, Gates of the Arctic National Park. USDI NPS Tech. Rept. AFA RNRINRTR-96/28. Anchorage, Alaska.

- Tape, K., M. Sturm, and C. Racine. 2006. The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. *Global Change Biology* 12:686–702.
- Viereck, L. A., C. T. Dyrness, A. R. Batten, and K. J. Wenzlick. 1992. The Alaska vegetation classification. Portland, Oregon, USA: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 278 pp.
- Walker, D. A. 1996. Disturbance and recovery of Arctic Alaskan vegetation. Pages 35-71 *in* Reynolds, J. F., and J. D. Tenhunen, eds. Landscape function and disturbance in Arctic tundra. *Ecological Studies* 120. Springer Verlag Berlin Heidelberg.
- Walker, D. A., N. A. Auerbach, J. G. Bockheim, F. S. Chapin, W. Eugster, J. Y. King, J. P. McFadden, G. J. Michaelson, F. E. Nelson, W. C. Oechel, C. L. Ping, W. S. Reeburg, S. Regli, N. I. Shiklomanov, and G. L. Vourlitis. 1998. Energy and trace-gas fluxes across a soil pH boundary in the Arctic. *Nature* 394:469–472.
- Walker, M. D., C. H. Wahren, R. D. Hollister, G. H. Henry, L. E. Ahlquist, J. M. Alatalo, M. S. Bret-Harte, M. P. Calef, T. V. Callaghan, A. B. Carroll, and H. E. Epstein. 2006. Plant community responses to experimental warming across the tundra biome. *Proceedings of the National Academy of Sciences* 103:1342–1346.
- Wein, R. W. 1971. Panel discussion. *In* Slaughter, C. W., R. J. Barney, and G. M. Hansen, eds. Fire in the northern environment – a symposium. Sponsors: Alaska Forest Fire Council and Society of American Foresters. Held at: The University of Alaska, Fairbanks. April 13-14, 1971. Published by: Pacific Northwest Forest and Range Experiment Station.
- Wein, R. W., and L. C. Bliss. 1973. Changes in Arctic *Eriophorum* tussock communities following fire. *Ecology* 54:845–852.

10. Alpine Dwarf Shrub Tundra

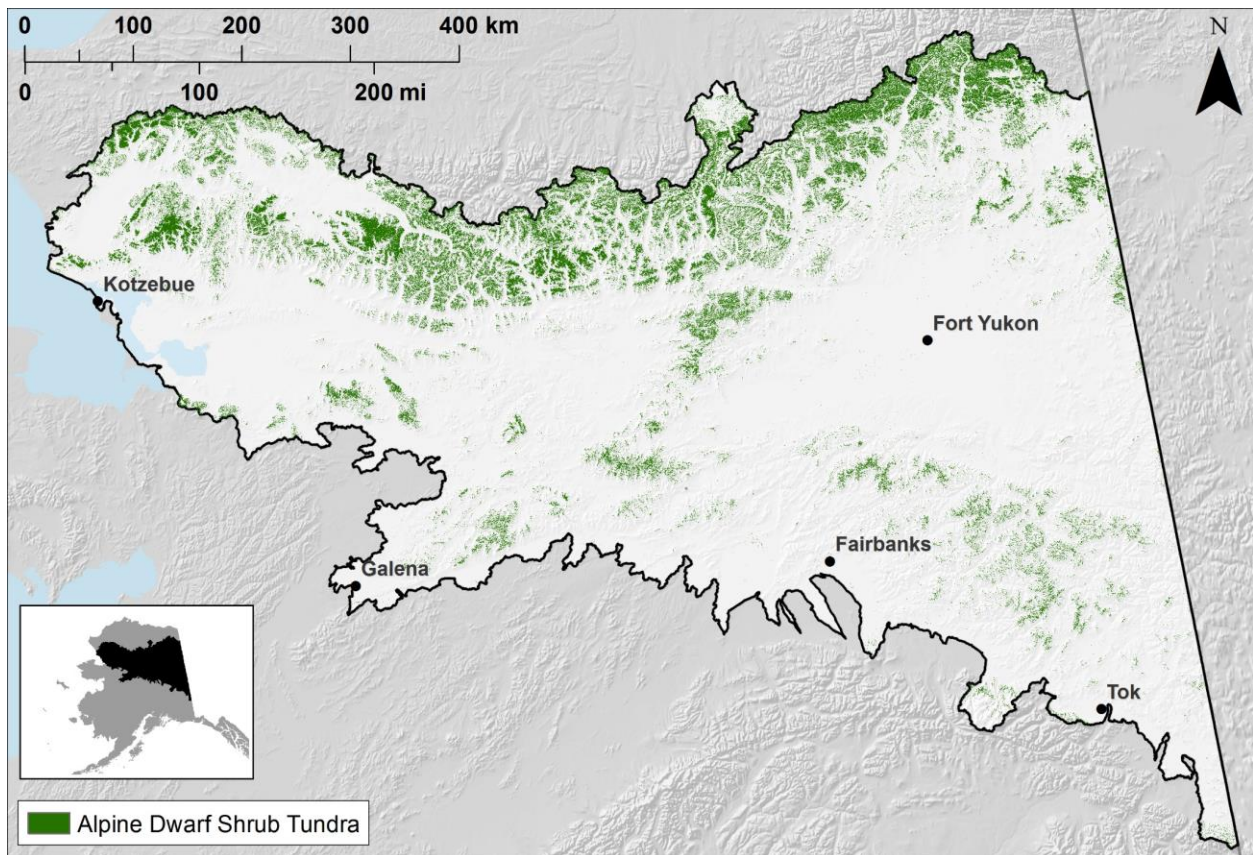


Figure G-56. Distribution map of the alpine dwarf shrub tundra CE.

10.1 Introduction

The alpine dwarf shrub tundra CE is widespread above treeline on ridges, summits, side slopes, late-lying snow beds, and high elevation valleys throughout the boreal, sub-boreal, and low Arctic regions of Alaska (Figure G-56). Dwarf and prostrate shrubs < 20-cm tall are the dominant canopy layer with at least 25% cover. In mountainous regions, dwarf shrub tundra typically represents the highest elevation zone of continuous vegetation. On protected sites, vegetation cover is continuous; on exposed or steep sites canopy cover is sparse due to wind desiccation and slope instability (Figure G-57). High elevation valley bottoms and northerly side slopes are



Figure G-57. Alpine dwarf shrub tundra CE in the southern Brooks Range.

typically moist and may retain late-lying snow, while summits and ridges are wind scoured and well-drained. Soils are typically thin, stony, and well-drained to excessively well-drained. Permafrost may be present, but sites are generally thaw-stable owing to the shallow, rocky soils.

Vegetation

Both plant community and species diversity are high in alpine dwarf-shrub tundra. Composition may be dominated by dwarf evergreen or deciduous shrubs, often in combination with grasses, sedges, and lichens. Common dwarf and prostrate shrubs include *Dryas ajanensis* ssp. *beringensis*, *Vaccinium uliginosum*, *V. vitis-idaea*, *Kalmia procumbens*, *Diapensia lapponica*, *Rhododendron tomentosum*, *Empetrum nigrum*, *Cassiope tetragona*, *Betula nana*, *Salix arctica*, *S. phlebophylla*, *S. reticulata*, *S. rotundifolia*, *Arctous rubra*, and *A. alpina*. Common grasses and sedges include *Anthoxanthum monticola* ssp. *alpina*, *Festuca altaica*, *Luzula* spp., *Carex bigelowii* ssp. *lugens*, *C. microchaeta*, *C. scirpoidea*, and *C. nardina*. Forb cover is usually low, but diversity can be high including species such as *Antennaria* spp., *Arnica lessingii*, *Boykinia richardsonii*, *Geum glaciale*, *G. rossii*, *Minuartia arctica*, *Oxytropis nigrescens*, *Pedicularis lanata*, *Bistorta plumosa*, *Saxifraga bronchialis*, *S. oppositifolia*, *S. tricuspidata*, and *Senecio lugens*. Common mosses include *Hylocomium splendens*, *Racomitrium lanuginosum*, *Rhytidium rugosum*, *Dicranum* spp. and *Polytrichum* spp. On dry exposed sites lichens, including *Cladina rangiferina*, *C. stellaris*, *Flavocetraria cucullata*, *F. nivalis*, *Stereocaulon* spp., *Alectoria* spp., and *Thamnolia vermicularis*, may be abundant (Jorgenson and Meidinger 2015, Viereck et al. 1992, Boggs et al. 2001, Boggs and Boucher 2008).

Ericaceous sites dominated by *Cassiope tetragona* are often associated with late lying snow and protected microtopography in mountainous terrain, while *Dryas ajanensis* ssp. *beringensis* sites are more common on drier, more exposed microsites often with southerly exposures.

Classification Synonymy

The alpine dwarf shrub tundra CE is equivalent to CBVM Central-Northern Alaska-Yukon Alpine Dwarf Scrub and Meadows, but excludes the moist to wet component (Jorgenson and Meidinger 2015); encompasses the following NVC groups: G613 Western Boreal Alpine Dwarf Shrub Tundra, G367 North American Arctic and Sub-Arctic Ericaceous Dwarf Shrub Tundra, G366 North American Arctic and Sub-Arctic *Dryas* Dwarf Shrub Tundra (FGDC 2008); and includes the following Viereck classes: IID1 (*Dryas* Dwarf Scrub, a and b), IID2 (Ericaceous Dwarf Scrub, a, b, and e), IID3a (Willow Dwarf Scrub) (Viereck et al. 1992).

Vegetation Dynamics

Common disturbances in alpine dwarf shrub tundra include wind scour and desiccation on ridges, and avalanches and rock slides on side slopes. There is little information about fire and successional dynamics of this type (Viereck et al. 1992). Fire spread is limited by the lack of fuel continuity and barren areas acting as fire breaks. Under stable climate conditions, this type likely represents a topopoedaphic climax, however, projected climate change, specifically warmer temperatures, longer growing season, and more precipitation, will facilitate vegetation transitions such as shrub expansion and treeline migration into higher elevations. The alpine tundra zone could shift up in elevation in locations with favorable growing conditions.

10.2 Conceptual Model

The conceptual model below is based on literature review and describes the relationships among the various CAs and natural drivers for alpine dwarf shrub tundra. Bold arrows indicate interactions with high ecological relevance and potential management implications, and for which spatial datasets can be intersected with the CE distribution. The primary CAs selected for this CE include climate change, permafrost, fire, and development (Figure G-58).

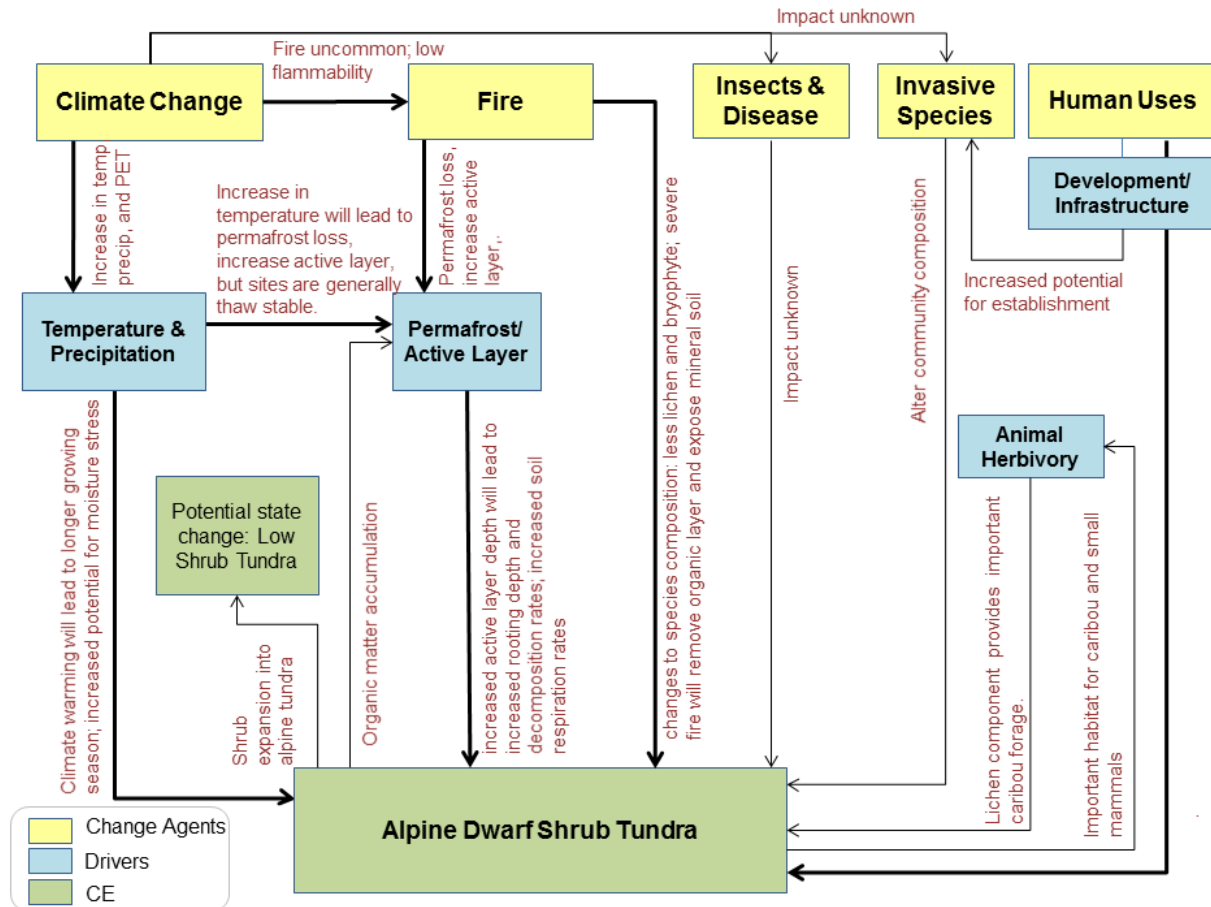


Figure G-58. Conceptual model for alpine dwarf shrub tundra.

10.3 Abiotic Change Agents Analysis

Length of Growing Season and Summer Warmth Index

The length of growing season for alpine dwarf shrub tundra is projected to increase by 10.5 days between the current condition to the long-term future (from 135.7 to 145.2 days), and the mean Summer Warmth Index (annual sum of mean monthly temperatures that are above freezing) is projected to increase from 32 to 38 °C mo for the same time frame (Figure G-54).

Temperature and Precipitation

Mean annual temperature for alpine dwarf shrub tundra is projected to increase by 2.2 °C between the current condition and the long-term future, while mean January temperature is expected to increase by 4.1 °C and mean July temperature is expected to increase by 1.5 °C (Table G-23).

Table G-23. Temperature summary for alpine dwarf shrub tundra.

Alpine Dwarf Shrub Tundra	Mean July Temperature (°C)				Mean January Temperature (°C)				Mean Annual Temperature (°C)			
	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change	2010s	2020s	2060s	Change
	11.5	11.5	13.1	+1.6	-22.3	-17.9	-18.5	+3.8	-5.6	-5.4	-5.4	+0.3

Mean annual precipitation is projected to increase by 66 mm between the current condition and the long-term future, with precipitation during the summer and winter months increasing by 20 and 21 mm, respectively (Table G-24).

Table G-24. Precipitation summary for alpine dwarf shrub tundra.

Alpine Dwarf Shrub Tundra	Precipitation (mm)														
	Summer					Winter					Mean Annual				
	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change	2010s	2020s	2060s	Change	% Change
	235	236	251	+16	+7	83	92	99	+16	+19	519	536	585	+66	+13

Fire and Vegetation Change

The ALFRESCO model does not explicitly model changes to alpine dwarf shrub tundra. In the ALFRESCO input map, the area represented by the dwarf shrub CE is mostly classified as graminoid (32%), no vegetation (32%), and shrub (21%). ALFRESCO projects a decrease in overall area of graminoid tundra but little change in the overall area of shrub tundra by the 2060s (Figure G-20).

The modeled results reflect the expansion of shrub into the graminoid class (which is the dominant vegetation type at the limit of vegetation in the Brooks Range suggested by the ALFRESCO input map). We can interpret these results to indicate a predicted expansion of taller shrubs into the alpine dwarf shrub zone. The best replicate model of shrub expansion (Figure G-23) also shows shrubs expanding into higher elevations particularly in the Davidson Mountains and Brooks Range.

Permafrost

Permafrost is currently continuous under the alpine dwarf shrub tundra CE and this is not expected to change in the near-term future; however, by the 2060s, 5% of the CE area is projected to lose permafrost or have permafrost deeper than 1 m (Table G-7).

The average active layer depth under tussock tundra is currently modeled at 53 cm, and this depth is projected to increase to 56 cm in the near-term and 59 cm in the long-term future (Figure G-13).

Only 12% of this CE is categorized as having a high thermokarst potential and 81% is categorized as low (Figure G-14). Low thermokarst potential is consistent with the rocky residual soils characteristic of this type.

Abiotic Change Agents Discussion

Under stable climate conditions, this type likely represents a topoedaphic climax. However, projected climate change, specifically warmer temperatures, longer growing season, and more precipitation, will facilitate vegetation transitions such as shrub expansion and treeline migration into higher elevations. Several authors have reported expansion of treeline across the boreal system (Suarez et al. 1999, Lloyd and Fastie 2003, Lloyd 2005), but these studies focus on the tundra ecotone near treeline, not specifically alpine dwarf shrub tundra. By the 2060s, the threshold values for Arctic treeline (SWI 35 °C mo and 12 °C mean July isotherm) will have been met and surpassed at the lower elevation boundary of the alpine dwarf shrub CE, suggesting that establishment of trees and deciduous shrubs will be possible in the alpine environment.

The expansion of deciduous shrubs into tundra has been linked to greater snow retention, higher winter soil temperatures, altered surface water hydrology during melt, and increased fire (Higuera et al. 2008, Liston et al. 2002, Sturm et al. 2001, Wahren et al. 2005, Tape et al. 2006).

The ALFRESCO model predicts an increase in shrub tundra and a decrease in graminoid tundra in Brooks Range and Davidson Mountain ecoregions (Figure G-23). Much of the alpine dwarf shrub CE is included in the ALFRESCO graminoid class (Figure G-21) and thus, these predicted changes can be interpreted as shrub expansion into alpine tundra in these ecoregions.

At the upper limits of the CE, warmer temperatures and a longer growing season could lead to the upward expansion of dwarf shrub tundra into previously unvegetated sites; however, we are not aware of any studies that have documented this upward migration of alpine tundra, and transitions into unvegetated terrain are not included in the ALFRESCO model.

Permafrost is expected to remain continuous over most of the CE; however, active layer thickness is projected to increase, which will provide increased rooting depth and may allow for increased productivity. Rocky residual and colluvial soils that dominate the CE distribution are thaw-stable and are not expected to exhibit substantial geomorphic change under a warmer climate regime (Martin et al. 2009).

10.4 Current Status and Future Landscape Condition

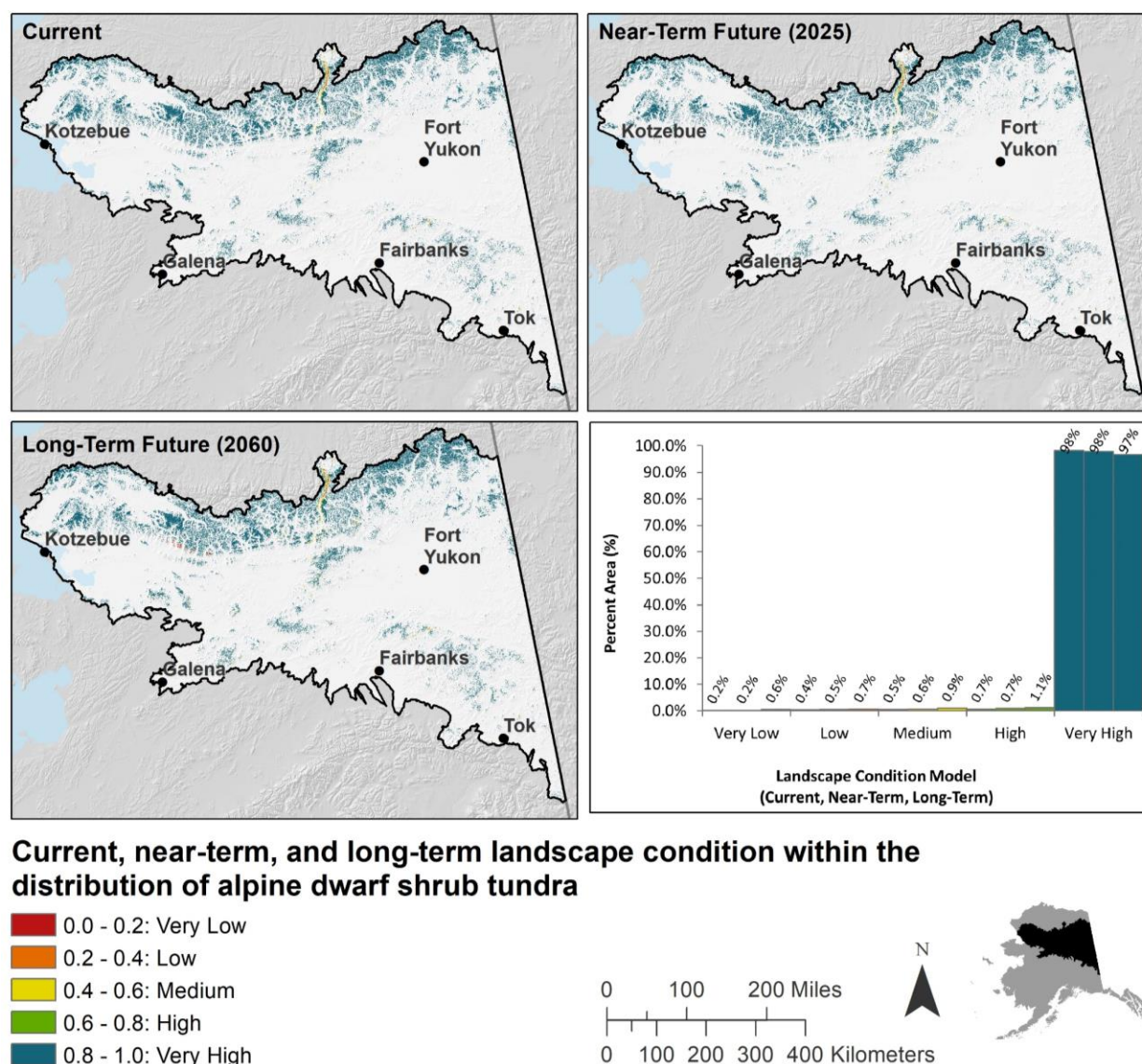


Figure G-59. Current, near-term, and long-term status of alpine dwarf shrub tundra in the CYR study area.

The overall status of the alpine dwarf shrub tundra CE was assessed by intersecting the LCM with the CE distribution model for the current condition, near-term, and long-term future. The LCM is a way to measure the impact of the human footprint on a landscape. In the current condition, the impact on alpine dwarf shrub tundra is minimal, with 98% of the area in the “very high” condition class, and this is not expected to change in the near future. In the current and near-term, the Dalton Highway through the alpine region of Atigun Pass accounts for the majority of the impact to landscape condition. In the long-term, development of the Ambler mining district, including the addition of the road, accounts for added impact, and the percentage area in the “very high” condition is expected to decrease to 97% (Figure G-59).

10.5 Literature Cited

- Boggs, K., and T. V. Boucher. 2008. Draft ecological systems descriptions for Alaska. *In* NatureServe. International Ecological Classification Standard: Terrestrial Ecological Classifications.
- Boggs, K., A. Garibaldi, J. Stevens, J. Grunblatt, and T. Helt. 2001. Denali National Park and Preserve Landcover mapping project. Volume 2: landcover classes and plant associations. Alaska Natural Heritage Program, Environment and Natural Resources Institute, University of Alaska Anchorage, 3211 Providence Drive, Anchorage, Alaska. 164 pp.
- FGDC. 2008. National vegetation classification standard, version 2. Federal Geographic Data Committee-Vegetation Subcommittee. FGDC-STD-005-2008 (Version 2).
- Higuera, P. E., L. B. Brubaker, P. M. Anderson, T. A. Brown, A. T. Kennedy, and F. S. Hu. 2008. Frequent fires in ancient shrub tundra: implications of paleorecords for Arctic environmental change. *PLoS One* 3:e1744.
- Liston, G. E., J. P. McFadden, M. Sturm, and R. A. Pielke. 2002. Modelled changes in Arctic tundra snow, energy and moisture fluxes due to increased shrubs. *Global Change Biology* 8:17–32.
- Lloyd, A. H. 2005. Ecological histories from Alaskan treeline sites provide insight into future change. *Ecology* 86:1687–1695.
- Lloyd, A. H., and C. Fastie. 2003. Recent changes in treeline forest distribution and structure in Interior Alaska. *Ecoscience* 10:176–185.
- Martin, P. D., J. L. Jenkins, F. J. Adams, M. T. Jorgenson, A. C. Matz, D. C. Payer, P. E. Reynolds, A. C. Tidwell, and J. R. Zelenak. 2009. Wildlife response to environmental Arctic change: predicting future habitats of Arctic Alaska. Report of the Wildlife Response to Environmental Arctic Change (WildREACH): Predicting Future Habitats of Arctic Alaska Workshop, 17-18 November 2008. Fairbanks, Alaska: U.S. Fish and Wildlife Service. 138 pp.
- Sturm, M., C. Racine, and K. Tape. 2001. Increasing shrub abundance in the Arctic. *Nature* 411:546–547.
- Suarez, F., D. Binkley, M. W. Kaye, and R. Stottlemeyer. 1999. Expansion of forest stands into the tundra in Noatak National Preserve, northwest Alaska. *Ecoscience* 6:465-470.
- Tape, K., M. Sturm, and C. Racine. 2006. The evidence for shrub expansion in Northern Alaska and the Pan-Arctic. *Global Change Biology* 12:686–702.
- Viereck, L. A., C. T. Dyrness, A. R. Batten, and K. J. Wenzlick. 1992. The Alaska vegetation classification. Pacific Northwest Research Station, U.S. Forest Service, Portland, Oregon. Gen. Tech. Rep. PNW-GTR286. 278 pp.
- Wahren, C. H., M. D. Walker, and M. S. Bret-Harte. 2005. Vegetation responses in Alaskan Arctic tundra after 8 years of a summer warming and winter snow manipulation experiment. *Global Change Biology* 11:537–552.

11. Rare Ecosystems (MQs G1 and AH1)

MQ G1: Where are refugia for unique vegetation communities (e.g., hot springs, bluffs, sand dunes), and what are the wildlife species associated with them?

MQ AH1: What rare, but important habitat types that are too fine to map at the REA scale and are associated with Coarse- (or Fine-) Filter CEs that could help identify areas where more detailed mapping or surveys are warranted before making land use allocations (such as steppe bluff association with dry aspen forest)?

11.1 Introduction to Rare Ecosystems

For management questions regarding unique vegetation communities (MQs G1 and AH1), we used the Alaska Center for Conservation Science (ACCS) designated Ecosystems of Conservation Concern as proxies for “refugia for unique vegetation communities.” Ecosystems of Conservation Concern, hereafter termed ‘rare ecosystems,’ are naturally uncommon assemblages of specialized and/or diverse flora and fauna occupying relatively small geographic areas. Since these ecosystems disproportionately contribute to biodiversity, they facilitate conservation efforts on relatively small areas that encompass a higher proportion of biodiversity than the surrounding landscape (Williams et al. 2007). Rare ecosystems in Alaska may be associated with uncommon substrates or geomorphic processes, unusual microclimates, or represent uncommon assemblages of dominant plants. Rare ecosystems that develop on uncommon substrates or derive from uncommon geomorphic processes are generally widespread and support stable plant associations (Boggs et al., in prep.), while those that develop from unusual microclimates or represent uncommon plant assemblages tend to be spatially restricted and potentially more ephemeral (Boggs et al., in prep.).

Because of the varying scales and processes associated with rare ecosystems addressed here, they are described at two levels of community classification: Biophysical Settings and Plant Associations. A Biophysical Setting (BpS) describes the vegetation that dominates the landscape in the absence of human disturbance and accounts for both the biophysical environment and its natural disturbance regime. Plant Associations (PAs), are defined as plant community types of definite floristic composition, uniform habitat conditions, and uniform physiognomy (Flahault and Schroter 1910, Jennings et al. 2006), and are comparable to successional stages within BpSs (see Boggs et al., in prep.).

For each rare ecosystem within the CYR study area, we provide a description and distribution, factors contributing to rarity, and potential threats. To answer MQ G1, we summarize unique vegetation or successional stages and provide a table of associated Terrestrial Coarse-filter CE and rare plant species. To answer MQ AH1, we provide a table of associated wildlife with our description. An additional MQ (MQ G2) related to rare ecosystems and climate change will refer to this section.

11.2 Methods

Conservation Status Ranking

Ecosystems of Conservation Concern designations are part of a larger effort by the Natural Heritage Program Network and Canadian Provincial Conservation Data Centres to identify biotic species and communities of conservation concern. The conservation status of BpSs and PAs were assessed with standardized nationwide methods set forth by the NatureServe Conservation Ranking methodology (Master et al. 2012). This method incorporates data such as ecosystem range, area of occupancy, number of occurrences, as well as trends and threats to calculate a Conservation Status Rank. A similar methodology is applied to rare plant species with the same result of conservation status rank. Conservation status ranks estimate elimination risk posed to an ecological community, are designated by a number from 1 to 5 (1: critically imperiled, 2: imperiled, 3: vulnerable, 4: apparently secure, 5: secure), and are preceded by either an 'S,' which indicates a state-level rank, or a 'G,' which indicates a global rank (see Master et al. 2012). The BpS and PAs of conservation concern included herein were advanced for formal ranking from a larger pool of candidate systems either described in published literature or recommended by professional botanists and ecologists. Plant Associations associated with a given BpS were described as part of the larger system. Plant associations that were not conclusively associated with a larger BpS were described individually at the association level. The full list of ecosystems of conservation concern has been peer-reviewed by state and federal agency ecologists and further refined by ACCS (Boggs et al., in prep.).

Datasets and Methods

We used the ACCS Ecosystems of Conservation Concern dataset to identify rare ecosystems within the CYR study area (Table G-25). We used the ACCS Rare Plant Database to identify rare plants within the CYR study area. We intersected rare ecosystem occurrences with Terrestrial Coarse-filter CEs and the rare plant database to identify associations and overlap (Table G-25, Figure G-60). Limitations of the input data are discussed in detail in the Data Gaps and Limitations section.

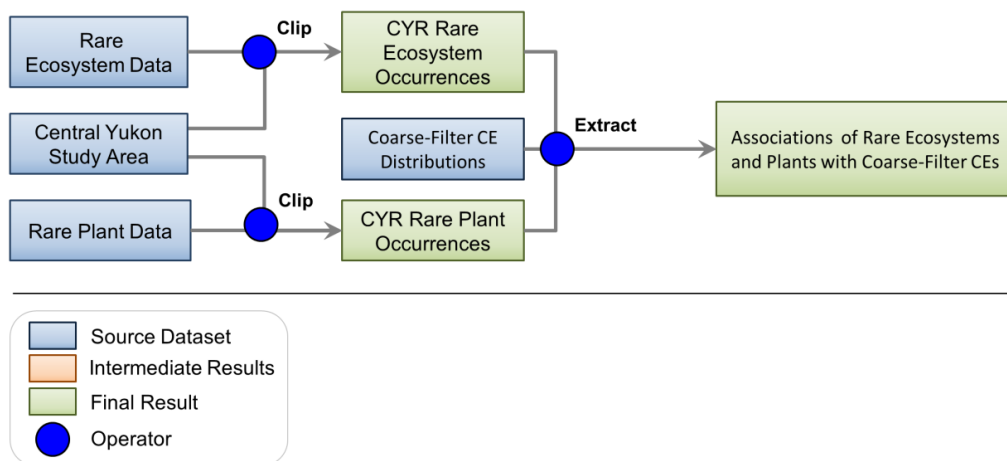


Figure G-60. Process Model of rare ecosystems and rare plants with Coarse-filter CEs. The same approach was taken with Fine-Filter CEs.

Table G-25. Datasets used for MQ AH1 and G1.

Dataset Name	Data Source
Alaska Rare Ecosystem Database	Alaska Center for Conservation Science
Alaska Rare Plant Database	Alaska Center for Conservation Science
BIOTICS Animal Data Portal	Alaska Center for Conservation Science
AKGAP Models	Alaska Center for Conservation Science
Habitat Association Database (HA Database)	Alaska Center for Conservation Science

To identify wildlife species associated with rare ecosystems within the context of an REA, we limited the inclusion of wildlife to Terrestrial Fine-filter Conservation Element wildlife species, Species of Conservation Concern, and those presented in literature review of the rare ecosystem. We used the ACCS BIOTICS Animal Data Portal to develop a list of wildlife Species of Conservation Concern with state conservation rank of S1, S2, and S3. To identify Terrestrial Fine-filter Conservation Element wildlife species associated with rare ecosystems, we intersected AKGAP Model wildlife distribution data and Habitat Association Database (HA Database) with the Rare Ecosystems Database to create an association list (Figure G-60). These presence/absence distribution models are discussed in Section H. Terrestrial Fine-Filter Conservation Elements. Lastly, we included other wildlife species from literature review of rare ecosystems and described the utilization of the habitat when possible.

We reviewed the list of wildlife species and retained those that could potentially utilize the habitat based on literature and external peer review (see Data Gaps and Limitations section). For example, the distribution models of Swainson's thrush, bar-tailed godwit, black scoter, surfbird, and Peregrine falcon AKGAP Models intersect with the inland dunes rare ecosystem. However, critical habitat requirements are absent, such as closed shrub cover in the case for Swainson's thrush; water resources for bar-tailed godwits, black Scoters, and surfbirds; and a lack of rocky cliffs/bluffs and a low number of prey species for Peregrine falcons. Therefore, we do not include questionable species for the ecosystem. When a species' AKGAP Model overlapped with a rare ecosystem and that rare ecosystem met habitat requirements, but no literature or observations were found to verify that association, we categorized that species as 'Suspected' within that rare ecosystem.

Additionally, due to the natural movement of birds, they are often only casually present in the rare ecosystem due to their reliance on adjacent habitat, thusly artificially inflating the significance of the rare ecosystem as critical habitat (DeCicco, pers. comm. 2016). Therefore, we only include bird species for two rare ecosystems that are explicitly critical for birds (Beringian Alpine Limestone *Dryas* and Tidal Marsh) and when supported by literature or observations.

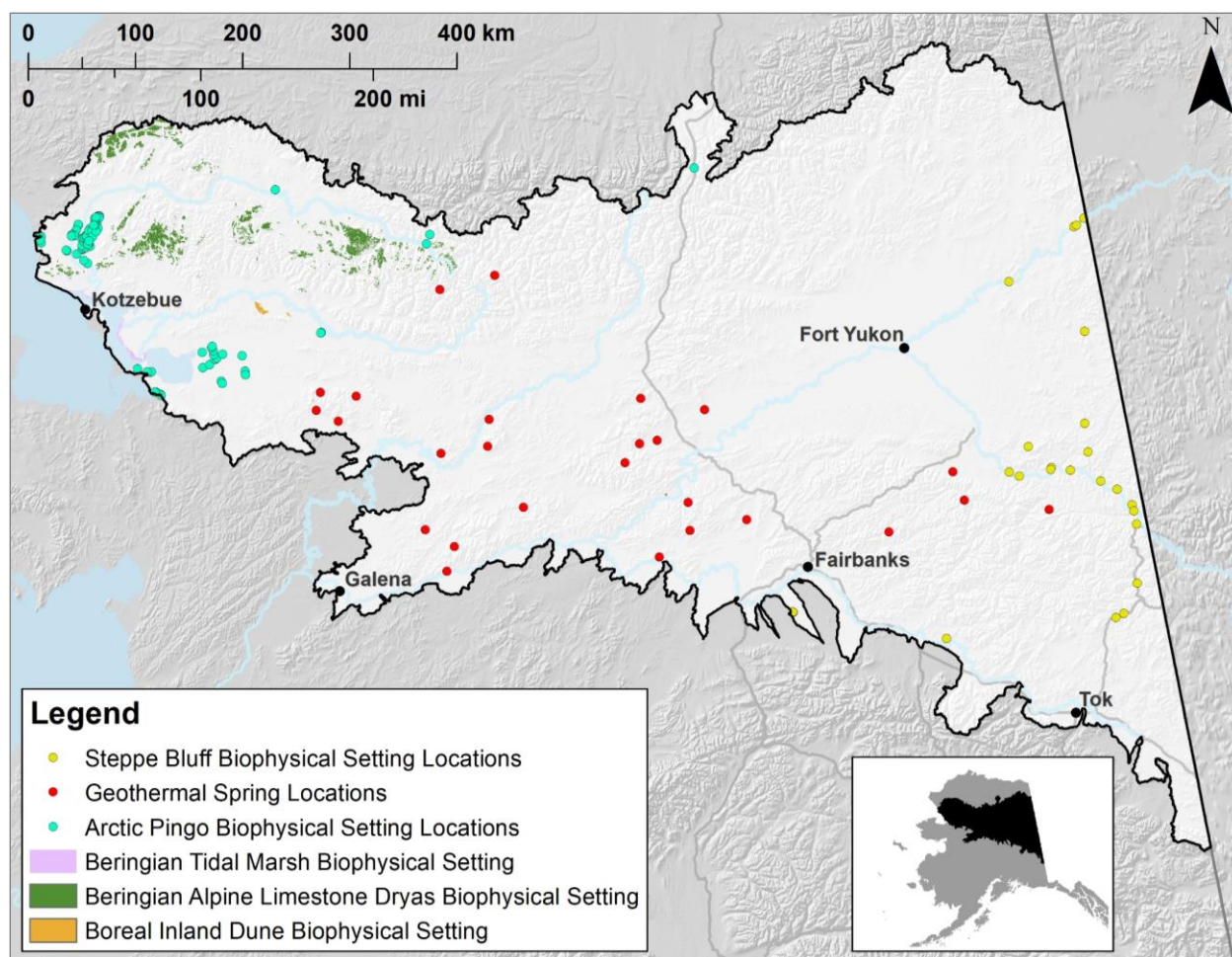
11.3 Results

Summary

We identified six rare ecosystems within the CYR study area: Inland Dune BpS, Arctic Pingo BpS, Steppe Bluff BpS, Beringian Alpine Limestone Barren *Dryas* BpS, Tidal Marsh Bps; and Geothermal Springs (Figure G-61, Table G-26).

Table G-26. Ecosystems of Conservation Concern within the Central Yukon Ecoregion and their respective categories of rarity.

Ecosystem	Conservation Status		Category of Rarity			
	Global Rank	State Rank	Uncommon Substrate	Unusual Geomorphic Process	Unusual Microclimate	Uncommon Plant Species
Inland Dune BpS	G3G4	S3S4	X			X
Arctic Pingo BpS	G3	S3		X	X	
Steppe Bluff BpS	G3	S3			X	X
Beringian Alpine Limestone <i>Dryas</i> BpS	G3	S3	X			X
Tidal Marsh BpS	G3	S3		X		
Geothermal Spring	G3	S3	X	X	X	X

**Figure G-61.** Six rare ecosystems were identified within the CYR study area. Note: Polygons and points in this map are exaggerated for visibility.

11.4 Inland Dune BpS

Conservation Status: G3, S3 (Vulnerable)



Figure G-62. Great Kobuk Sand Dunes.

Description and Distribution

The inland dune systems occurring in boreal Alaska are remnants of larger systems of dunes and sand sheets that developed in the late Pleistocene. Most of these sand deposits have been stabilized by tundra and forest vegetation; thus, active inland dunes are rare on the landscape. Only three large active dune fields, totaling 11,000 ha in area, are known in Alaska—the Great Kobuk Sand Dunes (62 km²), Little Kobuk Sand Dunes (8 km²), and Nogahabara Dunes (65 km²) (Koster 1988, Lea and Waythomas 1990). Only the Great Kobuk and Little Kobuk dunes occur in the CYR study area (Figure G-62). These dune fields, and related dune fields in western Canada, are strongly linked by their shared floristics, Quaternary origins, and geomorphic processes and landforms.

Vegetation and Succession

Inland dunes are largely barren; they support scattered plants of *Bromus pumpellianus* (Pumpelly's brome), *Festuca rubra* (red fescue), *Salix alaxensis* (feltnleaf willow), *Artemisia borealis* (field sagewort), *Oxytropis kobukensis* (Kobuk locoweed) and *Plantago canescens* (gray pubescent plantain). Due to the sparsity of vegetation, there are no Terrestrial Coarse-filter CEs associated with this BpS. The Great Kobuk Sand Dunes are surrounded by black spruce forest (Racine 1976). On well-drained sites within 50–100 m of the

active dune borders, this forest is dominated by 10- to 20-m tall *Picea glauca* with subordinate *Betula neoalaskana* and *Populus tremuloides*—a forest type that approximates the upland mesic spruce forest CE. Further from the active dunes, well-drained, stabilized dunes are vegetated by woodlands codominated by *Picea glauca*, *Betula neoalaskana*, and *Populus tremuloides* trees, with subordinate *Salix* species and *Alnus viridis* ssp. *crispa* shrubs, and a ground layer of dwarf ericaceous shrubs and foliose lichens (Young and Racine 1977). Lichens identified from the sand dunes and surrounding habitats comprise 160 species representing 63 genera, many with circumpolar Arctic-alpine and amphiberingian distributions (Dillman et al. 2001). Three rare plant species are associated with Inland Dune Interior BpS in the CYR study area (Figure G-63, Table G-27), one of which—*Oxytropis kobukensis*—is narrowly endemic to the dune system.

Dune margins are typically stabilized by *Leymus mollis* or *Festuca rubra*, although cover rarely exceeds 10%. Dead leaves of *L. mollis* accumulate at the base of the stem, providing increased cover along the sand surface. Here, windblown plant and lichen fragments are trapped providing germination sites for additional plants. In time, lichens replace grasses, and other vascular species become established. When cover of lichens and forbs reaches about 90% cover, *Picea glauca* (white spruce) colonizes and gradually develops into a *Picea glauca* woodland with lichen understory. However, active sand may, in turn, advance on spruce forests, killing them and resetting the successional pattern (Bowers 1982). Fire may also return forest- or tundra-stabilized dunes to activity (Mann et al. 2002). Active dunes are also dissected in many places by creeks, which facilitates the development of localized riparian plant communities. Interdune depressions, also known as slacks, may support wetlands.

Table G-27. Rare plant species associated with Inland Dunes BpS in the CYR study area.

Species	Global Rank	State Rank	Description
<i>Lupinus kuschei</i>	G3G4	S2	Occurs on sand dunes and glacial rivers. Most of the global population is in southwestern Yukon Territory, with additional occurrences in British Columbia and Alaska.
<i>Oxytropis kobukensis</i>	G2	S2	Narrowly endemic to a small stretch of the middle Kobuk River, where it grows on sparsely vegetated sand on active dunes, in dune slacks and on sheltered dune slopes.
<i>Symphyotrichum yukonense</i>	G3	S3	Mud flats, gravelly, stony or silty lakeshores, sometimes saline areas in Northwest Territories, Yukon, and Alaska.



Figure G-63. *Oxytropis kobukensis*, a rare plant endemic to the Kobuk Sand Dunes Photo by Mike Duffy.

Trend

The Great Kobuk Sand Dunes underwent a period of stabilization between 7,000 and 5,000 BP (before present), then returned to activity and expanded during the Medieval Warm Period (ca. AD 900–1,400). The dunes were relatively inactive early in the Little Ice Age (AD 1400–1800) and expanded briefly around 1900. Over the last century the dune field has contracted. Moisture balance appears to be the major control of aeolian activity at dune fields within boreal forests, with increased moisture promoting the establishment of vegetation and leading to contraction of the dune fields (Mann et al. 2002, Wolfe et al. 2000). Please see MQ G2 for more discussion.

Threats

Recreational and subsistence vehicle or foot traffic on the dunes could affect plant establishment and persistence, and could threaten rare plant populations in particular. However, these impacts are expected to be minimal due to low human population densities and localized around villages. Because vegetation colonization of active dunes is so closely tied to moisture regimes, changes in climate are likely to impact future ecological conditions more strongly than human activity (Parker and Mann 2000). Based on SNAP data, the inland dune system is anticipated to see an increase of 55 mm of rainwater equivalent increase in the long-term. The significant increase in precipitation may promote vegetation encroachment, contracting the dune system. See MQ G2

for further discussion. Non-native plant species such as *Melilotus alba* and *Viccia cracca* may pose a threat to the dune system if they spread to the region. *Melilotus alba* persists in finer silt deposits and can be spread easily down waterways into the dune system from the Noatak River. *Viccia cracca* would not establish on the dune system but in the forest margin.

Associated Wildlife

We identified eight wildlife species that have been documented to utilize or are suspected to utilize the Inland Dune BpS (Table G-28). The Alaska tiny shrew has been documented to occur at Kobuk Valley National Park, between the Great Kobuk and Little Kobuk dunes (UAM 2015). It primarily inhabits riparian scrub areas, but has also been observed in wetlands and bogs, and at forests and shrub tussock tundra at dune margins (Boggs et al., in prep). Mammals collected on dunes include North American porcupine (*Erethizon dorsatum*), northern red-backed vole (*Myodes rutilus*), root vole (*Microtus oeconomus*), dusky shrew (*Sorex monticolus*), taiga vole (*Microtus xanthognathus*), and American red squirrel (*Tamiasciurus hudsonicus*) (UAM 2015). Wildlife activity—particularly grazing and trampling by caribou (*Rangifer tarandus*) or burrowing by Arctic ground squirrels (*Spermophilus parryi*)—is known to disturb similar systems in the Arctic, thereby facilitating erosion and blowouts (Peterson and Billings 1978).

Table G-28. Wildlife species associated with the Inland Dune BpS in the CYR study area.

Common Name	Global Rank	State Rank	BLM Status	Dataset	Confirmed/Suspected
Alaska tiny shrew	NR	S3	Sensitive Species	AKGAP Model, HA Database	Suspected
American red squirrel	G5	S5	None	UAM	Confirmed
caribou	G5	S5	None	AKGAP Model, HA Database	Suspected
montane shrew	G5	S5	None	UAM	Confirmed
North American porcupine	G5	S5	None	UAM	Confirmed
northern red-backed vole	G5	S5	None	UAM	Confirmed
taiga vole	G5	S4S5	None	UAM	Confirmed
tundra vole	G5	S5	None	UAM	Confirmed

11.5 Arctic Pingo BpS

Conservation Status: G3, S3 (Vulnerable)

Description and Distribution

Pingos are perennial, ice-cored domes of soil and vegetation, formed by injection and freezing of water in near-surface permafrost (Boggs et al., in prep.). More than 1,500 pingos are estimated to occur in Alaska. Pingos have been classified into two categories based on their mechanisms of water pressurization. Hydrostatic pingos rely on continuous, ice-rich permafrost and are, thus, more common in the Arctic, whereas hydraulic pingos develop in areas of discontinuous permafrost and are, thus, more common in the boreal forest. Both types are found within the CYR study area; however, hydrostatic pingos, hereafter referred to as Arctic pingos, are recognized as a rare BpS while hydraulic pingos, hereafter referred to as boreal pingos are numerous within the CYR study area and are not considered a rare ecosystem. Arctic pingos are tightly concentrated in the western part of the CYR study area in the Kotzebue Sound Lowlands and west of the Baird Mountains north of Kotzebue, while boreal pingos are concentrated in the middle and eastern part of the CYR study (Figure G-64). There are 89 Arctic pingos documented in the CYR study area.

Arctic pingos normally form in drained lake basins underlain by continuous permafrost. In Alaska, lakes greater than 2-m deep do not freeze to the bottom in winter, which preserves an unfrozen, water-saturated zone known as a talik. When this talik is exposed by lake drainage or another event that reduces its insulation from freezing temperatures, permafrost encroaches inward from the lake basin margin. As freezing progresses, water is extracted from the pore spaces of the surrounding sands and gravels into the remaining unfrozen area, where pressure builds. When the basin eventually freezes, the increase in volume uplifts the overlying sediments and a pingo is formed (Mackay 1979, Mackay 1998, Everett 1980). Arctic pingos are generally between 5- to 20-m high with diameters of 70–400 m, but may reach heights of 50 m and basal diameters greater than 1 km (Walker et al. 1985).

Vegetation

Pingos of Alaska's Arctic Coastal Plain are known to support rare plants, unique vegetation, and important wildlife habitat (Koranda 1970, Walker et al. 1985). There are no rare plant or animal species or plant associations of conservation concern documented with pingos in the CYR study area, but further study is merited.

Arctic pingos are primarily associated with the alpine and Arctic tussock tundra CE. A diversity of plant communities has been described for pingos on the Seward Peninsula (Sigafos 1951, Pegau 1970, Wetterich et al. 2012), which would have a similar community as the pingos in the western region of the CYR study area. On drier sites, pingos support diverse dwarf and low shrub communities with *Dryas integrifolia*, *Andromeda polifolia*, *Betula nana*, *Spiraea stevenii*, and *Rhododendron tomentosum*, (Wetterich et al. 2012). On mesic sites a typical shrub-graminoid tundra community dominated by dwarf shrub, *Eriophorum* species, and *Carex* species may establish (Pegau 1970). Herbaceous communities including the grasses *Arctagrostis latifolia* var. *arundinacea*, *Calamagrostis neglecta*, *Poa arctica*, and the forbs *Aconitum delphiniifolium*, *Polemonium acutiflorum*, *Rubus arcticus*, *Rhodiola integrifolia*, *Trientalis europaea*, and *Petasites frigidus* may establish at the summit, with *Salix* shrubs on the slopes. On wetter sites a

graminoid tundra may develop; these may be dominated by *Carex aquatilis* over a thick layer of *Sphagnum* and *Polytrichum* mosses (Pegau 1970) or a thick sedge sod codominated by *Carex aquatilis* and *Eriophorum angustifolium* (Sigafos 1951).

Trend and Threats

Pingos will likely be negatively impacted by climate change. They occur within regions of continuous and discontinuous permafrost and, thus, exist at a threshold wherein a minor change in climate could impact their stability. Fifteen percent ($n = 13$) of Arctic pingos within the CYR study area are projected to experience change in permafrost from currently below 0 °C to above 0 °C by 2060s. These pingos are concentrated southeast of Kotzebue (Figure G-64). These pingos are likely to melt by the 2060s and form springs.

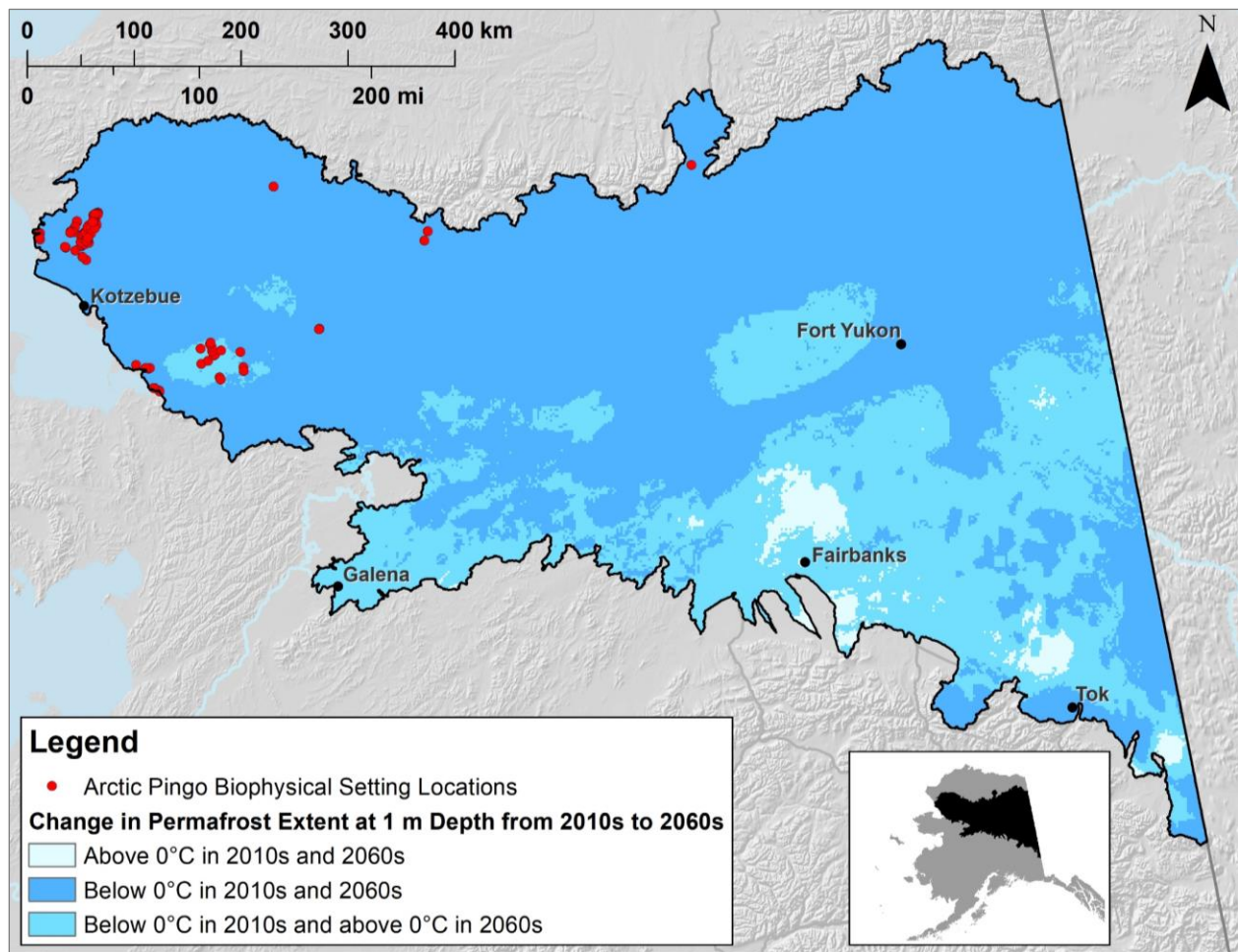


Figure G-64. Projected change in permafrost at 1-m depth from 2010s to 2060s and known locations of Arctic pingos. Mean annual ground temperature is predicted to rise above 0 °C for 13 pingos by the 2060s.

Associated Wildlife

We identified 11 wildlife species that have been documented to utilize or are suspected to utilize the Arctic Pingo BpS (Table G-29). On the Arctic Coastal Plain, Arctic foxes (*Vulpes lagopus*), Arctic ground squirrels (*Spermophilus parryii*), American mink (*Neovison vison*) and Nearctic collared lemmings (*Dicrostonyx groenlandicus*) all den in the unfrozen soils overlying pingos

(Eberhardt 1977). In the extensive low-lying marshy areas of the Yukon Kuskokwim Delta, pingos play an important role in the ecology of mink by providing the majority of suitable natal den sites. Grizzly bears are attracted to pingos because of the high densities of ground squirrels, and caribou utilize pingos for mosquito relief (Boggs et al., in prep.). South-facing aspects of pingos south of the Brooks Range often have greater thickets of *Salix* species that can offer browsing opportunities for moose (Boggs et al., in prep.). Long-tailed jaegers, rough-legged hawks, and golden eagles use pingos as hunting grounds and observation points in treeless landscapes (Walker et al. 1985). Lapland longspurs, buff-breasted sandpipers, and numerous other birds can regularly be found on pingos (Walker et al. 1985).

Table G-29. Wildlife species associated with the Arctic Pingo BpS in the CYR study area.

Common Name	Global Rank	State Rank	BLM Status	Dataset	Confirmed/Suspected
Alaskan hare	G3	S3	Sensitive Species	AKGAP Model, HA Database	Suspected
Alaska tiny shrew	NR	S3	Sensitive Species	AKGAP Model, HA Database	Suspected
American mink	G5	S5	None	Eberhardt 1977	Confirmed
Arctic fox	G5	S5	None	Eberhardt 1977	Confirmed
Arctic ground squirrel	G5	S5	None	Eberhardt 1977	Confirmed
brown bear	G4	S4	None	Boggs et al., in prep	Confirmed
caribou	G5	S5	None	Boggs et al., in prep	Confirmed
golden eagle	G5	S5	None	AKGAP Model, HA Database, Walker et al. 1985	Confirmed
long-tailed jaeger	G5	S5	None	Walker et al. 1985	Confirmed
moose	G5	S5	None	Boggs et al., in prep	Confirmed
nearctic collard lemmings	G5	S5	None	Eberhardt 1977	Confirmed

11.6 Steppe Bluff BpS

Conservation Status: G3G4 S3S4 (vulnerable to apparently secure)



Figure G-65. *Erigonum flavum* var. *aquilinum* amid Dall sheep scat in steppe bluff habitat near Eagle, Alaska.

Description and Distribution

Steppe bluffs are open, graminoid-sagebrush dominated sites that occur on steep, south-facing slopes in Interior and Southcentral Alaska (Figure G-65). Steppe habitat occurs primarily on bluffs adjacent to rivers, including the Tanana, Porcupine, Copper rivers and a section of the Yukon River east of Galena (Edwards and Armbruster 1989, Hanson 1951, Juday and Dyrness 1985, Kassler 1979, Lipkin and Tande 1991, Murray et al. 1983, Osgood 1909, Roland 1990, Tande 1996). Elsewhere in Alaska, steppe habitat occurs on pingos on the Arctic Coastal Plain of Alaska, bluffs in Denali National Park, and river systems in Southcentral Alaska, such as the Matanuska and Copper rivers and their tributaries (Boggs et al., in prep.). Only a small percentage of steppe bluff occurrences have been mapped. In the CYR study area, 23 Steppe Bluff BpS sites have been mapped based on literature and observations (Figure G-61).

Steppe bluffs typically occupy steep (slope 30–46°), south-facing (aspect 121–225°) slopes (Roland 1990). This topography facilitates microclimatic conditions that are divergent from nearby

areas. Slopes receive greater solar radiation, which promotes considerable daily and annual temperature fluctuations, reduced snow accumulation and persistence, and high soil evaporation and transpiration. Collectively these factors create uniquely warm, dry microclimates (Bliss et al. 1973, Lewis 1998, Lloyd et al. 1994, Kassler 1979, Roland 1990, Wesser 1989). Such conditions are thought to inhibit forest development, resulting in a distinctive flora that hosts numerous endemic plants and supports notable insect biodiversity (Edwards and Armbruster 1989, Murray et al. 1983, Roland 1996, Guinn and Armbruster 1985).

Vegetation

Steppe bluffs are generally vegetated with dry, open low shrub and graminoid-herbaceous associations characterized by the low shrubs *Artemisia frigida*, *Amelanchier alnifolia*, *Elaeagnus commutata*, *Shepherdia canadensis*, and *Juniperus communis*, the dwarf shrub *Arctostaphylos uva-ursi*, the grasses *Bromus pumpellianus*, *Festuca altaica*, *Calamagrostis purpurascens*, and *Poa glauca*, and the forbs *Artemisia arctica*, *A. alaskana*, *Bupleurum americanum*, and *Saxifraga tricuspidata* (Lipkin and Tande 1991). *Populus tremuloides* (quaking aspen) and *Picea glauca* (white spruce) associations occur along the margins of the bluff habitat, but small stands of *Populus tremuloides* sometimes occur within the habitat. Fire and mass wasting periodically remove forest taxa and expose mineral soil, thereby perpetuating the persistence of more disturbance-adapted taxa (Lewis 1998, Roland 1990, Roland 1996). Additionally, the warm and dry microclimates of the steppe bluffs are thought to exclude trees (Edwards and Armbruster 1989, Murray et al. 1983, Roland 1996). Steppe herbaceous and shrub associations are thought to be seral to *Populus tremuloides* woodlands (Vetter 2000, Boggs and Sturdy 2005). Vascular plant cover is often sparse (Lipkin and Tande 1991, Roland 1996) with bare soil or lichen occupying interstices between vascular plant cover (Batten et al. 1979, Lewis 1998, Roland 1996). Biological soil crusts are common in mature steppe bluff and may contribute significantly to the community's nitrogen budget (Dickson 2000, Marsh et al. 2006, Zazula et al. 2002).

Due to the steppe bluff's low herbaceous cover and unique vegetation community of graminoid-herbaceous-shrub association, there is not a definitive Terrestrial Coarse-filter CE associated with this BpS. Some steppe bluffs that occur at lower elevations adjacent to river systems are proximal to the floodplain forest and shrub CE, however, a majority of the known steppe bluff locations intersect with the upland mesic spruce-hardwood forest CEs or no CE. The margins of steppe bluffs are often forested with *Populus tremuloides* and/or *Picea glauca*. Pockets of *Populus tremuloides* occasionally occur within or bisect steppe bluff habitat, depending on the seral stage of the steppe bluff. When *Populus tremuloides* stands occur within the steppe bluff, it becomes associated with the upland mesic spruce-hardwood forest CE. The steppe bluffs with higher bare ground and graminoid-shrub cover do not correspond to any Terrestrial Coarse-filter CE.

There are 18 rare plant species associated with steppe bluff habitat in the CYR study area (Table G-30). Steppe bluff habitat supports a higher number of endemic plant species (Roland 1996), including a disproportionately high diversity and abundance of rare plant taxa (Table G-30; Murray et al. 1983, Shacklette 1966). Thus, this rare ecosystem provides an opportunity to conserve a

number of rare and endemic taxa by focusing management on a single habitat (Parker and Batten 1995).

Table G-30. Rare vascular plant species associated with Steppe Bluff BpS in the CYR study area.

Species	Global Rank	State Rank	Description
<i>Alyssum obovatum</i>	G5	S2S3	This perennial mustard occurs on south-facing steppe bluffs near the Porcupine River and South Fork Forty Mile River.
<i>Apocynum androsaemifolium</i>	G5	S3	This shrub reaches its northern distribution limit in steppe communities of Interior Alaska.
<i>Artemisia tanacetifolia</i>	GNR	S3	This forb is associated with grass-shrub steppes, grass-forb steppes, aspen woodland, and dwarf shrub tundra.
<i>Carex eburnea</i>	G5	S3	Occurs in various habitats, but can be found south-facing steppe bluffs near the Porcupine River.
<i>Chamaerhodos erecta</i>	G5	S2S3	Annual/biennial rose that reaches its northernmost distribution in steppe communities of Interior Alaska.
<i>Cryptantha shackletteana</i>	G1Q	S1	Recruitment is high on steppe bluff habitat. Visited frequently by solitary bees. Four populations in AK.
<i>Douglasia arctica</i>	G3	S3	Associated with sparsely-vegetated, aspen and spruce woodland, low birch scrub, graminoid steppe, and <i>Dryas</i> heath.
<i>Draba murrayi</i>	G2	S2S3	Small populations occur on open slopes or in graminoid steppes along the upper Yukon River.
<i>Elymus lanceolatus</i> ssp. <i>psammophilus</i>	G3G4	S1S2	Populations on steppe bluffs on the Yukon and Porcupine rivers.
<i>Erigeron ochroleucus</i>	G5	S1S2	This perennial aster occurs on sparsely-vegetated graminoid steppes.
<i>Eriogonum flavum</i> var. <i>aquilinum</i>	G5	S2	Associated with sparsely vegetated river bluffs and rock outcrops. Seedlings appear to be uncommon, suggesting that this species reproduces infrequently.
<i>Erysimum angustatum</i>	G5T2	S2	Found on sparsely-vegetated, open graminoid steppe, open sites in aspen or birch forest.
<i>Maianthemum stellatum</i>	G5	S3	Occurs on steppe slopes along the Yukon River.
<i>Orobancha fasciculata</i>	G4	S1	Two populations occur in Alaska, both on steppe bluffs on the Yukon and Porcupine rivers.
<i>Phacelia mollis</i>	G2G3	S3	Occurs in steppe communities in eastern Interior Alaska.

Species	Global Rank	State Rank	Description
<i>Phlox richardsonii</i>	G4	SNR	Reaches north and west distribution limits in steppe communities near Yukon and Porcupine rivers.
<i>Rosa woodsii</i> ssp. <i>woodsii</i>	G5T5	S2S3	Associated with steppe and hill prairie communities, open aspen-mixed forest woodlands.
<i>Townsendia hookeri</i>	G5	S1	In Alaska known only from a few locations at south-facing steppe bluffs along the Porcupine River.

Trend

Trends in the spatial extent of Alaska's steppe bluff community have not been evaluated. Climate change, however, is expected to significantly affect the biota of high-latitude regions, and should the sub-Arctic climate become drier, graminoid-dominated Biophysical Settings such as steppe bluffs could expand into areas currently occupied by xeric forests (Blinnikov et al. 2011, Chapin, III et al. 2006). See MQ G2 for further analysis.

Threats

Threats to steppe habitats in Alaska include invasion by non-native plant species and increased use and development. As one of the warmest and driest microclimates in Alaska, steppe bluffs may be susceptible to invasion by non-native species introduced from more temperate climates (Flagstad et al. 2012). The open and rocky substrates of steppe bluffs offer natural hiking routes, yet are unstable enough to be greatly disturbed by foot traffic (Parker and Batten 1995). Development of roads and pipelines, or material sourcing to support such development, poses additional threats (Batten et al. 1979, Parker and Batten 1995). However, the remote locations and steep topography of most steppe habitats would likely preclude the economic feasibility of such projects.

Associated Wildlife

We identified four wildlife species that have been documented to utilize or are suspected to utilize the Steppe Bluff BpS (Table G-31). Steppe systems in Alaska are also known to support high insect diversity, especially pollinators. Important solitary bees in the *Andrena*, *Lasioglossum*, *Halictus*, *Megachile*, *Osmia*, *Coelioxys*, *Anthophora*, *Nomada* and *Epeolis* genera appear to be restricted to the hottest and driest sites in the Interior (Guinn and Armbruster 1985). Peregrine falcons are thought to utilize steppe bluff habitats for nesting and hunting (Boggs et al., in prep., DeCicco, pers. comm. 2016). Dall sheep are known to use steppe bluffs along the Yukon River (Boggs et al., in prep.).

Table G-31. Wildlife species associated with the Steppe Bluff BpS in the CYR study area.

Common Name	Global Rank	State Rank	BLM Status	Dataset	Confirmed/Suspected
Peregrine falcon	G4	S3	None	AKGAP Model, HA Database, DeCicco, pers. comm. 2016, Boggs et al., in prep.	Confirmed
Dall sheep	G4	S4	None	Boggs et al., in prep	Confirmed
woodchuck	G5	S2	None	AKGAP Model, HA Database	Suspected
violet green swallow	G5	S5	None	AKGAP Model, HA Database, DeCicco, pers. comm. 2016	Confirmed

11.7 Beringian Alpine Limestone *Dryas* BpS

Conservation Status: G3 S3 (vulnerable)



Figure G-66. Calcareous slope and outcrops in the Seward Peninsula supporting a sparse cover of *Dryas* species. Photo by J.R. Fulkerson.

Description and Distribution

In the CYR study area, the Beringian Alpine Limestone *Dryas* BpS occurs on exposures of carbonate bedrock in the foothills of the western part of the Brooks Range and Seward Peninsula (Figure G-66). Occurrences on the Seward and Lisburne Peninsulas are of floristic interest, as this region was previously connected to Asia by the Bering Land Bridge and, during subsequent glacial advances, provided unglaciated refugia for various Beringian species (Kaufman and Hopkins 1986). These calcareous substrates now provide unique habitat for rare taxa, regional endemics, and disjunct plant species (Kelso 1989).

The Beringian Alpine Limestone *Dryas* BpS occurs on alkaline, well-drained soils derived from carbonate bedrock types such as limestone or marble (Swanson et al. 1985, Kelso 1989, Boggs et al. 2015). This BpS occurs above elevational treeline on rounded hilltops, shoulders and plateaus in areas that were not recently glaciated (Jorgenson et al. 2009). At these sites, exposure to high winds precludes the accumulation of loess or significant soil development.

Vegetation

Barren ground comprises a significant proportion (approximately $\geq 60\%$) of the Beringian Alpine Limestone *Dryas* BpS. Trees and shrubs taller than 20 cm are not present and dwarf shrubs such as *Dryas* species dominate the vegetation cover. Forbs and lichens do occur, but cumulatively cover less than 15% (Swanson et al. 1985, Kelso 1989, Jorgenson et al. 2009). *Dryas* species and *Saxifraga oppositifolia* usually have the most significant vegetation cover and frequency. Other common species include *Carex scirpoidea*, *Silene acaulis*, and *Minuartia arctica*. Common

non-vascular plants include *Flavocetraria cucullata*, *F. nivalis*, and *Thamnolia vermicularis*. While soil genesis and vegetation succession are expected to be retarded by exposure, these processes have not been studied within the Berigian Alpine Limestone *Dryas* BpS (Boggs et al., in prep.). The Berigian Alpine Limestone *Dryas* BpS is associated with the Alpine Dwarf Shrub Tundra CE; however, due to the paucity of vegetation cover, a majority of the habitat has no associated Terrestrial Coarse-filter CE. We identified seven rare vascular plant species that are associated with the Berigian Alpine Limestone *Dryas* BpS (Table G-32).

Table G-32. Rare vascular plant species associated with Berigian Alpine Limestone *Dryas* BpS in the CYR study area.

Species	Global Rank	State Rank	Description
<i>Cryptogramma stelleri</i>	G5	S3S4	Occasionally found on limestone cliff faces.
<i>Festuca viviparoidea</i> ssp. <i>viviparoidea</i>	G4G5TNR	SU	Alpine grass grows in rocky outcrops with <i>Dryas</i> . Found in Arrigetch Creek Valley.
<i>Oxytropis arctica</i> ssp. <i>barebyana</i>	G4?T2Q	SU	A locoweed found on alpine limestone outcrops in the western part of the CYR study area.
<i>Oxytropis kokrinesis</i>	G3	S3	A locoweed found in the alpine and endemic to northwestern Alaska. Not restricted to substrate but found on limestone outcrops in the Baird Mountains.
<i>Puccinellia wrightii</i> ssp. <i>wrightii</i>	G3G4TNR	S3	Grass found in alpine and Arctic tundra meadows. Associated with calcareous outcrops.
<i>Ranunculus ponojensis</i>	GNR	S2	From Russian far east and western Alaska, single occurrence in the CYR study area. Found in alpine meadows and slopes, sometimes on limestone substrate.
<i>Rumex krausei</i>	G2	S2S3	From Russian far east and western Alaska. Highly-associated with Berigian Alpine Limestone <i>Dryas</i> BpS in the CYR study area.

Trend

Trends in the distribution and abundance of Alaska's Berigian Alpine Limestone-*Dryas* BpS have not been evaluated.

Threats

Limestone is mined in various parts of the world, but the remote locations of most limestone hill tops would likely render any such mining operations economically unfeasible. It is not clear how changes in climate may affect this BpS.

Associated Wildlife

We identified seven wildlife species that have been documented to utilize or are suspected to utilize the Berigian Alpine Limestone *Dryas* BpS (Table G-33). The cliffs and ridgeline tors provide perch sites for golden eagles and Peregrine falcons (Juday 1989). Raptors use cliffs and ledges

to access updrafts. Small birds (unknown species) have been observed feeding on fruits and seeds of *Draba* species (Brassicaceae) growing on limestone tors and rock formations and may play an important role for seed dispersal among mountain tops for limestone-associated plant species (Boggs et al., in prep.). Caribou and grizzly bear scat have been observed in the Alpine Limestone *Dryas* BpS (Boggs et al., in prep.).

Table G-33. Wildlife species associated with the Berigian Alpine Limestone *Dryas* BpS in the CYR study area.

Common Name	Global Rank	State Rank	BLM Status	Dataset	Confirmed/Suspected
American Peregrine falcon	G4	S3	None	AKGAP Model, HA Database, Juday 1989	Confirmed
Arctic Peregrine falcon	G4	S3	None	AKGAP Model, HA Database	Suspected
caribou	G5	S5	None	AKGAP Model, HA Database,	Confirmed
golden eagle	G5	S4	Sensitive Species	AKGAP Model, HA Database,	Suspected
gray-crowned rosy-finch	G5	S3	None	AKNHP BIOTICS	Confirmed
grizzly bear	G5	S5	None	Boggs et al., in prep	Confirmed
snowy owl	G5	S3	None	AKGAP Model, HA Database	Suspected

11.8 Tidal Marsh BpS

Conservation Status: G3 S3 (vulnerable)



Figure G-67. Tidal marsh of the Noatak River Delta. Photo by J.R. Fulkerson.

Description and Distribution

Tidal marshes in the CYR Study Area occur along the Kotzebue Sound coastline and typically manifest as extensive inland complexes along tidally-influenced waters (Figure G-67) but may also include lagoons protected by barrier islands and spits or pocket marshes protected by more resistant coastal headlands. This BpS is widely distributed but small in total area, and it is highly specific in its component species. Because of their unique position at the interface of marine, freshwater, and terrestrial habitats, tidal marshes host a characteristic suite of species adapted to saturation and to brackish or saline conditions (Stone 1984).

Tidal marshes occur wherever there is flat land at sea level (Frohne 1953); however, three elements are required for their formation:

1. The input of tidal waters that ranges in frequency from the twice daily inundation of mudflats to the occasional exposure of upper marsh habitats to storm surges.
2. The deposition of sediment derived from rivers and deposited across deltas, or imported from adjacent coastlines via long-shore drift.
3. Protection from coastal erosion, critical for marsh development provided by topography (e.g., barrier islands, spits, peninsulas, shallow bays and headlands) and, at a smaller scale, by established vegetation which effectively slows the water current and/or wave energy (Chapman 1960).

Vegetation

This BpS is found in coastal habitats at low elevation and with flat to shallow slope. The zonation of vegetation within tidal marshes is conspicuous (Vince and Snow 1984, Hanson 1951). Vegetation communities of tidal marshes are generally patterned according to the frequency and duration of tidal inundation, which affects soil moisture and salinity and is usually a function of elevation (Stephens and Billings 1967, Batten et al. 1978, Dupre 1980, Byrd and Ronsse 1983, Kincheloe and Stehn 1991, Viereck et al. 1992). Where shoreline topography rises uniformly from the water, elongated zones of tidal marsh vegetation are common (e.g., Cook Inlet Basin; Hanson 1951). However, where permafrost produces an intricate topography, tidal marsh vegetation is often mosaicked, such as in the vicinity of Kotzebue (Hanson 1951, Kincheloe and Stehn 1991).

The general vegetation pattern in western Alaska tidal marshes is as follows: the lowest elevations are often barren mudflats to those sparsely vegetated by halophytic graminoids such as *Puccinellia phryganodes* and *Carex subspathacea* (Kincheloe and Stehn 1991, Jorgenson et al. 2004, Jorgenson et al. 2009). These mudflats and sparsely vegetated sites also occur on the banks of tidal rivers, sloughs, and margins of tidal ponds. Due to lesser salinity, river and slough, bank colonization transitions to *Arctophylla fulva* and *Carex ramenskii* upriver (Kincheloe and Stehn 1991). Moving inland from the coastline, extensive tidal meadows occur. As the elevation rises, the dominant species gradually shifts from *Carex ramenskii* or *Carex ramenskii-Dupontia fischeri*, to *Carex rariflora-Calamagrostis deschampsoides* and eventually *Carex rariflora-Salix ovalifolia*-mosses or *Salix ovalifolia-Deschampsia caespitosa* (Kincheloe and Stehn 1991, Jorgenson et al. 2009). *Hippuris tetraphylla* or *Carex ramenskii* may also dominate pond edges.

There are no Terrestrial Coarse-filter CEs associated with this BpS, but it is most closely associated with brackish sedge-grass meadows. We identified four rare plant species associated with the Tidal Marsh BpS: *Gentianopsis richardsonii*, *Zannichellia palustris* ssp. *palustris*, *Puccinellia vaginata* (Table G-34). *Potentilla fragiformis* occurs on the Tidal Marsh BpS margins, specifically on beach ridges and partially vegetated sand dunes (Table G-34).

Table G-34. Rare vascular plant species associated with Tidal Marsh Western Alaska BpS in the CYR study area.

Species	Global Rank	State Rank	Description
<i>Potentilla fragiformis</i>	G4	S2S2	Found in <i>Elymus</i> -forb beach meadows and sand dunes.
<i>Gentianopsis richardsonii</i>	GNR	S1S2	Found on gravel beaches, edges of lagoons, and brackish beach meadows.
<i>Puccinellia vaginata</i>	G4	S1S2	Gravel beaches and edges of lagoons.
<i>Zannichellia palustris</i> ssp. <i>palustris</i>	G5	S3S4	Found in fresh water ponds of tidal marsh and beach forb meadows.

Trend

Loss of coastal habitat due to climate change is difficult to predict as projections of sea level rise must account for concurrent change in temperature, precipitation, and permafrost. It is expected that impacts of climate-induced sea level rise and coastal erosion could be extensive in low-lying

coastal areas characterized by ice-rich permafrost such as along western Alaska's coastline (Glick et al. 2010, Lawler et al. 2009).

Threats

Low-lying, permafrost-affected areas like those of the western Alaskan coast are expected to be heavily impacted by climate-induced sea level rise and coastal erosion. The extent of land loss is difficult to predict due to the presence of multiple interrelated factors (e.g., permafrost thaw, sea level rise, change in precipitation regimes, etc.), but at least some coastal habitat is expected to be lost (Glick et al. 2010, Lawler et al. 2009). Due to their landscape position, tidal marshes are highly susceptible to damage from oil spills. The degree of damage from an oil spill to nearshore waters is expected to vary with factors such as degree of tidal influx, tide level, location, season, and extent and duration of the spill. Sites with a microtidal regime and high freshwater outflow are expected to be less susceptible (Crow 1977).

Associated Wildlife

We identified 24 wildlife species that have been documented to utilize or suspected to utilize the Tidal Marsh BpS (Table G-35). While tidal marshes only occupy a small percentage of the total landscape, they provide critical staging areas for migrating shorebirds, sea ducks, geese and swans. The spectacled eider (G2 S2) and the Steller's eider (G3 S2S3) utilize near-shore waters and tidal flats, respectively, during molting (Boggs et al., in prep.). Boundaries between *Puccinellia phryganodes*-*Carex subspathacea* associations and *Carex ramenskii* associations are maintained in part by grazing geese such as brant (Bergman et al. 1977, Kincheloe and Stehn 1991, Person and Ruess 2003).

Table G-35. Wildlife associated with the Tidal Marsh: western Alaska BpS in the CYR study area.

Common Name	Global Rank	State Rank	BLM Status	Dataset	Confirmed/ Suspected
Arctic loon	G5	S1	None	AKGAP Model, HA Database	Suspected
Alaskan hare	G3	S3	Sensitive Species	AKGAP Model, HA Database	Suspected
Alaska tiny shrew	NR	S3	Sensitive Species	AKGAP Model, HA Database	Suspected
Aleutian tern	G4	S3	None	AKGAP Model, HA Database	Suspected
bar-tailed godwit	G5	S3	Watch Species	AKGAP Model, HA Database	Suspected
black scoter	G5	S3	None	AKGAP Model, HA Database	Suspected
black turnstone	G5	S3	None	AKGAP Model, HA Database	Suspected

Section G. Terrestrial Coarse-filter Conservation Elements

Common Name	Global Rank	State Rank	BLM Status	Dataset	Confirmed/ Suspected
brant	G5	S4	None	Bergman et al. 1977, Kincheloe and Stehn 1991, Person and Ruess 2003	Confirmed
caribou	G5	S5	None	AKGAP Model, HA Database	Suspected
common eider	G5	S3	None	AKGAP Model, HA Database	Suspected
Hudsonian godwit	G4	S2	Watch Species	AKGAP Model, HA Database	Suspected
lesser scaup	G5	S3	None	AKGAP Model, HA Database	Suspected
osprey	G5	S3	None	AKGAP Model, HA Database	Suspected
polar bear	G3	S2	None	AKGAP Model, HA Database	Suspected
red knot	G4	S2	Sensitive Species	AKGAP Model, HA Database	Suspected
red-necked stint	G5	S3	None	AKGAP Model, HA Database	Suspected
rock sandpiper	G5	S3	Sensitive Species	AKGAP Model, HA Database	Suspected
snowy owl	G5	S3	None	AKGAP Model, HA Database	Suspected
spectacled eider	G2	S2	None	Boggs et al. 2015	Confirmed
Steller's eider	G3	S2S3	None	Boggs et al. 2015	Confirmed
surfbird	G5	S2	None	AKGAP Model, HA Database	Suspected
tundra swan	G5	S4	None	AKGAP Model, HA Database	Suspected
white wagtail	G5	S3	None	AKGAP Model, HA Database	Suspected
yellow-billed loon	G4	S2	Sensitive Species	AKGAP Model, HA Database	Suspected

11.9 Geothermal Springs

Conservation Rank: G3 S3 (vulnerable)

Description and Distribution

Geothermal springs are areas where geothermally heated groundwater emerges at the ground surface. Characteristics of geothermal springs vary widely and are largely dependent upon the subterranean thermal, physical and chemical conditions of origin. They are sensitive habitats that support rare and disjunct populations of plant species originating from more temperate regions, as well as thermophilic microbial organisms. Geothermal springs provide recreational, economic, scientific, and national heritage benefits. Only limited information is available on the plant associations and vegetation succession of Alaska's geothermal springs. Consequently, they are simply referred to as geothermal springs without the modifying term 'biophysical setting.'

In the CYR study area, 26 geothermal springs have been reported, but additional, undocumented thermal springs may exist (Miller 1994). Most of these geothermal springs are closely associated with the margins of granitic plutons and may be heated by these deep-seated intrusions of igneous rock. These springs show no apparent temporal or spatial association with Tertiary or Quaternary volcanism (Moll-Stalcup et al. 1994, Plafker and Berg 1994).

Vegetation

Plants in the immediate vicinity of the thermal springs generally include salt-tolerant graminoids in the *Carex*, *Eleocharis*, *Juncus* and *Puccinellia* genera. Mosses may be present; however, substrate salinity reduces their development. The forb, *Epilobium hornemannii*, consistently occurs in the wet ground near hot spring vents in Alaska and throughout the Chukchi Peninsula (Vekhov 1996). Cold soils generally limit forest growth in many regions of Alaska (Van Cleve and Yarie 1986, Van Cleve et al. 1983). However, diffuse geothermal heating of the ground some distance from the immediate hot spring vents may promote lush growth of vegetation, often including plants typical of warmer soils and more southerly regions. Halophytic plants of coastal environments may also occur at geothermal springs. In Arctic Alaska, geothermal springs are often indicated by groves of *Populus balsamifera* ssp. *balsamifera* surrounded by treeless tundra (Bockheim et al. 2003, Breen 2014).

Geothermal springs are dependent on geologic features and are a microhabitat in Alaska. Therefore, they have a limited spatial effect on the immediate surrounding vegetation community, too fine to be associated with a Terrestrial Coarse-Filter CE. There are eight thermal springs found within the floodplain forest and shrub CE and 14 associated with the upland mesic spruce forest CE. We identified eight rare plant species associated with geothermal springs (Table G-36).

Table G-36. Rare plant species associated with geothermal springs in the CYR study area.

Species	Global Rank	State Rank	Description
<i>Carex deflexa</i> var. <i>deflexa</i>	G5	S2S3	Dry herb meadows adjacent to thermal springs in the Reed River valley of the Schvatka Mts. The species is known from boreal North America and Greenland, and is found in the Yukon-Tanana uplands of Interior Alaska. This record of <i>C. deflexa</i> is a northwestward range extension of over 400 km.
<i>Geum aleppicum</i> ssp. <i>strictum</i>	G5T5	S3	All but two populations occur in coastal southwestern and Southeastern Alaska on stream and lake edges. Occurs at Kilo Hot Spring in the CYR study area, a north range extension of 475 km.
<i>Glyceria striata</i>	G5	S3S4	Three of five CYR populations occur at thermal springs, and several populations in coastal Southeastern and Southcentral Alaska.
<i>Lycopus asper</i>	G5	S1	The only population in the state grows at hot springs at Circle.
<i>Lycopus uniflorus</i>	G5	S3S4	One of seven populations in the CYR study area occurs in a thermal spring, Kanuti Hot Springs.
<i>Polypodium sibiricum</i>	G5?	S3	Two populations in the CYR study area occur near and adjacent to hot springs, the Reed River valley and Circle Hot Springs.
<i>Schizachne purpurascens</i>	G5	S2	Found growing in a dry meadow adjacent to Reed Hot Springs. This grass of boreal Asia and North America is known from south of the Alaska Range, hence this record documents a northward range extension of approximately 600 km.
<i>Schoenoplectus pungens</i>	G4G5	S1	The only population in the state occurs in the marshy edges of Circle Hot Springs.

Trend

Trends in Alaska's geothermal springs have not been evaluated.

Threats

Geothermal springs may be developed for recreation, energy or agriculture (Miller 1994). In Alaska, the push to develop alternative energy sources, particularly geothermal, puts Alaska's hot springs at risk (Boggs et al. 2015).

Associated Wildlife

We identified eleven wildlife species that have been documented to utilize or are suspected to utilize the geothermal springs (Table G-37). Evidence of moose, wolf, and Dall sheep disturbance has been observed at Big Windy Hot Springs in the Steese National Conservation Area (Juday 1998). Dall sheep have been observed to utilize the microhabitat as a source of salt. The water shrew, *Sorex palustris*, has been collected at this site representing the most northern part of its range (Juday 1998). There have also been collections of the northern red-backed vole and root vole.

The wildlife species listed below were determined by intersecting distribution models with known geothermal spring sites within the CYR study area. We removed taxa that were not likely to utilize the hot spring habitat itself and those listed would most likely utilize the surrounding habitat edge.

Table G-37. Wildlife species associated with the geothermal spring in the CYR study area.

Common Name	Global Rank	State Rank	BLM Status	Dataset	Confirmed/Suspected
Alaskan hare	G3	S3	Sensitive Species	AKGAP Model, HA Database	Suspected
Alaska tiny shrew	NR	S3	Sensitive Species	AKGAP Model, HA Database	Suspected
Dall sheep	G5	S5	None	Juday 1998	Confirmed
long-tailed vole	G5	S5	None	UAM	Confirmed
moose	G5	S5	None	Juday 1998	Confirmed
northern red-backed vole	G5	S5	None	UAM	Confirmed
root vole	G5	S5	None	UAM	Confirmed
snowshoe hare	G5	S5	None	AKGAP Model, HA Database	Suspected
water shrew	G5	S4	None	Juday 1998	Confirmed
wolf	G4	S4	None	Juday 1998	Confirmed
woodchuck	G5	S2	None	AKGAP Model, HA Database	Suspected

11.10 Data Gaps and Limitations

The rare ecosystems data are derived from a draft version of Boggs et al. (in prep). Rare ecosystems data are, therefore, limited by the completeness and precision of their respective map sources, which vary among ecosystems (Table G-38). Well-mapped ecosystems, such as the Inland Dunes, Arctic Pingos, or Tidal Marsh BpSs, have been studied extensively and are well-documented in the literature. However, spatial data for other rare ecosystems are only partially complete. For example, the Steppe Bluff BpS is not well-mapped throughout its range and is only indicated by literature and rare plant occurrence records. Some rare ecosystems have been mapped based on vegetation landcover maps and carry the limitations of the source maps (see Boggs et al., in prep.).

Table G-38. Map sources of each ACCS-designated rare ecosystem.

Rare Ecosystem	Map Source
Inland Dune BpS	Distribution was developed from bare ground classes of the Alaska Landcover Map (Boggs et al. 2012).
Arctic Pingo BpS	Distributions of both Boreal Pingo BpS and Arctic Pingo BpS were developed from ranges mapped by Jorgenson et al. (2008) and Jones et al. (2012).
Steppe Bluff BpS	Distribution was developed from locations described in literature and rare plant records (Boggs et al., in prep.).
Beringian Alpine Limestone- <i>Dryas</i> BpS	Derived from a combination of fine-scale landcover map by Alaska Landcover Map (Boggs et al. 2012), Jorgenson et al. (2009), and USGS geologic map.
Tidal Marshes: Western Alaska BpS	Distribution was developed from the Herbaceous (Wet-Marsh) (Tidal) landcover class as it occurs from Pt. Hope to the Alaska Peninsula in the Alaska Landcover Map (Boggs et al. 2012).
Geothermal Springs	Derived from literature (Boggs et al., in prep.).

Potential Ecosystems of Conservation Concern

Several Ecosystems of Conservation Concern (G1-G3) that occur in Interior Alaska have not been described nor mapped in sufficient detail to be included in our analyses (Table G-39). These undescribed ecosystems of Conservation Concern require further study or literature review for an accurate assessment of their rarity or intrinsic vulnerability, trends, and threats. Although these undescribed rare ecosystems were beyond the scope of this rapid assessment, they are listed in the table below for reference.

Table G-39. Potentially rare ecosystems that may warrant further investigation.

Undescribed Ecosystems of Potential Conservation Concern
Calcareous Fen BpS
Hill Prairie
Sky Islands in Boreal Alaska
Trona (hydrous sodium carbonate and bicarbonate in partially evaporated lake basins)
Vegetation Communities on Basalt Substrates

Wildlife Data Limitations

Although our list of wildlife species was built from the best available data consisting of Habitat Assessment Database (HA Database), AKGAP distribution models, ACCS BIOTICS Animal Data Portal, and additional literature review, it is still subject to fundamental limitations. The wildlife species list was developed from Terrestrial Fine-filter Conservation Element species and rare animal species from the Alaska Biotics database and, therefore, common animals (i.e., those not considered a species of concern) were not included. While AKGAP distribution models have been developed for a majority of Alaska rare animal species, distribution models do not exist for every rare species that occurs within the CYR study area, like, for example, the gray-crowned rosy-finch (*Leucosticte tephrocotis*, G5S3). Wildlife referred to in literature or personal communication from peer review were included. Additionally, our distribution sets for bird species are limited in that they model only breeding distribution.

Because we used HA Database and AKGAP analysis to infer potential relationships between rare ecosystems and rare animal species, our analysis is also subject to the limitations of those models and should be viewed as hypotheses. Distribution models are built by deriving predictive environmental parameters from a combination of literature review, expert opinion, and known occurrence records, to produce a “spatial arrangement of environments suitable for occupation by a species” (Beauvais et al. 2013, Gotthardt et al. 2014). Thus, the intersection of a distribution model with a rare ecosystem indicates only that suitable habitat for that species exists within that rare ecosystem; it does not indicate that the species is known to occur there. Furthermore, spatial correlation between a given ecosystem and a given wildlife species does not necessarily indicate that the species relies upon services provided by that ecosystem that cannot be provided by other, more common ecosystems.

To address these limitations, we removed wildlife species that were clearly not likely to utilize the microhabitat. For example, the bar-tailed godwit was removed from the Inland Dunes BpS because the species breeds and is found in wet sedge meadows and tundra which does not match the description of the Inland Dunes BpS. Generally, we removed bird species from rare ecosystems unless occurrences were supported in literature or the rare ecosystem fundamentally supports bird species (e.g., Beringian Alpine Limestone *Dryas* BpS and Tidal Marsh BpS). Including birds in a rare ecosystem may provide a biased view of the rare ecosystem with respect to birds as they are more likely to be using surrounding associated habitat instead of the rare ecosystem habitat itself (DeCicco, pers. comm. 2016).

AKGAP Models vary in accuracy but during development, each model was subjected to an accuracy assessment to quantify “classification success” — the percent of training points (known occurrence records) correctly predicted as present by the model. Thus, the higher the model’s classification success (CS) score, the better it was able to predict actual occurrences of the species. Though we did not include or exclude AKGAP Models based on CS scores, we include here a table of each model’s score for reference (Table G-40). See Gotthardt et al. (2014) for a more comprehensive explanation of these models’ limitations.

Table G-40. "Classification Success" accuracy assessment scores for all models used in MQ-G1. From Gotthardt et al. 2014. CS score is the percent of records of known occurrence predicted by the model to fall in suitable environments.

Common Name	Scientific Name	Distribution Model CS Score
Alaska tiny shrew	<i>Sorex yukonicus</i>	67.1
Alaskan hare	<i>Lepus othus</i>	87.1
aleutian tern	<i>Sterna aleutica</i>	85
Peregrine falcon	<i>Falco peregrinus anatum</i>	Expert Opinion
Arctic loon	<i>Gavia arctica</i>	56.3
bar-tailed godwit	<i>Limosa lapponica</i>	51
black scoter	<i>Melanitta americana</i>	69.8
black turnstone	<i>Arenaria melanocephala</i>	71.9
common eider	<i>Somateria mollissima</i>	86.5
Hudsonian godwit	<i>Limosa haemastica</i>	50.4
lesser scaup	<i>Aythya affinis</i>	61
osprey	<i>Pandion haliaetus</i>	54.2
polar bear	<i>Ursus maritimus</i>	88.5
red knot	<i>Calidris canutus</i>	Expert Opinion
red-necked stint	<i>Calidris ruficollis</i>	Expert Opinion
rock sandpiper	<i>Calidris ptilocnemis</i>	95
snowshoe hare	<i>Lepus americanus</i>	80.9
snowy owl	<i>Bubo scandiacus</i>	Expert Opinion
surfbird	<i>Aphriza virgata</i>	60.9
tundra swan	<i>Cygnus columbianus</i>	73.8
white wagtail	<i>Motacilla alba</i>	50.7
woodchuck	<i>Marmota monax</i>	91.7
yellow-billed loon	<i>Gavia adamsii</i>	79.3

11.11 Literature Cited

- Batten, A. R., D. F. Murray, and J. C. Dawe. 1979. Threatened and endangered plants in selected areas of the BLM Fortymile Planning Unit, Alaska. General Technical Report 3. U.S. Bureau of Land Management, Anchorage, Alaska.
- Batten, A. R., S. Murphy, and D. F. Murray. 1978. Definition of Alaska coastal wetlands by floristic criteria. EPA Rep. No. 804965-01. Corvallis Environmental Research Laboratory, Corvallis, Oregon. 490 pp.
- Beauvais, G., M. Andersen, D. Keinath, J. Aycrigg, and J. Lonneker. 2013. Predicted vertebrate species habitat distributions and species richness. Chapter 3 in Aycrigg, J. L., M. Andersen, G. Beauvais, M. Croft, A. Davidson, L. Duarte, J. Kagan, D. Keinath, S. Lennartz, J. Lonneker, T. Miewald, and J. Ohmann, eds. Ecoregional Gap Analysis of the Northwestern United States: Northwest Gap Analysis Project Draft Report. U.S. Geological Survey, Gap Analysis Program.
- Bergman, R. D., R. L. Howard, K. F. Abraham, and M. W. Weller. 1977. Water birds and their wetland resources in relation to oil development at Storkersen Point, Alaska. Resource Publ. 129. U.S. Fish and Wildlife Service, Washington, DC. 38 pp.
- Blinnikov, M. S., B. V. Gaglioti, D. A. Walker, M. J. Wooller, and G. D. Zazula. 2011. Pleistocene graminoid-dominated ecosystems in the Arctic. *Quaternary Science Reviews* 30:2906–2929.
- Bliss, L. C., G. M. Courtin, D. L. Pattie, R. R. Riewe, D. W. Whitfield, and P. Widdon. 1973. Arctic tundra ecosystems. *Annual Review of Ecology and Systematics* 4:359–399.
- Bockheim, J. G., J. D. O'Brien, J. S. Munroe, and K. M. Hinkel. 2003. Factors affecting the distribution of *Populus balsamifera* on the North Slope of Alaska, U.S.A. *Arctic, Antarctic, and Alpine Research* 35:331–340.
- Boggs, K., T. V. Boucher, T. T. Kuo, D. Fehring, and S. Guyer. 2012. Vegetation map and classification: Northern, Western and Interior Alaska. Alaska Natural Heritage Program, University of Alaska Anchorage, Anchorage, Alaska.
- Boggs, K., T. V. Boucher, and M. L. McTeague. 2015. Plant association classification for Northern Alaska. Alaska Center for Conservation Science. Alaska Natural Heritage Program, University of Alaska Anchorage.
- Boggs, K., L. Flagstad, T. Boucher, A. Steer, P. Lema, B. Bernard, B. Heitz, T. Kuo, and M. Aisu. *In preparation*. Alaska ecosystems of conservation concern: biophysical settings and plant associations. Report prepared by the Alaska Natural Heritage Program for the Alaska Department of Fish and Game. 267 pp.
- Boggs, K. W., 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, Environment and Natural Resources Institute, University of Alaska, Anchorage, Alaska.
- Bowers, J. E. 1982. The plant ecology of inland dunes in western North America. *Journal of Arid Environments* 5:199–220.
- Breen, A. L. 2014. Balsam poplar (*Populus balsamifera* L.) communities on the Arctic Slope of Alaska. *Phytocoenologia* 44:1–17.
- Byrd, G. V., and D. Ronsse. 1983. Preliminary classification of plant communities in the vegetated intertidal zone of the central Yukon Delta, Alaska. Unpubl. rep. U.S. Fish and Wildlife Service, Yukon Delta National Wildlife Refuge, Bethel, Alaska. 18 pp.
- Chapin, III, F. S., M. W. Oswood, K. Van Cleve, L. A. Viereck, and D. L. Verbyla. 2006. Alaska's changing boreal forest. Oxford University Press. New York.
- Chapman, V. J. 1960. Salt marshes and salt deserts of the world. Plant Science Monographs. Leonard Hill, New York. 392 pp.
- Crow, J. H. 1977. Salt marshes of Port Valdez, Alaska, and vicinity: a baseline study. Final Report. Rutgers University, Newark College of Arts and Sciences, Newark, New Jersey.

- Dickson, L. G. 2000. Constraints to nitrogen fixation by cyanobacterial crusts in a polar desert ecosystem. *Arctic, Antarctic and Alpine Research* 32:40–45.
- Dillman K. L., L. H. Geiser, J. Riley, and G. A. Laursen. 2001. Lichens of the Great Kobuk Sand Dunes of northwestern Alaska. *Botany 2001 Plants and People*. Albuquerque, New Mexico.
- Dupre, W. R. 1980. Yukon Delta coastal processes study. Pages 268-322 *in* National Oceanic and Atmospheric Administration, Washington, D.C. Environmental Assessment Alaskan Continental Shelf, Annual Rep.
- Eberhardt, W. L. 1977. The biology of Arctic and red foxes on the North Slope. M.S. Thesis, University of Alaska Fairbanks. 125 pp.
- Edwards, M. E., and W. S. Armbruster. 1989. A tundra-steppe transition on Kathul Mountain, Alaska, U.S.A. *Arctic and Alpine Research* 21:296–304.
- Everett, K. R. 1980. Geology and permafrost. Pages 8-9 *in* Walker, D. A., K. R. Everett, J. Brown, and P. J. Webber, eds. *Geobotanical Atlas of the Prudhoe Bay Region, Alaska*. U.S. Army Cold Regions Research and Engineering Laboratory, CRREL Report, 80-14.
- Flagstad, L. A., M. C. Carlson, H. Cortes-Burns, C. Jarnevich, and T. Holcombe. 2012. Will a changing climate increase interaction between rare and non-native plant species in Alaska? Presentation: Conference Conserving Plant Biodiversity in a Changing World: A View from Northwest North America. Seattle, Washington, March 13–14, 2012.
- Flahault, C., and C. Schroter. 1910. Rapport sur la nomenclature phytogéographique. *Proceedings of the Third International Botanical Congress, Brussels* 1:131–164.
- Frohne, W. C. 1953. Mosquito breeding in Alaskan salt marshes, with special reference to *Aedes punctodes* Dyar. *Mosquito News* 13:96–103.
- Glick, P., J. Clough, and B. Nunley. 2010. Assessing the vulnerability of Alaska's coastal habitats to accelerating sea-level rise using the SLAMM model: a case study for Cook Inlet. Report by the National Wildlife Federation. 17 pp.
- Gotthardt, T., S. Pyare, F. Huettmann, K. Walton, M. Spathelf, K. Nesvacil, A. Baltensperger, G. Humphries, and T. Fields. 2014. Predicting the range and distribution of terrestrial vertebrate species in Alaska. University of Alaska. Anchorage, Alaska. 42 pp. plus appendices.
- Guinn, D. A., and W. S. Armbruster. 1985. The bee fauna of Interior Alaska: habitat use, flower associations and phenological patterns. *In* *Proceedings of the 1985 Arctic Science Conference*, University of Alaska-Fairbanks.
- Hanson, H. C. 1951. Characteristics of some grassland, marsh, and other plant communities in western Alaska. *Ecology Monographs* 21:317–378.
- Jennings, M. D., D. Faber-Langendoen, R. K. Peet, O. L. Loucks, D. C. Glenn-Lewin, A. Damman, M. G. Barbour, R. Pfister, D. H. Grossman, D. Roberts, D. Tart, M. Walker, S. S. Talbot, J. Walker, G. S. Hartshorn, G. Waggoner, M. D. Abrams, A. Hill, and M. Rejmanek. 2006. Description, documentation, and evaluation of associations and alliances within the U.S. National Vegetation Classification, Version 4.5. Ecological Society of America, Vegetation Classification Panel. Washington, DC.
- Jones B. M., G. Grosse, K. M. Hinkel, C. D. Arp, S. Walker, R. A. Beck, and J. P. Galloway. 2012. Assessment of pingo distribution and morphometry using an IfSAR derived DSM, western Arctic Coastal Plain, northern Alaska. *Geomorphology* 138:1-14. DOI:10.1016/j.geomorph.2011.08.007.
- Jorgenson, M. T., J. E. Roth, M. Emers, W. Davis, S. F., Schlentner, and M. J. Macander. 2004. Landcover mapping for Bering Land Bridge National Preserve and Cape Krusenstern National Monument, northwestern Alaska. Final Report for U.S. National Park Service.
- 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/ARC/NRTR-2009/270. U.S. National Park Service.
- Jorgenson, T., K. Yoshikawa, M. Kanevskiy, Y. Shur, V. Romanovsky, S. Marchenko, G. Grosse, J. Brown, and B. Jones. 2008. Map of permafrost characteristics of Alaska. Institute of Northern

- Engineering, University of Alaska Fairbanks. Available:
http://permafrost.gi.alaska.edu/sites/default/files/AlaskaPermafrostMap_Front_Dec2008_Jorgenson_etal_2008.pdf
- Juday, G. P. 1989. Alaska research natural areas: 2. Limestone jags. University of Alaska Fairbanks. School of Agriculture and Land Resources Management. Agricultural and Forestry Experiment Station
- Juday, G. P. 1998. Alaska Research Natural Areas. 4: Big Windy Hot Springs. University of Alaska Fairbanks. School of Agriculture and Land Resources Management. Agricultural and Forestry Experiment Station.
- Juday, G. P., and C. T. Dyrness (eds.) 1985. Early results of the Rosie Creek Fire Research Project. University of Alaska, Agricultural and Forestry Experiment Station, Fairbanks, Alaska, USA. Miscellaneous Publication 85-2.
- Kassler, K. C. 1979. Relicts of the late Pleistocene Arctic-steppe: investigations of certain south-facing slopes in Interior Alaska. Middlebury College, Northern Studies Program, Middlebury, Vermont.
- Kaufman, D. S., and D. M. Hopkins. 1986. Glacial history of the Seward Peninsula. *Glaciation in Alaska: The Geologic Record*. pp 51–77.
- Kelso, S. 1989. Vascular flora and phytogeography of Cape Prince of Wales, Seward Peninsula, Alaska. *Canadian Journal of Botany* 67:3248–3259.
- Kincheloe, K. L., and R. A. Stehn. 1991. Vegetation patterns and environmental gradients in coastal meadows on the Yukon-Kuskokwim Delta, Alaska. *Canadian Journal of Botany* 69:1616–1627.
- Koranda, J. J. 1970. Pingos. *Pacific Discovery* 23:18–24.
- Koster, E. A. 1988. Ancient and modern cold-climate aeolian sand deposition: a review. *Journal of Quaternary Science* 3:69–83.
- Lawler, J. P., S. D. Miller, D. M. Sanzone, J. Ver Hoef, and S. B. Young. 2009. Arctic network vital signs monitoring plan. Natural Resource Report NPS/ARC/NRR—2009/088. National Park Service, Fort Collins, Colorado.
- Lea, P. D., and C. F. Waythomas. 1990. Late-Pleistocene eolian sand sheets in Alaska. *Quaternary Research* 34:269–281.
- Lewis, N. K. 1998. Landslide-driven distribution of aspen and steppe on Kathul Mountain, Alaska. Aspen Bibliography. Paper 1222. Available: http://digitalcommons.usu.edu/aspen_bib/1222
- Lipkin, R., and J. Tande. 1991. Field report: botanical survey of the Salmon Fork of the Black River. Alaska Natural Heritage Program, University of Alaska Anchorage, Anchorage, Alaska.
- Lloyd, A. H., W. S. Armbruster, and M. E. Edwards. 1994. Ecology of a steppe-tundra gradient in Interior Alaska. *Journal of Vegetation Science* 5:897–912.
- Mackay, J. R. 1979. Pingos of the Tuktoyaktuk Peninsula area, Northwest Territories. *Géographie Physique et Quaternaire* 33:3–61.
- Mackay, J. R. 1998. Pingo growth and collapse, Tuktoyaktuk Peninsula area, Western Arctic Coast, Canada: a long-term field study. *Géographie physique et Quaternaire (University of Montreal)* 52: 311.
- Mann, D. H., P. A. Heiser, and B. P. Finney. 2002. Holocene history of the Great Kobuk Sand Dunes, northwestern Alaska. *Quaternary Science Reviews* 21:709–731.
- Marsh J., S. Nouvet, P. Sanborn, and D. Coxson. 2006. Composition and function of biological crust communities along topographic gradients in grasslands of central Interior British Columbia (Chilcotin) and southwestern Yukon (Kluane). *Canadian Journal of Botany* 84:713–731.
- Master, L. L., D. Faber-Langendoen, R. Bittman, G. A. Hammerson, B. Heidel, L. Ramsay, K. Snow, A. Teucher, and A. Tomaino. 2012. NatureServe conservation status assessments: factors for evaluating species and ecosystem risk. NatureServe, Arlington, Virginia.

- Miller, T. P. 1994. Geothermal resources of Alaska. Pages 979-987 *in* Plafker, G., and H. C. Berg, eds. The Geology of Alaska, Geological Society of America, The Geology of North America series v. G-1. Boulder, Colorado.
- Moll-Stalcup, E. J., D. A. Brew, and T. L. Vellier. 1994. Map of latest Cretaceous and Cenozoic igneous rocks of Alaska. Plate 5 *in* Plafker, G., and H. C. Berg, eds. The Geology of Alaska, Geological Society of America, The Geology of North America series v. G-1. Boulder, Colorado. Scale 1:2,500,000.
- Murray, D. F., B. M. Murray, B. A. Yurtsev, and R. Howenstein. 1983. Biogeographic significance of steppe vegetation in sub-Arctic Alaska. *Permafrost: Fourth International Conference, Proceedings* 4:883–888.
- Osgood, W. H. 1909. Revision of the mice of the American genus *Peromyscus*. *North American Fauna* 28:1–285.
- Parker, C. L., and A. R. Batten. 1995. Status and trends survey of category 2 plants in the Yukon-Charley Rivers National Preserve. USDI-NBS. Washington, D.C.
- Parker, C. L., and D. H. Mann. 2000. Floristics and vegetation of active sand dunes in the Kobuk River Valley, northwestern Arctic Alaska. American Association for the Advancement of Science and Yukon Science Institute.
- Pegau, R. E. 1970. Succession in two exclosures near Unalakleet, Alaska. *Canadian Field Naturalist* 84:175–177.
- Person, B. T., and R. W. Ruess. 2003. Stability of a sub-Arctic saltmarsh: plant community resistance to tidal inundation. *Ecoscience* 10:351–360.
- Peterson, K. M., and W. D. Billings. 1978. Geomorphic processes and vegetational change along the Meade River sand bluffs, northern Alaska. *Arctic* 31:7–23.
- Plafker, G., and H. C. Berg. 1994. Overview of the geology and tectonic evolution of Alaska. Pages 989-1021 *in* Plafker, G., and H. C. Berg, eds. The Geology of Alaska, Geological Society of America, The Geology of North America series v. G-1. Boulder, Colorado.
- Racine, C. H. 1976. Flora and vegetation. Pages 39-139 *in* Melchior, H. R., ed. Biological survey of the proposed Kobuk Valley National Monument. Final Report to the United States National Park Service, Alaska Cooperative Park Studies Unit, University of Alaska, Fairbanks, Alaska.
- Roland, C. 1990. Arctic steppe survey: Yukon River sites, 1990. Research and Resource Management Report Series 90-04. U.S. National Park Service, Yukon-Charley National Preserve.
- Roland, C. 1996. The floristics and community ecology of extrazonal steppe in the Yukon and Kolyma river Drainages. Thesis, University of Alaska Fairbanks.
- Shacklette, H. T. 1966. Phytocology of a greenstone habitat at Eagle, Alaska. *Geological Survey Bulletin* 1198-F. U.S. Government Printing Office, Washington D.C.
- Sigafoos, R. S. 1951. Soil instability in tundra vegetation. *The Ohio Journal of Science* 51:281-298. Available: <http://hdl.handle.net/1811/3870>
- Stephens, F. R., and R. F. Billings. 1967. Plant communities of a tide-influenced meadow on Chichagof Island, Alaska. *Northwest Science* 41:178–183.
- Stone, C. S. 1984. Patterns in coastal marsh vegetation of the Juneau area, Alaska. Ph.D. dissertation, Oregon State University, Corvallis, Oregon. 259 pp.
- Swanson J. D., M. Schuman, and P. C. Scorup. 1985. Range survey of the Seward Peninsula reindeer ranges, Alaska. USDA Soil Conservation Service, Anchorage, Alaska. 77 pp.
- Tande, G. F. 1996. Vegetation of Fort Wainwright Military Reservation, Alaska. Appendix A *in* Racine, H., and R. Lichvar, eds. A Floristic Inventory for Fort Wainwright, Interior Alaska. U.S. Army Corps of Engineers Waterways Experiment Station (Vicksburg, MS) and Cold Regions Research and Engineering Laboratory (Hanover, NH). CRREL SR97-23.
- University of Alaska Museum (UAM). 2015. Fairbanks, Alaska, USA. Available: <http://arctos.database.museum/>

- Van Cleve, K., L. K. Oliver, B. Schlentner, L. A. Viereck, and C. T. Dyrness. 1983. Productivity and nutrient cycling in taiga forest ecosystems. *Canadian Journal of Forest Research* 13:747–766.
- Van Cleve, K., and J. Yarie. 1986. Interaction of temperature, moisture, and soil chemistry in controlling nutrient cycling and ecosystem development in the taiga of Alaska. Pages 160-189 *in* Van Cleve, K., F. S. Chapin, III, P. W. Flanagan, L. A. Viereck, and C. T. Dyrness, eds. *Forest ecosystems in the Alaskan taiga: a synthesis of structure and function*. Springer Verlag, New York, New York.
- Vekhov, N. V. 1996. Thermal and freshwater springs of the Chukchi Peninsula: unique sub-Arctic ecosystems. Part ii. Flora. *Polar Geography* 23:209–220.
- Vetter, M. A. 2000. Grasslands of the Aishihik-Sekulmun Lakes Area, Yukon Territory, Canada. *Arctic* 53:165-173.
- Viereck, L. A., C. T. Dyrness, A. R. Batten, and K. J. Wenzlick, 1992. The Alaska vegetation classification. General Technical Report PNW-GTR-286. Portland, Oregon: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 278 pp.
- Vince, S. W., and A. A. Snow. 1984. Plant zonation in an Alaskan salt marsh: I. Distribution, abundance, and environmental factors. *Journal of Ecology* 72:651–667.
- Walker, D. A., M. D. Walker, K. R. Everett, and P. J. Webber. 1985. Pingos of the Prudhoe Bay Region, Alaska. *Arctic and Alpine Research* (Institute of Arctic and Alpine Research, University of Colorado) 17:323.
- Wesser, S. D. 1989. Controls over species distribution across a forest-steppe transition in Interior Alaska: a correlative model and experimental tests. Thesis, University of Alaska Fairbanks.
- Wetterich, S., G. Grosse, L. Schirrmeister, A. A. Andreev, A. A. Bobrov, F. Kienast, N. H. Bigelow, and M. E. Edwards. 2012. Late Quaternary environmental and landscape dynamics revealed by a pingo sequence on the northern Seward Peninsula, Alaska. *Quaternary Science Review* 39:26–44.
- Williams, P. A., S. Wiser, B. Clarkson, and M. C. Stanley. 2007. New Zealand's historically rare terrestrial ecosystems set in a physical and physiognomic framework. *New Zealand Journal of Ecology* 31: 119–128
- Wolfe, S. A., D. R. Muhs, P. P. David, and J. P. McGeehin. 2000. Chronology and geochemistry of late Holocene eolian deposits in the Brandon Sand Hills, Manitoba, Canada. *Quaternary International* 67:61–74.
- Young, S. B., and C. H. Racine. 1977. Vegetational and floristic analysis and discussion of the Quaternary environment of the Kobuk valley. Report to the United States National Park Service, Center for Northern Studies, Wolcott, Vermont.
- Zazula, G. D., D. G. Froese, A. M. Telka, R. W. Mathewes, and J. A. Westgate. 2002. Plants, bugs, and a giant mammoth tusk: Paleoecology of Last Chance Creek, Yukon Territory. Pages 251-258 *in* Edmond, D. S., and L. L. Lewis, eds. *Yukon Exploration and Geology*. Exploration and Geological Services Division, Yukon Region, Indian and Northern Affairs Canada, Whitehorse, Yukon Territory, Canada.

12. Climate Change Vulnerability of Rare Plant Species (MQ G2)

MQ G2: Which unique vegetation communities (and specifically, which rare plant species) are most vulnerable to significant alteration due to climate change?

Changes in climate are expected to alter habitat conditions, which may shift species distributions or extirpate populations. Rare plant species are of particular concern due to their intrinsic risk of extinction. Rare ecosystems disproportionately contribute to biodiversity; therefore, they facilitate conservation efforts on relatively small areas that encompass a higher proportion of biodiversity than the surrounding landscape (Williams et al. 2007). Rare plants and rare ecosystems may be intrinsically vulnerable to changes in climate due to their limited geographic ranges, small population sizes, habitat specificity, and other natural history traits.

12.1 Data Summary

Rare Plants and Rare Ecosystems in the CYR Study Area

We first extracted rare plant occurrences and rare ecosystems known to occur in the CYR study area using the associated Alaska Center for Conservation Science Databases (Table G-41, Figure G-68). The conservation status of rare plants was assessed using the NatureServe Conservation Rank Calculator, a standardized nationally implemented method (Master et al. 2012). The NatureServe ranking method incorporates data such as population area, population size, number of occurrences, and threats to calculate a Conservation Status Rank (see Master et al. 2012). Number of occurrences or population number is defined by occurrences ≥ 1 km from each other (Master et al. 2012). Conservation status ranks estimate elimination risk posed to an ecological community. Conservation status is designated by a number from 1 to 5 (1: critically imperiled, 2: imperiled, 3: vulnerable, 4: apparently secure, 5: secure, U: unranked but preliminarily designated rare, NR: not ranked, usually due to new taxonomic status). Ranks are preceded by either an 'S,' which indicates a state-level rank, or a 'G,' which indicates a global rank.

Table G-41. Summary of additional datasets for MQ G2.

Dataset Name	Data Source
Alaska Rare Ecosystem Database	Alaska Center for Conservation Science
Alaska Rare Plant Database	Alaska Center for Conservation Science

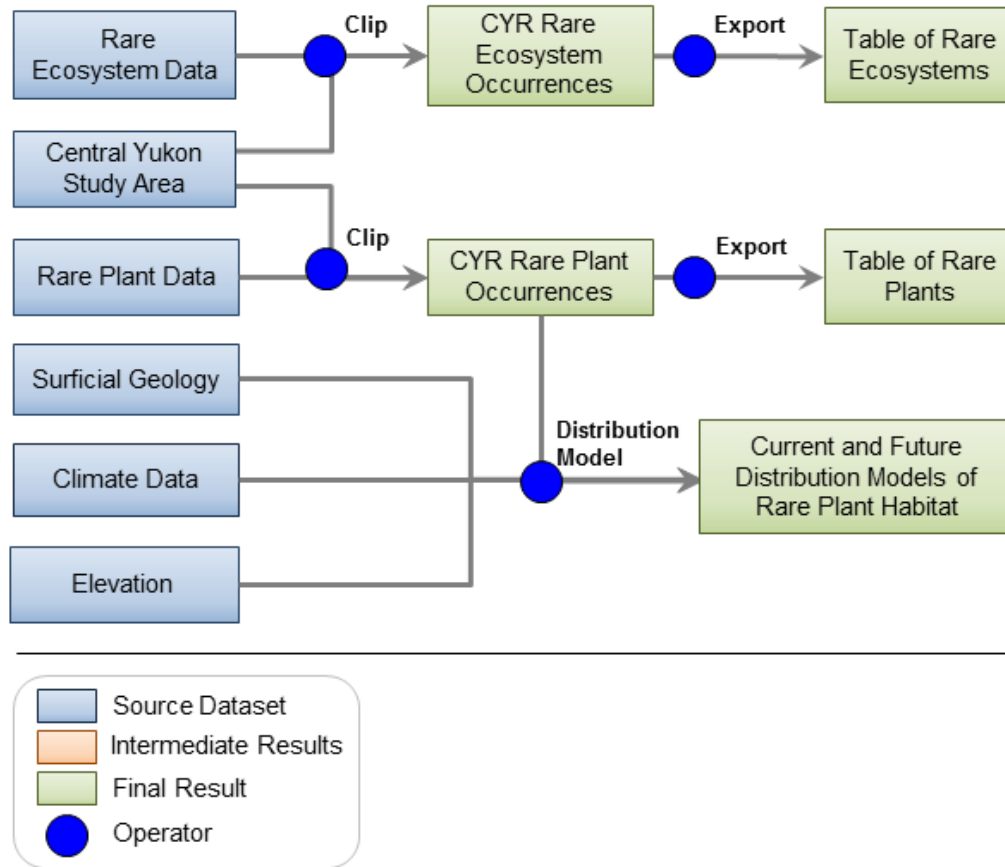


Figure G-68. Process model for the assessment of vulnerability of unique vegetation communities to significant alteration due to climate change (MQ G2).

There are 124 rare plant species that occur within the CYR study area (Table G-42, Figure G-69). Species populations vary from single populations to as many as 38 populations within the CYR study area. There are 26 species designated as BLM ‘Sensitive Species,’ 21 species designated as BLM ‘Watch Species,’ and two designated as U.S. Forest Service Sensitive Species. Species descriptions are out of scope for the REA; however, species biographies for many rare plant species are available in Nawrocki et al. (2013).

Table G-42. Summary of rare plant species occurring within the CYR study area with their respective conservation status ranks and numbers of populations.

Family	Species	State Rank	Global Rank	No. of Pops	Federal Status
Asparagaceae	<i>Maianthemum racemosum</i> ssp. <i>amplexicaule</i> (Nutt.) LaFrankie	S1	G5	1	
Asteraceae	<i>Townsendia hookeri</i> Beaman	S1	G5	4	
Asteraceae	<i>Bidens tripartita</i> L.	S1	G5	1	
Asteraceae	<i>Saussurea triangulata</i> Trautvetter and C. A. Meyer	S1	GNR	1	BLM Watch
Boraginaceae	<i>Cryptantha shackletteana</i> L.C.Higgins	S1	G1Q	2	BLM Sensitive

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Family	Species	State Rank	Global Rank	No. of Pops	Federal Status
Brassicaceae	<i>Draba ogilviensis</i> Hultén	S1	G3	2	BLM Sensitive
Cyperaceae	<i>Carex xerantica</i> L. H. Bailey	S1	G5	3	
Cyperaceae	<i>Schoenoplectus pungens</i> (Vahl) Palla	S1	G4G5	1	
Lamiaceae	<i>Lycopus asper</i> Greene	S1	G5	1	
Ophioglossaceae	<i>Botrychium spathulatum</i> W. H. Wagner	S1	G3	2	USFS Sensitive
Orobanchaceae	<i>Orobanche fasciculata</i> Nutt.	S1	G4	2	
Poaceae	<i>Scolochloa festucacea</i> (Willd.) Link	S1	G5	4	
Poaceae	<i>Sphenopholis intermedia</i> (Rydb.) Rydb.	S1	G5	2	
Poaceae	<i>Puccinellia vaginata</i> (Lange) Fernald and Weath.	S1	G4	1	
Brassicaceae	<i>Draba praealta</i> Greene	S1Q	G5	1	
Caryophyllaceae	<i>Silene uralensis</i> ssp. <i>ogilviensis</i> (A. E. Porsild) D. F. Brunt	S1Q	G4G5T2	1	
Amaranthaceae	<i>Suaeda calceoliformis</i> (Hook.) Moq.	S1S2	G5	1	
Apiaceae	<i>Podistera yukonensis</i> Mathias and Constance	S1S2	G2	6	BLM Watch
Asteraceae	<i>Symphyotrichum falcatum</i> var. <i>falcatum</i> (Lindl.) G.L. Nesom	S1S2	G5T4T5	4	BLM Watch
Asteraceae	<i>Arnica lonchophylla</i> ssp. <i>lonchophylla</i> Greene	S1S2	G4T4	3	BLM Sensitive
Asteraceae	<i>Erigeron ochroleucus</i> Nutt.	S1S2	G5	2	BLM Watch
Cyperaceae	<i>Carex bebbii</i> Olney ex Fernald	S1S2	G5	1	
Gentianaceae	<i>Gentianopsis richardsonii</i> (A. E. Porsild)	S1S2	GNR	2	BLM Sensitive
Juncaceae	<i>Juncus nodosus</i> L.	S1S2	G5	2	
Poaceae	<i>Elymus lanceolatus</i> ssp. <i>psammophilus</i> (J. M. Gillett and H. Senn) A. Löve	S1S2	G3G4	2	
Poaceae	<i>Poa secunda</i> J. Presl ssp. <i>secunda</i>	S1S2	G5TNR	2	
Poaceae	<i>Agrostis clavata</i> Trin.	S1S2	G4G5	1	
Rosaceae	<i>Potentilla fragiformis</i> Willd. ex Schldl.	S1S2	G4	2	
Asteraceae	<i>Antennaria densifolia</i> A. E. Porsild	S2	G3	11	BLM Sensitive
Brassicaceae	<i>Erysimum angustatum</i> Rydb.	S2	G5T2	16	BLM Sensitive
Brassicaceae	<i>Physaria calderi</i> (G.A. Mulligan and A.E. Porsild) O'Kane and Al-Shehbaz	S2	G3G4	10	BLM Sensitive
Brassicaceae	<i>Cardamine microphylla</i> J.E.Adams	S2	G3G4	3	BLM Watch

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Family	Species	State Rank	Global Rank	No. of Pops	Federal Status
Cyperaceae	<i>Carex peckii</i> Howe	S2	G4G5	5	
Cyperaceae	<i>Carex sychnocephala</i> J. Carey	S2	G4	5	
Fabaceae	<i>Oxytropis kobukensis</i> S.L. Welsh	S2	G2	9	BLM Sensitive
Fabaceae	<i>Lupinus kuschei</i> Eastw.	S2	G3G4	3	BLM Watch
Fabaceae	<i>Vicia americana</i> Muhl. ex Willd.	S2	G5	1	
Hydrophyllaceae	<i>Phacelia sericea</i> (Graham) A. Gray	S2	G5	8	
Juncaceae	<i>Juncus tenuis</i> Willd.	S2	G5	1	
Ophioglossaceae	<i>Botrychium yaaxudakeit</i> Stensvold and Farrar	S2	G3G4	1	USFS Sensitive
Poaceae	<i>Schizachne purpurascens</i> (Torr.) Swallen	S2	G5	2	
Polygonaceae	<i>Eriogonum flavum</i> Nuttall var. <i>aquilinum</i> Reveal	S2	G5T2	10	BLM Sensitive
Potamogetonaceae	<i>Potamogeton robbinsii</i> Oakes	S2	G5	1	BLM Watch
Ranunculaceae	<i>Ranunculus turneri</i> ssp. <i>turneri</i> Greene	S2	G3TNR	4	BLM Sensitive
Ranunculaceae	<i>Ranunculus ponojensis</i> (Markl.) Ericsson	S2	GNR	1	BLM Watch
Rosaceae	<i>Potentilla stipularis</i> L.	S2	G5	4	BLM Sensitive
Salicaceae	<i>Salix athabascensis</i> Raup.	S2	G4G5	3	
Salicaceae	<i>Salix planifolia</i> Pursh	S2	G5T5	2	
Saxifragaceae	<i>Micranthes porsildiana</i> (Calder and Savile) Elven and D. F. Murray	S2	G4	2	BLM Watch
Asteraceae	<i>Erigeron muirii</i> A. Gray	S2S3	G2	3	BLM Sensitive
Brassicaceae	<i>Draba murrayi</i> G. A. Mulligan	S2S3	G2	17	BLM Sensitive
Brassicaceae	<i>Alyssum obovatum</i> (C.A. Mey.) Turcz.	S2S3	G5	14	
Cyperaceae	<i>Carex deflexa</i> Hornem. var. <i>deflexa</i>	S2S3	G5	4	
Cyperaceae	<i>Carex deweyana</i> Schwein. var. <i>deweyana</i>	S2S3	G5	2	
Cyperaceae	<i>Eriophorum viridicarinatum</i> (Engelm.) Fernald	S2S3	G5	2	
Cyperaceae	<i>Carex deflexa</i> Hornem. var. <i>deflexa</i>	S2S3	G5	4	
Cyperaceae	<i>Carex deweyana</i> Schwein. var. <i>deweyana</i>	S2S3	G5	2	
Orchidaceae	<i>Cypripedium parviflorum</i> var. <i>exiliens</i> Sheviak	S2S3	G5	8	

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Family	Species	State Rank	Global Rank	No. of Pops	Federal Status
Papaveraceae	<i>Papaver gorodkovii</i> Tolmatchew and Petrovsky,	S2S3	G3	1	BLM Sensitive
Poaceae	<i>Poa porsildii</i> Gjærev.	S2S3	G3	20	BLM Sensitive
Polygonaceae	<i>Rumex krausei</i> V.V.Petrovsky	S2S3	G2	3	BLM Sensitive
Rosaceae	<i>Rosa woodsii</i> Lindl. ssp. <i>woodsii</i>	S2S3	G5T5	8	
Rosaceae	<i>Chamaerhodos erecta</i> (L.) Bunge	S2S3	G5	5	
Saxifragaceae	<i>Saxifraga adscendens</i> ssp. <i>oregonensis</i> (Raf.) Bacig.	S2S3	G5T4T5	1	
Brassicaceae	<i>Draba densifolia</i> Nuttall	S2S3Q	G5	11	BLM Watch
Amaranthaceae	<i>Corispermum ochotense</i> Ignatov	S3	G3G4	12	BLM Watch
Apiaceae	<i>Cicuta bulbifera</i> L.	S3	G5	10	
Apocynaceae	<i>Apocynum androsaemifolium</i> L.	S3	G5	15	
Asparagaceae	<i>Maianthemum stellatum</i> (L.) Link	S3	G5	3	
Asteraceae	<i>Artemisia tanacetifolia</i> L.	S3	GNR	21	BLM Sensitive
Asteraceae	<i>Symphyotrichum yukonense</i> (Cronquist) G.L. Nesom	S3	G3	21	
Brassicaceae	<i>Draba macounii</i> O. E. Schulz	S3	G3G4	6	
Brassicaceae	<i>Draba mulliganii</i> Al-Shehbaz	S3	GNR	6	
Cupressaceae	<i>Juniperus horizontalis</i> Moench.	S3	G5	1	
Cyperaceae	<i>Carex eburnea</i> Boott	S3	G5	17	
Cyperaceae	<i>Carex heleonastes</i> Ehrh. ex L. f.	S3	G4	5	BLM Watch
Cyperaceae	<i>Carex atratiformis</i> Britton	S3	G5	4	
Cyperaceae	<i>Carex interior</i> L. H. Bailey	S3	G5	2	
Fabaceae	<i>Oxytropis kokrinensis</i> A.E. Porsild	S3	G3	15	BLM Watch
Fabaceae	<i>Astragalus williamsii</i> Rydb.	S3	G4	4	
Hydrocharitaceae	<i>Najas flexilis</i> (Willd.) Rostk. and W. L. E. Schmidt	S3	G5	7	
Hydrophyllaceae	<i>Phacelia mollis</i> J.F. Macbr.	S3	G2G3	38	BLM Sensitive
Ophioglossaceae	<i>Botrychium alaskense</i> Wagner and Grant	S3	G4	4	
Ophioglossaceae	<i>Botrychium virginianum</i> (Linnaeus) Swartz	S3	G5	1	
Poaceae	<i>Glyceria striata</i> (Lam.) Hitchc.	S3	G5	5	

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Family	Species	State Rank	Global Rank	No. of Pops	Federal Status
Poaceae	<i>Puccinellia vahliana</i> (Liebm.) Scribn. and Merr.	S3	G4	3	BLM Watch
Poaceae	<i>Trisetum sibiricum</i> ssp. <i>litorale</i> Rupr. ex Roshev.	S3	G5T4Q	3	BLM Sensitive
Poaceae	<i>Puccinellia wrightii</i> (Scribn. and Merr.) Tzvelev ssp. <i>wrightii</i>	S3	G3G4T NR	2	BLM Sensitive
Polypodiaceae	<i>Polypodium sibiricum</i> Siplivinskij	S3	G5?	11	
Potamogetonaceae	<i>Potamogeton obtusifolius</i> Mert. and W. D. J. Koch	S3	G5	5	
Primulaceae	<i>Douglasia arctica</i> Hook.	S3	G3	19	BLM Sensitive
Ranunculaceae	<i>Ranunculus camissonis</i> Schtdl.	S3	GNR	7	BLM Sensitive
Rosaceae	<i>Geum aleppicum</i> ssp. <i>strictum</i> (Aiton) R. T. Clausen	S3	G5T5	1	
Salicaceae	<i>Salix candida</i> Flügge ex Willd.	S3	G5	9	
Gentianaceae	<i>Gentianopsis barbata</i> ssp. <i>barbata</i> (Froel) Ma	S3Q	GNR	8	BLM Sensitive
Montiaceae	<i>Montia vassilievii</i> (Kuzen.) McNeill ssp. <i>vassilievii</i>	S3Q	GNRTN R	11	BLM Sensitive
Amaranthaceae	<i>Chenopodium glaucum</i> Linnaeus var. <i>salinum</i> (Standley) B. Boivin	S3S4	G5T5	3	
Asteraceae	<i>Erigeron porsildii</i> G.L.Nesom and D.F.Murray	S3S4	G3G4	6	BLM Watch
Brassicaceae	<i>Cardamine blaisdellii</i> Eastwood	S3S4	G3G4	5	BLM Watch
Caryophyllaceae	<i>Minuartia dawsonensis</i> (Britt.) House	S3S4	G5	11	
Caryophyllaceae	<i>Arenaria longipedunculata</i> Hultén	S3S4	G3G4Q	9	BLM Watch
Caryophyllaceae	<i>Stellaria umbellata</i> Turczaninow	S3S4	G5	5	
Ceratophyllaceae	<i>Ceratophyllum demersum</i> L.	S3S4	G5	6	
Cyperaceae	<i>Carex lapponica</i> O. Lang	S3S4	G4G5Q	10	
Cyperaceae	<i>Carex atherodes</i> Spreng.	S3S4	G5	9	
Lamiaceae	<i>Lycopus uniflorus</i> Michx.	S3S4	G5	7	
Poaceae	<i>Glyceria pulchella</i> (Nash) K. Schum.	S3S4	G5	16	
Potamogetonaceae	<i>Potamogeton subsibiricus</i> Hagstrom	S3S4	G3G4	4	BLM Watch
Potamogetonaceae	<i>Zannichellia palustris</i> ssp. <i>palustris</i> L.	S3S4	G5	1	
Pteridaceae	<i>Cryptogramma stelleri</i> (S.G. Gmel.) Prantl	S3S4	G5	15	
Violaceae	<i>Viola selkirkii</i> Pursh ex Goldie	S3S4	G5?	3	
Boraginaceae	<i>Mertensia paniculata</i> (Aiton) G.Don var. <i>alaskana</i> (Britton) L.O.Williams	S3S4Q	G5TNR	12	

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Family	Species	State Rank	Global Rank	No. of Pops	Federal Status
Fabaceae	<i>Oxytropis tananensis</i> Jurtz.	S3S4Q	GNR	22	BLM Watch
Polemoniaceae	<i>Phlox richardsonii</i> Hook.	SNR	G5	4	BLM Watch
Cyperaceae	<i>Carex sartwellii</i> Dewey	SP	G4G5	2	
Cyperaceae	<i>Carex praegracilis</i> W. Boott	SP	G4	1	
Hydrophyllaceae	<i>Phacelia franklinii</i> (R. Br.) A. Gray	SP	G5	1	
Asteraceae	<i>Erigeron yukonensis</i> Rydberg	SU	G2G4	1	BLM Sensitive
Brassicaceae	<i>Boechera stricta</i> (Graham) Al-Shehbaz	SU	GNR	2	
Cyperaceae	<i>Carex brunnescens</i> ssp. <i>alaskana</i> Kalela	SU	G5T3T4	1	
Fabaceae	<i>Oxytropis arctica</i> var. <i>barnebyana</i> S.L. Welsh	SU	G4?T2Q	10	BLM Sensitive
Poaceae	<i>Festuca viviparoides</i> Krajina ex Pavlick	SU	G4G5	8	
Poaceae	<i>Festuca viviparoides</i> Krajina ex Pavlick ssp. <i>viviparoides</i>	SU	G4G5	5	
Poaceae	<i>Festuca viviparoides</i> ssp. <i>krajinae</i> Pavlick	SU	G4G5	3	
Polemoniaceae	<i>Phlox hoodii</i> Richardson	SU	G5	9	
Rosaceae	<i>Potentilla rubricaulis</i> Lehm.	SU	G4	2	BLM Watch

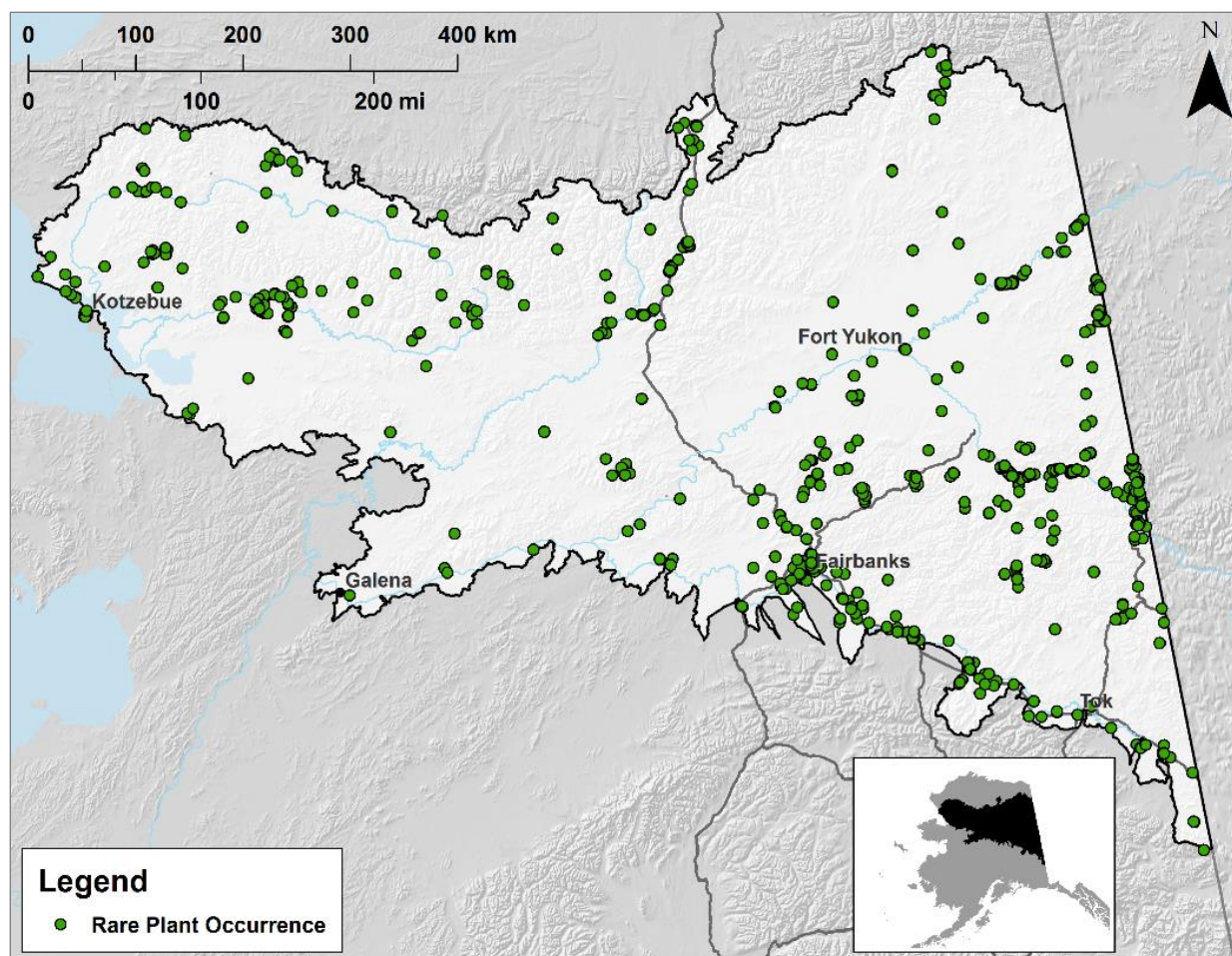


Figure G-69. Distribution of rare plant species across the CYR study area.

Modeling Response to Future Climate Change

The most common accepted approach to understanding potential shifts in rare plant species habitat is to create a Species Distribution Model (SDM), which is sometimes accompanied by the NatureServe Climate Change Vulnerability Calculator (Anacker et al. 2013, Still et al. 2015). The NatureServe Climate Change Vulnerability Calculator (Young et al. 2015) requires a specific moisture index of Actual Evapotranspiration/Predicted Evapotranspiration (AET:PET) for future scenarios, which has not been calculated for Alaska and is considered a data gap. We, therefore, utilized the SDM methodology (Figure G-68). We first summarize MaxEnt modeling and then describe specific model methods and results.

We used the maximum entropy modeling program MaxEnt version 3.3.1 (Phillips et al. 2006, Phillips and Dudik 2008) to produce SDMs. MaxEnt calculates expected levels of species presence using presence-only data, and has been shown to outperform more established modeling methods, such as GARP and BIOCLIM (Elith et al. 2006, Elith et al. 2011). In general, the MaxEnt approach seeks to estimate an unknown distribution using incomplete information about the distribution of the species and a given set of constraints. For modeling the potential geographical range of a species, the occurrence data are considered to be the incomplete sample of a larger, unknown geographical distribution, and the environmental data are used as

constraints (Dudik et al. 2004, Phillips et al. 2006, Phillips and Dudik 2008). While there is no minimum number of occurrences required to execute the MaxEnt algorithms, the recommended number of occurrences is > 30 as predictive accuracy declines with fewer occurrences (Wisz et al. 2008). However, if the study area is limited in size, then as few as 20 occurrences can produce acceptable results with limitations in the interpretation (Hernandez et al. 2006, Wisz et al. 2008).

Given the rapid nature of the REA and limited usefulness of small number of populations in SDMs, our analysis was limited to the five most abundant species in Table G-42: *Phacelia mollis*, *Oxytropis tananensis*, *Artemisia tanacetifolia*, *Symphyotrichum yukonense*, and *Poa porsildii*. Steppe bluff habitat supports a high number of endemic plant species (Roland 1996) and includes a disproportionately high diversity and abundance of rare plant taxa (Shacklette 1966, Murray et al. 1983). This rare ecosystem thus provides an opportunity to conserve a number of rare and endemic taxa by focusing management on a single habitat (Parker and Batten 1995). Eighteen rare plant species are associated with steppe bluff habitat in the CYR study area, including both *Phacelia mollis* and *Artemisia tanacetifolia* (Table G-30). *Oxytropis tananensis* is a taxonomically questionable species, and the current draft of Flora of North America reclassifies it as a variety of *Oxytropis campestris*, a commonly occurring species across Alaska (ITIS 2016). *Oxytropis tananensis* will be reviewed and likely dropped from the ACCS Rare Plant List. *Symphyotrichum yukonense* is restricted to the floodplains and gravel bars of the Noatak River and upper Koyukuk River. A SDM approach for this species would create false positive habitat across the CYR study area river systems. There were sufficient populations of *Poa porsildii* in the CYR study area. We, therefore, use the SDM approach to model the Steppe Bluff BpS and *Poa porsildii* in the CYR study area.

We were unable to address climate change with literature review for all 124 rare plant species; however, we highlighted potential climate change affects to rare ecosystems in MQ G1. In this section, we specifically focused the literature review on climate change impacts to *Oxytropis kobukensis*, a rare endemic to the rare ecosystem of Inland Dune BpS. A SDM approach is not possible for the species or BpS as there are inherent data gaps.

12.2 Methods

SteppeBluff BpS

Species Distribution Models were fitted to both current and future climate scenarios using the Scenarios Network for Alaska Planning (SNAP) data (see Section C. Abiotic Change Agents for more information on parameters of output climate models). We used annual total precipitation and Summer Warmth Index (SWI) for the current and long-term climate variables resampled to 60-meter resolution to match the elevation dataset. We used the National Elevation Dataset 60-m Digital Elevation Model (DEM; Gesch et al. 2002, Gesch 2007). From the DEM, we calculated a 'heat load index' that transforms slope and aspect into a linear scale, where the warmest slopes are closer to a value of '1' compared to coolest slopes with a value of '0' (McCune and Keon 2002, Evans et al. 2014). There were 24 mapped Steppe Bluff points in the Alaska Rare Ecosystem database. A summary of datasets is in Table G-43.

Table G-43. Environmental variables used to calculate current and future suitable habitat of Steppe Bluff BpS.

Environmental Variable	Source
Steppe Bluff BpS points	Alaska Rare Ecosystem Database, ACCS
Elevation 60m DEM	USGS
Heat Load Index	Calculated from 60-m DEM (according to methods in Evans et al. 2014)
Annual Precipitation Current	SNAP
Annual Precipitation Future (long-term)	SNAP
Summer Warmth Index Current	SNAP
Summer Warmth Index Future (long-term)	SNAP

The model analysis settings were set to ‘auto features,’ which allows MaxEnt to automatically adjust the amount of regularization based on the environmental data and number of populations (Phillips et al. 2006). We used a 10-fold cross-validation and 5,000 maximum number of iterations. For each model run, 10,000 points were selected at random as background. We used area under the curve (AUC), which is automatically calculated by MaxEnt, to estimate model performance. AUC values range between 0 and 1, with values between 0.5 and 0.7 indicating relatively poor model performance, those between 0.7 and 0.9 indicating useful model, and those above 0.9 indicating relatively high model accuracy (Swets 1988).

The final MaxEnt logistical outputs were reclassified into Moderate Potential Distribution (70%–79%), Likely Potential Distribution (80%–90%), and Very Likely Potential Distribution (> 90%). Note that MaxEnt does not calculate “probability of occurrence” directly. The output maps are presented in colors to illustrate predicted habitat suitability, with red indicating the highest suitability and shades of yellow indicating lower suitabilities. The background map is visible where conditions are deemed below 69% suitability (Unlikely Potential Distribution).

We calculated the response to climate change using equations by Anacker et al. (2013) and Still et al. (2015). Change in range size measures the expansion and/or contraction of projected future habitat. Values can range from -100% to > 100%, where negative value indicates a shrinkage of suitable distribution. Overlap in suitable distribution describes the area of future distribution that overlaps with the current distribution and can indicate the potential for ecosystem or species migration and shift. The suitability score indicates the change in climate suitability for the current known occurrences. Values range from -1 to +1, where negative values indicate a decrease of suitable distribution in the future. Finally, a SDM score was calculated to measure the total vulnerability to climate change and value ranges from 0 (ecosystem or species not vulnerable) to 1 (ecosystem or species highly vulnerable).

***Poa porsildii* Gjærev.**

Poa porsildii is imperiled to rare within the state and at moderate to high risk of extirpation (S2S3, ‘BLM Sensitive’; Nawrocki et al. 2013). This perennial grass occurs regionally in the White Mountains, Yukon-Tanana Uplands, and Ogilvie Mountains with additional disjunct populations

the Davidson Mountains, all of which are within the CYR study area. The range extends to Yukon, where this species is more prevalent. *Poa porsildii* is found on various aspects above treeline (900–1680 m) in graminoid forb meadows and dwarf shrub tundra on ridgetops, summits, and alpine plateaus. Associated soils are usually calcareous and mesic to wet. The species does not have stolons or rhizomes and appears to primarily reproduce by seed. *Poa porsildii* is dioceous and some populations have been observed to consist only of female plants. The species is wind-pollinated and seed is dispersed by wind.

There are 20 known populations of *Poa porsildii* in the CYR study area; however, 22 points were included in the analysis as some populations have sub-populations (points < 1 km apart). We used elevation, annual precipitation, and SWI as described above. The methods and settings for MaxEnt and calculations for response to climate change were the same as described above.

12.3 Results and Discussion

SteppeBluff BpS

The SDM produced for the current and long-term future scenarios for the Steppe Bluff BpS had an AUC value of 0.963, indicating the model was a strong predictive fit of the data. Of the environmental variables analyzed, the heat load index had the largest relative contribution to the model where it accounted for approximately 63.1% of relative contribution (Table G-44). Elevation was the lowest contributor with approximately 4.5% of relative contribution (Table G-44).

Table G-44. Results of environmental variable importance in contribution to the Steppe Bluff BpS MaxEnt model.

Environmental Variable	Contribution
Heat Load Index	63.1%
Annual Precipitation	21.6%
Summer Warmth Index	10.9%
Elevation	4.5%

Known and predicted future suitable distribution was dominant in the eastern section of the CYR study area. Notable areas of current predicted suitable distribution include the Fortymile River District, the Salmon Village area of Yukon Flats NWR, pockets along the Black River, the Yukon River below Steven's Village, the upper Yukon River (upriver of Circle), the confluence of the Christian River and Otter Creek in the Arctic NWR, the mountains near Volkmar Lake and the Tanana River, and the Porcupine River.

The predicted suitable distribution of the Porcupine River, Upper Yukon River, and Fortymile River region (Figure G-70) fits the known landscape and ecological niche of the Steppe Bluff BpS (see Roland 1996, Wesser and Armbruster 1991). The model is informative at a landscape scale and should be interpreted as potential suitable distribution rather than a microsite scale for absolute positive or negative occurrence.

In comparing the modeled current to the long-term future predicted suitable distribution, there is a significant decrease in area within the CYR study area of approximately 58%. Approximately 41% of the current suitable distribution is predicted to overlap with future predicted suitable

distribution, suggesting that there will be a contraction and shifting of the Steppe Bluff BpS. Due to the small size and isolation of predicted habitat locations, they are not easily visualized at the scale of the entire CYR study area, and we, therefore, display a close-up of a smaller region (Figure G-70). The average Suitability Score for the Steppe Bluff BpS is -0.22, indicating a vulnerability to the presently locations is predicted to decrease in the future. The SDM score is 0.55 suggested medium vulnerability score for the Steppe Bluff BpS.

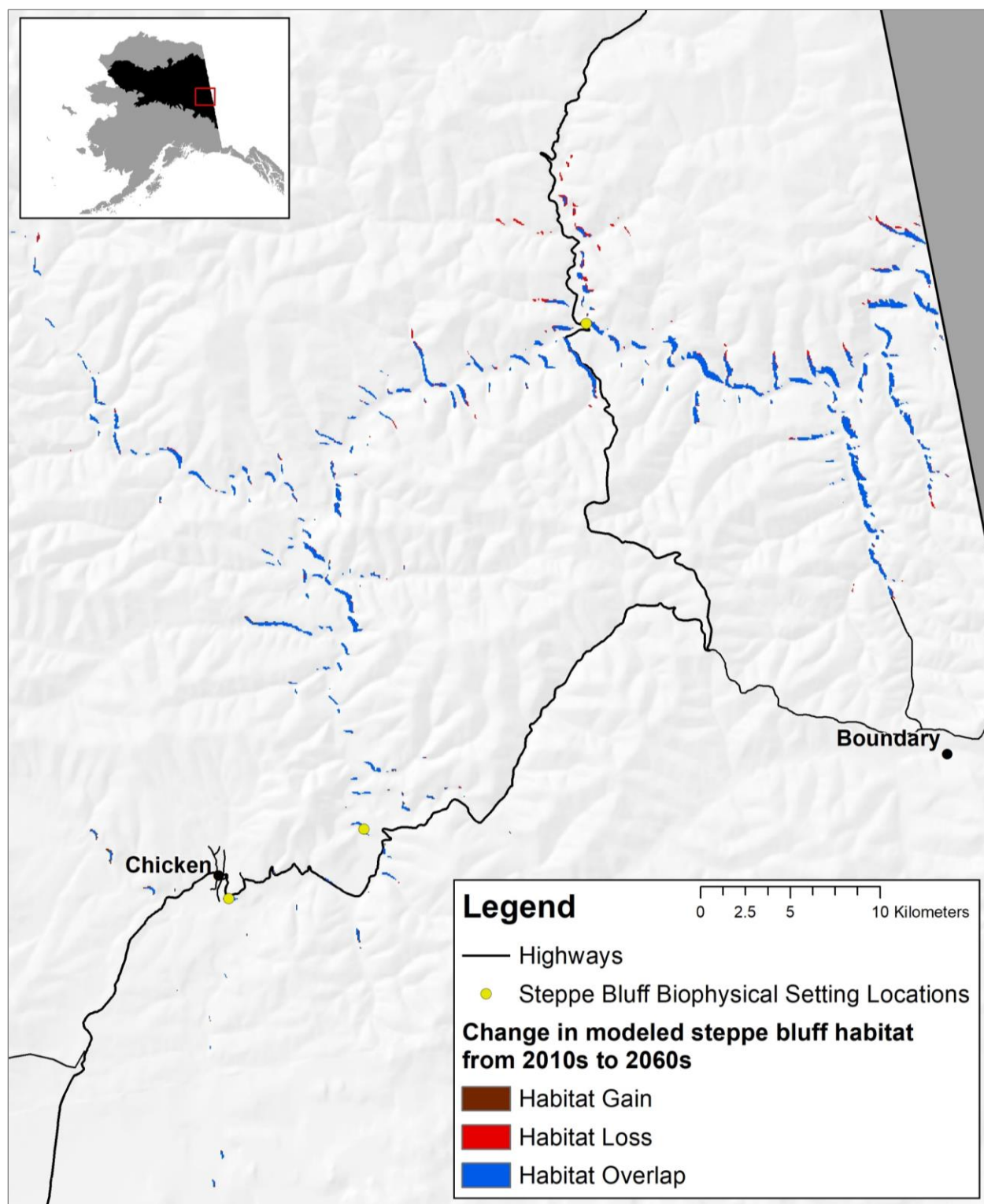


Figure G-70. MaxEnt current and long-term future predicted probability of suitability results for the Steppe Bluff BpS in the Fortymile River region. The difference between current and future distribution is shown in the legend. Modeled habitat and points are exaggerated for display. Points and pixels are enlarged for visibility.

There is a general trend of decrease in suitable distribution across the CYR study with insignificant increases of suitable habitat predicted around the town of Chicken (Figure G-70). There is a predicted increase of temperature in the eastern Interior portion of the CYR study area, but not a substantial increase in precipitation. The future climate may substantially increase moisture stress in to the biophysical setting beyond its current limits. Other studies have predicted alternative scenarios to habitat loss, where the loss of soil moisture will cause boreal forests on south- aspect slopes to dry out and shift to dry aspen forest or xeric steppe bluffs (Bonan et al. 1990). However, these studies were not meant to mimic the future conditions predicted by atmospheric models, but rather to identify consequences and thresholds of temperature and precipitation. Soil moisture may be a more significant variable for the Steppe Bluff BpS than air temperature and precipitation (Bonan et al. 1990, Wesser and Armbruster 1991). While there is a predicted significant decrease in suitable habitat across the CYR study area, it is difficult to identify biological aspects for the decrease. Additionally, the model does not account for the physiological limit (temperature and moisture) of plant species occurring within the biophysical setting. Precipitation is more variable than temperature across space and time; therefore, variability and uncertainty tend to be greater for precipitation than for temperature.

***Poa porsildii* Gjørev.**

The SDM produced for the current and long-term future scenarios for *Poa porsildii* had an AUC value of 0.967, indicating a strong model performance. Of the environmental variables analyzed, elevation had the largest relative contribution to the model, where it accounted for approximately 82.5% of relative contribution, followed by the SWI with a relative contribution of 17%, and annual precipitation with a relative contribution of 0.4% (Table G-45).

Table G-45. Results of environmental variable importance in contribution to the *Poa porsildii* MaxEnt model.

Environmental Variable	Contribution
Elevation	82.5%
Summer Warmth Index	17%
Annual Precipitation	0.4%

Predicted suitable habitat is projected to increase approximately 111% by long-term future scenarios. There is a significant increase of predicted suitable habitat in the White and Ogilvie mountains, where all but one populations of *P. porsildii* occur (Figure G-71). Suitable habitat may moderately increase in scattered pockets of the Davidson Mountains, where there is currently one known disjunct population (Figure G-71). The average suitability score for the known populations of *P. porsildii* is 0.13, indicating the present locations will be stable to slightly increasing in suitable habitat. Of the 22 occurrences, four have significant positive suitability scores, partially inflating the score. The SDM score (0.4) for *P. porsildii* indicates intermediate vulnerability. Overall, while there is predicted significant increase in suitable habitat, it is possible that some *P. porsildii* locations may not be located in suitable habitat in the future.

The length of growing season for tussock tundra is expected to increase by 9.8 days from the current 144.3 days to 154.2 days in the long-term future (Figure G 9), and the mean SWI (annual sum of mean monthly temperatures that are above freezing) is projected to increase from 42 °C to 48 °C for the same time frame (Figure G 54). As discussed earlier, the alpine tundra will

Section G. Terrestrial Coarse-filter Conservation Elements

experience significant changes in the future where warming temperatures, increased fire frequency, and loss of permafrost will likely result in a loss of tussock tundra habitat in the future. Generally, the alpine habitats that were once connected by ridgelines may become isolated patches or islands in the future. The contraction is likely related to an increase in low and tall shrub cover at higher elevations in this region predicted by the ALFRESCO model (see Section C. Abiotic Change Agents).

Indeed, while suitable habitat for this alpine grass is predicted to significantly increase, the overall alpine habitat will decrease. The SDM model strongly suggests that *Poa porsildii* currently occurs in warmer, wetter pockets of the alpine, thus explaining the increased suitable habitat in the future. This population may benefit, but the species will likely shift to higher elevations in this region as competition from shrub and trees and increased canopy cover that would shade out *P. porsildii* will likely occur. Additionally, *P. porsildii* may retreat to open pockets of remnant alpine habitat.

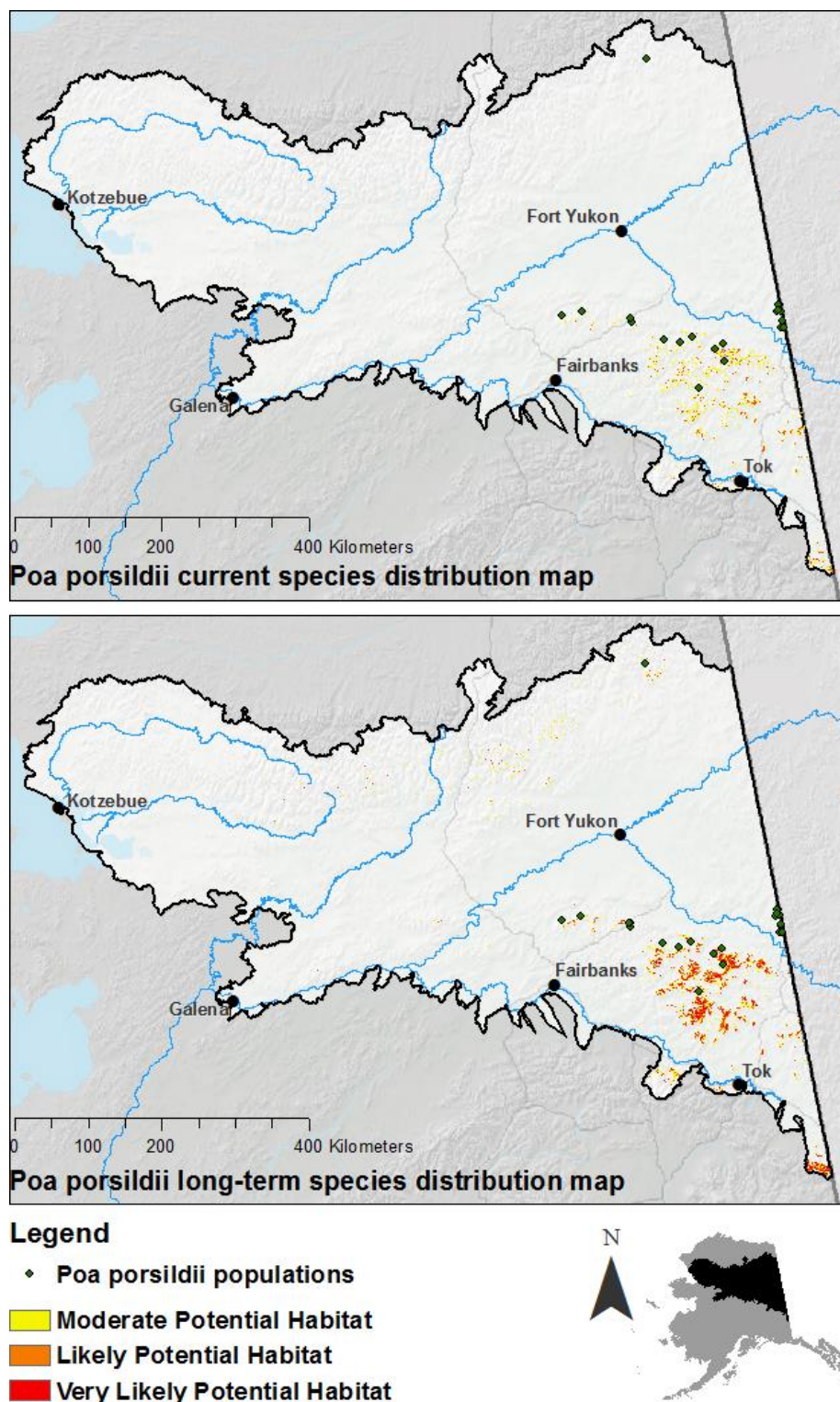


Figure G-71. MaxEnt predicted probability of suitability for *Poa porsildii* in the CYR study area. Predicted probability of suitability indicates likelihood of the existence of suitable conditions based on modeled environmental variables and does not indicate species predicted occurrence.

Oxytropis kobukensis

As described in MQ G1, the Inland Dune BpS occurring in the CYR study area are large, active dune fields, totaling 70 km² in area and consisting of the Great Kobuk Sand Dunes (62 km²) and Little Kobuk Sand Dunes (8 km²) in the CYR study area. The dunes are largely unvegetated but are surrounded by mesic spruce woodlands.

Oxytropis kobukensis is a rare, narrowly endemic species that occurs in both the Great and Little Kobuk Sand Dunes and on small dunes on the Kobuk River between the large dune systems. There are nine known populations that range from an estimated several thousand individuals to several individuals. While seeds are produced, seedlings are rarely observed and vegetative reproduction is common. *Oxytropis kobukensis* grows on stabilized sand, active dunes, dune slacks, sheltered dune slopes, and along the margins of the dune areas. On the Kobuk River system, plants are found on alluvial sand deposits but away from active and seasonally flooded sandbars, indicating a threshold of moisture tolerance. Within the dune system, the dune slope and slacks may have a higher water table where carbonate-rich groundwater percolates and gathers (Galloway 1984). *Oxytropis kobukensis* is found in open habitat, where vegetation is sparse. In both the river sand dune system and dune margin, it occurs away from willow scrub thickets and closed forest.

The margins of the active dune system are stabilized, preserved dunes vegetated with *Dryas* heath mats and white spruce woodland. Associated species are closed dwarf shrub scrub *Dryas* tundra and open dwarf shrub scrub. These vegetated dunes result from historical encroachment of vegetation as effective moisture increased in the region. Drying periods created widespread dune activation (Mann et al. 2002).

Based on SNAP data (see Section C. Abiotic Change Agents), annual precipitation is expected to increase for the sand dunes. Averaged for both the Little and Great Kobuk Sand Dunes, there is a predicted increase of 55 mm of rainwater equivalent by the long-term future. The increased precipitation will likely increase the advancement of the white spruce forest and willow scrub on the margins of the dune system. Greater vegetation canopy cover is also strongly correlated with more soil moisture as vegetation shades the ground surface in dune ecosystems (Mann et al. 2002, Li et al. 2013). *Oxytropis kobukensis* populations on dune margins will likely be shaded out and retreat into the dune system as scrub tundra encroaches the dune margins in the long-term future. However, a majority of the populations will likely be secure as they do not occur on the dune edge.

In similar systems, the upper 60 cm of soil contained less moisture, and lack of surficial soil moisture was the greatest contributing factor in restricting seedling growth and germination (Li et al. 2013). Increased seasonal precipitation increased the seed germination of observed xeric dune species. An increase of precipitation may increase the germination of *O. kobukensis*, but also of competing species. Soil moisture is influenced by elevation in the sand dune system, where depressions, windward slopes, and base elevation slacks have more soil moisture at shallow depths. With the increase of precipitation in the region, these microhabitats are likely to pool with more water as they have a water table closer to the surface. Though currently infrequent, the wetter slacks hold wetland plant associations (Boggs et al., in prep.). The occurrence of wetlands in the dune systems may increase in frequency in the long-term future. The physiological

limits of *O. kobukensis* are not known, but seasonally flooded habitats were absent of *O. kobukensis*, indicating that inundated soils are not tolerated. The depressions and slacks may not be favorable in the long-term future, causing *O. kobukensis* to occur more frequently on windward aspects of the dunes or margins of the slacks.

12.4 Data Gaps and Limitations

MaxEnt models predicted suitable habitat based on species locations and environmental inputs. The strength and reliability of the model is limited by the quality of the input variables. The model output provides a relative index of habitat suitability, not occurrence probability. Since the model output is reliant on current known locations and distributions, assumption of physiological limits of species or habitat should be taken with caution. For example, future predicted non-suitable habitat may be false because the physiological limits of the species may be wider than indicated by its current observed range and trend.

MaxEnt modeling relies on accurate species population locations. However, due to the nature of historical rare plant collections, some rare plant data contain imprecise locality data. In these cases, the population location is estimated as best as possible from the location description. Additionally, while point data may indicate a species occurrence, the lack of point data does not indicate absence and can create a sampling bias. Since we modeled within a defined boundary and absence data are a data gap, we assume the detection probability and sampling probability are constant across the space. However, we note that all model outputs produced are in agreement with current knowledge of ecosystem or species distribution and ecological requirements.

Climate change predictions are based on data downscaled by SNAP from the five best-performing GCMs (see Section C. Abiotic Change Agents). Surficial geology maps did not have the fine resolution associated with species distribution and were, therefore, not used. Surficial geology may not have contributed to the Steppe Bluff BpS but may have contributed to the *Poa porsildii* model as the species is sometimes associated with calcareous soil. Fine-scale surficial geology maps and soil maps are a data gap.

Future modeling of a smaller region, such as only the eastern Interior Alaska, with the 60 m DEM may yield more accurate current and long-term future results. However, the models produced are useful for land managers to prioritize resource and management needs but also for hypothesis testing in research. For example, there are suitable habitats on the lower Yukon River that were not previously known as suitable habitat for Steppe Bluff BpS. Use of the distribution map in its current form significantly decreases survey time and expense for finding new locations for Steppe Bluff BpS and *Poa porsildii*.

The Steppe Bluff BpS model could be improved by incorporating moisture. Specifically, soil moisture is correlated to Steppe Bluff habitat (Wesser and Armbruster 1991). A moisture index such Actual Evapotranspiration (AET), Potential Evapotranspiration (PET), or an AET:PET Index may have created a more accurate future scenario for the Steppe Bluff BpS, but such indices are a data gap.

How reliable are these predictions?

The limitations with MaxEnt modeling coincide with the limitations of the quality of data inputs. To evaluate overall model performance, we used the area under the curve (AUC) calculated from a receiver-operating characteristic plot that was automatically generated as part of the MaxEnt output from the training and test data. The receiver-operating characteristic curve measures a model's ability to correctly predict presence and absence, and the resulting AUC statistic can be interpreted as the probability that a presence site is correctly predicted relative to a random background site (Phillips et al. 2006, Phillips and Dudik 2008). Area under the curve (AUC) scores can range from 0 to 1.0, with a random prediction scoring 0.5. Hence, scores above 0.5 are more accurate than a random prediction. Both of our models were in the high range of accuracy and overall reflected literature and professional judgement of the rare ecosystems.

Are there other data/models which provide information that is different than the output presented?

No other data exist for rare plant or rare ecosystems for Alaska. See climate sections for other climate data/models. CART (classification and regression tree) and random forest modeling for habitat suitability is an alternative method. However, MaxEnt is more widely used, easier to simulate, and easier to compare results with other scientific studies. An alternative method for identifying species vulnerable to climate change is to use the NatureServe Climate Change Vulnerability Index. However, this index requires specific moisture data that are not available for Alaska.

12.5 Literature Cited

- Anacker, B. L., M. Gogol-Prokurat, K. Leidholm, and S. Schoenig. 2013. Climate change vulnerability assessment of rare plants in California. *Madroño* 60:193–210.
- Boggs, K., L. Flagstad, T. Boucher, A. Steer, P. Lema, B. Bernard, B. Heitz, T. Kuo, and M. Aisu. *In preparation*. Alaska ecosystems of conservation concern: biophysical settings and plant associations. Report prepared by the Alaska Natural Heritage Program for the Alaska Department of Fish and Game. 267 pp.
- Bonan, G. B., H. H. Shugart, and D. L. Urban. 1990. The sensitivity of some high-latitude boreal forests to climatic parameters. *Climatic Change* 16:9-29.
- Dudík, M., S. Phillips, and R. Schapire. 2004. Performance guarantees for regular maximum entropy density estimation. Pages 472–486 *in* J. Shawe-Taylor, and Y. Singer, eds. *Learning Theory*. SpringerVerlag Berlin, Germany.
- Elith, J., C. H. Graham, R. P. Anderson, M. Dudík, S. Ferrier, A. Guisan, R. J. Hijmans, F. Huettmann, J. R. Leathwick, A. Lehmann, J. Li, L. G. Lohmann, B. A. Loiselle, G. Manion, G. Moritz, M. Nakamura, Y. Nakazawa, J. McC. Overton, A. T. Peterson, S. J. Phillips, K. Richardson, R. Scachetti-Pereira, R. E. Schapire, J. Soberón, S. Williams, M. S. Wisz, and N. E. Zimmermann. 2006. Novel methods improve prediction of species' distributions from occurrence data. *Ecography* 29:129-151.
- Elith, J., S. J. Phillips, T. Hastie, M. Dudík, Y. E. Chee, and C. J. Yates. 2011. A statistical explanation of MaxEnt for ecologists. *Diversity and distributions* 17:43-57.
- Evans, J. S., J. Oakleaf, S. A. Cushman, and D. Theobald. 2014. An ArcGIS toolbox for surface gradient and geomorphometric modeling, version 2.0-0. Available: <http://evansmurphy.wix.com/evansspatial>
- Galloway, J. P. 1984. Scanning electron microscope microfeatures on sand grains and carbonate crusts from the Great Kobuk Sand Dunes, Kobuk River Valley, northwestern Alaska. *Geologic Society of America Abstracts with Programs, Cordilleran Sec.* vol. 16. Abstract no. 43619.
- Gesch, D. B. 2007. The national elevation dataset. *In* D. F. Maune, ed. *Digital elevation model technologies and applications: the DEM users manual*. Asprs Publications.
- Gesch, D., M. Oimoen, S. Greenlee, C. Nelson, M. Steuck, and D. Tyler. 2002. The national elevation dataset. *Photogrammetric engineering and remote sensing* 68:5–32.
- Hernandez, P. A., C. H. Graham, L. L. Master, and D. L. Albert. 2006. The effect of sample size and species characteristics on performance of different species distribution modeling methods. *Ecography* 29:773–785.
- ITIS. 2016. Integrated taxonomic information system on-line database. Available: <http://www.itis.gov>
- Li, H., W. Shen, C. Zou, J. Jiang, L. Fu, and G. She. 2013. Spatio-temporal variability of soil moisture and its effect on vegetation in a desertified aeolian riparian ecotone on the Tibetan Plateau, China. *Journal of Hydrology* 479:215–225.
- Mann, D. H., P. A. Heiser, and B. P. Finney. 2002. Holocene history of the Great Kobuk sand dunes, northwestern Alaska. *Quaternary Science Reviews* 21:709–731.
- Master, L. L., D. Faber-Langendoen, R. Bittman, G. A. Hammerson, B. Heidel, L. Ramsay, K. Snow, A. Teucher, and A. Tomaino. 2012. NatureServe conservation status assessments: factors for evaluating species and ecosystem risk. NatureServe, Arlington, Virginia.
- McCune, B., and D. Keon, 2002. Equations for potential annual direct incident radiation and heat load index. *Journal of Vegetation Science* 13:603–606.
- Murray, D. F., B. M. Murray, B. A. Yurtsev, and R. Howenstein. 1983. Biogeographic significance of steppe vegetation in sub-Arctic Alaska. *Permafrost: Fourth International Conference, Proceedings* 4:883–888.
- Nawrocki, T., J. Fulkerson, and M. Carlson. 2013. Alaska rare plant field guide. Alaska Natural Heritage Program, University of Alaska Anchorage. 350 pp.

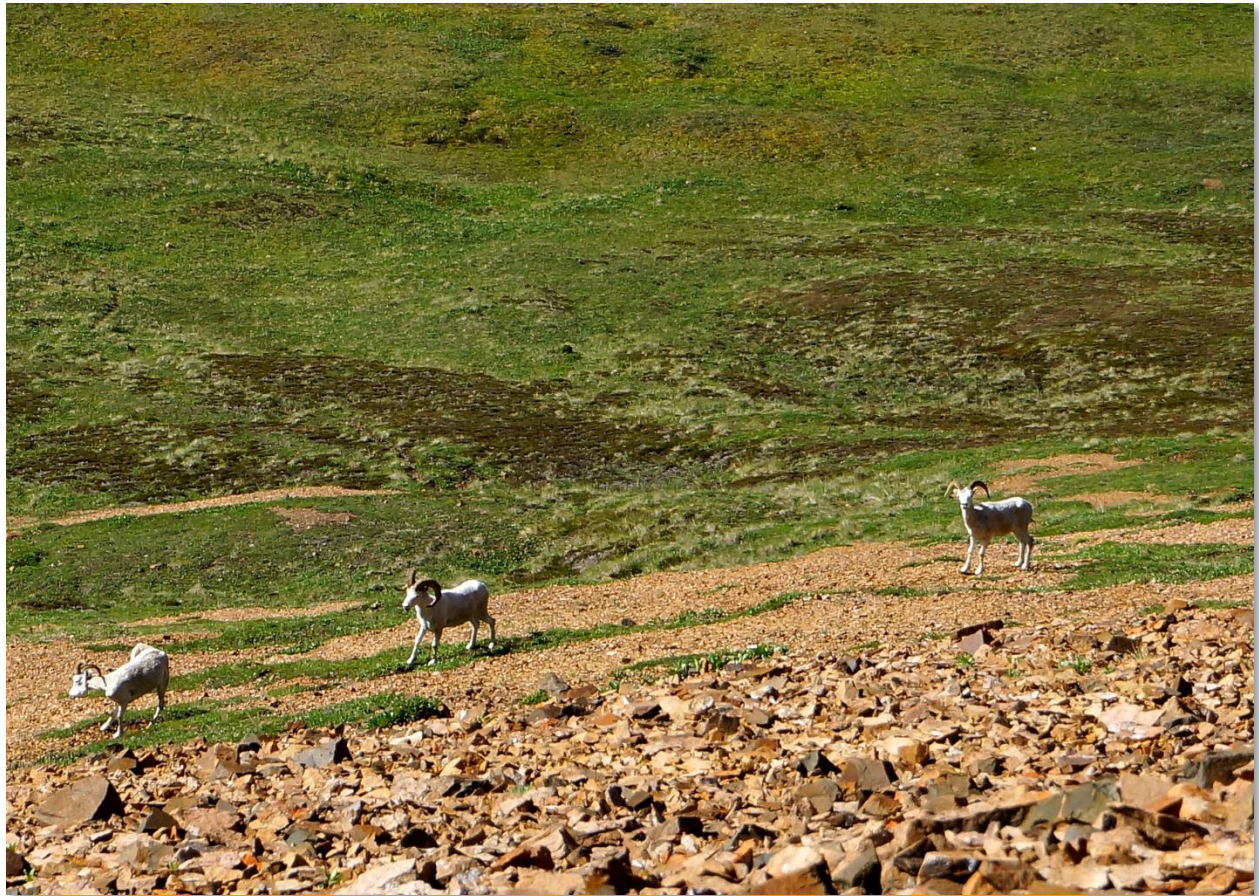
Section G. Terrestrial Coarse-filter Conservation Elements

- Parker, C. L., and A. R. Batten. 1995. Status and trends survey of Category 2 plants in the Yukon-Charley Rivers National Preserve. USDI-NBS. Washington, DC.
- Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190:231–259.
- Phillips, S. J., and M. Dudík. 2008. Modeling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography* 31:161–175.
- Roland, C. 1996. The floristics and community ecology of extrazonal steppe in the Yukon and Kolyma river Drainages. Thesis, University of Alaska Fairbanks.
- Shacklette, H. T. 1966. Phytocology of a greenstone habitat at Eagle, Alaska. Geological Survey Bulletin. 1198-F. U.S. Government Printing Office, Washington D.C.
- Still, S. M., A. L. Frances, A. C. Treher, and L. Oliver. 2015. Using two climate change vulnerability assessment methods to prioritize and manage rare plants: a case study. *Natural Areas Journal* 35:106-121.
- Swets, J. A. 1988. Measuring the accuracy of diagnostic systems. *Science* 240:1285–1293.
- Wesser, S. D., and W. S. Armbruster. 1991. Species distribution controls across a forest-steppe transition: a causal model and experimental test. *Ecological Monographs* 61:323–342.
- Williams P. A., S. Wiser, B. Clarkson, and M. C. Stanley. 2007. New Zealand's historically rare terrestrial ecosystems set in a physical and physiognomic framework. *New Zealand Journal of Ecology* 31:119–128.
- Wisz, M. S., R. J. Hijmans, J. Li, A. T. Peterson, C. H. Graham, and A. Guisan. 2008. Effects of sample size on the performance of species distribution models. *Diversity and Distributions* 14:763–773.
- Young B. E., E. Byers, G. Hammerson, A. Frances, L. Oliver, and A. Treher. 2015. Guidelines for using the NatureServe Climate Change Vulnerability Index Release 3.0. Arlington, Virginia: NatureServe.

H. Terrestrial Fine-filter Conservation Elements

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Summary

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

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1. Introduction to Terrestrial Fine-filter CEs

Many northern ecosystems are undergoing major transitions related to climate change. It is critical that we understand the implications of this transformation on wildlife populations and initiate appropriate mitigation strategies (Berteaux 2013, Marcot et al. 2015). In general, we lack comprehensive baseline data on natural systems and are faced with complex interactions among wildlife species, ecosystems, and humans amid a changing climate. The goal of the Rapid Ecoregional Assessment (REA) is to provide land managers in the Central Yukon (CYR) study area with current baseline data on key resources that can provide a sound basis to better understand the current and anticipated effects of Change Agents (CAs) on select wildlife and the habitats that support them.

Fine-filter Conservation Elements (CEs) provide critical ecosystem functions and services that are not adequately represented by the Coarse-filter CEs but are important for overall ecological integrity. Seven regionally important wildlife species were selected as Terrestrial Fine-filter CEs for the Central Yukon REA (Table H-1). A collaborative effort was made with the Bureau of Land Management (BLM) to select species representative of different ecological niches and functions.

The Terrestrial Fine-filter CEs represent key wildlife resources in the ecoregion and were selected because they were: 1) identified directly through management questions, 2) provided specific ecological services and/or functions identified in the ecoregional conceptual model, 3) were considered important subsistence resources in the ecoregion, or 4) were suggested specifically by managers for their ecological significance.

Table H-1. Terrestrial Fine-filter Conservation Elements used for analysis in the CYR study area.

Conservation Element	Habitat	Seasonality	Reason for Inclusion
Caribou	Tundra, open woodlands	Year-round	Caribou were identified directly through management questions and are an important subsistence resource to the region. Ecosystem function: food availability (prey), herbivory, trampling.
Dall sheep	Open alpine ridges, meadows, and steep slopes with extremely rugged ground (for predator avoidance)	Year-round, non-migratory	Sheep were identified directly through management questions and are an important subsistence resource to the region. Ecosystem function: food availability (prey), herbivory.
American beaver	2 nd to 4 th order streams. Deciduous forest, tall shrub, lakes, rivers	Year-round, non-migratory	Ecosystem function: mechanical disturbance, major driver of hydrologic change on aquatic and riparian ecosystems.

Section H. Terrestrial Fine-filter Conservation Elements

Conservation Element	Habitat	Seasonality	Reason for Inclusion
Snowshoe hare	Coniferous and mixed forests with abundant understory.	Year-round, non-migratory	Key prey for a variety of avian and mammalian predators. Population dynamics are characterized by large inter-annual fluctuations, which is a driver for predator populations. Ecosystem function: food availability (prey) and herbivory.
Golden eagle	Cliffs, riparian areas	Summer: Alaska; Winter: South	Representative of cliffs and riparian habitats.
Swainson's thrush	Forest, tall shrub	Summer: Alaska; Winter: South (e.g., Equator)	Representative for small aerial insectivores and forest habitat.
Trumpeter swan	Summer/breeding: Close to waterbodies	Summer: Alaska; Winter: South	Representative of waterfowl species and wetlands.

This section describes analyses between the Terrestrial Fine-filter CEs and CAs, including climate and anthropogenic variables. Subsection H-3 summarizes core analyses across all CEs to provide an overall picture of change for CEs in the CYR study area. Further detail and species-specific analysis are described for each CE individually following the core analysis summary.

2. Methods

2.1 Distribution Modeling

We generated a distribution for each CE using existing or new habitat models or species range datasets depending on the type and quality of data available for each CE (Table H-2).

Table H-2. Distribution types, datasets, and model accuracies for each distribution model used for Terrestrial Fine-filter Conservation Element.

Terrestrial Fine-filter CE	Distribution Type	Range, Habitat, or Occurrence Data Sets	Model Accuracy
Caribou	Polygon	ADF&G seasonal caribou herd ranges (2009); ADF&G updated caribou herd ranges (2015)	N/A
American beaver	AKGAP raster distribution model	AKGAP beaver potential habitat distribution model	76% sensitivity
Dall sheep	Random forest raster distribution model	AKGAP Dall sheep occurrence records; BISON Dall sheep occurrence records; NPS Dall sheep collar data; ADF&G annual range polygon; ACCS modified annual range polygon	0.795 kappa
Snowshoe hare	Random forest raster distribution model	AKGAP snowshoe hare occurrence records; BISON snowshoe hare occurrence records	0.603 kappa
Golden eagle	Random forest raster distribution model	AKGAP golden eagle occurrence records; BISON golden eagle occurrence records	0.646 kappa
Swainson's thrush	Random forest raster distribution model	AKGAP Swainson's thrush occurrence records; BISON Swainson's thrush occurrence records	0.615 kappa
Trumpeter swan	AKGAP raster distribution model	AKGAP trumpeter swan potential breeding habitat distribution model	44% sensitivity

Acronyms: ADF&G = Alaska Department of Fish and Game; AKGAP = Alaska Gap Analysis Project; NPS = National Parks Service; BISON = Biodiversity Information Serving Our Nation; GBIF = Global Biodiversity Information Facility; NLCD = National Land Cover Database.

Polygon Distribution Models

Polygon feature classes for caribou seasonal ranges in the CYR study area were obtained from the Alaska Department of Fish and Game (ADF&G). We used ranges described by herd and season developed by ADF&G in 2009 and updated by local biologists in 2015 for the CYR region in particular. There are 13 caribou herds with ranges partially or wholly contained in the CYR study area. We illustrated seasonal ranges for ten of the herds including: Central Arctic, Fortymile, Galena Mountain, Hodzana, Macomb, Porcupine, Ray Mountains, Western Arctic, White

Mountains and Wolf Mountain. Three herds from the original list (Mentasta, Nelchina, and Teshekpuk) were omitted because most of their range occurs outside the CYR study area.

AKGAP Habitat Distribution Models

Alaska Gap Analysis Project (AKGAP) models provide spatial representations of potential habitat distribution for a single species within known range limits at 60-m cell resolution (Gotthardt et al. 2014). Models were generated through a combination of deductive and inductive modeling techniques using the [LandFire vegetation map](#)¹ as a base and have been statistically assessed for accuracy and peer-reviewed. Although AKGAP models were available for all Terrestrial Fine-filter CEs, these models were developed to depict species' distributions across their full range in Alaska, not specifically within the CYR study area. To assess the sensitivity of the AKGAP models within the CYR study area, we compiled existing occurrence data for each CE to perform an accuracy assessment for each model. We overlaid occurrence records within the CYR study area on each AKGAP model and calculated the proportion of occurrence points correctly classified as occurring within potential habitat. The CEs with acceptable model sensitivity (> 75%) were the American beaver and Swainson's thrush (Table H-3). However, after reviewing the spatial distribution of the Swainson's thrush AKGAP model, we decided that, while it had relatively high sensitivity (86%), large areas of Swainson's thrush habitat and range were not represented. We, therefore, retained the American beaver AKGAP model but developed new distribution models specific to the CYR study area for the remaining species, with the exception of trumpeter swan.

Table H-3. Model sensitivity results for CE-specific AKGAP distribution models within the CYR study area.

Terrestrial Fine-filter CE	No. Assessment Points	Model Sensitivity
Caribou	N/A	N/A
American beaver	501	76%
Dall sheep	334147	28%
Snowshoe hare	310	65%
Golden eagle	185	7%
Swainson's thrush	887	86%
Trumpeter swan	1366	44%

Trumpeter Swan

For trumpeter swan, we compared the AKGAP model to small and large lake distributions available from the USGS [National Hydrography Dataset](#) (NHD)² and wetland distributions delineated in the [Vegetation Map of Northern, Western, and Interior Alaska](#).³ Trumpeter swan habitat identified in these two datasets aligned well with the AKGAP model and contributed no new information to the current habitat model. However, we did notice that the match between occurrence point locations and habitat location seemed to be slightly misaligned. This may be due to inaccuracy of GPS occurrence points and/or inaccuracies in the exact location of wetlands/waterbodies in the landcover map. In general, the distribution model provides a good

¹ See <http://www.landfire.gov/>

² See <http://nhd.usgs.gov/data.html>

³ See <http://accs.uaa.alaska.edu/vegetation-ecology/vegetation-map-northern-western-and-interior-alaska/>

representation of general habitat use, but modeled distribution is likely underrepresenting actual distribution.

Random Forest Habitat Distribution Models

For Dall sheep, Snowshoe hare, Golden eagle and Swainson's thrush (Terrestrial Fine-filter CEs that had AKGAP potential habitat distribution models with relatively low sensitivity; < 75%), we modeled species habitat within the CYR study area using a random forest approach. An advantage of machine learning techniques in modeling species distributions is the ability to explore potential non-linear or non-intuitive interactions between species and environmental factors and generate resulting predictions (Evans et al. 2011). Random forest is a collection of non-parametric, weak learning trees that converge on an optimal solution (Breiman et al. 2001).

Presence points were generated as random subsets of available occurrence points from the USGS BISON database and the AKGAP database. Points within 5 to 10 km of one another were excluded from the random subset with the exact exclusion distance depending on the resulting number of selected occurrence points. For Dall sheep, an additional random subset of presence points was selected from National Park Service (NPS) telemetry data. Presence points could not be selected for a range of years to match predictor climate variables because too few points were available for each species for a single decade. Absence data were not available in the BISON or AKGAP databases.

Random Forest requires absence data in addition to presence data. Pseudo-absences were generated by selecting a stratified random point distribution from an area of potential absence. The density of absences approximately reflected the density of presences on the landscape. Area of potential absence was determined by comparing presence points to the Vegetation Map for Northern, Western, and Interior Alaska. The landcover classes with the greatest number of corresponding occurrences were removed from vegetation dataset until enough landcover classes had been removed to account for approximately 50% of all presences. The 50% threshold prevented forcing artificial importance onto vegetation as a predictive environmental factor. The remaining vegetation classes were resampled to a lower resolution and converted to simplified polygons from which pseudo-absences were drawn.

Unbalanced samples in Random Forest models introduce bias when the minority class has much less representation in the sample dataset than the majority class (Kubat and Matwin 1997, Drummond and Holte 2003). Biased classification accuracy is introduced as the probability of drawing the minority class per bootstrap becomes low. Highly unbalanced samples, therefore, lead to unreliable classification accuracy (Evans et al. 2011). A 1:1 sample ratio can also become problematic because of the potential to overfit the model in data structures where the minority class has little variation (Evans, pers. comm.). One technique to mitigate sample bias is to down-sample the majority class (Evans et al. 2011). Although not ideal when using true absences because of the risk of adding bias to the spatial estimate (Evans, pers. comm.), it is also possible to mitigate sample bias by oversampling the minority class with the addition of synthetic data (Chawla et al. 2002). Because our entire minority class consisted of synthetic data and because we had relatively low numbers of presences (the majority class) for all target species, we oversampled the minority class by generating twice as many pseudo-absences as presences, resulting in a 2:1 sample balance.

We selected a suite of 24 predictor raster datasets with 21 datasets representing abiotic environmental factors (topography, hydrography, and climate averages for the 2010s decade) plus three datasets representing biotic environmental factors (vegetation class, distance from forest, and distance from low or tall shrub). Topographic variables included or were derived from the USGS National Elevation Dataset 2 Arc-second Digital Elevation Model because that was the only available resolution of elevation data providing continuous coverage over the study area. When converted to a projected coordinate system, the 2 Arc-second resolution was resampled to a 60-m grid, which is approximately equivalent to 2 Arc-second within the study area. An additional topographic predictor dataset was generated by calculating distance from floodplains. Hydrographic predictor variables included distance from large streams and rivers (stream orders 3-9), distance from small streams (stream orders 1 and 2), distance from large lakes (area > 0.1 sq km), and distance from small lakes (area < 0.1 sq km). Climate data included seasonal temperature and precipitation, snow day fraction for shoulder months of May and September, and date of thaw. Additional climate variables were considered, but were removed as model inputs because they were multicollinear. Multivariate redundant variables were removed using qr matrix decomposition following methods implemented in the R package *rfUtilities* by Jeffrey Evans with a threshold of 0.5 and a parsimony rule to retain the smallest number of non-redundant metrics (see Murphy et al. 2010 for further details).

Input presences and pseudo-absences and predictor datasets were pre-processed in ArcGIS 10.3.1 and passed via python as inputs into the random forest implementation in R (Breiman 2001, Liaw and Wiener 2002). A subset of the 24 predictor datasets was selected by following methods implemented in the R package *rfUtilities* by Jeffrey Evans: random forest assigns importance (*I*) to variables based on the number of times each variable reduces mean squared error. An initial random forest model run calculated *I* for all variables, and a model improvement ratio (*MIR*) was calculated per variable (I/I_{max}). Progressive random forest models were run for iterations of variables subset from the initial run based on *MIR* thresholds at intervals of 0.05 from 0.05 to 1. A selected variable set was optimized for fewest retained metrics, lowest model mean squared error, and maximized percentage of variation explained (see Murphy et al. 2010 for further details). Random forest was run with the selected variable set and 5,000 bootstraps to obtain a model kappa. This process was repeated 100 times to ensure that all possible optimized variable sets were considered in the selection of a final model.

The three resulting random forest models with the highest kappa values were cross-validated with 1,000 permutations and 10% of data withheld per permutation. The model with the highest mean cross-validation kappa was selected as the final model, and a potential habitat distribution raster was predicted using the final model and selected predictor datasets as inputs. The initial prediction output was a continuous dataset of values between 0 and 1. Although the continuous dataset is a useful product for some applications and better represents the natural variability in habitat quality, a presence-absence distribution is much easier to interpret, standardized between models, more applicable to management considerations, and better suited for comparison with changing environmental and anthropogenic factors. Continuous potential habitat datasets were converted to presence-absence by identifying the lowest probability threshold that minimized the absolute value of the difference between sensitivity and specificity, a technique that has been

shown to perform better than other common methods, especially compared to the a priori assumption of 0.5 as a threshold (Liu et al. 2005, Jiménez-Valverde and Lobo 2007).

The resulting distributions represented potential habitat distribution: the distribution that the species could have in the absence of historical, biotic, and other restrictive factors not considered in the model. Distribution models for Swainson's thrush, golden eagle, and snowshoe hare were retained as potential habitat. Dall sheep distribution was converted to realized habitat, the actual occupied habitat (Jiménez-Valverde 2012), by extracting potential habitat to a manually modified version of Dall sheep annual range from ADF&G.

Dall Sheep

The potential habitat distribution predicted using random forest performed well when cross-validated against subsets of the training data. Model kappa was 0.795 and area under curve (AUC) was 0.960. Kappa values greater than 0.6 indicate good model performance (Manel et al. 2001). Because the threshold for conversion to presence-absence was derived from minimizing the absolute value of the difference between sensitivity and specificity, the sensitivity and specificity of the model compared to the training data are both 100%. Not enough data were available to perform assessments of kappa, AUC, sensitivity, and specificity independent from the training data beyond cross-validation.

Thirteen variables out of 24 were selected into the final random forest model, indicating that, of the variables tested, this subset had the strongest explanatory power for the Dall sheep occurrences: **a.) Climate:** date of thaw, spring precipitation, summer precipitation, winter precipitation, May snow day fraction, September snow day fraction, spring temperature, and summer warmth index; **b.) Topographic:** elevation, roughness, slope, and wetness; **c.) Hydrographic:** none; and **d.) Biotic:** distance from forest. Of these, slope, roughness, spring precipitation, and summer warmth index stood out as the most important variables, each having $I \geq 0.6$.

Statistics for the realized habitat distribution were not calculated but should be comparable to the potential habitat distribution. The realized habitat distribution likely has higher specificity than the potential habitat distribution, but does not show potential but unoccupied habitat locations.

Snowshoe Hare

The potential habitat distribution predicted using random forest performed well when cross-validated against subsets of the training data. Model kappa was 0.603 and area under curve (AUC) was 0.883. Kappa values greater than 0.6 indicate good model performance (Manel et al. 2001). Because the threshold for conversion to presence-absence was derived from minimizing the absolute value of the difference between sensitivity and specificity, the sensitivity and specificity of the model compared to the training data are both 100%. Not enough data were available to perform assessments of kappa, AUC, sensitivity, and specificity independent from the training data beyond cross-validation.

Nine variables out of 24 were selected into the final random forest model, indicating that, of the variables tested, this subset had the strongest explanatory power for the snowshoe hare occurrences: **a.) Climate:** date of thaw, spring temperature, winter precipitation, May snow day fraction, and September snow day fraction; **b.) Topographic:** elevation and distance from floodplain; **c.) Hydrographic:** none; and **d.) Biotic:** vegetation and distance from forest. Of these, date of thaw, elevation, distance from forest, and September snow day fraction stood out as the

most important variables, each having $I \geq 0.8$. Despite being selected for the final model, vegetation had very low relative variable importance (I/I_{max}).

Golden Eagle

The potential habitat distribution predicted using random forest performed well when cross-validated against subsets of the training data. Model kappa was 0.646 and area under curve (AUC) was 0.907. Kappa values greater than 0.6 indicate good model performance (Manel et al. 2001). Because the threshold for conversion to presence-absence was derived from minimizing the absolute value of the difference between sensitivity and specificity, the sensitivity and specificity of the model compared to the training data are both 100%. Not enough data were available to perform assessments of kappa, AUC, sensitivity, and specificity independent from the training data beyond cross-validation.

Fourteen variables out of 24 were selected into the final random forest model, indicating that, of the variables tested, this subset had the strongest explanatory power for the golden eagle occurrences: **a.) Climate:** date of thaw, summer precipitation, winter precipitation, May snow day fraction, September snow day fraction, spring temperature, winter temperature, and summer warmth index; **b.) Topographic:** elevation and distance from floodplain; **c.) Hydrographic:** distance from rivers; and **d.) Biotic:** vegetation, distance from forest, and distance from low or tall shrub. Of these, distance from floodplain and distance from forest stood out as the two most important variables, each having $I \geq 0.8$ and more than twice the variable importance of the third most important variable. Despite being selected for the final model, vegetation had very low relative variable importance (I/I_{max}).

Swainson's Thrush

The potential habitat distribution predicted using random forest performed well when cross-validated against subsets of the training data. Model kappa was 0.615 and area under curve (AUC) was 0.894. Kappa values greater than 0.6 indicate good model performance (Manel et al. 2001). Because the threshold for conversion to presence-absence was derived from minimizing the absolute value of the difference between sensitivity and specificity, the sensitivity and specificity of the model compared to the training data are both 100%. Not enough data were available to perform assessments of kappa, AUC, sensitivity, and specificity independent from the training data beyond cross-validation.

Nine variables out of 24 were selected into the final random forest model, indicating that, of the variables tested, this subset had the strongest explanatory power for the Swainson's thrush occurrences: **a.) Climate:** date of thaw, May snow day fraction, September snow day fraction, spring temperature, and summer warmth index; **b.) Topographic:** elevation and distance from floodplain; **c.) Hydrographic:** none; and **d.) Biotic:** vegetation and distance from forest. Of these, May and September snow day fraction had the two highest relative variable importances (I/I_{max}), but only marginally.

2.2 Conceptual Models

The CE \times CA assessment was aided by the development of CE-specific conceptual models. Conceptual models were developed for each Coarse- and Fine-filter CE and are essentially "stressor" models, which depict the effects that environmental stress (i.e., CAs) impose on key ecological components. The CE-specific conceptual models were used to identify indicators and metrics with high ecological and management relevance for use in the REA, which helped guide

the evaluation of potential responses to perceived impacts (Noon et al. 2003, Tierney et al. 2009). The CE-specific conceptual models represent the state of knowledge between the CE, CAs, and other resources. Conceptual models are based on extensive literature review and describe the relationship between the various CAs and natural drivers in both tabular and graphical formats. Conceptual models for the Terrestrial Fine-filter CEs are presented within the individual CE subsections.

2.3 Attributes and Indicators

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

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

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Breeding season length ³⁴	Length of growing season	Breeding is limited by the number of ice-free days (i.e., 145-150 days; Hansen et al. 1971). In years with cold springs, pairs may not breed. Range expansion in Alaska has likely occurred as a result of climate warming (Schmidt et al. 2011).	<145 ice-free days			145-150 ice-free days

Figure H-1. Example and explanation of attributes and indicators for trumpeter swan (*Cygnus buccinator*).

2.4 CE × CA Intersections

The CE × CA assessment was aided by the development of CE-specific conceptual models, attributes and indicators tables, and the availability of relevant spatial datasets. Specific relationships between CEs and CAs identified in the attributes and indicators tables were examined spatially by intersecting the CE-specific distribution model with the associated climatic or anthropogenic dataset. Results are typically extractions of the CA (see Section C. Abiotic Change Agents) within the distribution of the CE. When possible, outputs were reclassified to match specific threshold values identified in the assessment of attributes and indicators.

In many cases, spatial overlays of the CAs on CEs were not specific enough to provide additional information beyond that already specified in the conceptual model. Rather than include maps of all the CE × CA intersections in this report, we limited the graphics to those intersections that provided new information and summarized many of the results for the CE × CA analysis in tables in the core analysis subsection.

For climate variables, temperature and precipitation, we used a threshold of ± 1 standard deviation to identify significant change across CE distributions. This value was calculated as an average of monthly ± 1 standard deviations over the months being considered (e.g., mean summer temperature was an average of the SD ± 1 values derived for June, July and August). These values are listed as footnotes for each associated table.

2.5 Status Assessments

To assess the “status” of each CE, we used a Landscape Condition Model (LCM) developed for the CYR study area (see Section F. Landscape and Ecological Integrity). The LCM is a simple yet robust way to measure the impact of the human footprint on a landscape. We weighted the relative influence of different types of human footprints based on factors such as permanence and nature of the activity. Permanent human modifications were weighted the highest, while temporary uses, such as snow machine trails, received less weight. Intensive land uses (e.g., mining) were weighted higher than less intensive land uses (e.g., hunting/trapping cabins). Weights were summed across the landscape and coalesced into a single surface that represents the extent and intensity of human impacts.

For this assessment, we assumed a linear distance decay function (gradual decrease in impact as distance from human activity/infrastructure increases until a maximum distance is reached at which the impact is negligible). These values were based on extensive meta-analysis of the impacts on many species/habitats/contexts. For Dall sheep, American beaver, snowshoe hare, and Swainson’s thrush, we used the distance decay values set for the general assessment of landscape condition. However, for trumpeter swan, caribou, and golden eagle, we found empirically-derived values in the literature relating to distances associated with impacts, which are summarized in the respective attributes and indicators tables for those CEs. Therefore, we modified the distance decay values to be more representative of the biology and avoidance behaviors of those CEs (Table H-4). We assumed that distance decay values would remain constant across the considered time periods: current (2010), near-term future (2025), and long-term future (2060).

Table H-4. List of human modification variables used in the Landscape Condition Model (LCM) for historic (H), current (C), near-term future (NF) and long-term future (LF) development scenarios. Decay scores marked with an asterisk (*) are modified from the original LCM values based on additional information from the literature. Standard LCM values were used to assess status of Dall sheep, American beaver, snowshoe hare, and Swainson's thrush.

Scenario	Category	Theme	Distance Decay (m)			
			Landscape Condition Model	Trumpeter Swan	Caribou	Golden Eagle
H	Alternative Transportation	Forestry	200	200	200	200
H	Alternative Transportation	Historical Trail	250	250	250	250
H	Alternative Transportation	Historical Trail-Primary Roads	250	250	250	250
H	Alternative Transportation	Historical Trail-rails, Spur Roads	250	250	250	250
H	Mining	Mining	500	500	500	500
C	Agriculture	Agriculture	200	200	200	200
C	Invasive Plants	AKEPIC	200	200	200	200
C	Development Area	Community (Medium Development)	1000	10000*	1000	3000*
C	Contaminated Sites	Contaminated Sites	100	100	100	100
C	Alternative Transportation	Forestry	200	200	200	200
C	Contaminated Sites	Formerly Used Defense Sites	100	100	100	100
C	Development Area	High Development	2000	10000*	2000	3000*
C	Highways	Highway (Dalton Highway included)	5000	60*	2000*	5000
C	Industrial Lines	Industrial Lines	500	500	500	500
C	Development Area	Low Development	1000	10000*	1000	3000*
C	Contaminated Sites	Material Sites	100	100	100	100
C	Development Area	Medium Development	1000	10000*	1000	3000*
C	Mining	Mining	1500	1500	1500	1500
C	Alternative Transportation	Northern Railline Expansion	500	500	500	500
C	Alternative Transportation	Northern Railline Expansion Bridge	500	500	500	500
C	Alternative Transportation	Rail Road	500	500	500	500
C	Secondary Roads	Secondary Road	500	60*	1000*	3000*
C	Alternative Transportation	Trail	500	500	500	500

Section H. Terrestrial Fine-filter Conservation Elements

Scenario	Category	Theme	Distance Decay (m)			
			Landscape Condition Model	Trumpeter Swan	Caribou	Golden Eagle
C	Alternative Transportation	Yukon River (Alternative Transportation)	500	500	500	500
NF	Mining	Mining	1500	1500	1500	1500
NF	Alternative Transportation	Northern Railline Expansion	500	500	500	500
NF, LF	Alternative Transportation	Forestry	200	200	200	200
NF, LF	Industrial Lines	Future Pipeline	500	500	500	500
NF, LF	Contaminated Sites	Material Sites	100	100	100	100
NF, LF	Development Area	Population Projection	1000	10000*	1000	3000*
NF, LF	Alternative Transportation	Trails	500	60*	500	500
LF	Mining	Mining	1500	1500	1500	1500
LF	Secondary Roads	Nome Road	500	60*	1000*	3000*
LF	Alternative Transportation	Northern Railline Expansion	500	500	500	500
LF	Alternative Transportation	Northern Railline Expansion Access Roads	500	500	500	500
LF	Secondary Roads	Road to Umiat	500	60*	1000*	3000*
LF	Secondary Roads	Secondary Roads (Ambler Route)	500	60*	1000	3000*

2.6 Relative Management Responsibility

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

2.7 Management Questions

Six Management Questions (MQs) are addressed in this section. MQ L1 and N3 are addressed within the analysis of the appropriate CE. Management Question AE1, T1, X1, and X2 are addressed at the end of this section.

MQ AE1: Where is primary waterfowl (black scoter or trumpeter swan) habitat located?

MQ L1: What are caribou seasonal distribution and movement patterns?

MQ N3: How might sheep distribution shift in relation to climate change?

MQ T1: The introduction of free-ranging reindeer herds to this region has been proposed. What areas would be most likely to biologically support a reindeer herd?

MQ X1: What have the past cumulative impacts of road construction and mineral extraction been on terrestrial CE habitat and population dynamics?

MQ X2: How might future road construction and mineral extraction infrastructure (e.g., both temporary and permanent roads [Umiat, Ambler, Stevens Village], pads, pipeline, both permanent and temporary) affect species habitat, distribution, movements and population dynamics (especially caribou, moose, sheep)?

2.8 Summary Tables

To summarize the results of the CE × CA assessment for each species, a simple table was developed to indicate the projected change of relevant CAs for each time period in the CYR study area, and describe the general effect of these changes on a CE (Table H-5). In the ‘Near-term’ and ‘Long-term change’ columns, the grey boxes indicate minimal to no change, the orange boxes indicate an increase in the CA (e.g., increased length of growing season, increased winter precipitation) and the blue boxes indicate a decrease in the CA (e.g., decreased landscape condition, decreased winter precipitation) as determined by the spatial analysis results. The ‘Effect on CE’ column attempts to generalize whether the change observed in the near-term and long-term will have a positive or negative effect on the CE as determined by the literature (e.g., an increase in winter precipitation has a negative impact on juvenile survival for Caribou). The orange and blue boxes indicate a positive or negative effect, and the green box indicates a mixed effect with the potential for both positive and negative effects on the CE.

Table H-5. Sample table summarizing the anticipated changes and effects of relevant Change Agents (CAs) on a Terrestrial Fine-Filter Conservation Element (CE) in the CYR study area.

Indicator	Near-term Change	Long-term Change	Effect on CE in CYR Study Area	Impact
Length of growing season	+	+	+/-	Forage and insect abundance and phenology
Date of thaw	No change	+	+/-	Forage and insect abundance and phenology
Summer temperature	No change	+	+/-	Forage and insect abundance and phenology
Winter precipitation	+	+	-	Juvenile survival
Rain-on-snow events: Snow day fraction	Not assessed	+	-	Forage accessibility
Fire	Unknown	+	+/-	Winter forage availability
Landscape condition	Minimal change	-	-	Body condition/Survival
Invasive species	N/A	N/A	None	None

These summary tables are meant to be a tool to look at the general trends for various CAs across CE habitat in the CYR study area. The text descriptions associated with each analyses in the results section provide a further in-depth discussion about the limitations of each analyses. In addition, the suggested “effect on CE” is limited to our interpretation of the literature in conjunction with the CA changes predicted on the landscape. We do not describe all of the CAs that will affect each CE and understand that the CAs do not affect each CE independently.

2.9 Literature Cited

- Berteaux, D. 2013. Effects of climate change on the Canadian Arctic Wildlife. ArcticNet Annual Research Compendium (2012-2013).
- Boggs, K., T. V. Boucher, and T. T. Kuo. 2014. Vegetation map for Northern, Western, and Interior Alaska. Alaska Natural Heritage Program, University of Alaska Anchorage. Available: <http://accs.uaa.alaska.edu/vegetation-ecology/vegetation-map-northern-western-and-interior-alaska/>
- Breiman, L. 2001. Random forests. *Machine Learning* 45:5-32.
- Chawla, N., K. Bowyer, L. Hall, and W. Kegelmeyer. 2002. SMOTE: Synthetic Minority Over-sampling Technique. *Journal of Artificial Intelligence Research* 16:321-357.
- Drummond, C., and R. C. Holte. 2003. C4.5, class imbalance, and cost sensitivity: why under-sampling beats over-sampling. In *Proceedings of the ICML-2003 Workshop: Learning with Imbalanced Data Sets II*.
- Evans, J. Personal communication. Senior Landscape Ecologist. Conservation Lands, Global Science Team. The Nature Conservancy, Laramie, Wyoming.
- Evans, J., M. Murphy, Z. Holden, and S. Cushman. 2011. Modeling species distribution and change using random forest. Pages 139-159 in C. Drew, Y. Wiersma, and F. Huettmann, eds. *Predictive Species and Habitat Modeling in Landscape Ecology*. Springer, New York.
- Gotthardt, T., S. Pyare, F. Huettmann, K. Walton, M. Spathelf, K. Nesvacil, A. Baltensperger, G. Humphries, and T. L. Fields. 2014. Predicting the range and distribution of terrestrial vertebrate species in Alaska draft report. The Alaska Gap Analysis Project, University of Alaska.
- Jiménez-Valverde, A. 2012. Insights into the area under the receiver operating characteristic curve (AUC) as a discrimination measure in species distribution modeling. *Global Ecology and Biogeography* 21:498-507.
- Jiménez-Valverde, A., and J. Lobo. 2007. Threshold criteria for conversion of probability of species presence to either-or presence-absence. *Acta Oecologica* 31:361-369.
- Kubat, M., and S. Matwin. 1997. Addressing the curse of imbalanced data sets: one-sided sampling. In *Proceedings of the 14th International conference on Machine Learning* 179-186.
- Liaw, A., and M. Wiener. 2002. Classification and regression by randomForest. *R News* 2:18-22.
- Liu, C., P. Berry, T. Dawson, and R. Pearson. 2005. Selecting thresholds of occurrence in the prediction of species distributions. *Ecography* 28:385-393.
- Manel, S., H. Williams, and S. Ormerod. 2001. Evaluating presence-absence models in ecology: the need to account for prevalence. *Journal of Applied Ecology* 38:921-931.
- Marcot, B. G., M. T. Jorgenson, J. P. Lawler, C. M. Handel, and A. R. DeGange. 2015. Projected changes in wildlife habitats in Arctic natural areas of northwest Alaska. *Climatic Change* 130:145-154.
- Murphy, M., J. Evans, and A. Storfer. 2010. Quantifying Bufo boreas connectivity in Yellowstone National Park with landscape genetics. *Ecology* 91:252-261.
- Noon, B. R., D. D. Murphy, S. R. Beissinger, M. L. Shaffer, and D. Dellasala. 2003. Conservation planning for U.S. National forests: conducting comprehensive biodiversity assessments. *BioScience* 53:2-5.
- Tierney, G. L., D. Faber-Langendoen, B. R. Mitchell, W. G. Shriver, and J. P. Gibbs. 2009. Monitoring and evaluating the ecological integrity of forest ecosystems. *Frontiers in Ecology and the Environment* 7:308-316.
- United States Geological Survey (USGS). National hydrography dataset. Available: <http://nhd.usgs.gov/data.html>

3. Core Analysis–Summary Results

In the near-term future (2020s), little measurable change can be expected for many climate variables within habitats used by Terrestrial Fine-filter CEs. Larger responses, however, are predicted by the long-term future (2060s). A summary of predicted changes for Abiotic CAs within the Terrestrial Fine-filter CE distributions are summarized below. More details on the expected effects of these changes are found in the individual Terrestrial Fine-filter CE subsections.

3.1 Annual Temperature

Warming trends are expected across all Terrestrial Fine-filter CE habitats in the CYR study area by the 2060s, with the greatest increases in temperature occurring during the winter months (Table H-6). Warming temperatures in the near-term future (2020s) are not expected to fall outside the bounds of current (2010s) temperature ranges.

Of the seven Terrestrial Fine-filter CEs, the four mammal species are year-round residents, while the three avian species are migratory and generally only present in the CYR study area during the spring and summer seasons. All seven CEs will experience significant increases in spring and summer temperature by the 2060s (Table H-6). Temperature increases are expected to influence habitat availability, forage quality, and reproductive success for each CE, and are discussed under the individual Terrestrial Fine-filter CE subsections.

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Table H-6. The proportion of each Terrestrial Fine-filter CE distribution that is predicted to experience a significant increase in spring, summer, and winter temperature in the CYR study area from the current (2010s) to the near-term future (2020s) and long-term future (2060s).

Terrestrial Fine-filter CE		Δ Spring Temperature (A-M)			Δ Summer Temperature (J-J-A)			Δ Winter Temperature (D-J-F)		
		No change	Significant Increase ¹	RANGE (°C)	No change	Significant Increase ²	RANGE (°C)	No change	Significant Increase ³	RANGE (°C)
American Beaver	Near-Term	100%	0%	-0.15 to 0.45	100%	0%	0.00 to 0.60	100%	0%	-0.30 to 0.80
	Long-Term	0%	100%	0.75 to 1.75	5%	95%	1.00 to 1.50	0%	100%	2.30 to 3.90
Trumpeter Swan	Near-Term	100%	0%	-0.15 to 0.40	100%	0%	0.00 to 0.50	100%	0%	-0.30 to 0.80
	Long-Term	0%	100%	0.75 to 1.60	3%	97%	1.00 to 1.50	0%	100%	2.30 to 3.80
Caribou (All Herds)	Near-Term	100%	0%	-0.15 to 0.45	100%	0%	0.00 to 0.60	100%	0%	-0.30 to 0.80
	Long-Term	0%	100%	0.75 to 1.75	11%	89%	0.90 to 1.50	0%	100%	2.30 to 3.90
Dall Sheep	Near-Term	100%	0%	-0.15 to 0.45	100%	0%	0.00 to 0.60	100%	0%	-0.20 to 0.80
	Long-Term	0%	100%	0.75 to 1.75	22%	78%	0.90 to 1.40	0%	100%	2.50 to 3.80
Golden Eagle	Near-Term	100%	0%	-0.15 to 0.45	100%	0%	0.00 to 0.60	100%	0%	-0.30 to 0.80
	Long-Term	0%	100%	0.75 to 1.75	14%	86%	0.90 to 1.50	0%	100%	2.30 to 3.90
Swainson's Thrush	Near-Term	100%	0%	-0.15 to 0.45	100%	0%	0.00 to 0.60	100%	0%	-0.30 to 0.80
	Long-Term	0%	100%	0.75 to 1.75	3%	97%	1.00 to 1.50	0%	100%	2.30 to 3.90
Snowshoe Hare	Near-Term	100%	0%	-0.15 to 0.45	100%	0%	0.00 to 0.60	100%	0%	-0.30 to 0.80
	Long-Term	0%	100%	0.75 to 1.70	3%	97%	1.00 to 1.50	0%	100%	2.30 to 3.90

¹Based on a mean standard deviation of 1 (near-term: ±1.15 °C; long-term: ±0.7 °C)

²Based on a mean standard deviation of 1 (near-term: ±0.6 °C; long-term: ±1.17 °C)

³Based on a mean standard deviation of 1 (near-term: ±2.17 °C; long-term: ±1.7 °C)

3.2 Growing Season Length

Growing season length (estimated as the number of days between date of thaw and date of freeze; see Section C. Abiotic Change Agents) is expected to increase by both the near-term and long-term future (Table H-7). Average growing season length is expected to increase by the long-term future by 6–52 days across Terrestrial Fine-filter CE distributions. These changes are expected to have a positive effect on caribou, Dall sheep, golden eagle, Swainson's thrush, and snowshoe hare through increased forage availability and reproductive success. Results are discussed further in the individual Terrestrial Fine-filter CE subsections.

Table H-7. The proportion of each Terrestrial Fine-filter CE distribution that is predicted to experience an increase in length of growing season from the current (2010s) to the near-term future (2020s) and long-term future (2060s).

Terrestrial Fine-filter CE		Δ Length of Growing Season				
		No Change	0–6 days	7–14 days	> 14 days	Range (days)
American Beaver	Near-Term	55%	45%	0%	0%	-3 to 5
	Long-Term	0%	0%	100%	0%	6 to 16
Trumpeter Swan	Near-Term	57%	43%	0%	0%	-2 to 4
	Long-Term	0%	0%	100%	0%	6 to 15
Caribou (All Herds)	Near-Term	35%	65%	0%	0%	-3 to 5
	Long-Term	0%	0%	100%	0%	6 to 32
Dall Sheep	Near-Term	21%	79%	0%	0%	-3 to 10
	Long-Term	0%	0%	99%	1%	6 to 48
Golden Eagle	Near-Term	32%	68%	0%	0%	-3 to 15
	Long-Term	0%	0%	100%	0%	6 to 52
Swainson's Thrush	Near-Term	61%	39%	0%	0%	-3 to 4
	Long-Term	0%	0%	100%	0%	6 to 16
Snowshoe Hare	Near-Term	61%	39%	0%	0%	-3 to 5
	Long-Term	0%	0%	100%	0%	6 to 17

3.3 Precipitation

We evaluated the relationship between Terrestrial Fine-filter CEs and changes in mean annual precipitation, spring (April, May) precipitation, and winter (December, January, and February) precipitation. Changes in spring precipitation are likely to have large effects on caribou, American beaver, and trumpeter swan because their movement, foraging, and reproductive patterns are closely linked to precipitation (see individual CE subsections below). Increases in spring precipitation could have potential negative influences on reproduction and survival of many wildlife species (see individual CE subsections). In addition, winter precipitation can be used as a proxy for snow depth, which can affect forage accessibility and movements of caribou and snowshoe hare. The expected effects of changes in precipitation are detailed in the individual Terrestrial Fine-filter CE subsections.

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Table H-8. The proportion of each Terrestrial Fine-filter CE distribution that is predicted to experience a significant increase in spring, winter, and annual precipitation in the CYR study area from the current (2010s) to the near-term future (2020s) and long-term future (2060s).

Terrestrial Fine-filter CE		Δ Spring Precipitation (A-M)			Δ Winter Precipitation (D-J-F)			Δ Annual Precipitation		
		No Change	Significant Increase ¹	Range (mm)	No Change	Significant Increase ²	Range (mm)	No Change	Significant Increase ³	Range (mm)
American Beaver	Near-term	100%	0%	-7 to 2	2%	98%	1 to 21	1%	99%	-1 to 50
	Long-term	34%	66%	0 to 13	14%	86%	2 to 31	0%	100%	17 to 141
Trumpeter Swan	Near-term	100%	0%	-7 to 2	3%	97%	1 to 33	1%	99%	-3 to 49
	Long-term	52%	48%	0 to 12	17%	91%	2 to 34	0%	100%	17 to 157
Caribou (All Herds)	Near-term	100%	0%	-7 to 2	2%	98%	1 to 43	3%	97%	-7 to 61
	Long-term	17%	83%	0 to 15	17%	83%	2 to 44	0%	100%	17 to 198
Dall Sheep	Near-term	100%	0%	-9 to 2	2%	98%	1 to 51	7%	93%	-7 to 73
	Long-term	3%	97%	1 to 15	3%	97%	3 to 53	0%	100%	17 to 229
Golden Eagle	Near-term	100%	0%	-9 to 2	2%	98%	1 to 51	3%	97%	-7 to 73
	Long-term	18%	82%	0 to 15	10%	90%	2 to 53	0%	100%	17 to 229
Swainson's Thrush	Near-term	100%	0%	-7 to 2	2%	98%	2 to 23	0%	100%	-2 to 44
	Long-term	35%	65%	0 to 13	14%	86%	2 to 31	0%	100%	17 to 128
Snowshoe Hare	Near-term	100%	0%	-7 to 2	2%	98%	1 to 37	1%	99%	-4 to 54
	Long-term	37%	63%	0 to 13	15%	85%	2 to 38	0%	100%	17 to 173

¹Based on a mean standard deviation of 1 (near: ±2.55 mm; long: ±3.45 mm)

²Based on a mean standard deviation of 1 (near: ±4.17 mm; long: ±5.17 mm)

³Based on a mean standard deviation of 1 (near: ±5.71 mm; long: ±6.28 mm)

3.4 Species Habitat Status

Most of the CYR study area is considered connected and pristine (i.e., very high landscape condition). Highly impacted areas predicted for the future are primarily associated with the Ambler mining district and new forestry roads around Fairbanks (see Section F. Landscape and Ecological Integrity). When the current distributions of the Terrestrial Fine-filter CEs were compared to current, near-term, and long-term landscape condition, over 86% of habitat for each CE was classified as very high condition for all time frames (Table H-9). Among CEs, golden eagle is predicted to experience the greatest reduction in landscape condition across its habitat, while trumpeter swan is predicted to experience the least; however, trumpeter swan has the lowest current landscape condition throughout its habitat. When applicable, the implications of localized impacts due to development are discussed within the individual Terrestrial Fine-filter CE subsections.

Table H-9. Percent of Terrestrial Fine-filter CE distribution attributed to varying levels of landscape condition in the current, near-term (2025), and long-term (2060) time periods.

Conservation Element	Time Period	Landscape Condition				
		Very Low	Low	Medium	High	Very High
American Beaver	Current	0.9	1.3	1.2	1.9	94.6
	Near-term	0.9	1.3	1.3	2.0	94.5
	Long-term	1.0	1.6	1.7	2.4	93.3
	Change to Long-term	0.1	0.3	0.5	0.5	-1.3
Trumpeter Swan	Current	0.1	0.9	3.4	8.8	86.9
	Near-term	0.1	0.9	3.4	8.8	86.8
	Long-term	0.1	1.0	3.6	8.9	86.4
	Change to Long-term	0	0.1	0.2	0.1	-0.5
Golden Eagle	Current	0.7	1.5	1.3	1.6	94.9
	Near-term	0.7	1.5	1.3	1.7	94.7
	Long-term	1.0	2.1	1.9	2.3	92.7
	Change to Long-term	0.3	0.6	0.6	0.7	-2.2
Caribou (Summer Range)	Current	0.2	0.3	0.3	0.5	98.7
	Near-term	-	-	-	-	-
	Long-term	0.3	0.6	0.8	1.1	97.2
	Change to Long-term	0.1	0.3	0.5	0.6	-1.5
Caribou (Winter Range)	Current	0.2	0.4	0.5	0.7	98.2
	Near-term	-	-	-	-	-
	Long-term	0.3	0.7	0.9	1.2	96.9
	Change to Long-term	0.1	0.3	0.4	0.5	-1.3
Dall Sheep	Current	0.4	0.7	0.8	0.9	97.2
	Near-term	0.4	0.7	0.9	1.0	97.0
	Long-term	0.9	1.0	1.3	1.5	95.4
	Change to Long-term	0.5	0.3	0.5	0.6	-1.8

Conservation Element	Time Period	Landscape Condition				
		Very Low	Low	Medium	High	Very High
Swainson's Thrush	Current	1.1	1.7	1.6	2.2	93.4
	Near-Term	1.1	1.8	1.7	2.3	93.1
	Long-Term	1.3	2.2	2.3	2.9	91.4
	Change to Long-Term	0.2	0.5	0.7	0.7	-2.0
Snowshoe Hare	Current	1.1	1.7	1.5	2.1	93.6
	Near-Term	1.1	1.7	1.6	2.3	93.3
	Long-Term	1.2	2.1	2.1	2.8	91.8
	Change to Long-Term	0.1	0.4	0.6	0.7	-1.8

3.5 Relative Management Responsibility

Federal and state agencies must balance the demands for resource extraction, energy development, recreation, and other human land uses with wildlife management and conservation. Inter-agency collaboration is crucial for effectively managing public lands and their dependent species that range across political boundaries. We used the proportion of each species' distribution falling within each agency's boundary as a measure of the amount of management responsibility.

Species distributions in relation to areas managed both publicly and privately reflect the overall ratio of land ownership within the CYR study area, with the highest percentages of species distributions occurring on USFWS land and State Patent land, respectively (Table H-10, Figure H-2).

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Table H-10. Total area of each Terrestrial Fine-filter CE distribution associated with land ownership in the CYR study area.

Terrestrial Fine-filter CE	BLM (km ²)	USFWS (km ²)	Military (km ²)	NPS (km ²)	Native Patent or IC (km ²)	Native Selected (km ²)	Private (km ²)	State Patent or TA (km ²)	State Selected (km ²)	TOTAL AREA (km ²)
Caribou	42,195	82,247	148	63,967	33,333	6,139	43	65,942	17,395	311,409
Dall sheep	7,929	14,272	35	36,086	2,730	1,182	32	20,164	1,926	84,356
American beaver	13,950	33,933	1,903	13,964	21,430	2,345	121	27,421	5,597	120,664
Snowshoe hare	26,513	59,203	2,940	16,715	37,536	4,299	232	62,592	8,885	218,915
Swainson's Thrush	26,708	52,380	2,907	16,548	36,800	4,657	219	63,356	8,441	212,016
Golden Eagle	21,519	55,255	1,786	57,534	28,680	4,018	153	49,408	10,755	229,108
Trumpeter Swan	743	4,287	81	306	3,740	219	3	1,722	423	11,524
STUDY AREA	48,318	103,004	3,034	66,959	49,510	7,223	238	93,758	20,108	

Section H. Terrestrial Fine-filter Conservation Elements

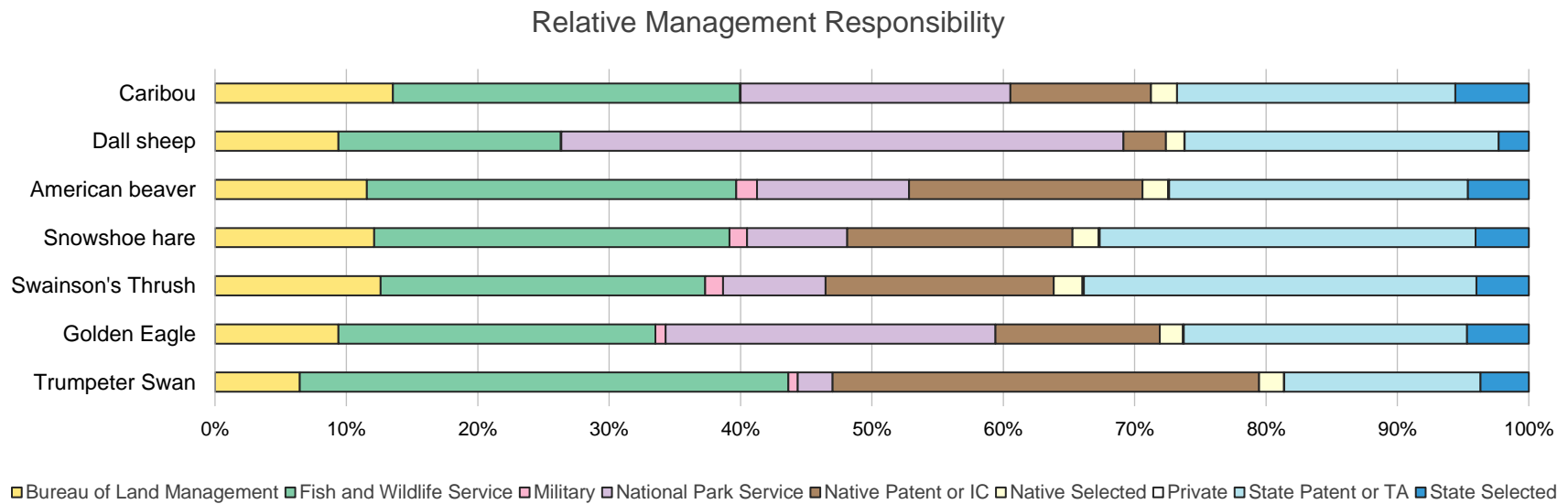


Figure H-2. Percent of Terrestrial Fine-filter CE distribution attributed to each management body in the CYR study area.

4. Caribou (*Rangifer tarandus*)

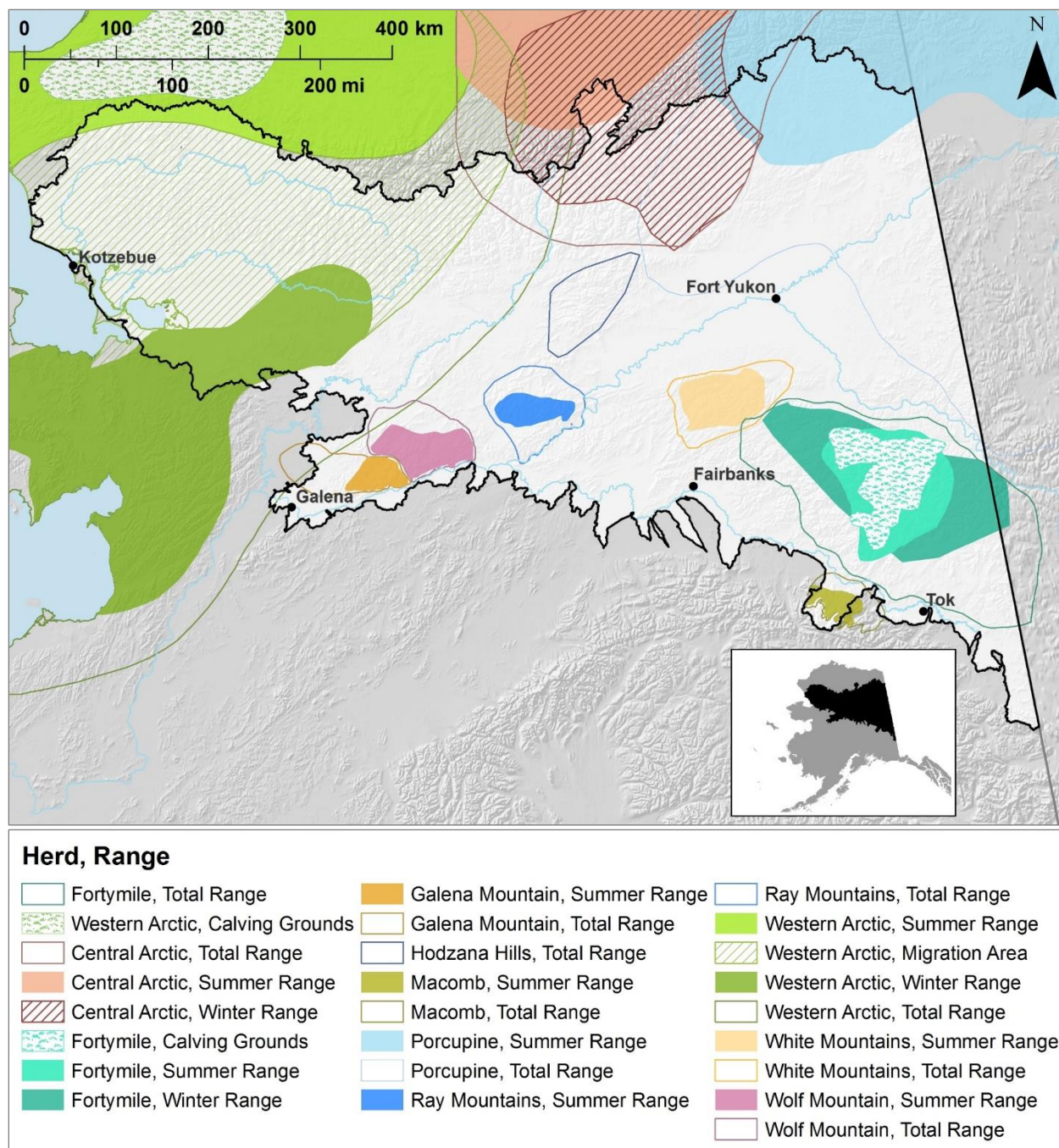


Figure H-3. Seasonal ranges of caribou herds in the CYR study area.

4.1 Introduction

Caribou are circumpolar in their distribution, occurring in Arctic tundra and boreal forest regions in North America and Eurasia (MacDonald and Cook 2009). They are an important prey item to apex predators, including wolves (*Canis lupus*), grizzly (brown) bears (*Ursus arctos*), and golden

eagles (*Aquila chrysaetos*), which primarily feed on calves. Caribou are highly valued by sport and subsistence hunters, providing an important source of food that sustains the health and culture of northern communities (McLennan et al. 2012).

Caribou generally migrate seasonally to access available forage, calving grounds, and insect-free refuges. Caribou calve during late spring and early summer in tundra, mountains, or open areas along the coast. Summer forage includes leaves of willows, sedges, forbs, and mushrooms (ADF&G 2013), which provide energy for reproduction and lactation, body and antler growth, pelage replacement, and replenishment of nutrient stores for the upcoming winter (Boertje 1985, Joly and Klein 2011). Post-calving, caribou typically aggregate into large herds and move away from calving grounds into higher elevation habitats to decrease predation risk and escape from insects. During autumn, caribou move to lower elevations and some herds migrate long distance to access winter forage, which primarily consists of ground-dwelling lichens (ADF&G 2013).

In Alaska, there are 32 recognized herds of which thirteen have ranges that overlap with, or are contained within the CYR study area. A herd is defined by the repeated use of a specific calving ground (ADF&G 2013). In this study, we focus on the ten herds with ranges that are wholly contained within, or occupy large areas of the CYR study: Central Arctic, Fortymile, Galena Mountain, Hodzana, Macomb, Porcupine, Ray Mountains, Western Arctic, White Mountains, and Wolf Mountain herds (Figure H-3).

4.2 Conceptual Model

The conceptual model below (Figure H-4) is based on literature review and describes the relationship between the various CAs and natural drivers for caribou. The boxes and arrows represent the state of knowledge about the caribou and its relationships to each CA. The arrows and red text represent/describe relationships between the CAs, natural drivers, and primary habitat for caribou. The primary CAs selected for this CE include: climate change and human uses such as land use change.

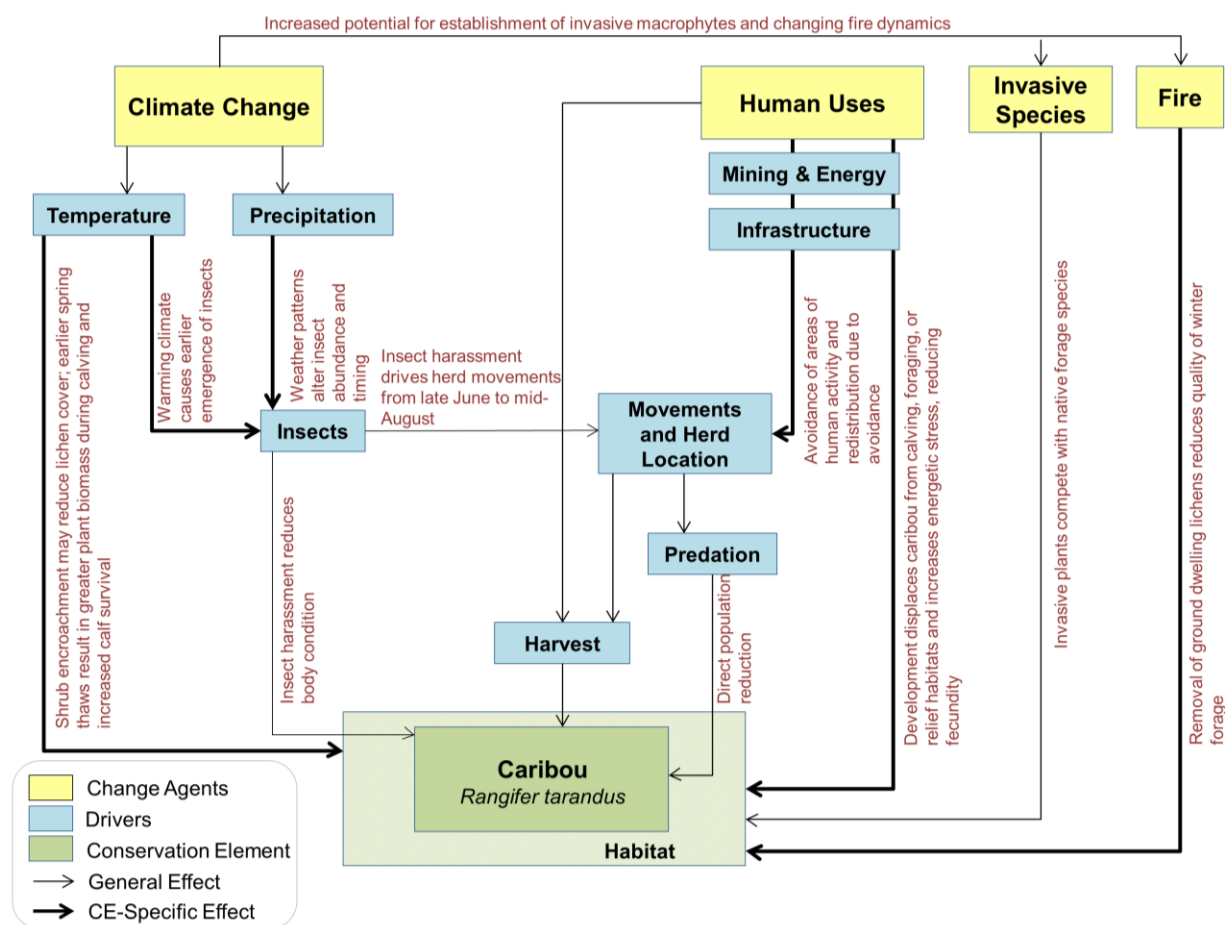


Figure H-4. Conceptual model describing the relationship between important CAs and natural drivers for caribou.

4.3 Attributes and Indicators

Attributes and indicators helped to define the relationships between CEs and CAs and, where possible, the thresholds associated with these relationships. Based on the assessment of available indicators, spatial data used to assess the status of caribou included: length of growing season, date of thaw, mean summer temperature, winter precipitation, and snow day fraction. In addition, we developed a landscape condition model unique to caribou to identify areas of future reduced landscape condition (Table H-11).

Table H-11. Attributes and indicators for the potential effect of various CAs and natural drivers on caribou.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Length of growing season	Number of days between date of spring thaw and date of spring freeze ⁴	Earlier spring thaw and a longer growing season could result in earlier parturition and increased calf survival	Less than average		Average	More than average
	Timing of snow melt	Date of thaw ¹		Earlier than average		Average	Later than average
	Winter weather ice	Snow fraction ⁵	Icing or rain on snow events can harden the snow pack and restrict access to forage	Snow fraction below 80% for more than one winter month (thresholds unclear)	Snow fraction below 80% for one winter month	Snow fraction below 90% for one winter month	Snow fraction over 90% for all winter months

⁴ Based on Post et al. 2003, Sparks and Menzel 2002, Stone et al. 2002, Griffith et al. 2002

⁵ Based on Hansen et al. 2011

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CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter Weather Snow depth	Snow depth/winter precipitation ⁶	Areas with low snow levels provide easy travel and easy access to forage	Above average		Average	Below average
	Insect emergence and abundance	Frost-free days ⁷	Seasonal change in daily availability of arthropods is determined by the number of frost-free days (temp. > 32 °F). Longer growing season length can cause an increase in insect populations and earlier hatches can cause caribou movements to occur earlier in the season.	Below average		Average	Above average
		Mean summer temperature ⁸	Insect abundance (pests) is directly influenced by mean daily temperature. Increased pest-insect abundance (mosquitoes, blackflies, etc.) can cause increased/altered movement of herds.	Below average		Average	Above average
Anthropogenic	Human disturbance	Landscape condition ⁹	During calving, cows and calves avoid roads, even with low traffic use (< 100 vehicles per day), and as a result, are not typically found within one km of the roadway. Proximity of roads to caribou ranges and migration routes increases human access and predation pressure.	LCM = 0.05 on calving grounds			LCM = 1 on calving grounds

⁶ Based on Joly and Klein 2011

⁷ Based on Bolduc et al. 2013

⁸ Based on Downes et al. 1986, Witter et al. 2012, Bolduc et al. 2013

⁹ Based on Cronin et al. 1994

4.4 MQ L1: Caribou Seasonal Distribution and Movement Patterns

MQ L1: What are caribou seasonal distribution and movement patterns?

Annual Range

Caribou herds range throughout most of the CYR study area but vary in range size and seasonal distribution (Figure H-5, Table H-12). There are four herds with ranges wholly contained within the CYR study area: Hodzana Hills, Ray Mountains, White Mountains, and Wolf Mountain herds (Figure H-5, Table H-12). The three largest herd ranges are located in the northern part of the CYR study area: Western Arctic, Central Arctic, and Porcupine herds. These three Arctic herds migrate much farther between summer and winter ranges compared to the smaller, more localized herds. Only 31–34% of the Arctic herd ranges overlap with the CYR study area. Additional herds present in the CYR study area include the Galena Mountain, Macomb, and Fortymile herds.

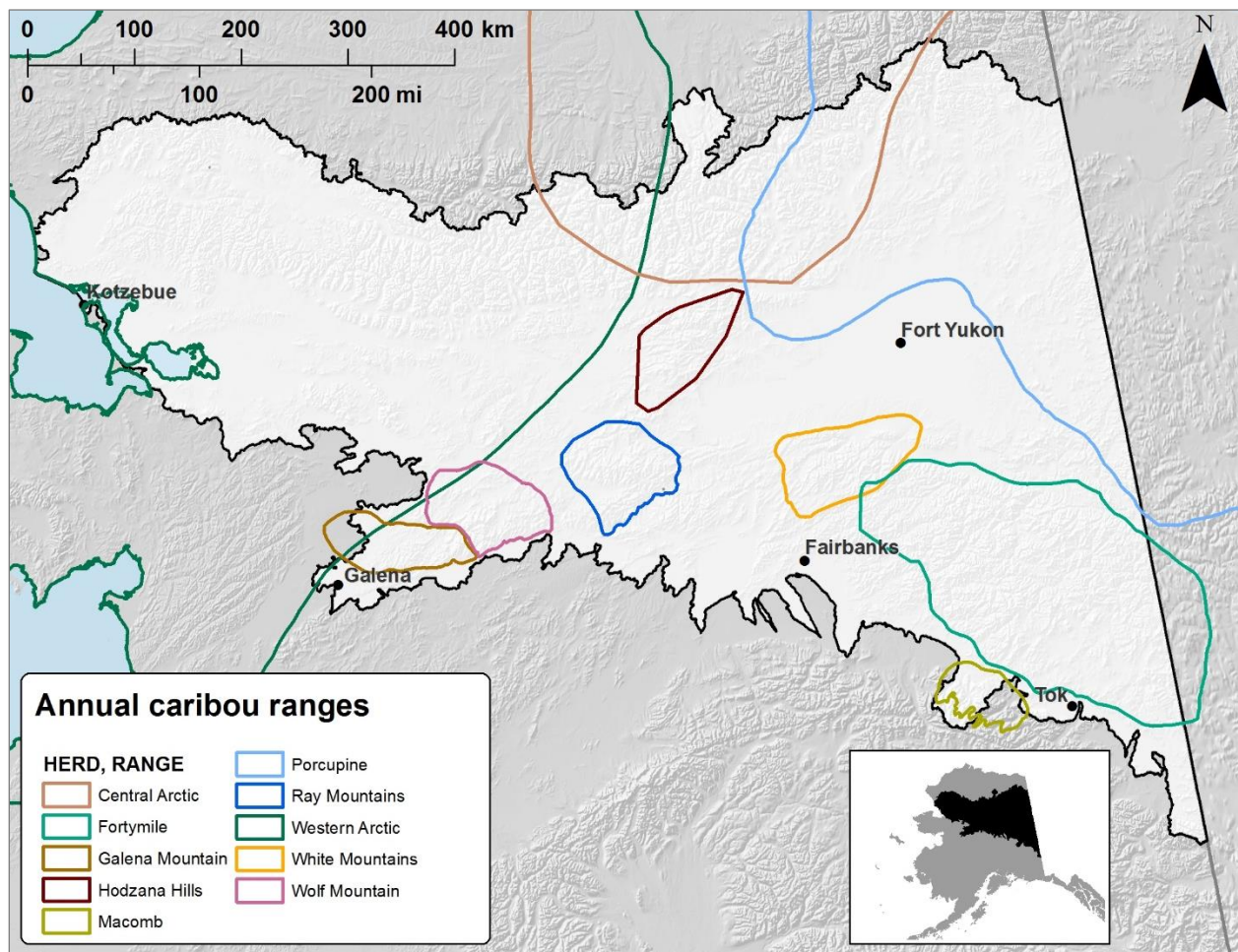


Figure H-5. Annual ranges of caribou herds in the CYR study area.

Table H-12. Population size, total range area, and percent range area of caribou herds in the CYR study area (data obtained from Alaska Department of Fish and Game).

Herd	Herd Size (population)	Herd Range (km ²)		% Range within CYR study area	Population Count/Update (Year)	Population Trend ¹
		Total	Within CYR study area			
Central Arctic	51,000	114,996	35,687	31%	2013	Stable (Increased 1998-2008)
Fortymile	52,000	49,751	44,556	90%	2010	Increasing/ Stable
Galena Mountain	100	5,486	4,362	79%	2009	Declining
Hodzana Hills	780	6,164	6,164	100%	2009	Unknown
Macomb	1,503	3,338	1,927	58%	2013	Unknown
Porcupine	197,000	223,713	74,794	33%	2013	Increasing
Ray Mountains	1,213	7,268	7,268	100%	2011	Stable
Western Arctic	235,000	366,310	123,636	34%	2013	Declining
White Mountains	650	8,094	8,094	100%	2011	Unknown
Wolf Mountain	450	6,695	6,695	100%	2011	Stable

¹Trends inferred from Caribou management reports of survey and inventory activities 2013 and 2015, produced by Alaska Department of Fish and Game.

Central Arctic Herd

The Central Arctic herd ranges on both the south side of the Brooks Range from the Chandalar River valley to the North Fork Koyukuk River and the East Fork Chandalar River, and the north side of the Brooks Range from the Iktillik River to the Canadian border. This herd's range extends to the eastern Arctic coastal plain from just west of the Colville River to the Canadian border (Lenart 2015). Within the CYR study area, this herd is found in the northern region between the Western Arctic and Porcupine herds and is not fully contained within the study area (Figure H-5, Table H-12). An annual kernel density from 2004 to 2014 developed by ADF&G using radio collar data suggests that a much smaller portion of the CYR study area is used as a core range for the herd than the annual range polygon suggests (Figure H-6). The Central Arctic herd occasionally mixes with the Western Arctic, Teshepuk, and Porcupine herds (Lenart 2015).

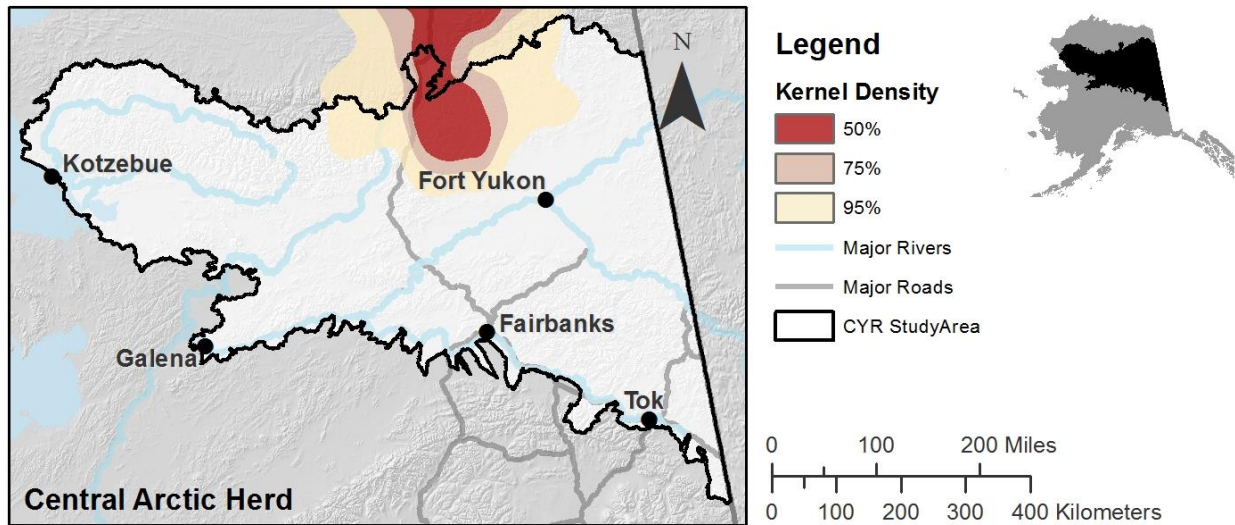


Figure H-6. Annual kernel density of the Central Arctic Herd from 2004 to 2014. Kernel density was generated by ADF&G from telemetry data.

Fortymile herd

The Fortymile herd ranges within portions of the upper Fortymile, Tanana and Yukon River drainages within Alaska and into the Yukon Territory, Canada (Gross 2015). This herd has the third largest range within the CYR study area, and is found in the southeastern portion of the region and is not fully contained in the study area (Figure H-5, Table H-12). Historically, the Fortymile herd was larger in size and ranged farther than it does presently (LeResche 1975, Valkenburg et al. 1994). The Fortymile herd occasionally crosses over into the White Mountain herd range (Young, Jr. 2015).

Galena Mountain herd

The Galena Mountain herd ranges north of the Yukon River in the Kokrines Hills (Pamperin 2015). Within the CYR study area, this herd is found in the southwestern arm of the region, northeast of Galena and west of the Melozitna River (Figure H-5). Majority of the Galena Mountain herd range is within the CYR study area (Table H-12).

Hodzana Hills herd

The Hodzana Hills herd ranges north of the Yukon River in the Hodzana Hills (Pamperin 2015). Its range is wholly contained within the CYR study area (Table H-12) and is located north of the Ray Mountains herd range (Figure H-5). The Hodzana Hills herd was originally considered part of the Ray Mountains herd (Pamperin 2015), which is located on the southern edge of the herd's range.

Macomb herd

The Macomb herd ranges in the Eastern Alaska Range between Delta River and Yerrick Creek to Mentasta Highway. The core of its range is found between the Robertson River and the Richardson Highway (Bruning 2013). Approximately 60% of the herd's range is within the CYR study area (Table H-12) and is in the southeastern portion of the region, directly south of the Fortymile herd (Figure H-5).

Porcupine herd

The Porcupine herd has a relatively large range (Table H-12) throughout northeastern Alaska and the Yukon Territory. Approximately 30% of the herd's range overlaps with the CYR study area and is located in the northeastern portion of the region (Figure H-5).

Ray Mountains herd

The Ray Mountains herd ranges in the Ray Mountains north of the Yukon River (Pamperin 2015). This herd is wholly contained within the CYR study area (Table H-12) and is located south of the Hodzana Hills herd (Figure H-5).

Western Arctic herd

The Western Arctic herd has a relatively large range (Table H-12) throughout northwestern Alaska (Dau 2013). Approximately 30% of the Western Arctic herd range overlaps with the CYR study area and covers the western portion of the region (Figure H-5). An annual kernel density from 2004 to 2014 developed by ADF&G using radio collar data suggests that the core areas of the Western Arctic herd range exist on the periphery of the CYR study area (Figure H-7).

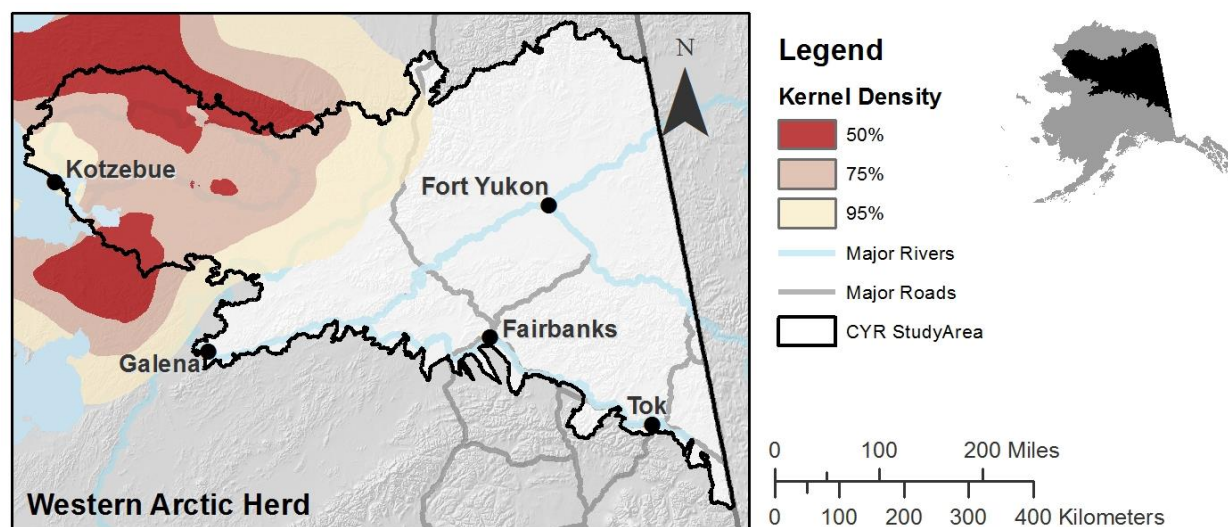


Figure H-7. Annual kernel density of the Western Arctic Herd from 2004 to 2014. Kernel density was generated by ADF&G from telemetry data.

White Mountains herd

The White Mountain herd has a relatively small range (Table H-12) and resides in the White Mountains year-round (Young, Jr. 2015). This herd is wholly contained within the CYR study area and is on the northwestern border of the Fortymile herd range (Figure H-5).

Wolf Mountain herd

The Wolf Mountain herd ranges north of the Yukon River in the Kokrines hills (Pamperin 2015). This herd is wholly contained within the CYR study area (Table H-12) and is located directly north of the Galena Mountain herd (Figure H-5).

Summer and Calving Ranges

During summer, reproductive females experience increased energetic demands and seek out areas of high forage quality (Boertje 1985). Post-calving, caribou typically aggregate into large herds and move away from calving grounds into higher elevation habitats to decrease predation risk and escape from insects (Downes et al. 1986, Walsh et al. 1992). Females typically show high fidelity to both calving and insect-relief sites, and return to the same areas each year (Gunn and Miller 1986, Schaefer et al. 2000). The majority of the summer and calving ranges for the three Arctic herds, are outside of the CYR study area (Figure H-8).

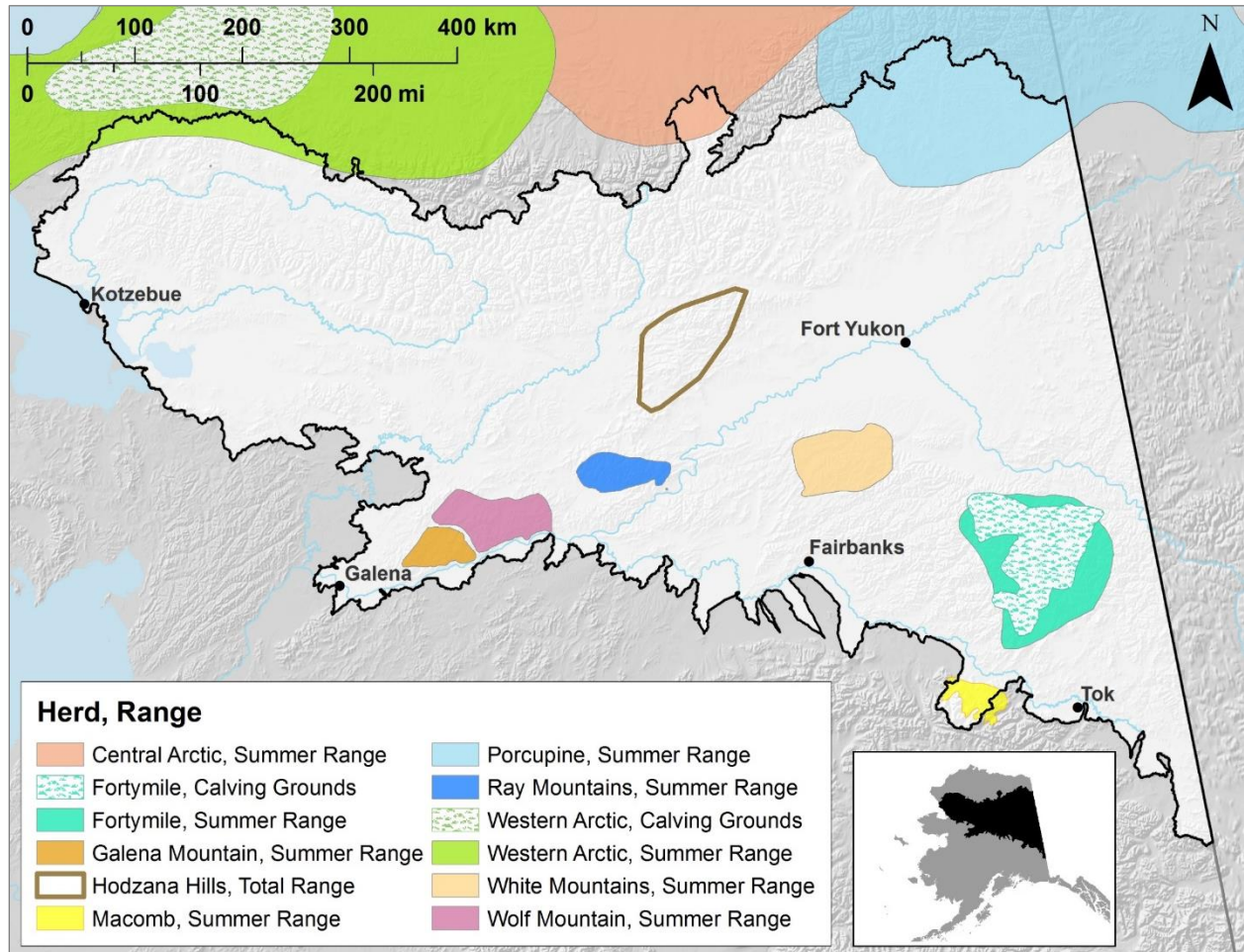


Figure H-8. Summer and calving ranges of caribou herds in the CYR study area. Hollow outlines were used to depict total range area for herds where summer and calving ranges were unavailable.

Central Arctic herd

The summer range of the Central Arctic herd has very little overlap with the CYR study area (Figure H-8) and is more concentrated along the north slope from west of the Colville River headwaters, east to the Canadian border (Lenart 2015). Calving grounds for this herd are not within the CYR study area.

Fortymile herd

The summer and calving ranges of the Fortymile herd are wholly contained within the eastern portion of the CYR study area (Figure H-8). The Fortymile herd typically spends the post-calving summer season (June) in the same general area as calving. Calving areas during 2012 to 2014 have included Middle Fork and North Fork of the Fortymile River, upper portions of the Charley River, the eastern and southern edges of the Yukon-Charley Rivers National Preserve, and more recently (2014), the headwaters of the Salcha and Goodpaster river drainages (Gross 2015).

Galena Mountain herd

The summer and calving ranges of the Galena Mountain herd are wholly contained within the central portion of the CYR study area (Figure H-8). Specifically, this herd calves east of Galena Mountain in the Kokrines Hills at elevations between 760 to 1,160 meters, and occasionally a portion of the herd may overlap with the Wolf Mountain herd near Black Sand Creek (Robinson 1991, Pamperin 2015). During the 1990's, a concentration of collared caribou used a small portion of the summer range from March through September (Robinson 1991).

Hodzana Hills herd

The calving and summer range of the Hodzana Hills herd is in the hills at the headwaters of the Dall, Kanuti and Hodzana rivers, in the central portion of the CYR study area (Figure H-8; Pamperin 2015).

Macomb herd

The summer range of the Macomb herd overlaps with the southeastern portion of the CYR study area (Figure H-8). Calving grounds for this herd are on the Macomb Plateau (Bruning 2013).

Porcupine herd

During summer, there is relatively little overlap between the Porcupine herd range and the CYR study area (Figure H-8). This herd typically spends summers on the coastal plain with some movements west to the Canning River, into the northern foothills of the Brooks Range, and along the upper Firth, Coleen and Sheenjek river drainages (Caikoski 2015), all of which are outside the CYR study area.

Ray Mountains herd

The summer range of the Ray Mountains herd is located in the Ray Mountains, in the central portion of the CYR study area (Figure H-8). Calving grounds for this herd are around Kilo Hot Springs (Pamperin 2015).

Western Arctic herd

Very little of the summer range for the Western Arctic herd overlaps with the CYR study area (Figure H-8). The calving grounds for this herd are located outside of the study area entirely, in the Utukok hills (Dau 2013).

White Mountains herd

The White Mountains summer and calving ranges are wholly contained within the CYR study area (Figure H-8). This herd typically calves at higher elevations east of Beaver Creek, including the

Nome, Fossil, Cache and Preacher Creek drainages (Young, Jr. 2015). Post-calving summer ranges include east of Beaver Creek to Mount Prindle.

Wolf Mountain herd

The Wolf Mountain herd both calves and winters in the Melozitna and Little Melozitna river drainages to the north and east of Wolf Mountain (Pamperin 2015). This range is located in the central region of the CYR study area (Figure H-8).

Winter Ranges

Winter is a critical season for caribou herds since they must cope with low temperatures, snow cover, and reduced forage availability (Russel et al. 1993). During winter, caribou typically use areas that have accessible forage (e.g., lichens; Klein 1982, Russel et al. 1993), and that promote easy movement and predator avoidance (Thomas et al. 1996). Caribou generally use the same winter range each year; however, they may shift their winter locations in response to wildfire damage to lichens and increased snow-depths or snow hardness (Anderson and Johnson 2014, Thomas et al. 1996).

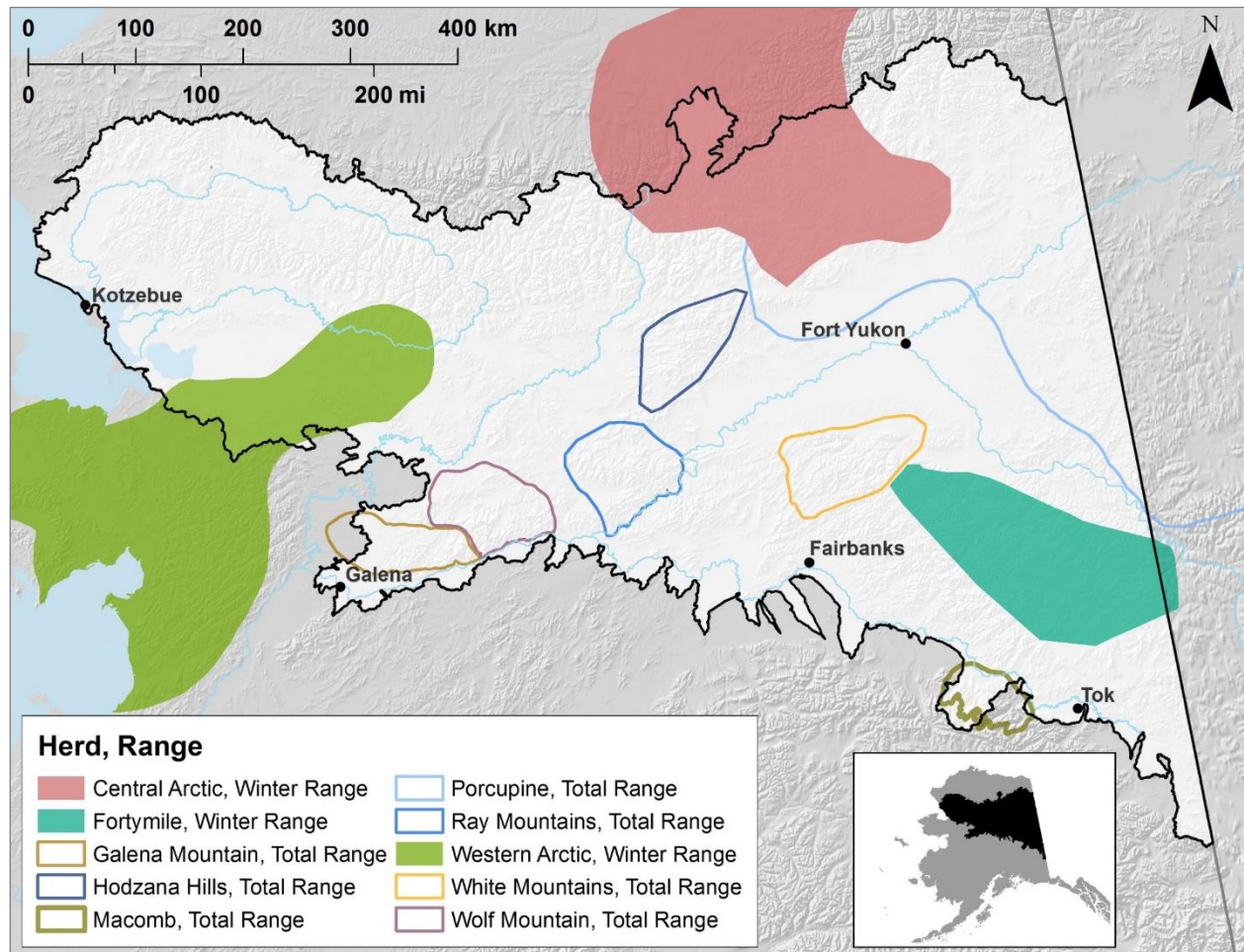


Figure H-9. Winter ranges of caribou herds in the CYR study area. Hollow outlines were used to depict total range area for herds where winter ranges were unavailable.

Central Arctic herd

A relatively small portion of the winter range for the Central Arctic herd overlaps with the CYR study area (Figure H-9), and depending on the year, during the rut, caribou may remain north of the Brooks Range and outside the CYR study area completely (Lenart 2015). When the herd is within the study area, south of the Brooks Range, they range on Chandalar Shelf near Your and Thru creeks, the North Fork and Middle Fork Chandalar River, and as far east as the East Fork Chandalar River. During the rut in 2013, most of the Central Arctic herd was found between Bob Johnson and Ackerman Lakes, and further south in the northern part of the Hodzana Hills.

Fortymile herd

The majority of the winter range for the Fortymile herd is contained within the CYR study area (Figure H-9). During the winter, the Fortymile herd primarily ranges in the White Mountains and Birch Creek areas near the Steese Highway (Gross 2015). Most recently (winter 2014–2015), the majority of the herd was concentrated in the drainages of Birch Creek, middle fork of the Chena River, and the upper Goodpaster River. They were also concentrated in the northwest portion of the Yukon-Charley Rivers National Preserve south of the Yukon River, with a small portion of the herd residing in the eastern portion of the winter range near the Top of the World Highway (Gross 2015).

Galena Mountain herd

During winter, the Galena Mountain herd ranges to the west of Galena Mountain (Robinson 1991, Pamperin 2015).

Hodzana Hills herd

The winter range of the Hodzana Hills herd is the same as the summer and calving areas, in the hills at the headwaters of the Dall, Kanuti and Hodzana rivers, in the central portion of the CYR study area (Figure H-8; Pamperin 2015).

Macomb herd

The core range of the Macomb herd is between the Robertson River and the Richardson Highway. During winter, the herd also uses the lowlands of the Tanana River Valley (Bruning 2013).

Porcupine herd

The winter range for the Porcupine herd overlaps with the eastern region of the CYR study area including the upper Coleen river drainage, the North Fork of the Chandalar river drainage and the Hodzana Hills (Caikoski 2015). During 2013-2014, approximately 50% of the herd wintered in the Alaska portion of the range, and 50% of the herd wintered in the Yukon portion of the range. The winter range in Alaska overlaps with the Central Arctic, Hodzana and Teshekpuk caribou herds. The Porcupine herd also ranges outside of the CYR study area in Yukon including the Ogilvie Mountains and Old Crow Flats where it mixes with the Hart River, Fortymile and Nelchina caribou herds (Caikoski 2015).

Ray Mountains herd

During winter, the Ray Mountain herd ranges north of the Ray Mountains in the Kanuti and Kilolitna River area. They also occasionally use the Tozitna drainage to the south (Pamperin 2015).

Western Arctic herd

Winter range for the Western Arctic herd varies from year to year (see figures in Dau 2013). Since the late 1990s, the Western Arctic herd typically winters on the Seward Peninsula or upper Kobuk and Koyukuk drainages. Occasionally, a small portion of the herd winters on the North Slope, outside of the CYR study area (Dau 2013).

White Mountains herd

Since 2004, the White Mountains herd has been wintering in the Preacher Creek and Beaver drainages. More recently (2012), the herd has also used the Upper Birch creek drainage (Young, Jr. 2015).

Wolf Mountain herd

The Wolf Mountain herd both calves and winters in the Melozitna and Little Melozitna river drainages to the north and east of Wolf Mountain (Pamperin 2015). This range is located in the central region of the CYR study area (Figure H-8).

Migration and Movement Patterns

Caribou typically undergo seasonal migrations between summer calving grounds, mosquito-relief areas, and winter foraging sites (Figure H-10), with migration distances varying between herds. In the CYR study area, the larger, Arctic herds undergo seasonal migrations of distances up to 640 km (ADF&G 2013), with annual movements of some caribou totaling more than 5,000 km (Fancy et al. 1989, Nicholson et al. 2016). The smaller, more regional herds farther south tend to undergo much shorter seasonal movements (Robinson 1991, Pamperin 2015, Bruning 2013). Wider ranging herds include the Western Arctic, Central Arctic and Porcupine herds. The more localized herds include the Fortymile, Galena, Hodzana Hills, Macomb, Ray Mountains, White Mountains, and Wolf Mountain herds.

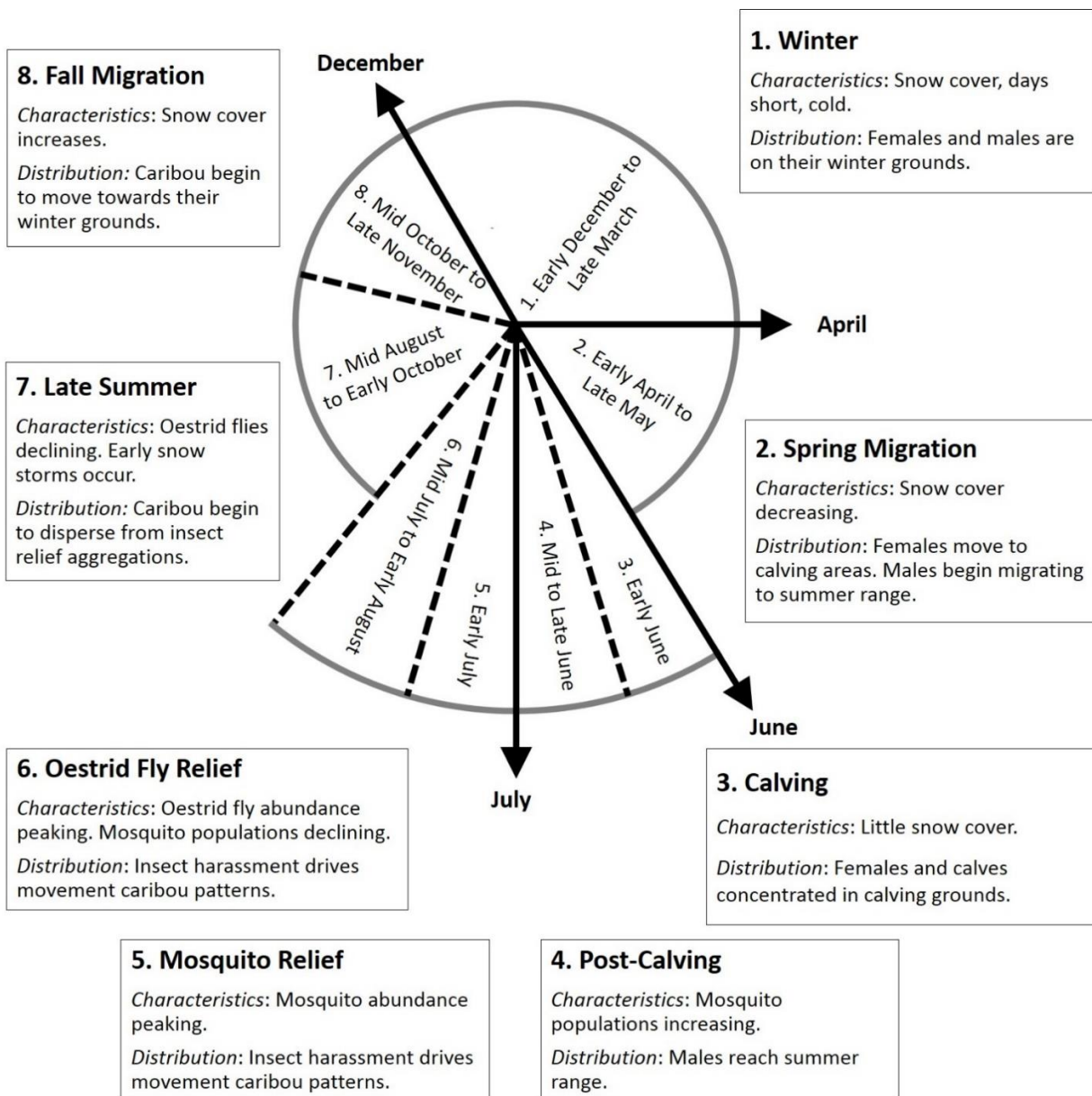


Figure H-10. Generalized seasonal movement patterns of caribou herds. Modified from Gotthardt et al. (2015).

Central Arctic herd

Caribou in the Central Arctic herd generally move into the Brooks foothills during autumn (August to early September), including the Toolik Lake, Galbraith Lake, Accomplishment Creek, the Ivishak River and the upper Sagavanirktok River. By the end of September, most of the caribou move north, out of the CYR study area onto the coastal plain, before moving south toward the mountains for rut (Lenart 2015).

Fortymile herd

During autumn (late-September to mid-October), the Fortymile herd generally moves along river drainages from the Seventymile river drainage and American Summit area northeast into Yukon, Canada, outside of the CYR study area (Gross 2015).

Galena Mountain herd

During the spring (April), prior to calving, the Galena Mountain herd usually migrates toward the alpine areas east of Galena Mountain to calve on the alpine slopes of the southern Kokrines Hills. During autumn (October), the herd migrates from the alpine, across the mountain to their wintering grounds in the Holtnakatna Hills and Hozatka Lakes areas (Robinson 1991, Pamperin 2015).

Hodzana Hills herd

The Hodzana Hills herd does not undertake significant migrations throughout the year (Pamperin 2015).

Macomb herd

The Macomb herd does not undertake significant migrations throughout the year (Bruning 2013).

Porcupine herd

The Porcupine herd migrates long distances between Alaska, Yukon and the Northwest Territories, Canada. During autumn (September) most of the herd moves west into Alaska (Caikoski 2015). During spring, caribou move back east into Yukon and Northwest Territories for calving.

Ray Mountains herd

The Ray Mountains herd does not undertake significant migrations throughout the year (Pamperin 2015).

Western Arctic herd

The Western Arctic herd has the largest range and most extensive migrations compared to other herds in the CYR study area. During spring, reproductive females travel north to the calving grounds in the Utukok hills, outside of the CYR study area (Figure H-11). Bulls and non-pregnant females migrate a little later and move toward the Wulik Peaks and Lisburne Hills. Post-calving, reproductive females and their calves move southwest toward the Lisburne Hills where they rejoin the bulls and non-reproductive females. During summer, the herd moves east through the Brooks Range, north of the CYR study area. During autumn, the herd becomes more dispersed and migrate south toward the winter range in the Nulato Hills and Unalakleet River drainage (Figure H-12; Dau 2013).

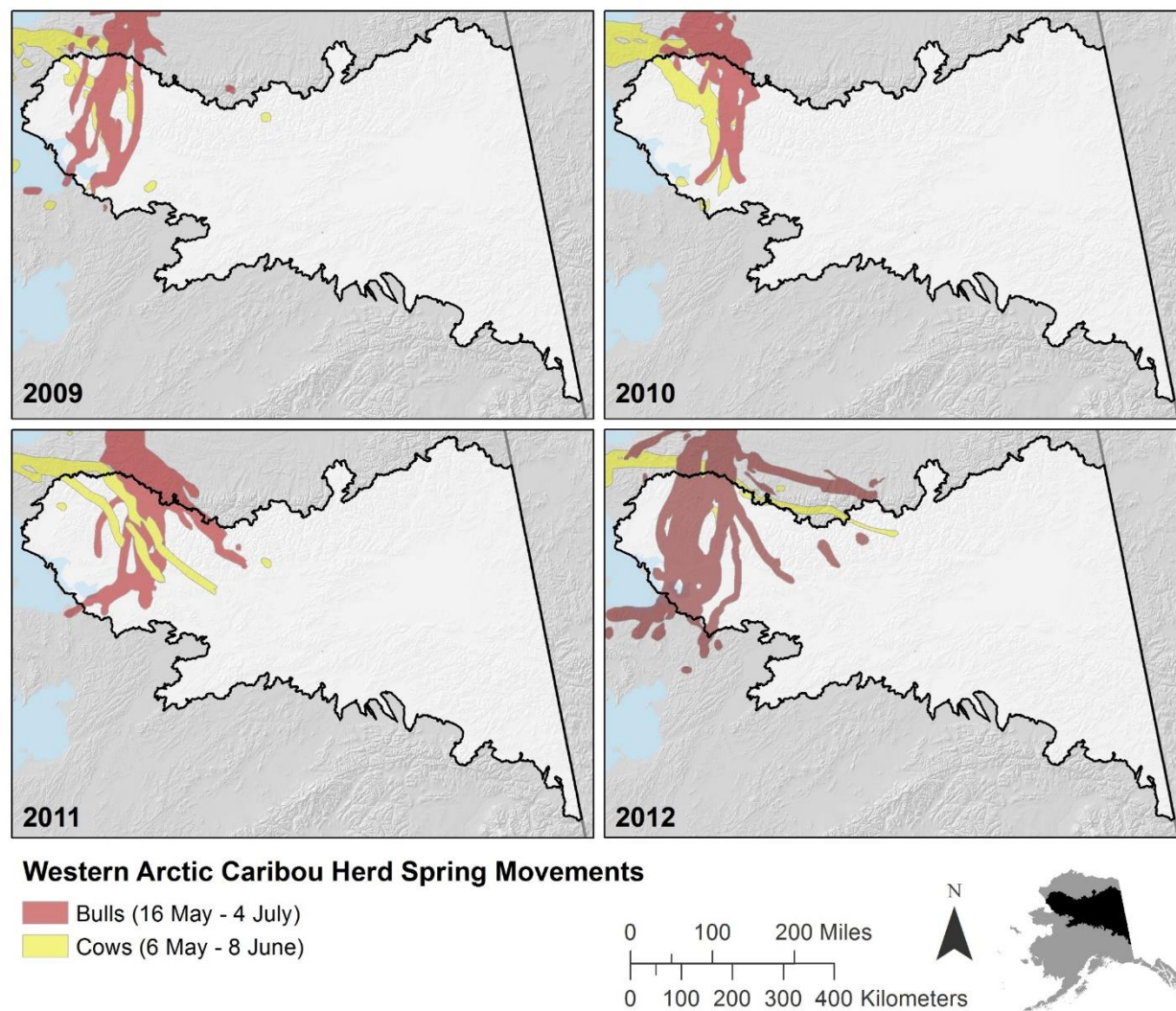


Figure H-11. Spring movement corridors of satellite-collared Western Arctic herd caribou, 2009–2012. Digitized from Dau (2013).

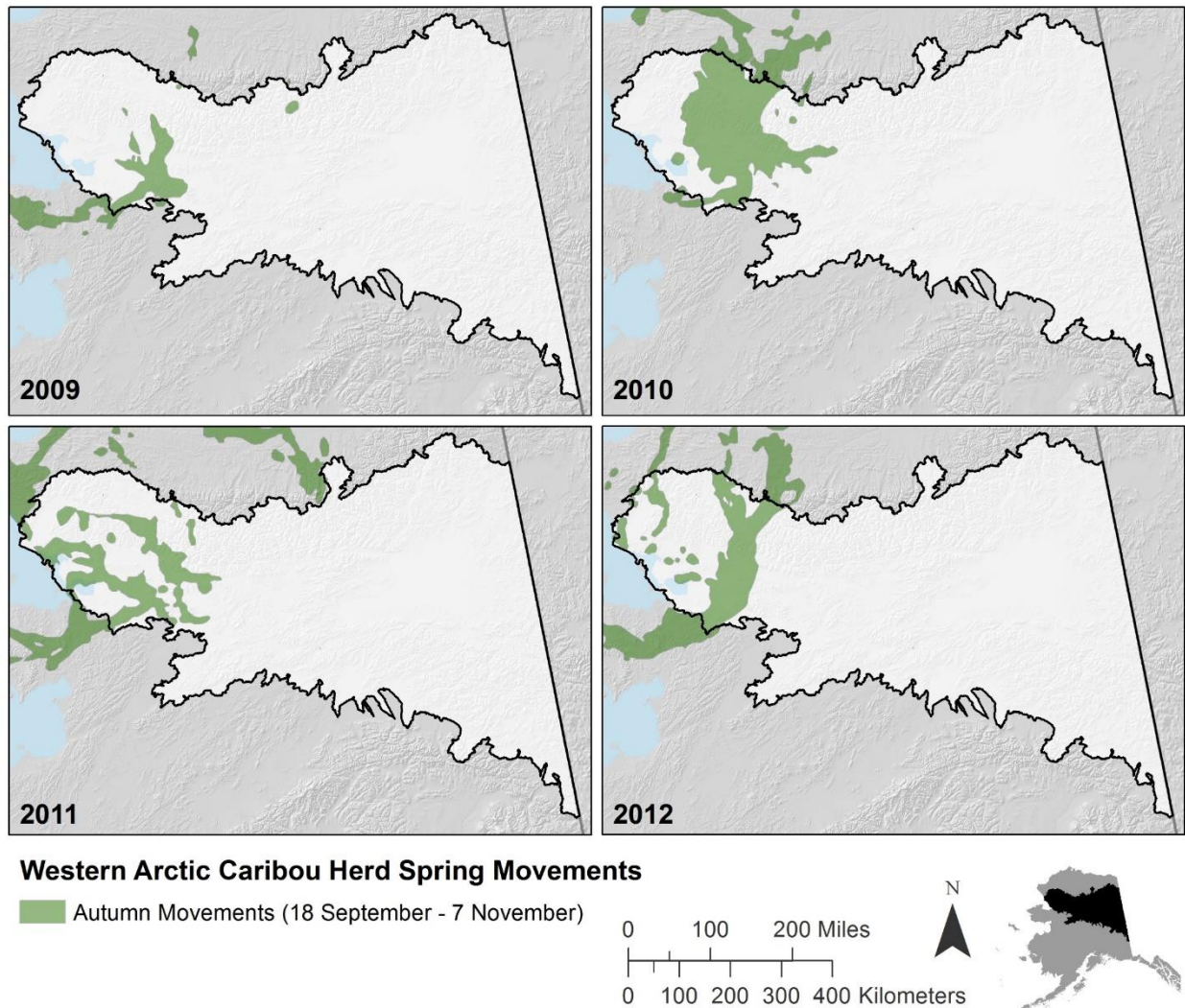


Figure H-12. Autumn (18 Sept.–7 November) movement corridors of satellite-collared Western Arctic herd caribou, 2009–2012. Digitized from Dau (2013).

White Mountains herd

The White Mountains herd does not undertake significant migrations throughout the year (Young, Jr. 2015).

Wolf Mountain herd

The White Mountains herd does not undertake significant migrations throughout the year (Pamperine 2015).

4.5 Abiotic Change Agents Analysis

We explored the relationship between caribou and five climate variables: length of growing season, date of spring thaw, mean summer temperature, total winter precipitation, and February snow day fraction at three time periods (current, near-term, and long-term).

For caribou, climate projections have the potential to both positively and/or negatively affect caribou forage and habitat. The potentially negative factors of icing and insect harassment need to be balanced against the potentially positive effects of increased biomass of caribou forage, and overall warmer winter temperatures (Griffith et al. 2002, McLennan et al. 2012). In addition, changes to forage and habitat quality may impact the smaller regional herds differently than the larger migratory herds that have a larger range size (Sharma et al. 2009).

Growing Season Length and Date of Thaw

Warming temperatures will increase the likelihood of advanced spring thaw, expediting vegetation emergence and increasing forage abundance during calving. Earlier plant emergence may result in earlier parturition (Post et al. 2003) and increased calf survival (Griffith et al. 2002). Alternatively, early onset of the growing season may result in caribou arriving on the calving grounds after the vegetation has passed through its optimal state of nutrition. This timing mismatch could have adverse effects on calf survival (McLennan et al. 2012). In addition, while earlier plant emergence and increased plant growth may be beneficial for summer foraging, an increase in graminoid and shrub biomass can be detrimental to the growth of nearby shade-intolerant lichens that are important winter forage (Walker et al. 2006).

Earlier spring thaw and warmer spring temperatures may also result in earlier insect emergence. In addition, a longer growing season may result in increased insect abundance (Bolduc et al. 2013). This may cause a longer and more intense season of insect harassment and advance the need for insect-avoidance strategies (Fancy 1983, Murphy and Lawhead 2000, Walsh et al. 1992, Witter et al. 2012).

Early spring advancement is expected to be greatest in the midwest and southeastern portion of the CYR study areas. Within the CYR study area, no caribou herds summer in the area of greatest advancement in date of thaw (Figure H-13).

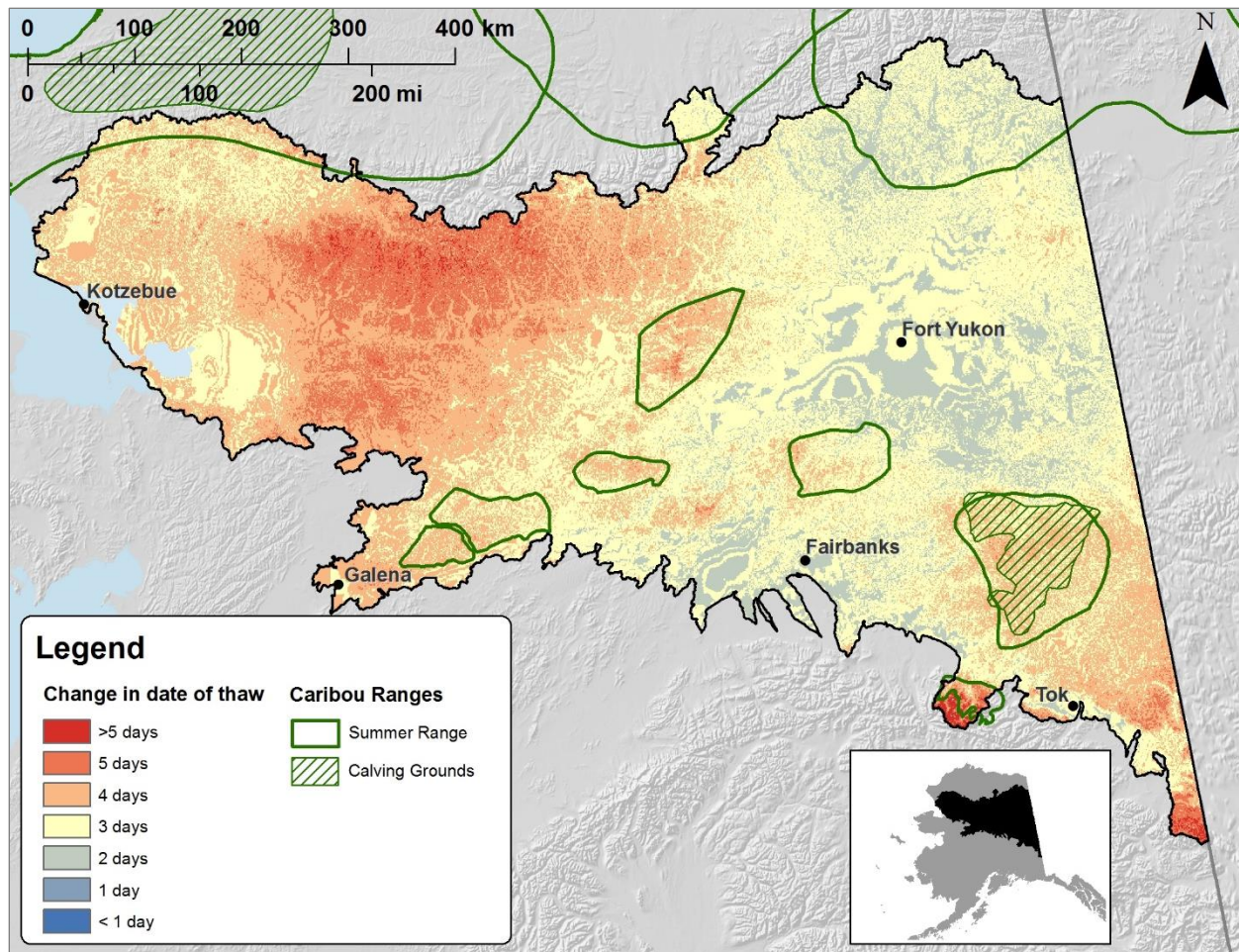


Figure H-13. Change in date of thaw from the 2010s to the 2060s in the CYR study area with caribou summer and calving ranges.

Similar to date of thaw, the greatest increase in length of growing season is expected in the midwest portion of the CYR study area (Figure H-14). While the Western Arctic caribou herd will experience the greatest increase in growing season length, increases of 9–11 days are expected in most of the caribou herd ranges.

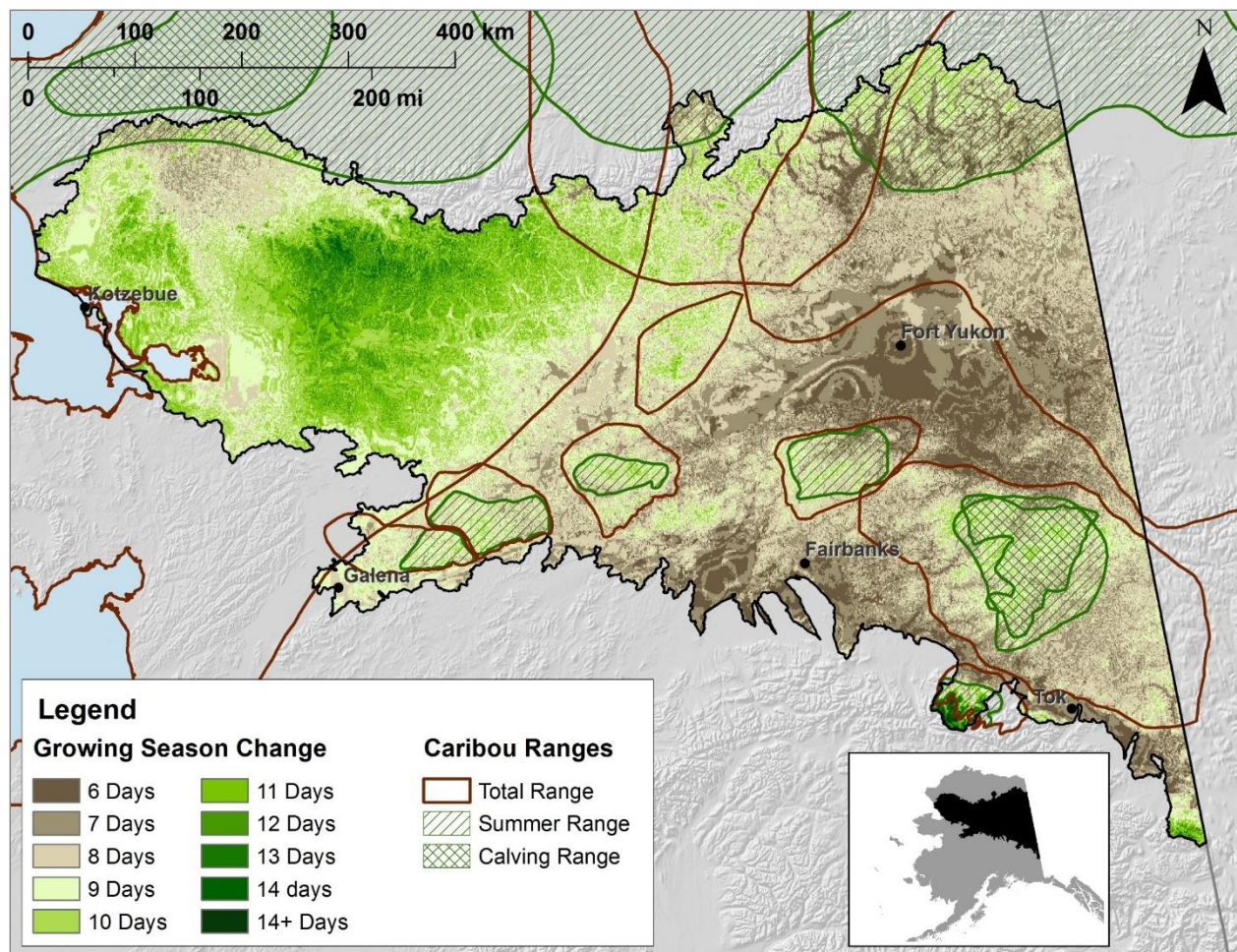


Figure H-14. Change in growing season length from the 2010s to the 2060s in the CYR study area with caribou total, summer, and calving ranges.

Summer Temperature

Warming temperatures are anticipated for the CYR study area in both the near-term and long-term future (see Section C. Abiotic Change Agents). Warming temperatures are expected to cause earlier snowmelt and alter the overall phenology of the region, including earlier onset of plant growth (Sparks and Menzel 2002, Stone et al. 2002). In addition, insect abundance is directly influenced by mean daily temperature and increased pest-insect abundance can cause increased/alterd herd movements (Downes et al. 1986, Witter et al. 2012, Bolduc et al. 2013). These changes will affect the abundance and timing of both caribou forage and insect abundance/emergence.

Future warming of summer temperatures will be most prevalent in the ranges of the eastern caribou herds such as the Fortymile, Hodzana Hills, Macomb, and White Mountains herds (Figure H-15). An increase in mean summer temperature of up to 1.4 °C is expected for these areas.

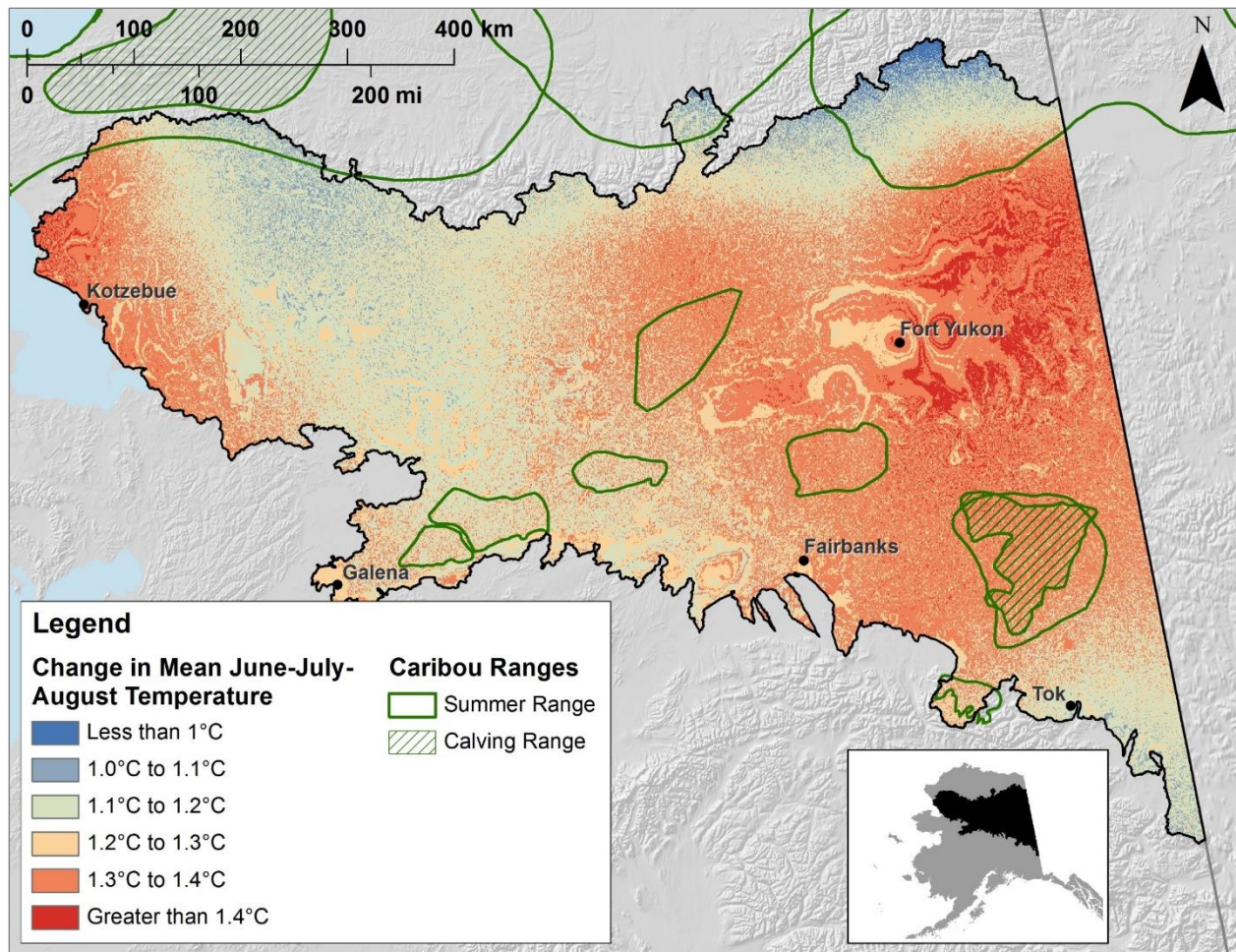


Figure H-15. Change in mean June-July-August temperature from the 2010s to the 2060s in the CYR study area with caribou summer and calving ranges.

Winter Precipitation and Snow Day Fraction

Rain-on-snow (icing) events are expected to increase in frequency as winter temperatures increase (Hansen et al. 2011). Icing alters the snowpack and can restrict foraging or increase energy expenditure, causing negative effects on reproduction and recruitment. Icing may also result in habitat avoidance (Hansen et al. 2011, Joly et al. 2010, Tucker et al. 1991).

Figure H-16 highlights areas that will experience an increase in the percent of precipitation that falls as rain (decreased snow day fraction) during the month of February. Areas with a lower snow day fraction have a higher probability of experiencing rain on snow events. For example, in areas with a snow day fraction value of 80%, 20% of the precipitation is predicted to fall as rain. Reductions in snow day fraction are predicted to be greatest in the southeast portion of the CYR study area (Figure H-16). The Fortymile, Hodzana Hills, and Macomb caribou herds currently experience the highest proportion of rain on snow events. Herds farther to the west, such as the Western Arctic caribou herd, are likely to begin experiencing more frequent rain on snow events in the long-term future.

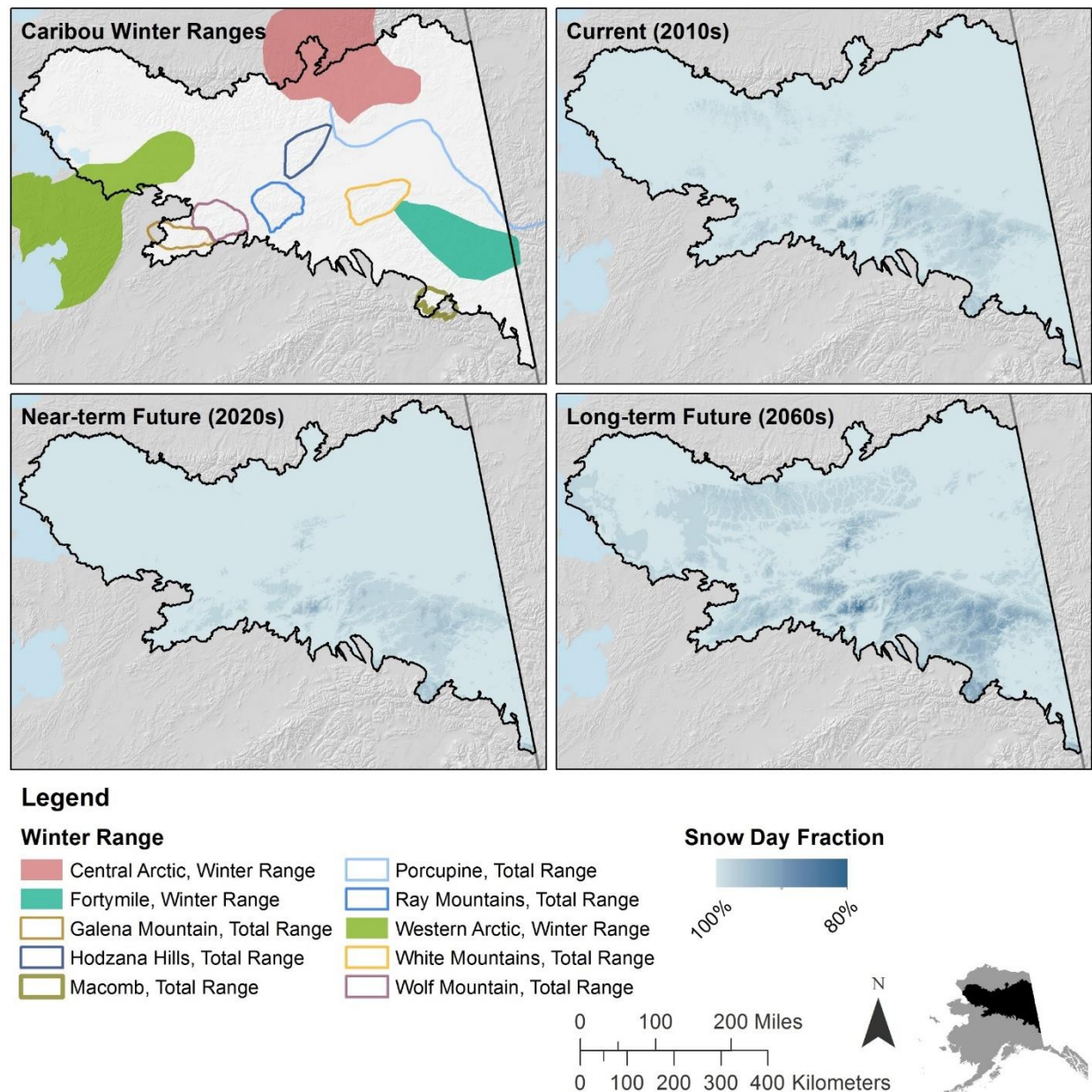


Figure H-16. Change in February snow day fraction from the 2010s to the 2060s in the CYR study area with caribou winter or total ranges.

Areas with low snow accumulation provide easy travel and easy access to forage (Joly and Klein 2011). Within the CYR study area, an increase in winter precipitation of 15 mm or more is expected in the northern portion of the region (Figure H-17; see Section C. Abiotic Change Agents). This is likely to have the greatest impact on the Western Arctic, Central Arctic, Hodzana Hills, and Ray Mountains herds. Please note, however, that due to variation in wind and topography at the site level, winter precipitation does not directly translate to increased snow depth.

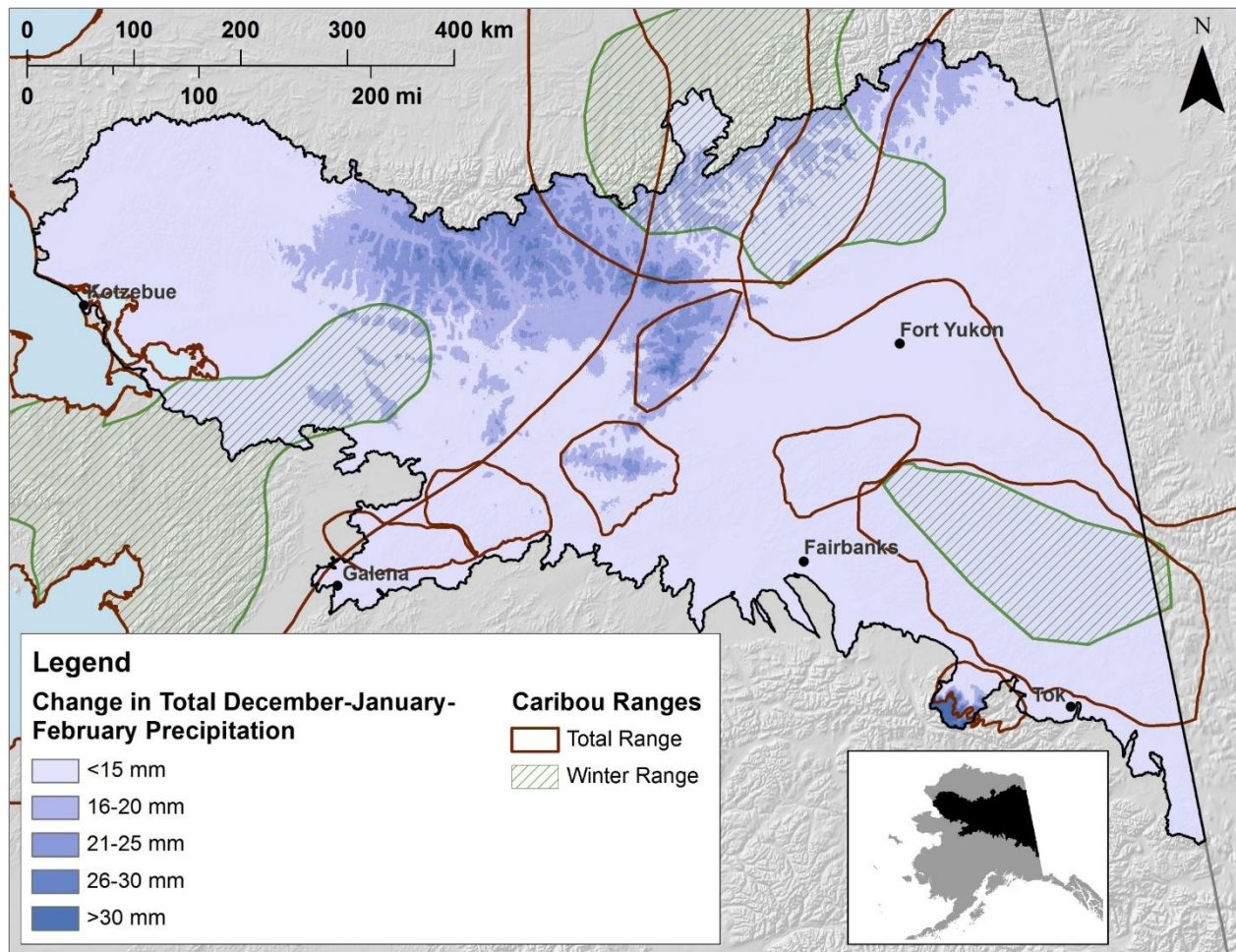


Figure H-17. Change in December-January-February precipitation from the 2010s to the 2060s in the CYR study area with caribou winter ranges.

Fire

Wildfires can burn ground dwelling lichens, which are important winter caribou forage, and can take several decades to regenerate to pre-burn levels (Jandt et al. 2008, Rupp et al. 2006, Fulkerson and Carlson 2014). Reduced lichen abundance can lead to shifts in winter distribution (Collins et al. 2011, Joly et al. 2003, Sharma et al. 2009, Joly et al. 2010, Gustine et al. 2014). The quality of winter forage influences body condition and reproductive success, including fetal development, birth weights and growth rates of calves, and milk production (White 1983, Parker et al. 2005). With warming temperatures, increasing fire frequency and area burned are predicted for the CYR study area (see Section C. Abiotic Change Agents).

Invasive Species

Invasive plant species may compete with native forage species in the future. However, invasive species are currently limited in the CYR study area and are not likely to expand enough within the next 50 years to have major impacts on caribou habitat.

4.6 Current Status and Future Landscape Condition

Human activities and resource development can cause herd disturbance, fragmentation of caribou habitat, and increased hunting access to herd ranges. Human activities may result in increased vigilance, avoidance behaviors, and redistribution of animals (Wolfe et al. 2000). During calving, cows and calves exhibit road avoidance and are typically not found within 1 km of roads (Cronin et al 1994). Road development and increased human access to current caribou ranges may cause herd displacement and/or increased hunting pressure.

Landscape condition, which is a measure of anthropogenic impact and fragmentation on the landscape, is very high throughout majority of the CYR study area (Figure H-18). Current landscape condition is consistent between summer and calving, and winter ranges, however, projected changes in the near-term and long-term future indicated a greater decrease in landscape condition throughout the summer and calving ranges as compared to winter ranges (Table H-13).

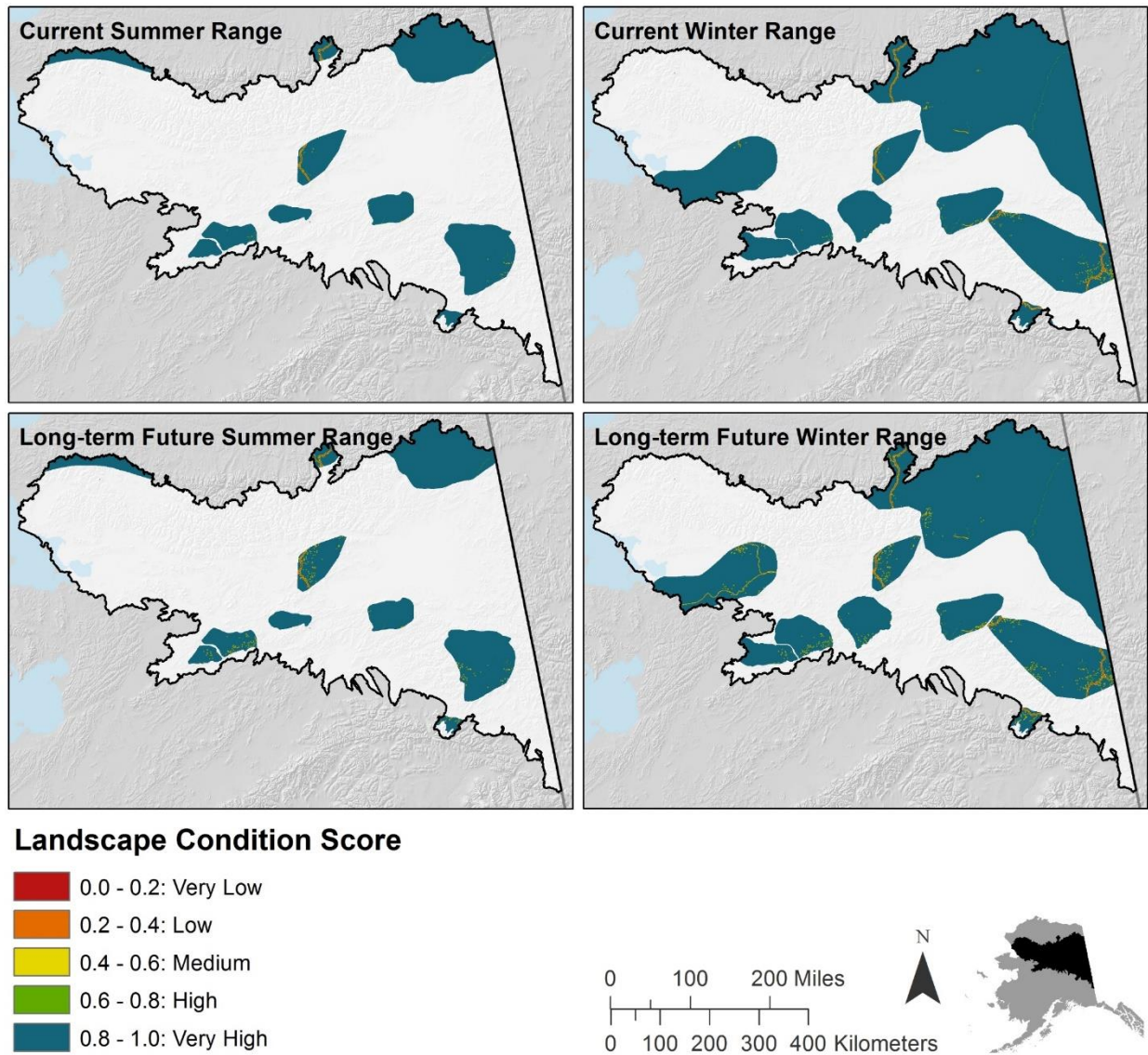


Figure H-18. Current and long-term future landscape condition in caribou summer and winter ranges within the CYR study area.

Table H-13. Current and long-term future landscape condition in caribou summer and winter ranges within the CYR study area.

Seasonal range	Time Period	Landscape Condition (% Area)				
		Very Low	Low	Medium	High	Very High
Summer Range	Current	0.2	0.3	0.3	0.5	98.7
	Long-term	0.3	0.6	0.8	1.1	97.2
	Change to Long-term	0.1	0.3	0.5	0.6	-1.5
Winter Range	Current	0.2	0.4	0.5	0.7	98.2
	Long-term	0.3	0.7	0.9	1.2	96.9
	Change to Long-term	0.1	0.3	0.4	0.5	-1.3

4.7 Summary

Future projections relevant to caribou suggest that throughout the CYR study area, there will be an advanced date of thaw and an increase in length of growing season and summer temperature (Table H-14). These changes may increase juvenile survival through warming temperatures, increased forage abundance, and earlier forage emergence; however, increased insect abundance and earlier emergence associated with these climate variables may also have a negative effect on caribou survival and energy expenditure during summer. During winter, increased precipitation and rain-on-snow events may have a negative impact on juvenile survival, and forage accessibility. In addition, increases in the frequency and extent of wildfires may have a direct negative impact on winter forage availability. Other variables considered in this analysis, such as invasive species and landscape condition, are not expected to have a significant impact on caribou in the next fifty years. Overall, changes in climate are expected to have mixed effects, both positive and negative on caribou herds in the near to long-term future, and these effects may have a stronger impact on smaller regional herds who are restricted to smaller ranges and a more limited area of habitat.

Table H-14. Summary and projected effects of change agents used in the assessment for caribou in the CYR study area.

Indicator	Near-term change	Long-term change	Effect on CE in CYR study area	Impact
Length of growing season	+	+	+/-	Forage and insect abundance and phenology
Date of thaw	No change	+	+/-	Forage and insect abundance and phenology
Summer temperature	No change	+	+/-	Forage and insect abundance and phenology
Winter precipitation	+	+	-	Juvenile survival
Rain-on-snow events: Snow day fraction	Not assessed	+	-	Forage accessibility
Fire	Unknown	+	+/-	Winter forage availability
Landscape condition	Minimal change	-	-	Body condition/ Survival
Invasive species	N/A	N/A	None	None

4.8 Limitation and Data Gaps

The spatial representations of caribou seasonal distribution are based on the best available and obtainable information. This included annual kernel densities for the Western Arctic and Central Arctic herds; however, such fine-scale data were not available for the other herds. ADF&G are currently working on developing kernel densities for other herds in the region that may be available at a future date. Much of the fine detail for herd distributions were obtained through the ADF&G management guides. Pairing these descriptions with radio collar data would provide further insight into migration corridors and seasonal habitat use. Considerable inter-annual variability exists, and herd ranges also shift more generally over decades. For some herds, especially the arctic herds, the ADF&G seasonal range polygons do not reflect telemetry data from the past 10 years.

ALFRESCO (ALaska FRame-based EcoSystem Code) outputs do not include fire severity or precise spatial/temporal predictions of future fires (see Section C. Abiotic Change Agents); therefore, identifying areas where increased wildfire may have a negative effect on caribou forage was not possible with these data.

It should also be noted when considering winter precipitation predictions, uncertainty in precipitation projections is relatively high (see Section C. Abiotic Change Agents). In addition, due to variation in wind and topography at the site level, winter precipitation does not directly translate to increased snow depth. An accurate snow depth spatial layer would greatly improve this analysis.

It is also important to note that this study was limited to assessing the effect of specific CAs on CEs that we could spatially model and that had strong cause-and-effect linkages in the literature. There may be additional factors not addressed in this study that play an important role in determining the status of caribou throughout the CYR study area.

4.9 Datasets and Literature Cited

Table H-15. Datasets used for analysis of caribou in the CYR study area.

Dataset	Dataset Description	Dataset Provider	Data Type	Dataset Last Updated	Restrictions
Seasonal range polygons of all caribou herds in Alaska	This dataset provides a statewide perspective on location of recognized caribou herds in Alaska. The dataset describes the extent of seasonal and total range for 33 caribou herds in Alaska, but does not include telemetry data.	Alaska Department of Fish and Game	Polygon shape file	2009 (2015 for total ranges)	None
Annual kernel density of Western Arctic Herd	This dataset displays the annual kernel density of Western Arctic Caribou Herd 2004 to 2014	Alaska Department of Fish and Game	Polygon shape file	2014	None
Annual kernel density of Central Arctic Herd	This dataset displays the annual kernel density of Central Arctic Caribou Herd 2004 to 2014	Alaska Department of Fish and Game	Polygon shape file	2014	None
Autumn movements of Western Arctic Herd from 2009 to 2012	Autumn movement corridors of satellite-collared caribou of the Western Arctic Herd from 2009 to 2012. Autumn movements are defined from 18 September to 7 November. Digitized from Dau (2013).	Alaska Department of Fish and Game	Digitized from Publication	2013	None
Spring movements of Western Arctic Herd from 2009 to 2012	Spring movement corridors of satellite-collared caribou of the Western Arctic Herd during 2009. Bull movements are defined from 16 May to 4 July while cow movements are defined from 6 May to 8 June. Digitized from Dau (2013).	Alaska Department of Fish and Game	Digitized from Publications	2013	None

Literature Cited

- Alaska Department of Fish and Game (ADF&G). 2013. Species profile: caribou. Available: <http://www.adfg.alaska.gov/index.cfm?adfg=caribou.main>
- Anderson, T. A., and C. J. Johnson. 2014. Distribution of barren-ground caribou during winter in response to fire. *Ecosphere* 5:1-17.
- Boertje, R. D. 1985. An energy model for adult female caribou of the Denali herd, Alaska. *Journal of Range Management* 38:468-473.
- 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* 145:155-170.
- Bruning, D. L. 2013. Units 12 and 20D caribou. Pages 89–103 *in* P. Harper, ed. Caribou management report of survey and inventory activities 1 July 2010–30 June 2012. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2013-3, Juneau.
- Caikoski, J. R. 2015. Units 25A, 25B, 25D, and 26C caribou. Chapter 15, pages 15-1 through 15-24 *in* P. Harper, and L. A. McCarthy, eds. Caribou management report of survey and inventory activities 1 July 2012–30 June 2014. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2015-4, Juneau.
- Collins, W. B., B. W. Dale, L. G. Adams, D. E. McElwain, and K. Joly. 2011. Fire, grazing history, lichen abundance, and winter distribution of caribou in Alaska's taiga. *Journal of Wildlife Management* 75:369-377.
- Cronin, M., W. Ballard, J. Truett, and R. Pollard. 1994. Mitigation of the effects of oil field development and transportation corridors on caribou. Final report to the Alaska caribou steering committee. LGL Alaska Research Associates, Inc. Anchorage, Alaska.
- Dau, J. 2013. Units 21D, 22A, 22B, 22C, 22D, 22E, 23, 24 and 26A. Pages 201–280 *in* P. Harper, ed. Caribou management report of survey and inventory activities 1 July 2010– 30 June 2012. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2013-3, Juneau.
- Downes, C. M., J. B. Theberge, and S. M. Smith. 1986. The influence of insects on the distribution, microhabitat choice, and behavior of the Burwash caribou herd. *Canadian Journal of Zoology* 64:622-629.
- Fancy, S. G. 1983. Movements and activity budgets of caribou near oil drilling sites in the Sagavanirktok River floodplain, Alaska. *Arctic* 36:193-197.
- Fancy, S. G., L. F. Pank, K. R. Whitten, and W. L. Regelin. 1989. Seasonal movements of caribou in Arctic Alaska as determined by satellite. *Canadian Journal of Zoology* 67: 644-650.
- Fulkerson, J., and M. Carlson. 2014. Summary of the 2013 Western Arctic caribou herd project in McCarthy's Marsh, Seward Peninsula, Alaska. Prepared for the Fairbanks District Office, Bureau of Land Management, U.S. Department of the Interior. Alaska Natural Heritage Program, University of Alaska Anchorage. 9 pp. plus appendices.
- Gotthardt, T., T. Nawrocki, and N. Fresco. 2015. Terrestrial fine-filter conservation elements. *In* E. J. Trammell, M. L. Carlson, N. Fresco, T. Gotthardt, M. L. McTeague, and D. Vadapalli, eds. North Slope rapid ecoregional assessment. Prepared for: the Bureau of Land Management, U.S. Department of the Interior, Anchorage, Alaska. 117 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. The Porcupine caribou herd. Pages 8-37 *in* D. C. Douglas, P. E. Reynolds, and E. B. Rhode, eds. Arctic refuge coastal plain terrestrial wildlife research summaries. Biological Science Report USGS/BRD BSR-2002-0001. U.S. Geological Survey, Biological Resources Division.
- Gross, J. A. 2015. Units 20B, 20C, 20D, 20E, and 25C caribou. Chapter 12, 12–1 through 12–34 *in* P. Harper, and L. A. McCarthy, eds. Caribou management report of survey and inventory activities 1 July 2012–30 June 2014. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2015-4, Juneau.
- Gunn, A., and F. L. Miller. 1986. Traditional behaviour and fidelity to caribou calving grounds by barren-ground caribou. *Rangifer* 6:151-158.
- Gustine D. D., T. J. Brinkman, M. A. Lindgren, J. I. Schmidt, T. S. Rupp, and L. G. Adams. 2014. Climate-driven effects of fire on winter habitat for caribou in the Alaskan-Yukon Arctic. *PLoS ONE* 9:e100588. DOI: 10.1371/journal.pone.0100588.
- Hansen, B. B., R. Aanes, I. Harfindal, J. Kohler, and B. Sæther. 2011. Climate, icing, and wild Arctic reindeer: past relationships and future prospects. *Ecology* 92:1917-1923.

Section H. Terrestrial Fine-filter Conservation Elements

- Jandt, R., K. Joly, C. 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.
- Joly, K., and D. Klein. 2011. Complexity of caribou population dynamics in a changing climate. *Alaska Park Science* 10:27-31.
- Joly, K., F. Chapin, III, and D. 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. W. 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.
- Klein, D. R. 1982. Fire, lichens, and caribou. *Journal of Range Management*:390-395.
- Lenart, E. A. 2015. Units 26B and 26C caribou. Chapter 18, pages 18–1 through 18–38 in P. Harper, and L. A. McCarthy, eds. Caribou management report of survey and inventory activities 1 July 2012–30 June 2014. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2015-4, Juneau.
- LeResche, R. E. 1975. The international herds: present knowledge of the Fortymile and Porcupine caribou herds. *Biological Papers of the University of Alaska Special Report* 1:127-39.
- MacDonald, S. O., and J. A. Cook. 2009. Recent mammals of Alaska. University of Alaska Press, Fairbanks, Alaska.
- McLennan, D. S., T. Bell, D. Berteaux, W. Chen, L. Copland, R. Fraser, D. Gallant, G. Gauthier, D. Hik, and C. J. Krebs. 2012. Recent climate-related terrestrial biodiversity research in Canada's Arctic national parks: review, summary, and management implications. *Biodiversity* 13:157-173.
- Murphy, S., and B. Lawhead. 2000. Caribou. Pages 59-84 in J. Truett, and S. Johnson, eds. *The natural history of an Arctic oil field: development and the biota*. Academic Press, San Diego, California. 422 pp.
- Nicholson, K., S. Arthur, J. Horne, E. Garton, and P. del Vecchio. 2016. Modeling caribou movements: seasonal ranges and migration routes of the Central Arctic Herd. *PLoS ONE*. 11: e0150333
- Pamperin, N. J. 2015. Units 20F, 21B, 21C, 21D, 24A, 24B, and 25D caribou. Chapter 13, pages 13-1 through 13-15 in P. Harper, and L. A. McCarthy, eds. Caribou management report of survey and inventory activities 1 July 2012–30 June 2014. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2015-4, Juneau.
- Parker, K., P. Barboza, and T. Stephenson. 2005. Protein conservation in female caribou (*Rangifer tarandus*): effects of decreasing diet quality during winter. *Journal of Mammalogy* 86:610-622.
- Post, E., P. S. Bøving, C. Pedersen, and M. A. MacArthur. 2003. Synchrony between caribou calving and plant phenology in depredated and non-depredated populations. *Canadian Journal of Zoology* 81:1709-1714.
- Robinson, S. 1991. Status of the Galena Mountain caribou herd. *Rangifer*. 11: 116-122.
- Rupp, T., M. Olson, L. Adams, B. Dale, K. Joly, J. Henkelman, W. Collins, and A. Starfield. 2006. Simulating the influences of various fire regimes on caribou winter habitat. *Ecological Applications* 16:1730-1743.
- Russell, D. E., A. M. Martell, and W. A. C. Nixon. 1993 Range ecology of the Porcupine caribou herd in Canada. *Rangifer* 13:1-168.
- Schaefer, J. A., C. M. Bergman, and S. N. Luttich. 2000. Site fidelity of female caribou at multiple spatial scales. *Landscape Ecology* 15:731-739.
- Sharma, S., S. Couturier, and S. D. Cote. 2009. Impacts of climate change on the seasonal distribution of migratory caribou. *Global Change Biology* 15:2549-2562.
- Sparks, T. H., and A. Menzel. 2002. Observed changes in seasons: an overview. *International Journal of Climatology* 22:1715-1725.

- Stone, R. S., E. G. Dutton, J. M. Harris, and D. Longenecker. 2002. Earlier spring snowmelt in northern Alaska as an indicator of climate change. *Journal of Geophysical Research* 104:ACL10-1 – ACL 10-13.
- Thomas, D. C., S. J. Barry, and G. Alaie. 1996. Fire-caribou-winter range relationships in northern Canada. *Rangifer* 16:57-67.
- Tucker, B., S. Mahoney, B. Greene, E. Menchenton, and L. Russell. 1991. The influence of snow depth and hardness on winter habitat selection by caribou on the southwest coast of Newfoundland. *Rangifer* 11:160-163.
- Valkenburg, P., D. G. Kellyhouse, J. L. Davis, and J. M. Ver Hoef. 1994. Case-history of the Fortymile Caribou Herd, 1920-1990. *Rangier* 14:11-22.
- Walker, M. D., C. H. Wahren, R. D. Hollister, G. H. R. Henry, L. E. Ahlquist, J. M. Alatalo, M. S. Bret-Harte, M. P. Calef, T. V. Callaghan, A. B. Carroll, H. E. Epstein, I. S. Jo´nsdo´ttir, J. A. Klein, B. Magnu´sson, U. Molau, S. F. Oberbauer, S. P. Rewa, C. H. Robinson, G. R. Shaver, K. N. Suding, C. C. Thompson, A. Tolvanen, Ø. Totland, P. L. Turner, C. E. Tweedie, P. J. Webber, and P. A. Wookey. 2006. Plant community responses to experimental warming across the tundra biome. *Proceedings of the National Academy of Sciences* 103:1342–1346.
- Walsh, N. E., S. G. Fancy, T. R. McCabe, and L. F. Pank. 1992. Habitat use by the Porcupine caribou herd during predicted insect harassment. *The Journal of wildlife management*:465-473.
- White, R. 1983. Foraging patterns and their multiplier effects on productivity of northern ungulates. *Oikos* 40:377-384.
- 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., B. Griffith, and C. Wolfe. 2000. Response of reindeer and caribou to human activities. *Polar Research* 19:63-73.
- Young, Jr., D. D. 2015. Unit 20A caribou. Chapter 16, pages 16-1 through 16-12 *in* P. Harper, and L. A. McCarthy, eds. Caribou management report of survey and inventory activities 1 July 2012–30 June 2014. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2015-4, Juneau.

5. Dall Sheep (*Ovis dalli*)

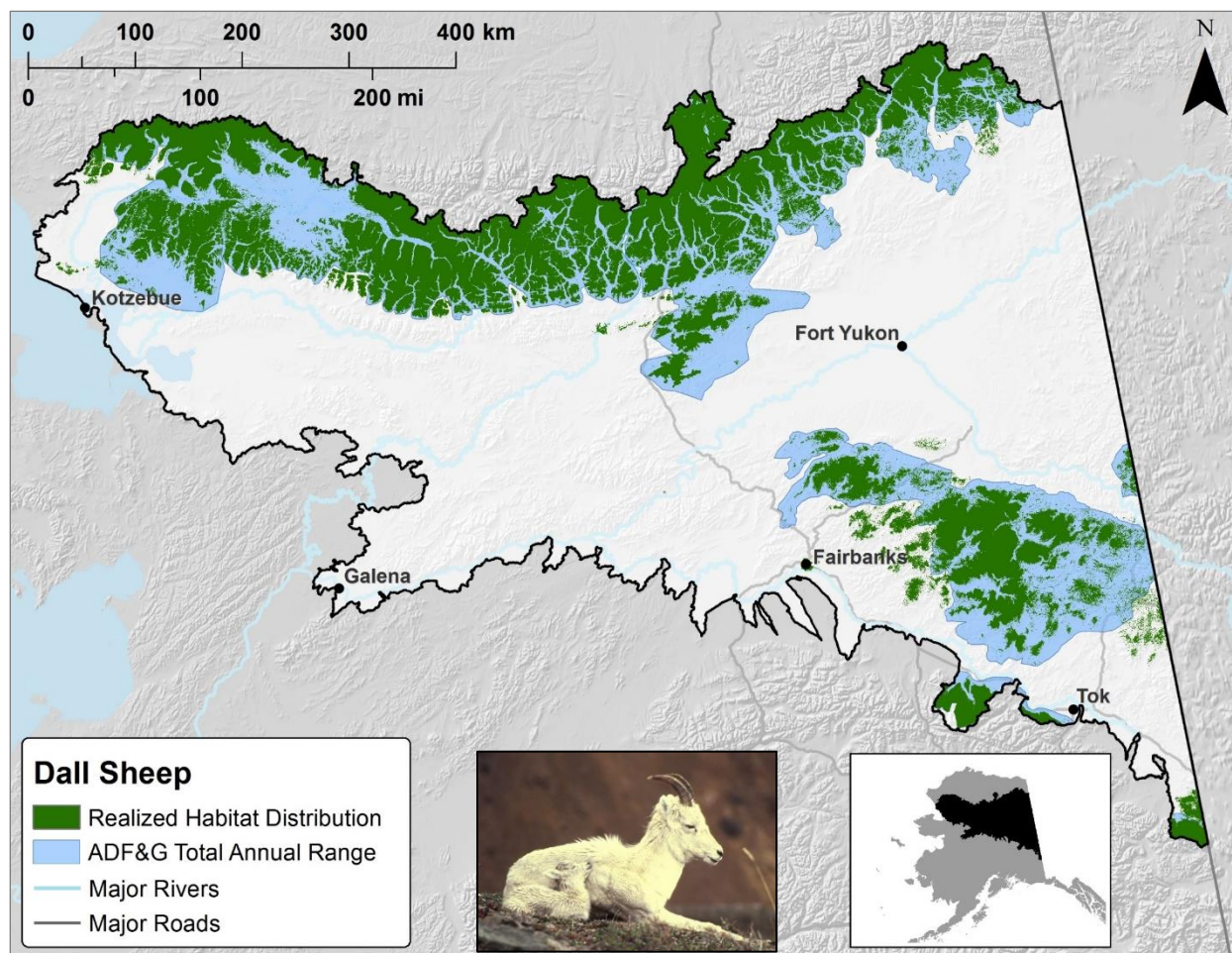


Figure H-19. Current realized habitat distribution and annual range of Dall sheep in the CYR study area. Dall sheep photo credit: J.R. Nickles, USFWS.

5.1 Introduction

Dall sheep inhabit Alaska's mountain ranges and are found in the highest, most rugged peaks and cliffs in the Central Alaska region (MacDonald and Cook 2009). They typically inhabit semi-open, steep terrain with rocky slopes, ridges, and cliffs or rugged canyons; dry mountainous terrain; and subalpine, low shrub-graminoid communities (Figure H-19). They are mainly present in alpine habitats or subalpine, low shrub areas (Craig and Leonard 2009) and forage on a variety of vegetation, such as forbs and grasses, during summer (Hansen 1996). During winter when vegetation is sparse, sheep seek out locations with shallow snow and increased forage accessibility. Winter forage consists of grasses, sedge stems, lichens, and mosses exposed on windblown slopes (Summerfield 1974, Craig and Leonard 2009).

Males and females typically live in sexually segregated groups throughout the year, coming together in late November and early December for mating. In spring (late May/early June), when

lambs are born, reproductive females prefer higher altitude habitat and rely on steep mountain areas for protection from predators (Lawson and Johnson 1982, Rachlow and Bowyer 1998).

Dall sheep are a valued subsistence and sport hunting species. Throughout the 1990s, large population declines were observed after several severe winters, causing the temporary closure of the hunting season (Shults 2004). General harvest season occurs primarily in August and September. Dall sheep lambs are preyed up by golden eagles (*Aquila chrysaetos*), wolverines (*Gulo gulo*), wolves (*Canis lupus*), brown bears (*Ursus arctos*), black bears (*Ursus americanus*), and coyotes (*Canis latrans*) (Koizumi 2012, Scotton 1997).

5.2 Conceptual Model

The conceptual model below (Figure H-20) is based on literature review and describes the relationship between the various CAs and natural drivers for Dall sheep. The boxes and arrows represent the state of knowledge about the Dall sheep and its relationships to each CA. The arrows and red text represent/describe relationships between the CAs, natural drivers, and primary habitat for Dall sheep. The primary CAs selected for this CE include: climate change and human uses (i.e., human development and land use change).

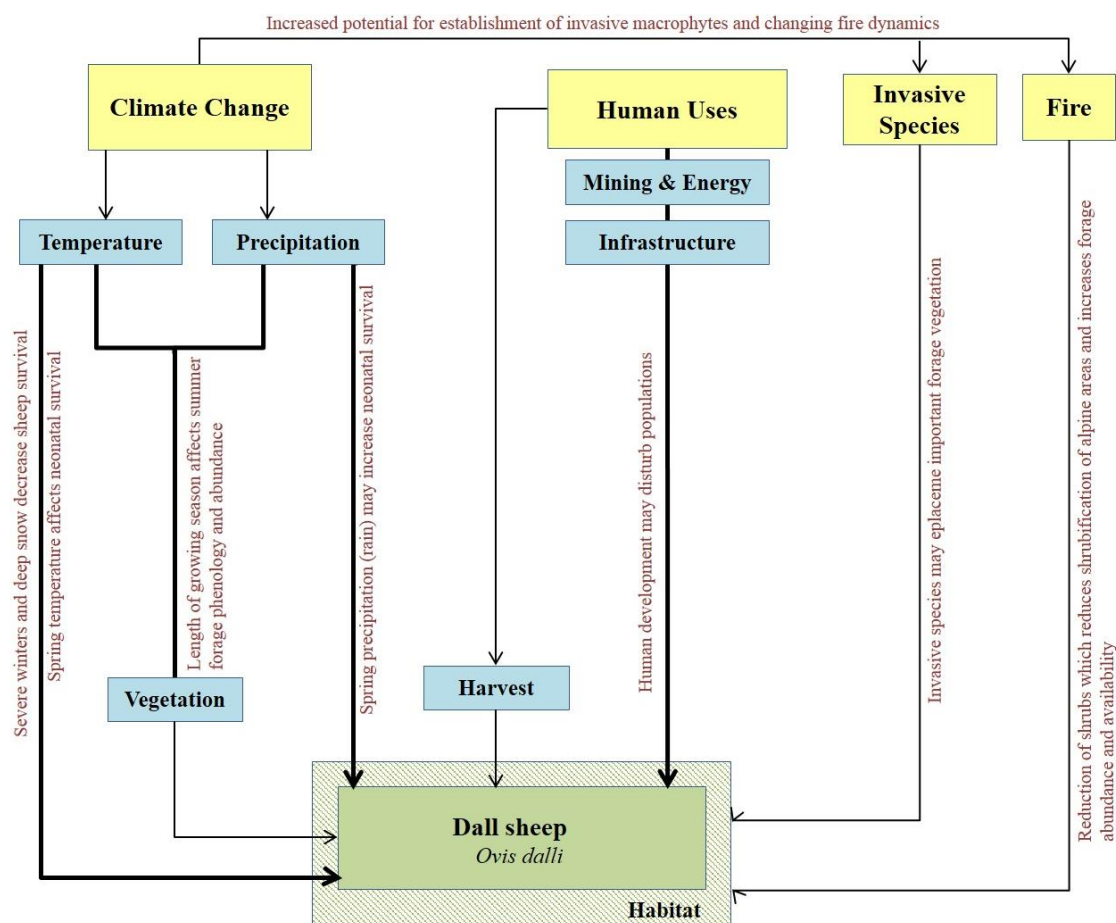


Figure H-20. Conceptual model describing the relationship between important CAs and natural drivers for Dall sheep.

5.3 Attributes and Indicators

Attributes and indicators helped to define the relationships between CEs and CAs, and, where possible, the thresholds associated with these relationships. Based on the assessment of available indicators, spatial data used to assess the status of Dall sheep included: length of growing season, spring temperature, spring precipitation, winter temperature, winter precipitation, and future treeline advancement (Table H-16).

Table H-16. Attributes and Indicators for the potential effect of various CAs and natural drivers on Dall sheep.

CA or Driver	Key Attribute	Indicator	Effect/ Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Vegetation shift ¹⁰	Shrub/treeline encroachment	Reduced habitat	Advancement of treeline into current habitat		Current treeline	Treeline retreat
	Pre-lambing forage availability ¹¹	Length of growing season	Late spring storms (i.e., snow) delay plant phenology and sheep parturition. Short growing season length reduces forage availability and reproductive success.	Shorter than average			Longer than average

¹⁰ Based on Lloyd and Fastie 2003, Myers-Smith et al. 2011

¹¹ Based on Rachlow and Bowyer 1998

Section H. Terrestrial Fine-filter Conservation Elements

CA or Driver	Key Attribute	Indicator	Effect/ Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Spring precipitation ¹²	Mean precipitation (AMJ)	Neonatal survival is positively affected by spring precipitation (independent of population density; Bighorn sheep)	Lower than average precipitation			Higher than average precipitation
	Spring temperature ¹³	Mean temperature (AMJ)	Neonatal winter survival is positively correlated with previous spring temperature (bighorn sheep)	Lower than average			
	Snow depth ¹⁴	Winter precipitation as snow	Population declines correlated with winters of deep snow	Deeper than average			Shallower than average
	Winter temperature ¹⁵	Mean temperature (DJF)	Severe winters decrease sheep survival	Colder than average			Warmer than average

¹² Based on Portier et al. 1998

¹³ Based on Portier et al. 1998

¹⁴ Based on Stephenson 2002, Nichols 1978

¹⁵ Based on Schults 2004

Section H. Terrestrial Fine-filter Conservation Elements

CA or Driver	Key Attribute	Indicator	Effect/ Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Fire	Fire ¹⁶	Relative fire frequency	Frequent wildfires reduce shrubification of alpine habitats and increase the abundance and availability of sheep forage.	Fire suppression; no burning			Frequent wildfires or prescribed burnings

¹⁶ Based on Bruning 2014

5.4 Abiotic Change Agents Analysis

To explore the relationship between Dall sheep and climate change, we assessed the effect of five climate variables on current Dall sheep habitat: length of growing season, mean spring temperature, mean spring precipitation, mean winter temperature, and mean winter precipitation at three time periods (current, near-term, and long-term). We also explored the potential for expansion of favored dwarf and low shrub habitats through comparison with ALFRESCO model outputs.

Length of Growing Season, Spring Temperature, and Spring Precipitation

Climate variables in the spring and summer have a large impact on Dall sheep reproduction and survival. Parturition timing and winter survival of lambs are linked to previous spring temperature and growing season length, with warmer springs and longer growing seasons resulting in earlier parturition and increased forage availability (Rachlow and Bowyer 1998, Portier et al. 1998). In addition, Dall sheep neonatal survival is positively correlated with spring temperatures of the previous year (Portier et al. 1998).

Throughout the Dall sheep habitat distribution in the CYR study area, climate models predict an increase in growing season length, a warming of spring temperatures, and an increase in spring precipitation (Figure H-21, Table H-17). These climatic changes may allow for earlier sheep parturition and greater reproductive success, especially for populations in the northern region of the CYR study area.

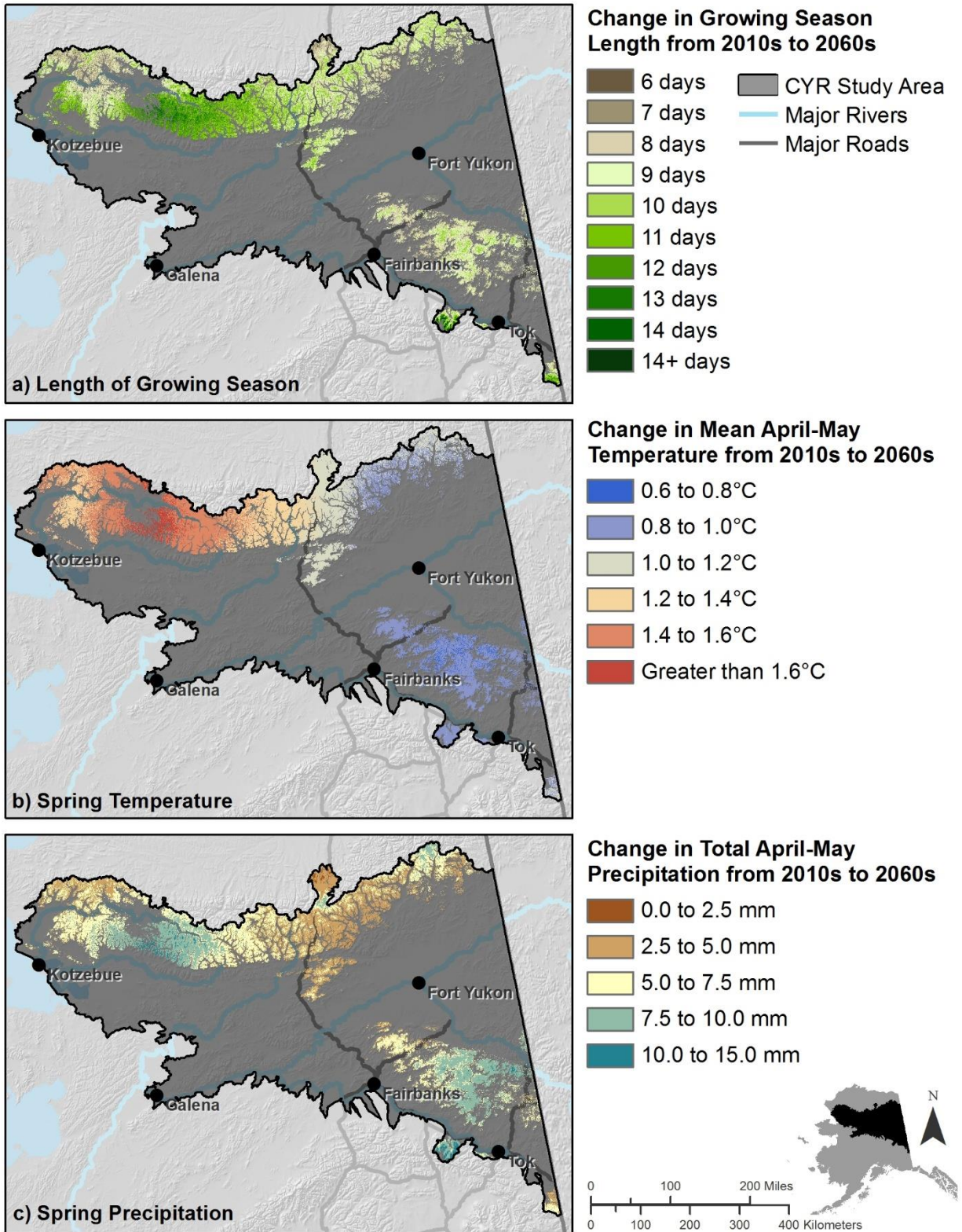


Figure H-21. Change in growing season length, mean April-May temperature, and total April-May precipitation from the 2010s to the 2060s within the realized habitat distribution of Dall sheep.

Table H-17. Percent of Dall sheep realized habitat distribution affected by change in length of growing season, mean April-May temperature, and total April-May precipitation for the near-term (2020s) and long-term (2060s) future.

Dall Sheep Habitat Distribution		Near-Term	Long-Term
Δ Length of Growing Season	No Change	21%	-
	0–6 Days	79%	-
	7–14 Days	-	99%
	> 14 Days	-	1%
	Range (Days)	-3 to 10	6 to 48
Δ Spring Temperature (April, May)	No Change	100%	-
	Significant Increase	-	100%
	Range (°C)	-0.15 to 0.45	0.75 to 1.75
Δ Spring Precipitation (April, May)	No Change	100%	3%
	Significant Increase	-	97%
	Range (mm)	-9 to 2	1 to 15

Winter Temperature

Dall sheep reproductive success and winter survival are highly correlated with winter weather (Shults 2004). Deep snow and severe winter temperatures can decrease sheep survival and result in population declines (Stephenson 2002, Schults 2004).

Throughout the Dall sheep habitat distribution in the CYR study area, a general winter warming trend is expected for the long-term future. This effect will be greatest in the northeastern region of the Dall sheep habitat distribution (Figure H-22).

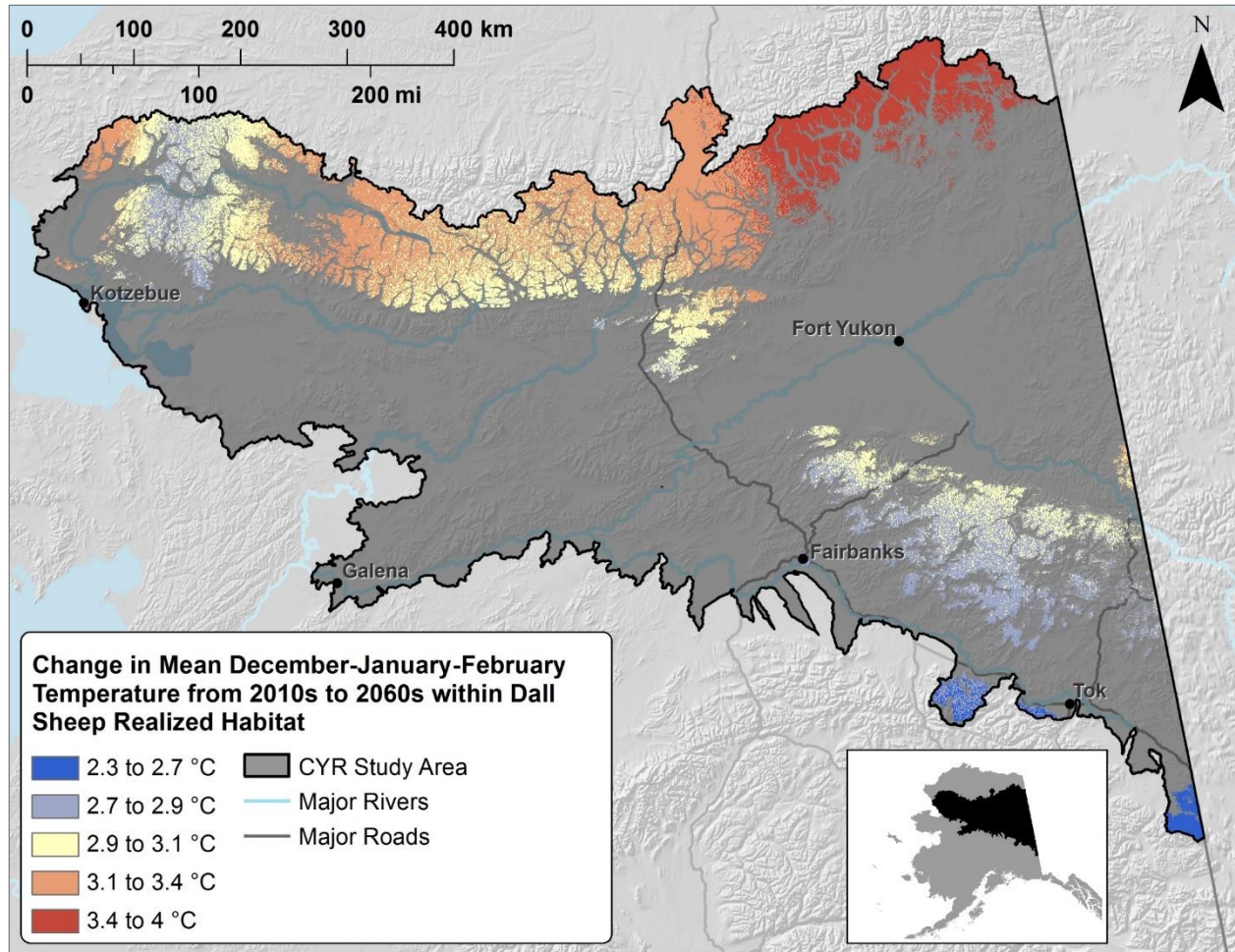


Figure H-22. Change in mean December-January-February temperature from the 2010s to the 2060s within the realized habitat distribution of Dall sheep.

Invasive Species

Direct impacts of invasive species on the Terrestrial Fine-filter CEs in these time periods seem unlikely. Invasive plant species may compete with native forage species in the future; however, invasive species are currently limited in the CYR study area and are not likely to expand enough within the next 50 years to have major impacts on Dall sheep habitat.

5.5 MQ N3: Sheep Distribution and Climate Change

MQ N3: How might Dall sheep distribution shift in relation to climate change?

Dall sheep habitat choices vary between seasons and are comprised of summer range, winter range, mineral licks, lambing areas, escape terrains, and travel routes between these areas (Bruning 2014, Hollis 2014, Wells 2014). During summer, sheep rely on *Dryas* dominated tundra with available forage (grasses and forbs) that is close to escape terrain (Bowyer and Leslie, Jr. 1992, Rachlow and Bowyer 1998, Walker et al. 2007). Predicted increases in low and tall shrub extent and the encroachment of forests into *Dryas* dominated alpine tundra may result in reduced habitat for Dall sheep in the CYR study area (Bruning 2014, Hollis 2014). In addition, Dial et al.

(2016) recently showed that declines in sheep populations over the past thirty years may be associated with the encroachment of taller shrubs into alpine habitat, which may reduce forage availability and/or support deeper winter snowpacks that restrict sheep movements and forage accessibility. Similar results have been found in Kluane National Park, Yukon (Henry et al. 2006).

To assess future shrub and treeline advancement throughout the CYR study area, we used the SNAP ALFRESCO model (see Section C. Abiotic Change Agents) restricted to the current Dall sheep habitat distribution. ALFRESCO classes do not correlate to Terrestrial Coarse-filter CEs or to traditional vegetation classifications used in Alaska. Therefore, an interpretation of how ALFRESCO predictions relate to Dall sheep habitat is tenuous. Because ALFRESCO classes were compiled to predict future fire behavior rather than vegetation change, many uncertainties remain regarding what ALFRESCO predictions mean in an ecological sense.

Within current Dall sheep habitat, the ALFRESCO shrub tundra class is predicted to shift with a gain of 3.2% and a loss of 1.6%. The net gain of 1.6% in the ALFRESCO shrub tundra class suggests an overall increase in available alpine dwarf shrub and alpine and Arctic tussock tundra (Figure H-23). However, the predicted gain in ALFRESCO shrub tundra does not necessarily correlate to an overall increase in Dall sheep habitat because likely habitat is spread among additional ALFRESCO classes, most notably ALFRESCO graminoid tundra. Instead, 1.1% predicted gain and no predicted loss in the ALFRESCO forest classes, which include low and tall shrub tundra, suggest that an overall loss of Dall sheep habitat is likely as forest and low and tall shrub tundra encroach on alpine vegetation that constitute most current Dall sheep habitat. Another possibility is that Dall sheep habitat in the southern half of the study area will shrink while habitat in the Brooks Range will shift to higher elevations as the alpine dwarf shrub and graminoid tundra expand upward to elevations where they do not currently exist. Shrubification is likely to reduce forage and habitat availability, at least in the southern portion of the study area; however, because females show high site fidelity to summer and lambing areas (Walker et al. 2007), displacement or movements of females to new summer sites may not occur.

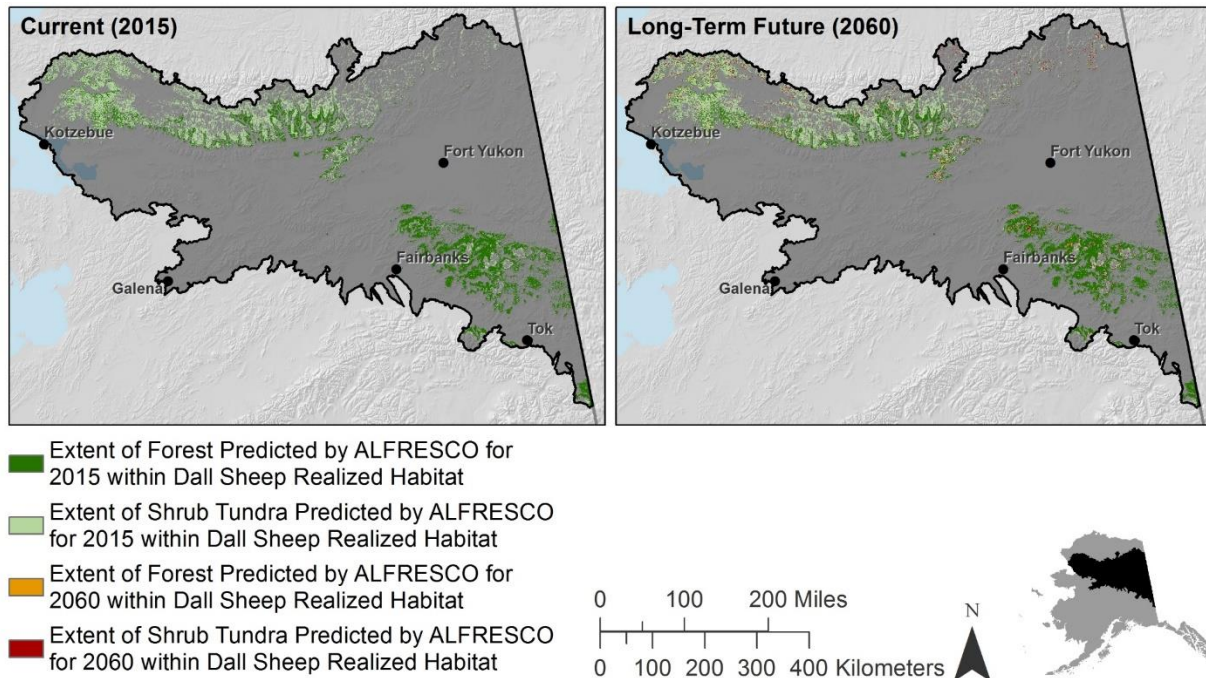


Figure H-23. Current (2015) and long-term future (2060) extent of ALFRESCO forest and shrub tundra classes within the realized habitat distribution of Dall sheep.

Snow depth is also an important factor in determining Dall sheep movements and distribution amongst foraging grounds (Siep and Bunnell 1985, Walker et al. 2007). Sheep tend to avoid areas with snow depths greater than 30 cm (Seip and Bunnell 1985) and will congregate and overgraze in other parts of their range when snow depths reach these levels.

An increase in winter precipitation is expected throughout the northwestern portion of the Dall sheep habitat distribution in the CYR study area (Figure H-24). In the Brooks Range (the northern portion of the study area), a majority of the precipitation is expected to fall as snow, which potentially suggests deeper snow packs in this region, however, given variation in wind and topography at the site level, this may not occur equally across sites and may be more relevant for valley sites. An increase in precipitation falling as rain (Figure H-25) may indicate more rain-on-snow events in the southeast portion of the Dall sheep habitat distribution. Both deep and hard snow packs deter sheep movements in these areas and can reduce reproductive success (Nichols 1978, Walker et al. 2007).

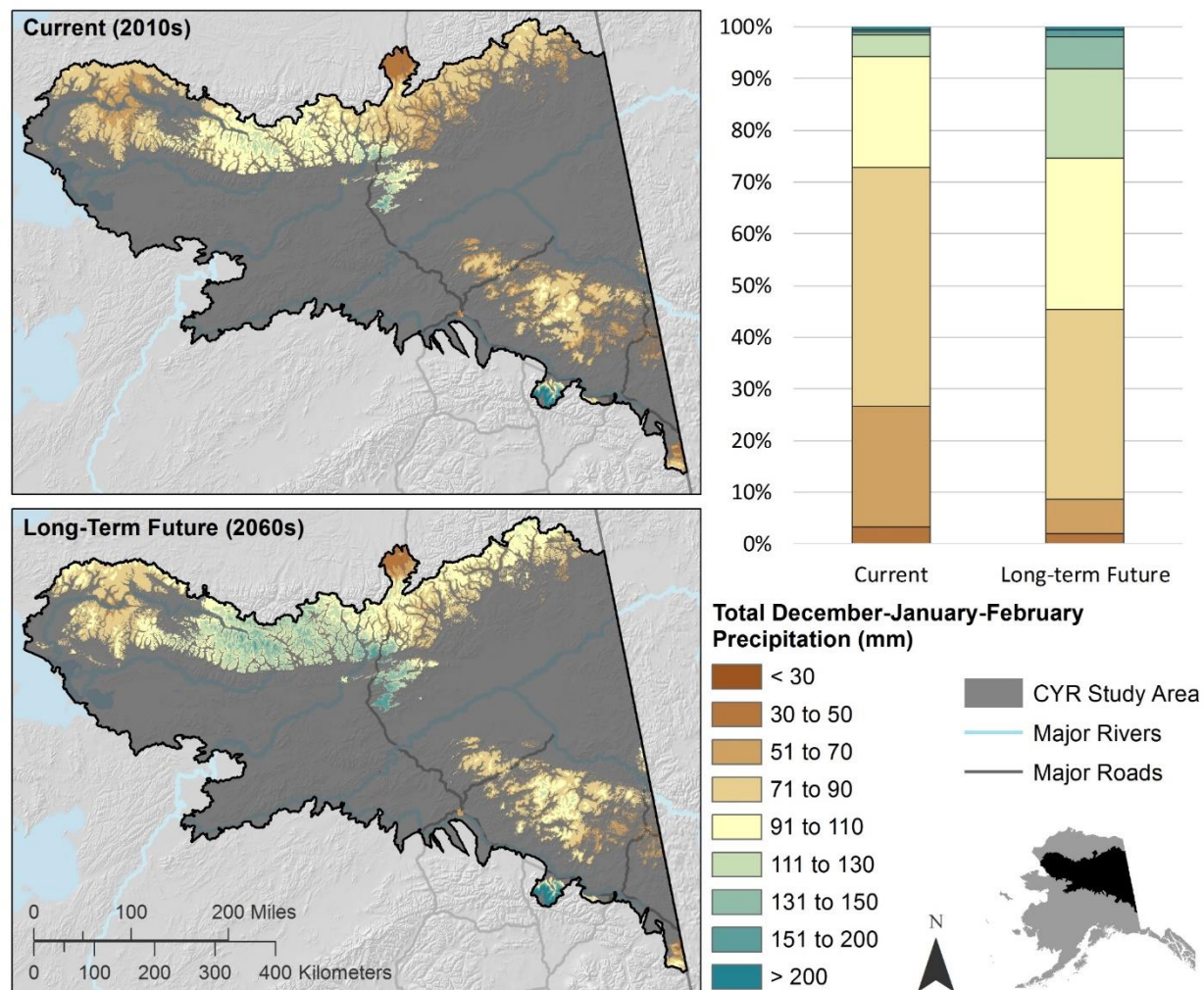


Figure H-24. Current (2010s) and long-term future (2060s) total December-January-February precipitation within the realized habitat distribution of Dall sheep.

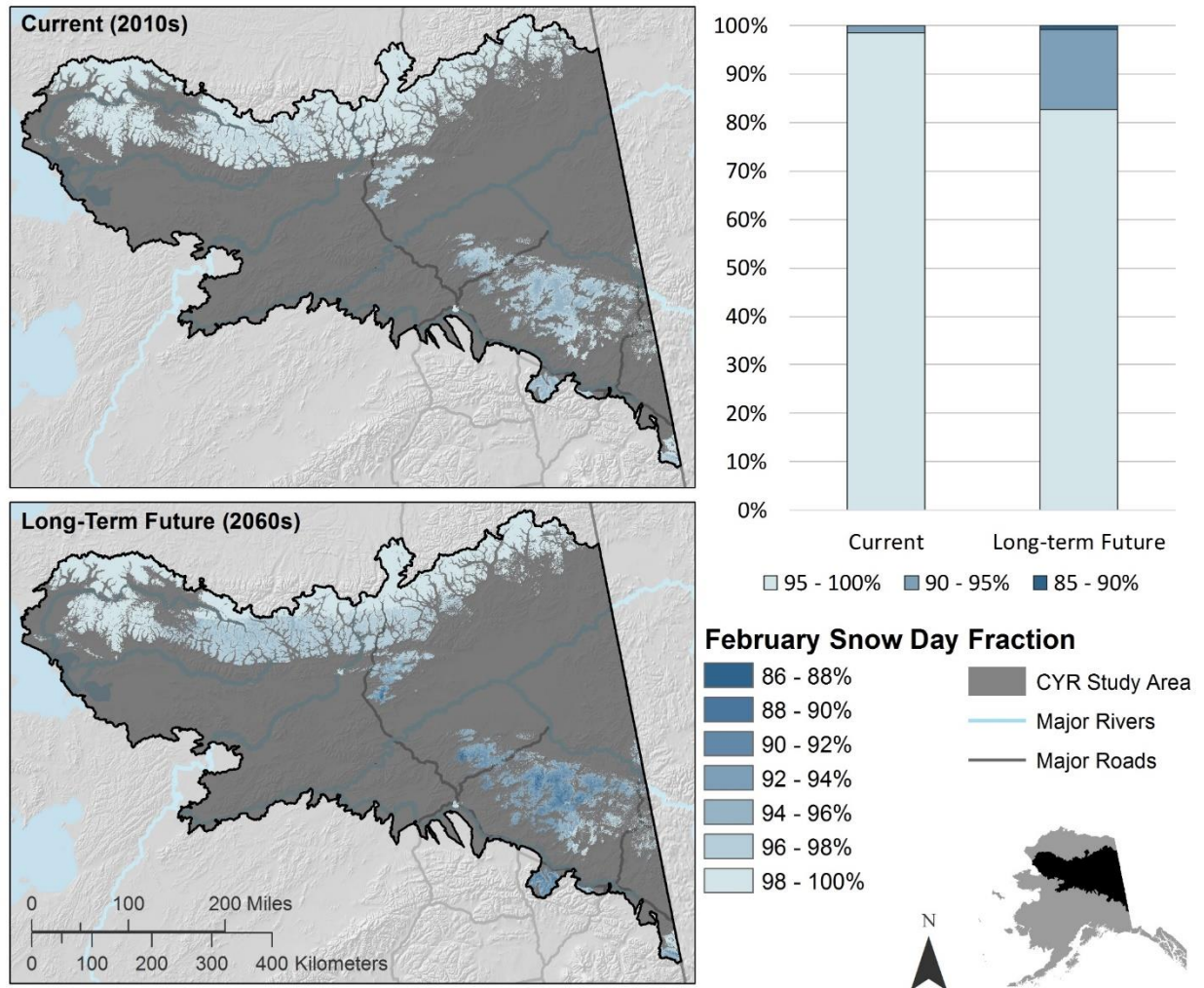


Figure H-25. Current (2010s) and long-term future (2060s) February snow day fraction within the realized habitat distribution of Dall sheep.

5.6 Current Status and Future Landscape Condition

Human disturbance can have a negative effect on Dall sheep, and aside from shrubification of current habitat, is considered to be one of the main threats for Dall sheep populations in the CYR study area (Bruning 2014, Hollis 2014, Wells 2014). Low-flying aircraft and loud machinery can disturb sheep and cause increased energy expenditure and/or reduced foraging (Frid 2002, Lawler et al. 2005). Sheep are also susceptible to disease introduced by domestic livestock (Foreyt et al. 1996). Landscape condition in much of the CYR study area is considered ‘very high.’ The main areas of impact for Dall sheep are associated with the Ambler mining district and new forestry roads around Fairbanks. The area associated with very high landscape condition is expected to decrease by 1.8% within the current Dall sheep habitat distribution, possibly resulting in localized impacts to Dall sheep populations throughout the CYR study area (Figure H-26).

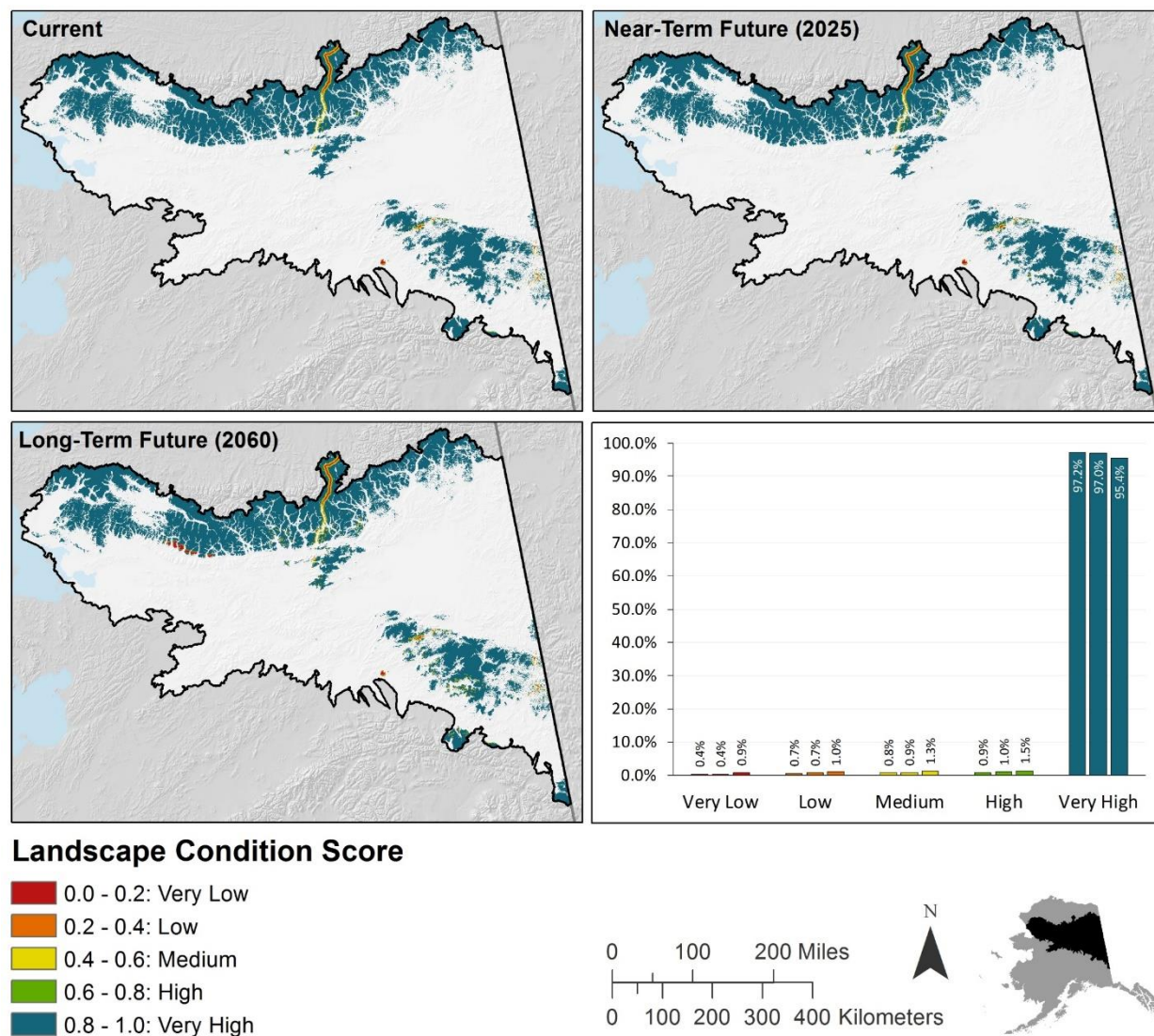


Figure H-26. Current, near-term, and long-term landscape condition within the realized habitat distribution of Dall sheep.

5.7 Summary

Future projections relevant to Dall sheep suggest that throughout the CYR study area, there will be an increase in length of growing season, spring temperature, spring precipitation, and winter temperature (Table H-18). Increased growing season length, spring temperature, and spring precipitation may promote juvenile survival throughout the Dall sheep distribution in the CYR study area. In addition, increased winter temperature may promote adult winter survival, suggesting that climate change will have a positive effect on Dall sheep populations. However, these changes in climate variables may also support shifts in vegetation (e.g., shrubification) and increased disease, which may reduce forage and habitat availability and cause negative effects for sheep populations. Furthermore, future increases in the extent of low and tall shrub and increased winter snow depth may reduce Dall sheep habitat and drive populations to higher altitudes. Mineral exploration and human development are also expected to have a negative

impact on sheep populations in localized regions. Invasive species are not expected to have a significant impact on Dall sheep in the next 50 years.

Table H-18. Summary and projected effects of change agents used in the assessment for Dall sheep in the CYR study area.

Indicator	Short-term change	Long-term change	Effect on CE in CYR study area	Impact
Length of growing season	+	+	+/-	Forage availability and reproductive success
Spring temperature	No change	+	+/-	Juvenile survival
Spring precipitation	+	+	+	Juvenile survival
Winter temperature	+	+	+	Survival
Winter precipitation	+	+	-	Forage and habitat availability
Snow day fraction	-	-	-	Forage and habitat availability
Treeline advancement and shrubification	+	+	-	Forage and habitat availability
Landscape condition	Minimal change	-	-	Body condition/survival
Invasive species	N/A	N/A	None	None

5.8 Limitation and Data Gaps

Snow depth is an important climate variable that has an impact on sheep survival (Stephenson 2002). Having accurate measures of snow depth will allow for more accurate predictions of future climate impacts on Dall sheep populations in the CYR area. It should be noted that when considering winter precipitation predictions, uncertainty in precipitation projections is relatively high, and due to variation in wind and topography across sites, winter precipitation does not directly translate to increased snow depth.

It is important to note that this study was limited to assessing the effect of specific CAs on CEs that we could spatially model and that had strong cause-and-effect linkages in the literature. There may be additional factors not addressed in this study that play an important role in determining the status of Dall sheep throughout the CYR study area.

ALFRESCO classes do not correlate to Terrestrial Coarse-filter CEs or to traditional vegetation classifications used in Alaska. Because ALFRESCO classes were compiled to predict future fire behavior rather than vegetation change, many uncertainties remain regarding what ALFRESCO predictions mean in an ecological sense. Interpretation of ALFRESCO predictions is more difficult because ALFRESCO classes do not correlate to Dall sheep habitat. For example, occurrence records exist in what ALFRESCO classifies as "forest." A finer scale and ecologically oriented

vegetation prediction model would greatly enhance the ability to determine potential climate change impacts to Dall sheep habitat within a 50-year time frame.

5.9 Datasets and Literature Cited

Table H-19. Datasets used for analysis of Dall sheep in the CYR study area.

Dataset	Dataset Description	Dataset Provider	Data Type	Dataset Last Updated	Restrictions
Alaska GAP Analysis terrestrial vertebrate occurrence database—Dall sheep	This dataset contains 135 point occurrence records for Dall sheep acquired from numerous data sources for the Alaska Gap Analysis Project.	Alaska Center for Conservation Science	Point	2009	Not for publication and/or redistribution
Dall sheep occurrence points—Gates of the Arctic NPP, Noatak NP, Kobuk Valley NP	Sheep survey data 2005–2011 (July). During 2005–2007 NPS was testing a stratified random sampling design and surveying random units of varying sizes. 2009–2011 distance sampling surveys were conducted, therefore, locations are limited to the units or transects surveyed.	National Park Service	Point	2011	Data points are sensitive and are not available for re-distribution or replication in any published documents.
Dall sheep occurrence points—Tanana Hills-White Mountains	Dall sheep radio collar location data for Tanana Hills-White Mountains collected from 2004-2008.	US Fish and Wildlife Service	Point	2008	Data points are sensitive and are not available for re-distribution or replication in any published documents.
Dall sheep range maps	Polygon ranges of Dall sheep in Alaska. Digitized from the 1985 ADF&G Habitat Management Guide and modified in 2015 by ADF&G to reflect updates in known sheep ranges.	Alaska Department of Fish and Game	Polygon shape file	2015	None
BISON Dall sheep occurrence records	This dataset contains 215 point occurrence records for Dall sheep compiled by Biodiversity Information Serving Our Nation (BISON), an integrated and permanent resource for biological occurrence data from the United States. Date range of occurrence records is 1952 through 2014.	Biodiversity Information Serving Our Nation (BISON)	Point	2014	Use of data must be cited according to BISON data user agreement [†]

[†]Data user agreement available online: <http://bison.usgs.gov/about>

Literature Cited

- Alaska Department of Fish and Game (ADF&G). 1985. Alaska habitat management guides – Interior and Arctic regions MAP ATLAS. Alaska Department of Fish and Game Division of Habitat, Juneau, Alaska.
- Bowyer, R. T., and D. M. Leslie, Jr. 1992. *Ovis dalli*. Mammalian Species 393:1-7.
- Bruning, D. L. 2014. Units 20B, 20D and 20E Dall sheep. Chapter 13, pages 13-1 through 13-13 in P. Harper, and L. A. McCarthy, eds. Dall sheep management report of survey and inventory activities 1 July 2010–30 June 2013. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2014-4, Juneau.
- Craig, T. H. and P. Leonard. 2009. Dall sheep use of areas of critical environmental concern in the utility corridor management area, Alaska. U.S. Department of the Interior, Bureau of Land Management, Alaska.
- Dial, R. J., T. S. Smeltz, P. F. Sullivan, C. L. Rinas, K. Timm, J. E. Geck, S. C. Tobin, T. S. Golden, and E. C. Berg. 2016. Shrubline but not treeline advance matches climate velocity in montane ecosystems of Southcentral Alaska. *Global Change Biology* 22:1841-1856.
- Foreyt, W. J., R. M. Silflow, and J. E. Lagerquist. 1996. Susceptibility of Dall sheep (*Ovis dalli dalli*) to pneumonia caused by *Pasteurella haemolytica*. *Journal of Wildlife Diseases* 32:586-593.
- Frid, A. 2002. Dall sheep responses to overflights by helicopter and fixed-wing aircraft. *Biological Conservation* 110:387-399.
- Hansen, M. C. 1996. Foraging ecology of female Dall's sheep in the Brooks Range, Alaska. PhD thesis. University of Alaska Fairbanks, Fairbanks, Alaska.
- Henry, J. D., C. J. Krebs, E. Hofer, A. J. Kenney, and A. Chilibeck. 2006. The Kluane ecological monitoring project annual report 2005/2006. Prepared for: Kluane National Park and Reserve of Canada, Parks Canada Agency. Haines Junction, Yukon Territory. 29 pp.
- Hollis, A. L. 2014. Units 20B, 20F, and 25C Dall sheep. Chapter 12, pages 12-1 through 12-12 in P. Harper, and L. A. McCarthy, eds. Dall sheep management report of survey and inventory activities 1 July 2010–30 June 2013. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2014-4, Juneau.
- Koizumi, C. L. 2012. Dall sheep (*Ovis dalli dalli*), grizzly bear (*Ursus arctos*) and wolf (*Canis lupus*) interactions in the northern Richardson Mountains, Canada. Ph.D. Dissertation, University of Alberta, Edmonton, Alberta.
- Lawler, J. P., B. Griffith, D. Johnson, and J. Burch. 2005. The effects of military jet overflights on Dall's sheep in Interior Alaska: report to the Department of the Air Force, 11th U.S. Air Force, Elmendorf Air Force Base, Alaska. U.S. Department of the Interior, National Park Service, Technical Report NPS/AR/NRTR-2005-50; NPS D-31, Alaska Support Office, Anchorage, Alaska.
- Lawson, B., and R. Johnson. 1982. Mountain sheep. In J. A. Chapman, and G. A. Feldhamer, eds. *Wild mammals of North America: biology, management, and economics*. Johns Hopkins University Press, Baltimore. 1147 pp.
- Lloyd, A. H., and C. L. Fastie. 2003. Recent changes in treeline forest distribution and structure in Interior Alaska. *Ecoscience* 10:176-185.
- MacDonald, S. O., and J. A. Cook. 2009. *Recent mammals of Alaska*. University of Alaska Press, Fairbanks, Alaska.
- 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. L'évesque, 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. Hi. 2011. Shrub expansion in tundra ecosystems: dynamics, impacts and research priorities. *Environmental Research Letters* 6:045509.

Section H. Terrestrial Fine-filter Conservation Elements

- Nichols, L. 1978. Dall sheep reproduction. *The Journal of Wildlife Management* 42:570-580.
- Portier, C., M. Festa-Bianchet, J. M. Gaillard, J. T. Jorgenson, and N. G. Yoccoz. 1998. Effects of density and weather on survival of bighorn sheep lambs (*Ovis canadensis*). *Journal of Zoology* 245:271-278.
- Rachlow, J. L., and R. T. Bowyer. 1998. Habitat selection by Dall sheep (*Ovis dalli*): maternal trade-offs. *Journal of Zoological Society of London* 245:457-465.
- Scotton, B. D. 1997. Estimating rates and causes of neonatal lamb mortality of Dall sheep in the Central Alaska Range. Federal Aid in Wildlife Restoration Research Report: Study 6.12. Alaska Department of Fish and Game.
- Seip, D. R., and F. L. Bunnell. 1985. Foraging behaviour and food habits of Stone's sheep. *Canadian Journal of Zoology* 63:1638-1646.
- Shults, B. S. 2004. Abundance survey of Dall sheep in the western Baird Mountains, Alaska, July 2004. Technical Report NPS/AR/NRTR-2004-46. U.S. Department of the Interior, National Park Service. Anchorage, Alaska.
- Stephenson R. O. 2002. Game Management Units 24 East, 25A, 26B, and 26C (49,600 mi²). Pages 172–185 in C. Healy, ed. Dall sheep management report of survey-inventory activities: 1 July 1998–30 June 2001, Alaska Department of Fish and Game, Project 6.0, Juneau, Alaska.
- Summerfield, B. L. 1974. Population dynamics and seasonal movement patterns of Dall sheep in the Atigun Canyon area, Brooks Range, Alaska. M.S.Thesis, University of Alaska Fairbanks.
- Walker, A. B. D., K. L. Parker, M. P. Gillingham, D. D. Gustine, and R. J. Lay. 2007. Habitat selection by female Stone's sheep in relation to vegetation, topography, and risk of predation. *Ecoscience* 14:55-70.
- Wells, J. J. 2014. Portions of units 12, 13C, and 20D Dall sheep. Chapter 6, pages 6-1 through 6- 16 in P. Harper, and L. A. McCarthy, eds. Dall sheep management report of survey and inventory activities 1 July 2010–30 June 2013. Alaska Department of Fish and Game, Species Management Report ADF&G/DWC/SMR-2014-4, Juneau.

6. American Beaver (*Castor canadensis*)

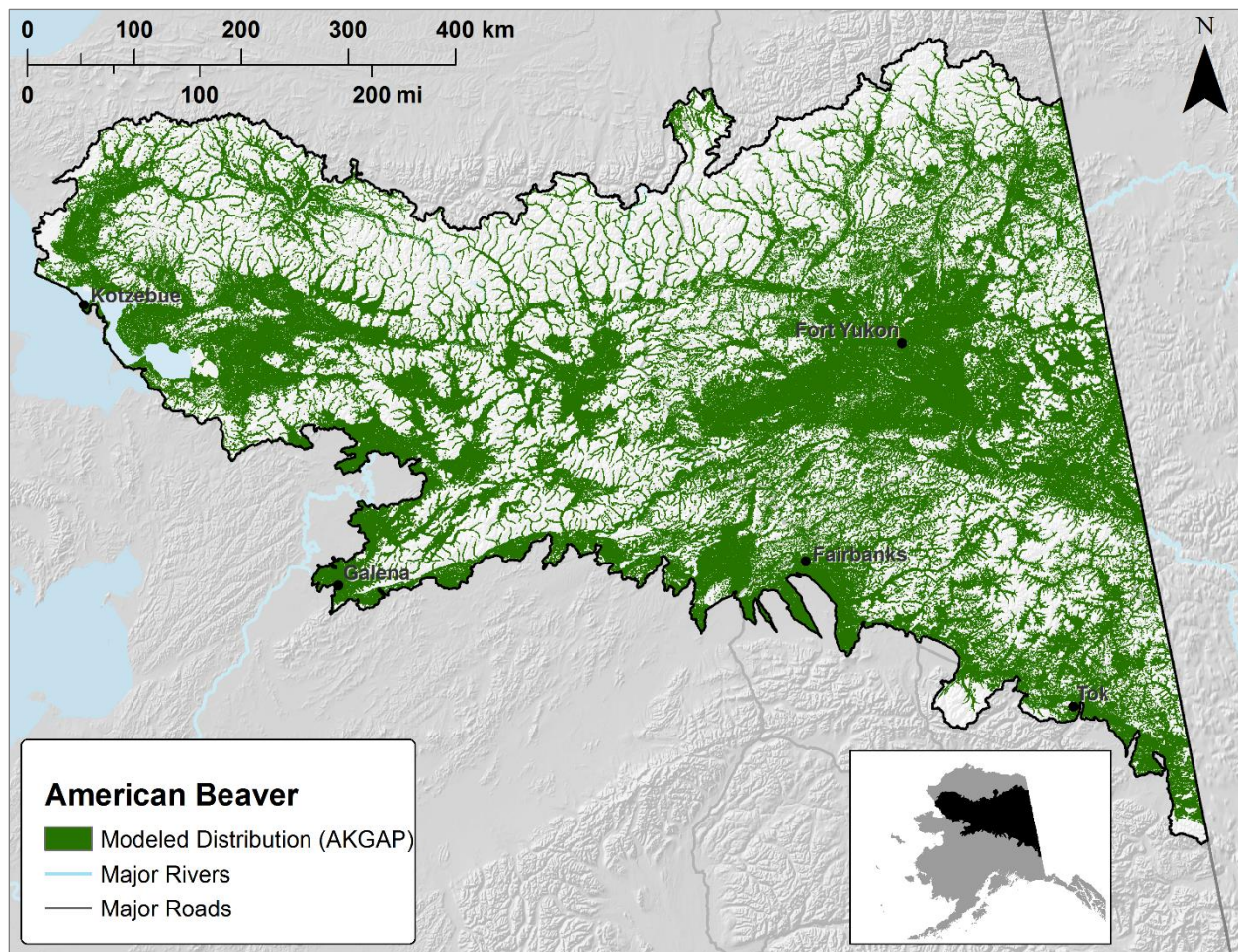


Figure H-27. Current potential habitat distribution of American beaver in the CYR study area.

6.1 Introduction

American beaver is found throughout Alaska and is an important subsistence species. It inhabits permanent waterbodies such as lakes, ponds, rivers, and streams (MacDonald and Cook 2009) and typically prefers wide valleys and streams with low gradient channels (Allen 1983, Baker and Hill 2003; Figure H-27). Beavers forage close to the waterbody they inhabit (within 200 m), using resources that are closer first and then moving out in distance as resources are depleted. Population size is typically limited by food availability. In summer, their diet consists of herbaceous and deciduous woody vegetation, and in late fall, winter, and early spring they consume primarily trees and shrubs stored in their winter cache (Allen 1983). Willow, aspen, cottonwood, and alder are preferred over other tree/shrub species (Boyle and Owens 2007).

Beavers create suitable habitat by building dams, lodges, and dens. Lodges and dens provide protection from predation and weather. Dams act to restrict water flow, increase water depth, and expand the surrounding shoreline. This obstruction alters the flow and availability of nutrients in

the water, increases water depth that assists winter survival, and increases shoreline forage availability for beaver (Baker and Hill 2003, Boyle and Owens 2007).

Predators include large predators such as wolves, brown bears, and black bears (Boertje et al.1988). Beaver pelts are used for cold weather clothing such as coats, hats, and mittens. Approximately 1,300 beavers are harvested annually, many for personal use (ADF&G 2013).

6.2 Conceptual Model

The conceptual model below (Figure H-28) is based on literature review and describes the relationship between the various CAs and natural drivers for American beaver. The boxes and arrows represent the state of knowledge about the American beaver and its relationships to each CA. The arrows and red text represent/describe relationships between the CAs, natural drivers, and primary habitat for American beaver. The primary CAs selected for this CE include: climate change and human uses, such as land use change.

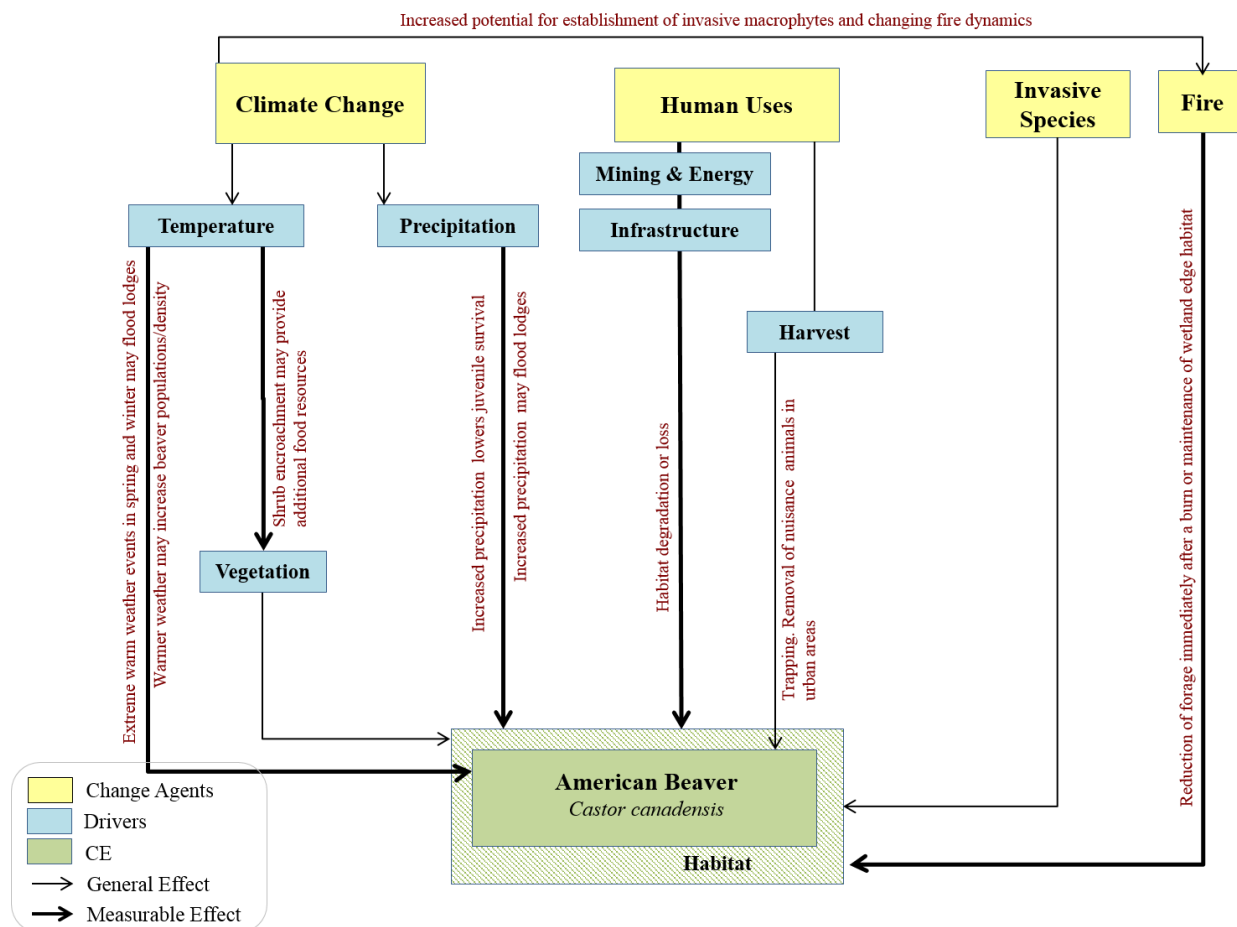


Figure H-28. Conceptual model describing the relationship between important CAs and natural drivers for American beaver.

6.3 Attributes and Indicators

Attributes and indicators helped to define the relationships between CEs and CAs, and, where possible, the thresholds associated with these relationships. Based on the assessment of available indicators, spatial data used to assess the status of American beaver included: spring precipitation, summer temperature and landscape condition (Table H-20).

Table H-20. Attributes and Indicators for the potential effect of various CAs and natural drivers on American beaver.

CA or Driver	Key Attribute	Indicator	Effect/ Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Temperature	Mean annual temp; Spring temp (April, May); Max summer (JJA) temp ¹⁷	Beaver population densities are limited by mean annual temperature and maximum spring and summer temperatures	Mean annual temp <5.1C, max spring temp <-1.4C, max summer temp <15.2C		Mean annual temp >5.1C, max spring temp >-1.4C, max summer temp >15.2C	
	Spring/summer precipitation	Mean precipitation (April, May, June, July) ¹⁸	Higher juvenile survival rates are linked to lower mean precipitation	Higher mean precipitation (flooding)			Lower mean precipitation

¹⁷ Based on Jarema et al. 2009

¹⁸ Based on Campbell et al. 2012

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CA or Driver	Key Attribute	Indicator	Effect/ Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Anthropogenic Development	Human disturbance ¹⁹	Landscape condition model	Human development can cause habitat degradation and loss due to changes in stream morphology and hydrology.	High levels of human disturbance/development	Moderate levels of human disturbance/development	Low levels of human disturbance/development	No human disturbance/development

¹⁹ Based on Slough and Sadleir 1977, Boyle and Owens 2007

6.4 Abiotic Change Agents Analysis

We explored the relationship between American beaver and two climate variables: spring precipitation and mean summer temperature at three time steps (current, near-term, and long-term).

Annual Temperature and Spring Precipitation

Beaver population densities are limited by mean annual temperature, maximum spring (April, May) temperature, and maximum summer (June, July, August) temperatures (Figure H-29; Jarema et al. 2009). Mean annual temperatures colder than 5.1 °C inhibit population growth, while temperatures warmer than 5.1 °C allow for higher population densities.

Currently, over 95% of the CYR study area meets the minimum summer temperature threshold necessary for beaver presence (Table H-21, Figure H-30). A general warming trend projected for the long-term future may support summer conditions that favor high beaver densities. This effect will be most prominent in the central part of the region.

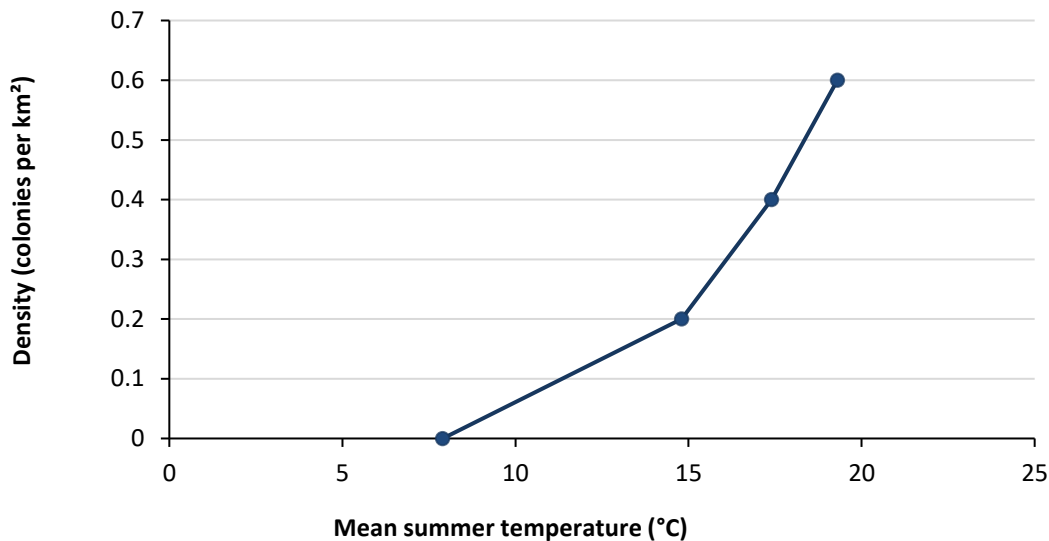


Figure H-29. Relationship between summer temperature and beaver density (Sampson and Murray, pers. comm. 2014, Jarema et al. 2009).

Table H-21. Percent area of current beaver habitat distribution in the CYR study area categorized by mean decadal June-July-August temperatures (°C) for current (2010s), near-term future (2020s), and long-term future (2060s). 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).

Time Period	Percent Area (%)		
	< 7.9 °C	7.9–14.8 °C	> 14.8 °C
Current	3.4	80	16.5
Near-Term	2.9	76.1	20
Long-Term	1.7	53.5	28.3

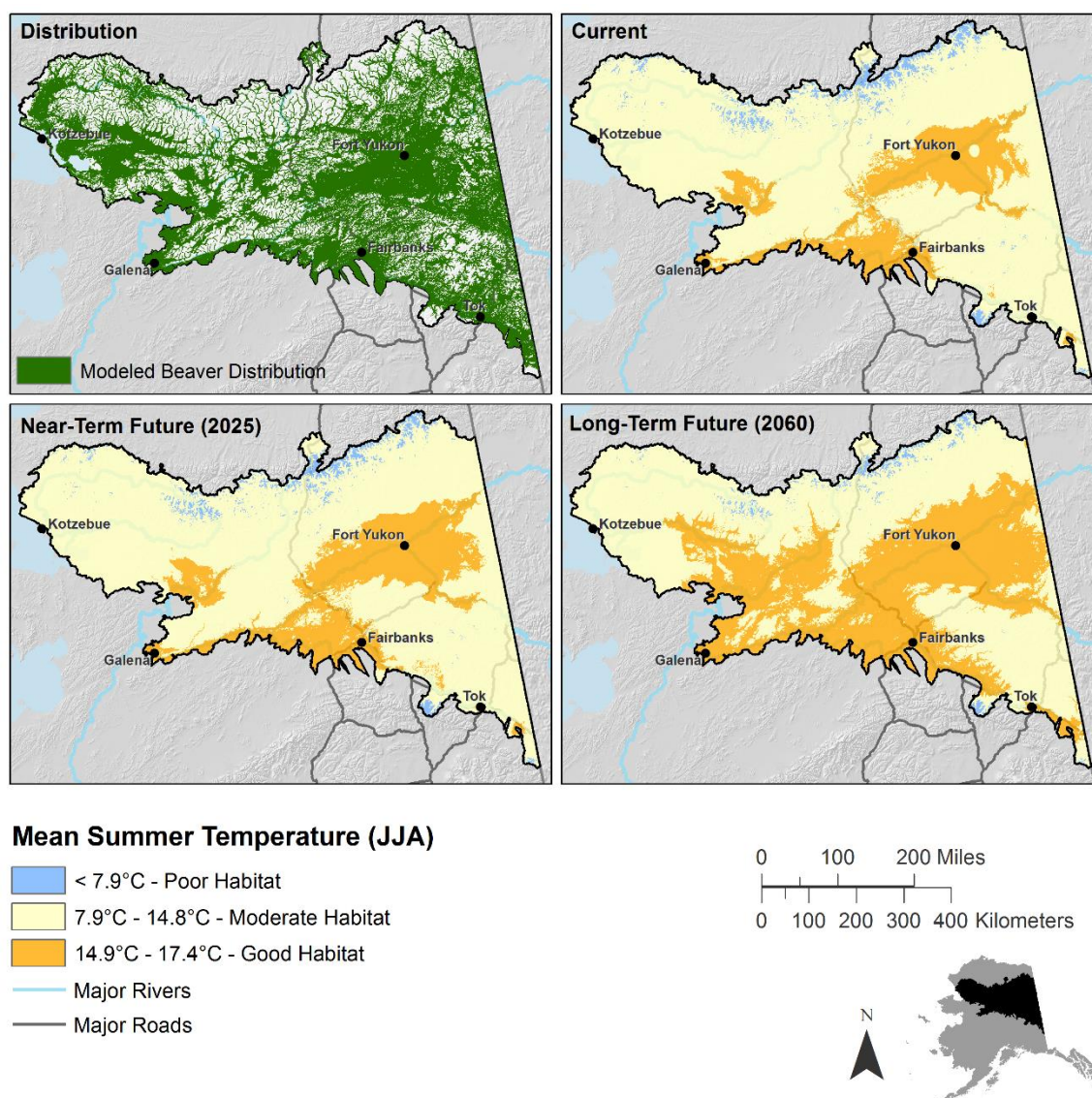


Figure H-30. Current (2010s), near-term future (2020s), and long-term future (2060s) mean June-July-August temperature categorized by American beaver habitat quality (Jarema et al. 2009) and current American beaver potential habitat distribution within the CYR study area.

Potential adverse effects of climate change on beavers include the reduction in habitat caused by the drying and warming of wetlands and increased spring precipitation, which can negatively impact juvenile survival (Campbell et al. 2012). However, future increases in spring precipitation are expected to be relatively low (Table H-22, Figure H-31), and beavers can create and maintain areas of open water. Beavers are often able to regulate water levels in their ponds during cycles of drought and flooding (Hood and Bayley 2008, Bird et al. 2011). Although beavers are resilient and less likely to be impacted by climate change than other species, extreme warm weather events in winter and spring can cause sudden snowmelt and violent ice breakups that raise water levels, destroy lodges, and drown large numbers of beavers (Hakala 1952).

Table H-22. Current (2010s) and long-term future (2060s) April-May precipitation within the potential habitat distribution of American Beaver.

American Beaver	Δ Spring Precipitation (AM)		
	No Change	Significant Increase	Range (mm)
Near-term	100%	-	-7 to 2
Long-term	34%	66%	0 to 12

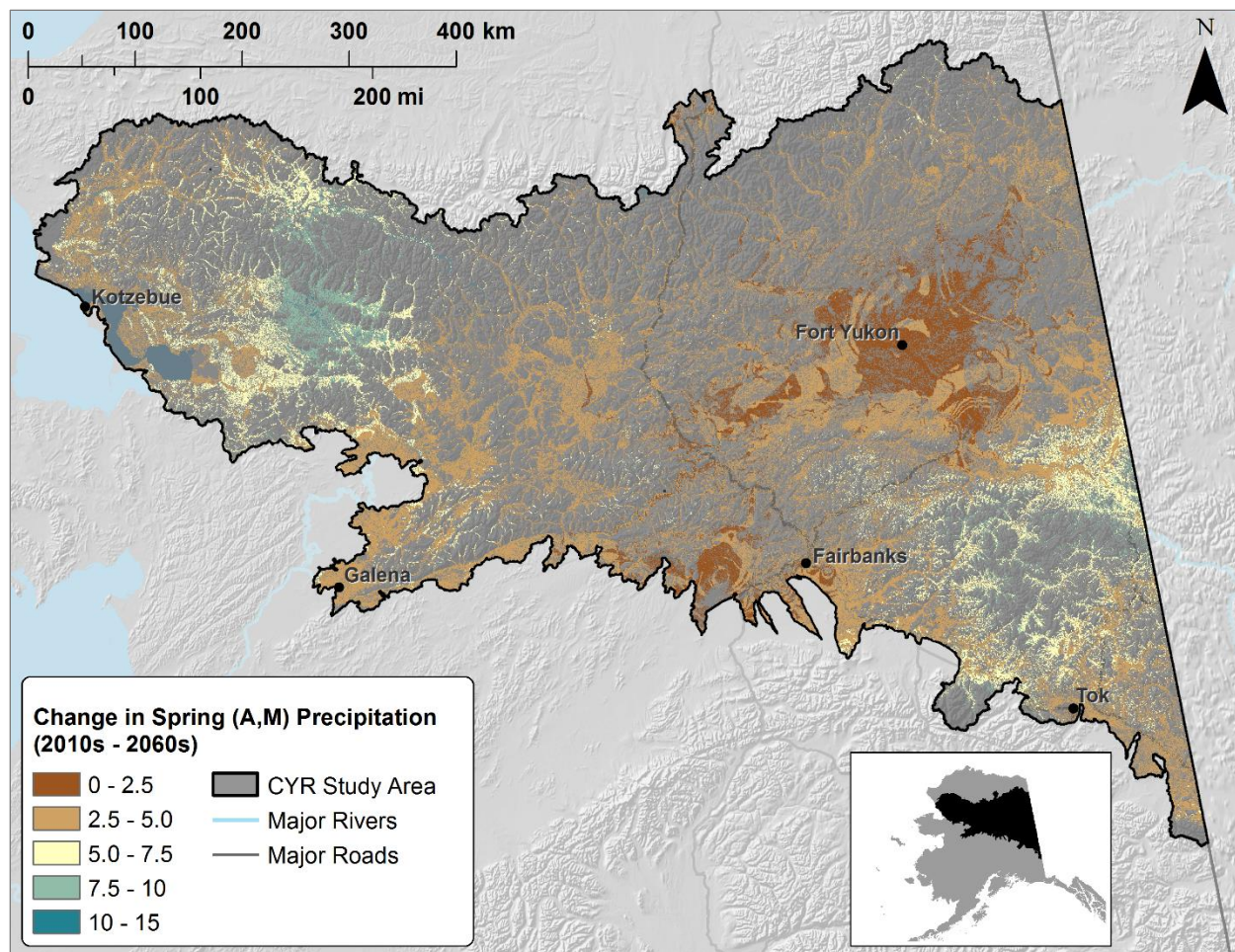


Figure H-31. Change in mean April-May precipitation from the 2010s to the 2060s within the potential habitat distribution of American beaver.

Fire

Forest fires within beaver habitat can have both positive and negative effects on beaver populations. Reduced woody vegetation in extensively burned areas decreases forage availability, requiring greater foraging distances and/or relocation. Predation risk may increase as beavers move through open burned areas. Studies in central Canada have shown that beaver lodge occupancy was greatly reduced in areas that had been repeatedly burned (Hood et al. 2007). However, fire does promote the regeneration of many woody plant species used by beaver. The benefits likely depend on the combination of fire severity and frequency (Hood et al. 2007). Two other studies in Canada found that burns were beneficial to beaver habitat when comprised of disturbance-reliant early successional aspen (Slough and Sadleir 1977, Barnes and Mallik 2001). With warming temperatures, increasing fire frequency and area burned are predicted for the CYR study area (see Section C. Abiotic Change Agents).

Invasive Species

Direct impacts of invasive species on the Terrestrial Fine-filter CEs in these time periods seem unlikely. It is unclear how the establishment of *Elodea* may impact Trumpeter swans or Beavers.

The movement of American beaver, Trumpeter swans, and other waterfowl may result in increased spread of *Elodea* in the CYR study area. Invasive plant species may also compete with native forage species in the future; however, invasive species are currently limited in the CYR study area and are not likely to expand enough within the next 50 years to have major impacts on beaver habitat.

6.5 Current Status and Future Landscape Condition

Beavers occur in areas with low to moderate human activity and disturbance (Slough and Sadleir 1977). 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).

Human development can cause habitat degradation and loss due to changes in stream morphology and hydrology (Slough and Sadleir 1977, Boyle and Owens 2007). This figure illustrates changes in landscape condition throughout the current (modeled) beaver habitat.

Landscape condition throughout majority of the American beaver habitat distribution in CYR study area is considered to be very high (Figure H-32). The main areas of impact are the major road systems that bisect the study area, and the region around Fairbanks. The area associated with very high landscape condition is expected to decrease by 1.3% within the American beaver potential habitat distribution in the CYR study area (Figure H-32).

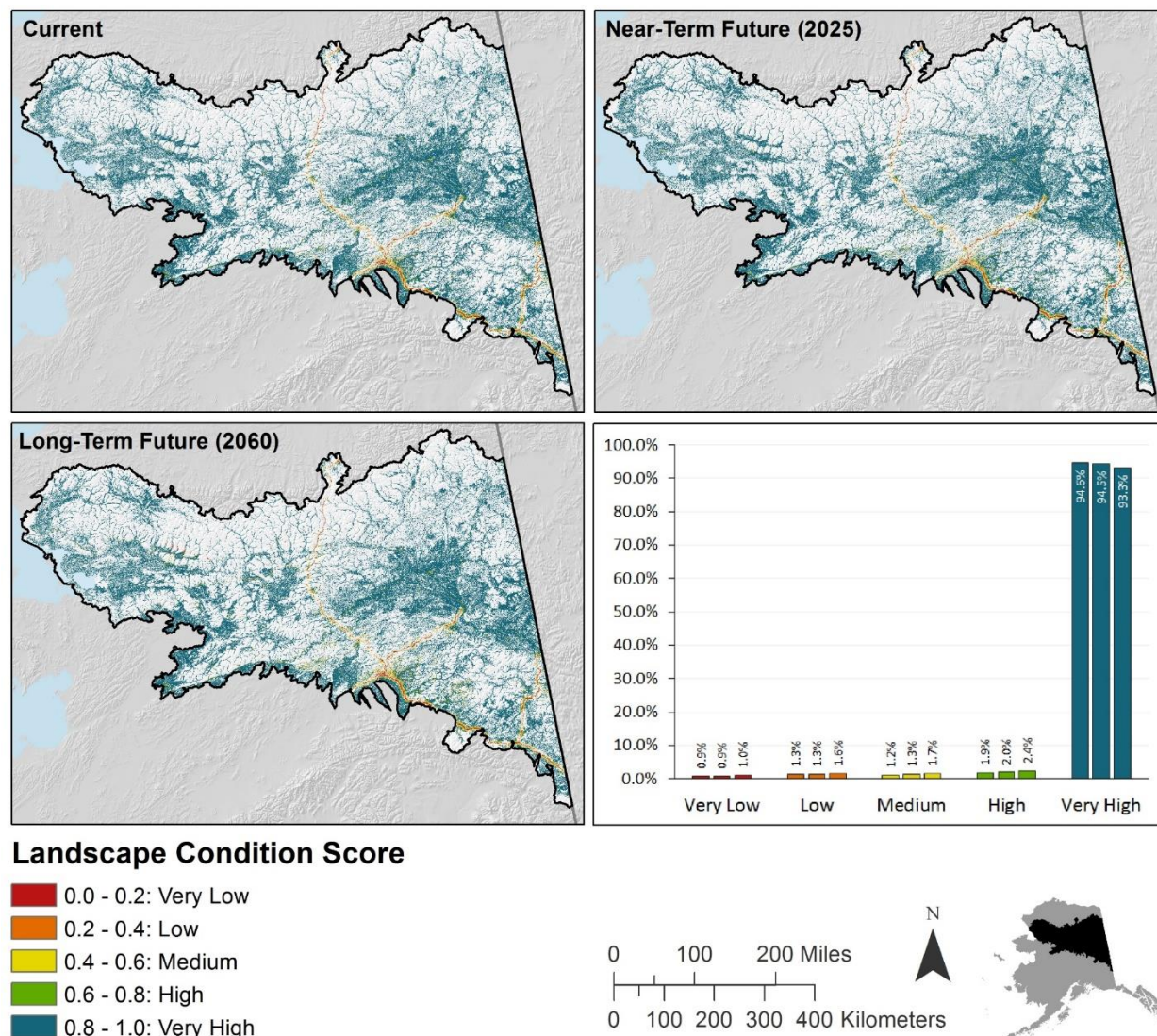


Figure H-32. Current, near-term, and long-term landscape condition within the potential habitat distribution of American Beaver.

6.6 Summary

Future projections relevant to American beaver suggest that throughout the CYR study area, there will be an increase in summer temperature, summer precipitation, and fire frequency (Table H-25). Increased summer temperature may promote beaver population growth; however, increased spring precipitation may hinder juvenile survival and forage availability. Since beavers can manipulate their surroundings and habitat, these changes in spring precipitation may not have a large impact on current populations. Other variables considered in this analysis, such as invasive species and landscape condition, are not expected to have a significant impact on American beaver in the next 50 years.

Table H-23. Summary and projected effects of change agents used in the assessment for American beaver in the CYR study area.

Indicator	Near-term change	Long-term change	Effect on CE in CYR study area	Impact
Summer temperature	No change	+	+	Predator avoidance
Spring precipitation	+	+	-	Juvenile survival
Landscape condition	Minimal change	-	-	Habitat and forage availability
Fire	+	+	+/-	Reduced habitat, Increased forage
Invasive species	N/A	N/A	None	None

6.7 Limitation and Data Gaps

The AKGAP American beaver habitat distribution model used for this assessment was clipped to the study area from a larger statewide habitat distribution model. GAP Analysis data are derived from remote sensing and modeling to make general assessments about distributions and habitat.

The ALFRESCO projections do not include fire severity or precise spatial/temporal predictions of future fires (see Section C. Abiotic Change Agents). Therefore, identifying areas where increased wildfire may impact beaver habitat and forage was not possible with these data.

It is important to note that this study was limited to assessing the effect of specific CAs on CEs that we could spatially model and that had strong cause-and-effect linkages in the literature. There may be additional factors not addressed in this study that play an important role in determining the status of American beaver throughout the CYR study area.

6.8 Datasets and Literature Cited

Table H-24. Datasets used for analysis of American beaver in the CYR study area.

Dataset	Dataset Description	Dataset Provider	Data Type	Dataset Last Updated	Restrictions
Alaska GAP Analysis terrestrial vertebrate occurrence database—American beaver	This dataset contains 501 point occurrence records for American beaver acquired from numerous data sources for the Alaska Gap Analysis Project.	Alaska Center for Conservation Science	Point	2009	Not for publication and/or redistribution
Alaska GAP Modeled Habitat Distribution of American beaver	GAP habitat distribution models represent the areas where species are predicted to occur based on habitat associations. Models have a 60-meter resolution and are delimited by GAP species range.	Alaska Gap Analysis Project	Raster	2009	None
Beaver cache survey points-Kanuti NWR (report)	Hand digitized cache locations from Kanuti Wildlife Refuge as described in a USFWS Report (Craig and Saperstein 2010).	US Fish and Wildlife Service	Report; AKNHP digitized survey points	2010	None
BISON American beaver occurrence records	This dataset contains 467-point occurrence records for American beaver compiled by Biodiversity Information Serving Our Nation (BISON), an integrated and permanent resource for biological occurrence data from the United States. Date range of occurrence records is 1943 through 2012.	Biodiversity Information Serving Our Nation (BISON)	Point	2012	Use of data must be cited according to BISON data user agreement [†]

[†]Data user agreement available online: <http://bison.usgs.ornl.gov/#about>

Literature Cited

- Alaska Department of Fish and Game (ADF&G). 2013. Beaver (*Castor canadensis*). Available: <http://www.adfg.alaska.gov/index.cfm?adfg=beaver.uses>
- Allen, A. W. 1983. Habitat suitability index models: beaver. U.S. Fish and Wildlife Service. FWS/OBS-82/10.30.

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- Baker, B. W., and E. P. Hill. 2003. Beaver (*Castor canadensis*). Pages 288-310 in G. A. Feldhamer, B. C. Thompson, and J. A. Chapman, eds. Wild mammals of North America: biology, management, and conservation. Second Edition. The Johns Hopkins University Press, Baltimore, Maryland, USA.
- 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.
- Bird, B., M. O'Brien, and M. Petersen. 2011. Beaver and climate change adaptation in North America. A simple, cost-effective strategy. Wild Earth Guardians.
- Boertje, R. D., W. C. Gasaway, D. V. Grangaard, and D. G. Kelleyhouse. 1988. Predation on moose and caribou by radio-collared grizzly bears in east Central Alaska. Canadian Journal of Zoology 66:2492-2499.
- 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>
- Campbell, R. D., P. Nouvellet, C. Newman, D. W. Macdonald, and F. Rosell. 2012. The influence of mean climate trends and climate variance on beaver survival and recruitment dynamics. Global Change Biology 18:2730-2742.
- Craig, T., and L. Saperstein. 2010. Beaver cache surveys on the Kanuti National Wildlife Refuge. U.S. Fish and Wildlife Service. 20 pp.
- 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.
- 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.
- 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.
- 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 Changes in Biology 15:508–522.
- Lloyd, A. H., and C. L. Fastie. 2003. Recent changes in treeline forest distribution and structure in Interior Alaska. Ecoscience 10:176-185.
- MacDonald, S. O., and J. A. Cook. 2009. Recent mammals of Alaska. University of Alaska Press, Fairbanks, Alaska.
- Slough, B. G., and R. M. F. S. Sadleir. 1977. A land capability classification system for beaver (*Castor canadensis*). Canadian Journal of Zoology 55:1324-1335.

7. Snowshoe Hare (*Lepus americana*)

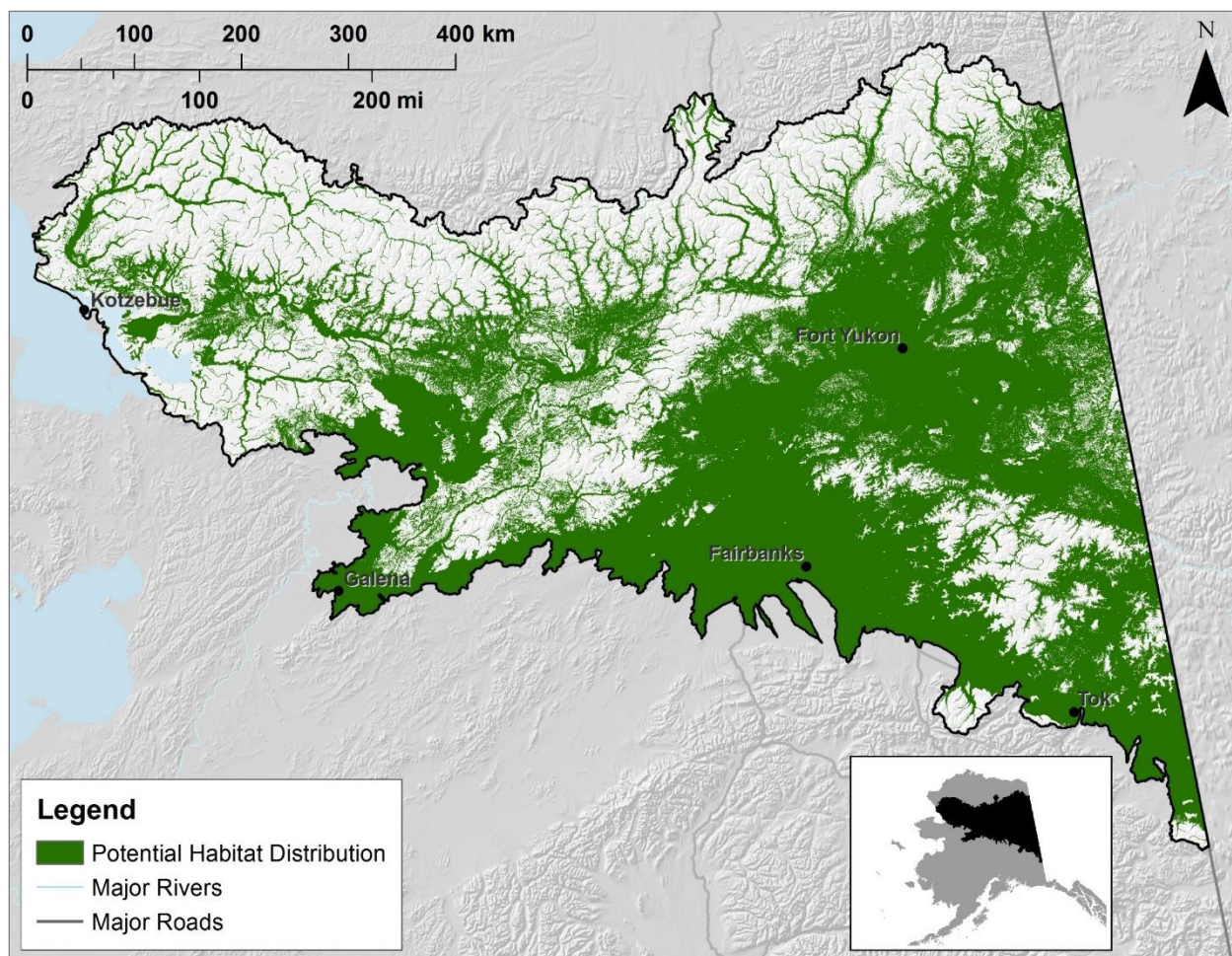


Figure H-33. Current potential habitat distribution of snowshoe hare in the CYR study area.

7.1 Introduction

Snowshoe hare occur year-round throughout the taiga of Alaska (MacDonald and Cook 2009) and inhabit mixed spruce forests, wooded swamps, and brushy areas including low and tall shrub (ADF&G 2015; Figure H-33). They prefer dense shrub and forest cover, which provide protection from both avian and terrestrial predators (Pietz and Tester 1983, Rohner and Krebs 1996, Wolff 1980).

Their diet varies between summer and winter depending on forage availability. In the summer, forage consists mainly of grasses, buds, twigs and leaves, while in the winter, spruce twigs and needles, bark and willow buds are consumed (ADF&G 2015, Dodds 1960, Wolff 1978). They are a rapid reproducing species with females producing 2–3 litters per year. The breeding season is between mid-May and the end of August.

Snowshoe hare typically exhibit a ten-year population cycle with density highs and lows dictated by both food availability and predation (Boonstra et al. 1998, Todd and Keith 1983, Krebs et al.

Section H. Terrestrial Fine-filter Conservation Elements

1995, Krebs et al. 2001). Main predators include: lynx (*Lynx canadensis*), coyote (*Canis latrans*), golden eagle (*Aquila chrysaetos*), great horned owls (*Bubo virginianus*), and wolverine (*Gulo gulo*) (McIntyre and Adams 1999, O'Donoghue et al. 1998, Rohner 1996, Magoun 1987). Predators in turn, follow snowshoe hare cycles with a one- or two-year lag in effects on population densities (Rohner 1996). The last high in the snowshoe hare population cycle was observed between 2008 and 2010, with the low likely occurring during 2014. While there is currently no active monitoring by ADF&G, increases in abundance were noted around Fairbanks during spring 2015. Population levels are still relatively low and the next cycle high is expected between 2018 and 2020 (Merizon and Carroll 2015). Snowshoe hare is a popular small game species, which are harvested year round and managed by ADF&G (ADF&G 2015).

7.2 Conceptual Model

The conceptual model below (Figure H-34) is based on literature review and describes the relationship between the various CAs and natural drivers for snowshoe hare. The boxes and arrows represent the state of knowledge about the snowshoe hare and its relationships to each CA. The arrows and red text represent relationships between the CAs, natural drivers, and primary habitat for snowshoe hare. The primary CAs selected for this CE include: climate change, human uses such as land use change, and wildland fire.

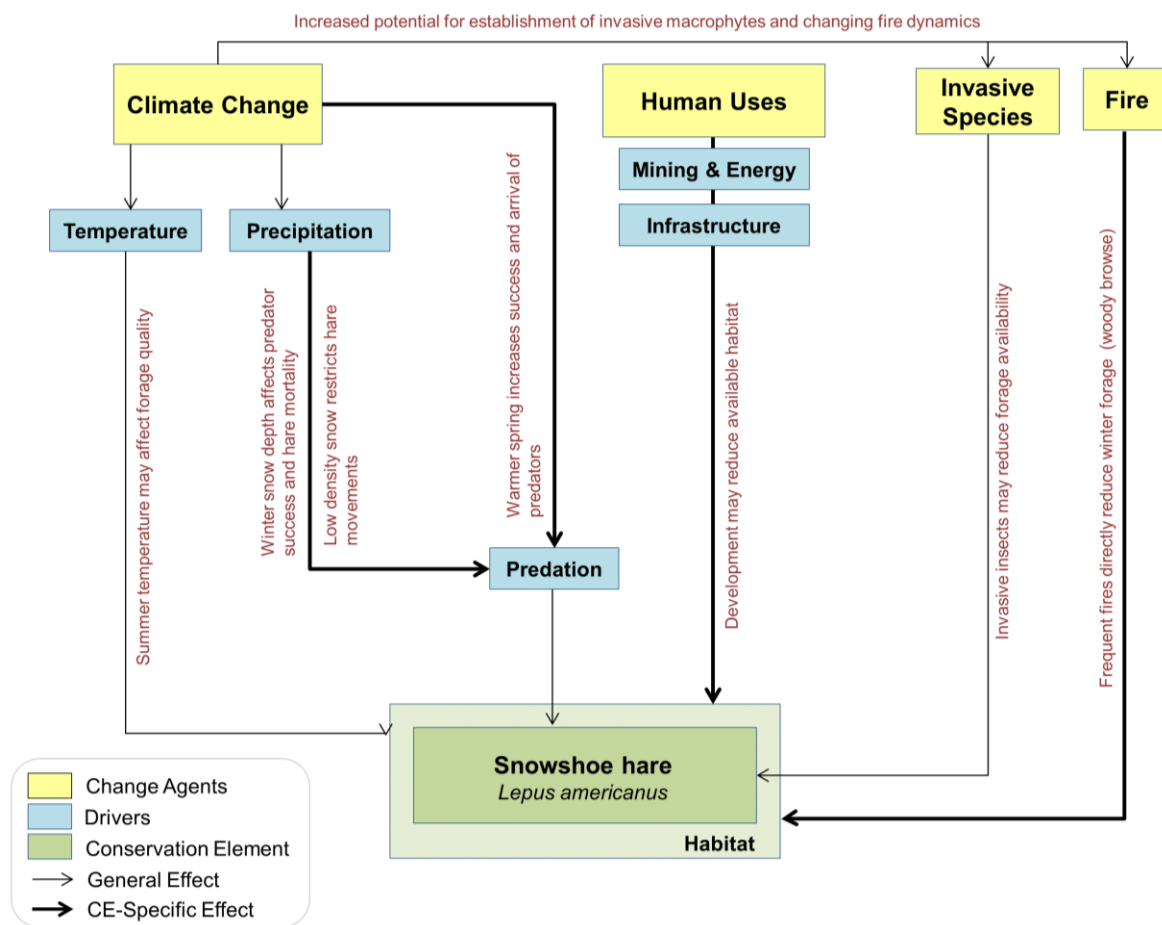


Figure H-34. Conceptual model describing the relationship between various CAs and natural drivers for snowshoe hare.

7.3 Attributes and Indicators

Attributes and indicators helped to define the relationships between CEs and CAs, and, where possible, the thresholds associated with these relationships. Based on the assessment of available indicators, spatial data used to assess the status of Snowshoe hare included: winter precipitation, snow day fraction, and relative flammability (Table H-25).

Table H-25. Attributes and Indicators for the potential effect of various CAs and natural drivers on snowshoe hare.

CA or Driver	Key Attribute	Indicator	Effect/ Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Precipitation	Snow density ²⁰	When snow is below critical density levels, hare movements are restricted to runways (i.e., do not disperse across areas).	Low density snow			High density snow
	Predation	Winter snow depth ²¹	Decreased snow depth may increase predator success and hare mortality.	Snow depth 15-30 cm			Snow depth > 30 cm
Fire	Fire frequency ²²	Fire return interval	Frequent fires may reduce winter forage (wood browse; i.e., spruce and birch); Early to mid-successional stands provide optimal habitat.	< 20-yr burn interval	80-yr burn interval	40-yr burn interval	20-yr burn interval
	Fire extent ²³	Percent burn area	Large fires and insect outbreaks may change mature forests into early to mid-successional stands, which provide optimal habitat for hares.	0% burn area			Large burn areas
Invasive Species	Insect outbreaks ²⁴	Invasive species		No outbreaks			Frequent outbreaks

²⁰ Based on O'Farrell 1965

²¹ Based on Schmitz et al. 2003

²² Based on Koehler 1990

²³ Based on Bull et al. 2001

²⁴ Based on Bull et al. 2001

7.4 Abiotic Change Agents Analysis

We explored the relationship between snowshoe hare and two climate variables: winter precipitation and snow day fraction at three time steps (current, near-term, and long-term).

Winter Precipitation and Snow Day Fraction

Near-term and long-term future December-January-February precipitation is predicted to increase throughout majority of snowshoe hare habitat in the CYR study area (Table H-26, Figure H-36). Increases of up to 38 mm in total precipitation are predicted for the central and northern areas of snowshoe hare range (Figure H-35). Snow density is critical for predator avoidance (Schmitz et al. 2003) and general movements and dispersal. Snowshoe hare mortality rates (due to predation) are closely linked with winter precipitation and low snow density as it can restrict hares to localized runways, increasing predation risk (O'Farrell 1965). Additionally, decreased snow depth may allow for increased predator mobility and predation success (Kielland et al. 2010, Schmitz et al. 2003). Decreased snow depth or snow density may increase predator success and hare mortality. Increased winter precipitation and simultaneous increased winter temperature are likely to create high snow depth and density conditions that are favorable to snowshoe hare survival.

Table H-26. Percent of snowshoe hare potential habitat distribution affected by change in total December-January-February precipitation for the near-term (2020s) and long-term (2060s) future.

Snowshoe Hare	Δ Winter Precipitation (DJF)		
	No Change	Significant Increase ²	TOTAL RANGE (mm)
Near-Term	2%	98%	1 to 37
Long-Term	15%	85%	2 to 38

²Based on a mean standard deviation of 1 (near: ± 4.17 mm; long: ± 5.17 mm)

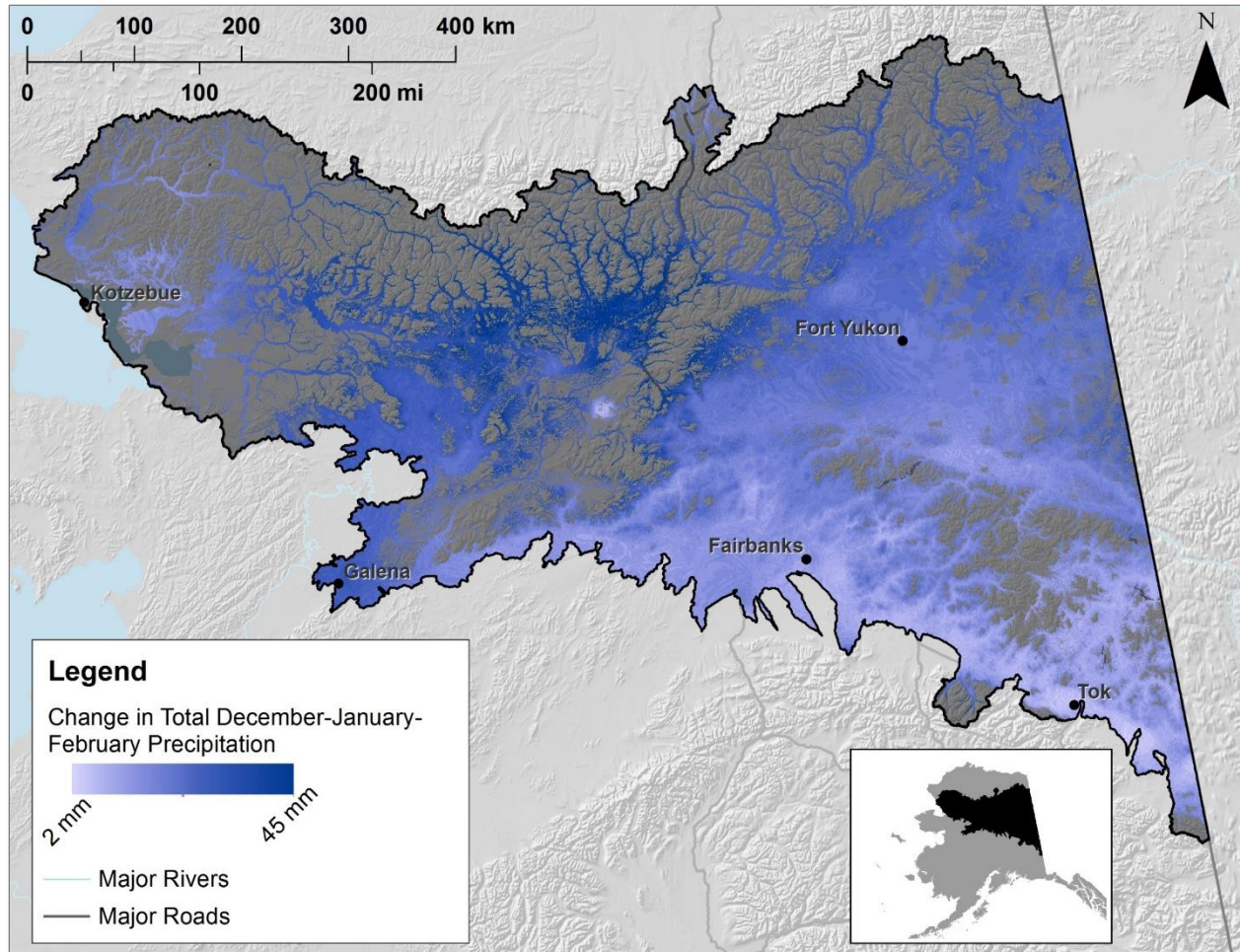


Figure H-35. Change in total December-January-February precipitation from the 2010s to the 2060s within the snowshoe hare potential habitat distribution.

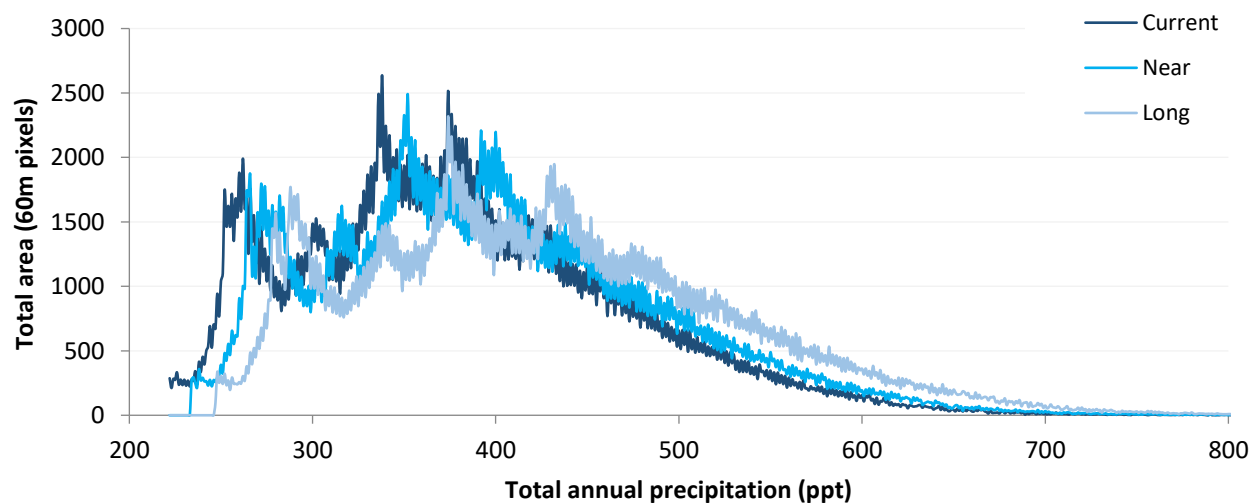


Figure H-36. Projected shifts in total annual precipitation within the snowshoe hare potential habitat distribution.

Rain-on-snow events can create an ice layer on the snow that increases mobility for both snowshoe hare and their predators across the landscape (O'Farrell 1965, Schmitz et al. 2003). Snow day fraction can be used as an estimator for rain-on-snow events during winter as it measures the proportion of precipitation falling as snow (and, inversely, rain). Snow day fraction during February is predicted to increase slightly by the long-term future (2060s). A majority of the snowshoe hare habitat distribution will experience minimal changes (1%–3%) in snow day fraction; however, in the southern portion of the study area, shifts of up to an additional 5% of precipitation is expected to fall as rain (Figure H-37).

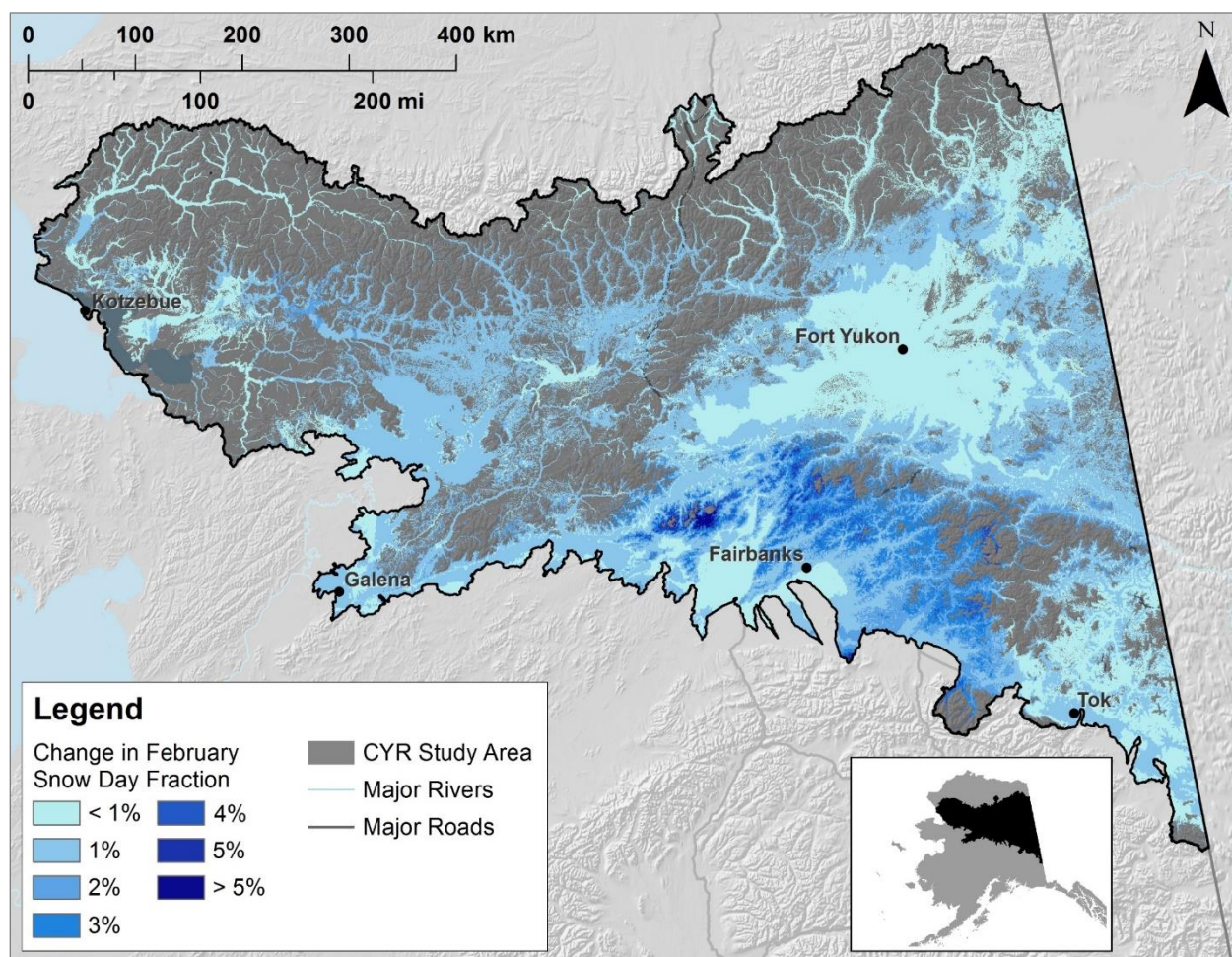


Figure H-37. Change in February snow day fraction from the 2010s to the 2060s within the snowshoe hare potential habitat distribution. Values indicate a change in percent precipitation falling as rain.

Fire

Fire can result in the immediate destruction of snowshoe hare habitat and winter forage. However, large fires may be beneficial as they change mature forests into early to mid-successional stands that provide additional optimal hare habitat (Koehler 1990, Bull et al. 2001). With warming temperatures, increasing fire frequency and area burned are predicted for the CYR study area (see Section C. Abiotic Change Agents).

Invasive Species

Direct impacts of invasive species on the Terrestrial Fine-filter CEs in these time periods seem unlikely. Increased establishment of the invasive *Melilotus albus* on early successional floodplains could impact snowshoe hares indirectly through reductions in willow browse, as *M. albus* has been shown to depress willow and native forb establishment (see Spellman and Wurtz 2011).

7.5 Current Status and Future Landscape Condition

Landscape condition throughout most of the snowshoe hare habitat distribution in the CYR study area is very high (Figure H-38). The main areas of impact to snowshoe hare are the major road systems in the study area and the region around Fairbanks. The area associated with very high landscape condition is expected to decrease by 1.8% within the snowshoe hare potential habitat distribution. This shift in landscape condition may result in localized impacts on habitat availability; however, hare abundance and population cycles are thought to be driven more by climate and predator forces than anthropogenic activities (Smith 1983, Krebs et al. 2001).

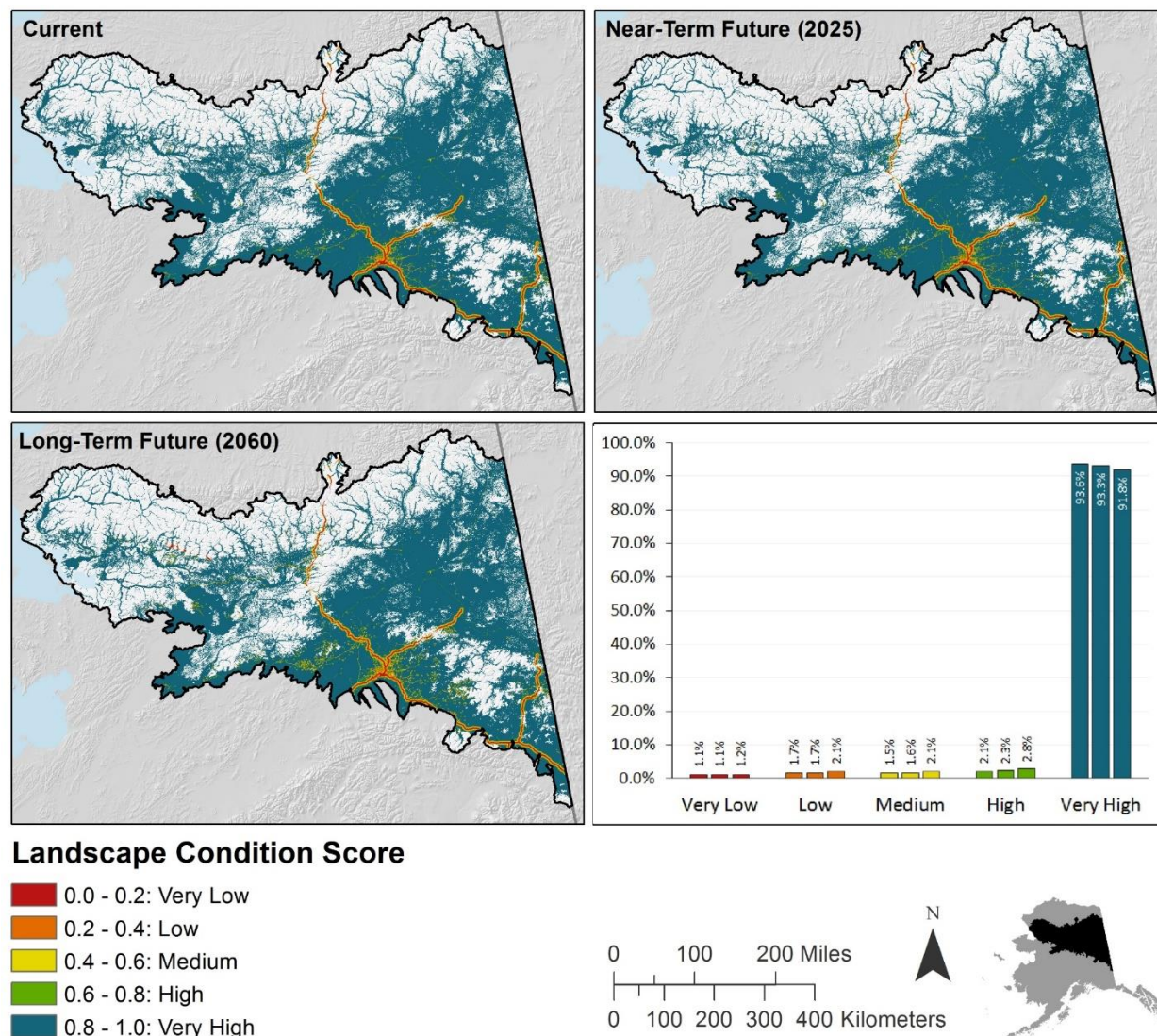


Figure H-38. Current, near-term, and long-term landscape condition within the potential habitat distribution of snowshoe hare.

7.6 Summary

Future projections relevant to snowshoe hare suggest that throughout the CYR study area, there will be an increase in winter precipitation, rain-on-snow events (snow day fraction), and habitat flammability (Table H-41). These changes may assist predator avoidance and increase snowshoe hare forage quality; however, variables such as snow density and wildfire frequency can have both positive and negative effects for snowshoe hare on the landscape. Other variables considered in this analysis, such as invasive species and landscape condition, are not expected to have a significant impact on snowshoe hare in the next 50 years.

Table H-27. Summary and projected effects of CAs used in the assessment for snowshoe hare in the CYR study area.

Indicator	Near-term change	Long-term change	Effect in CYR study area	Impact
Winter precipitation	+	+	+	Predator avoidance
Snow day fraction	Not assessed	-	+	Reproductive success; predator avoidance
Fire	Unknown	+	+/-	Habitat and forage availability
Landscape condition	Minimal change	-	-	Reproductive success
Invasive species	N/A	N/A	None	None

7.7 Limitation and Data Gaps

It is important to note that this study was limited to assessing the effect of specific CAs on CEs that we could spatially model and that had strong cause-and-effect linkages in the literature. There may be additional factors not addressed in this study that play an important role in determining the status of snowshoe hare throughout the CYR study area.

7.8 Datasets and Literature Cited

Table H-28. Datasets used for analysis of snowshoe hare in the CYR study area.

Dataset	Dataset Description	Dataset Provider	Data Type	Dataset Last Updated	Restrictions
Alaska GAP Analysis terrestrial vertebrate occurrence database- Snowshoe hare	This dataset contains 821-point occurrence records for snowshoe hare acquired from numerous data sources for the Alaska Gap Analysis Project.	Alaska Center for Conservation Science	Point	2009	Not for publication and/or redistribution
BISON snowshoe hare occurrence records	This dataset contains 986-point occurrence records for snowshoe hare compiled by Biodiversity Information Serving Our Nation (BISON), an integrated and permanent resource for biological occurrence data from the United States. Date range of occurrence records is 1936 through 2014.	Biodiversity Information Serving Our Nation (BISON)	Point	2014	Use of data must be cited according to BISON data user agreement [†]

[†]Data user agreement available online: <http://bison.usgs.ornl.gov/#about>

Literature Cited

- Alaska Department of Fish and Game (ADF&G). 2015. Small game hunting in Alaska: small game species - Alaska and Snowshoe Hare. Available: <http://www.adfg.alaska.gov/index.cfm?adfg=smallgamehunting.hare>
- Boonstra, R., D. Hik, G. R. Singleton, and A. Tinnikov. 1998. The impact of predator-induced stress on the snowshoe hare cycle. *Ecology Monographs* 79:371-394.
- Bull, E. L., K. B. Aubry, and B. C. Wales. 2001. Effects of disturbance on forest carnivores of conservation concern in eastern Oregon and Washington. *Northwest Science* 75:180-184.
- Dodds, D. G. 1960. Food competition and range relationships of moose and snowshoe hare in Newfoundland. *The Journal of Wildlife Management* 24:52-60.
- Kielland, K., K. Olson, and E. Euskirchen. 2010. Demography of snowshoe hares in relation to regional climate variability during a 10-year population cycle in Interior Alaska. *Canadian Journal of Forest Research* 40:1265-1272.
- Koehler, G. M. 1990. Population and habitat characteristics of lynx and snowshoe hares in north central Washington. *Canadian Journal of Zoology* 68:845-851.
- Krebs, C. J., R. Boonstra, S. Boutin, and A. R. E. Sinclair. 2001. What drive the 10-year cycle of snowshoe hares? *BioScience* 51:25-35.
- Krebs, C. J., R. Boonstra, V. Nams, M. O'Donoghue, K. E. Hodges, and S. Boutin. 2001. Estimating snowshoe hare population density from pellet plots: a further evaluation. *Canadian Journal of Zoology* 79:1-4.
- Krebs, C. J., S. Boutin, R. Boonstra, A. R. E. Sinclair, J. N. M. Smith, M. R. T. Dale, K. Martin, and R. Turkington. 1995. Impact of food and predation on the snowshoe hare cycle. *Science* 269:1112-1115.
- MacDonald, S. O., and J. A. Cook. 2009. Recent mammals of Alaska. University of Alaska Press, Fairbanks, Alaska. 387 pp.
- Magoun, A. J. 1987. Summer and winter diets of wolverine, *Gulo gulo*, in Arctic Alaska. *Canadian Field Naturalist* 101:392-397.

- McIntyre, C. L., and L. G. Adams. 1999. Reproductive characteristics of migratory golden eagles in Denali National Park, Alaska. *The Condor* 101:115-123.
- Merizon, R. A., and C. J. Carroll. 2015. Alaska small game summary 2015. Alaska Department of Fish and Game. Available: http://www.adfg.alaska.gov/static/research/programs/smallgame/pdfs/small_game_status_2015_summary_report.pdf
- O'Donoghue, M., S. Boutin, C. J. Krebs, G. Zuleta, D. L. Murray, and E. J. Hofer. 1998. Functional responses of coyotes and lynx to the snowshoe hare cycle. *Ecology* 79:1193-1208.
- O'Farrell, T. P. 1965. Home range and ecology of snowshoe hares in Interior Alaska. *American Society of Mammalogists* 46:406-418.
- Pietz, P. J., and J. R. Tester. 1983. Habitat selection by snowshoe hares in North Central Minnesota. *Journal of Wildlife Management* 47:686-696.
- Rohner, C. 1996. The numerical response of great horned owls to the snowshoe hare cycle: consequences of non-territorial 'floaters' on demography. *Journal of Animal Ecology* 65:359-370.
- Rohner, C., and C. J. Krebs. 1996. Owl predation on snowshoe hares: consequences of antipredator behaviour. *Oecologia* 108:303-310.
- Schmitz, O. J., E. Post, C. E. Burns, and K. M. Johnston. 2003. Ecosystem responses to global climate change: moving beyond color mapping. *BioScience* 53:1199-1205.
- Smith, C. H. 1983. Spatial trends in Canadian snowshoe hare, *Lepus americanus*, population cycles. *Canadian Field-Naturalist* 97:151-160.
- 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.
- Todd, A. W., and L. B. Keith. 1983. Coyote demography during a snowshoe hare decline in Alberta. *The Journal of Wildlife Management* 47:394-404.
- Wolff, J. O. 1978. Food habits of snowshoe hares in Interior Alaska. *The Journal of Wildlife Management* 42:148-153.
- Wolff, J. O. 1980. The role of habitat patchiness in the population dynamics of snowshoe hares. *Ecological Monographs* 50:111-130.

8. Golden Eagle (*Aquila chrysaetos*)

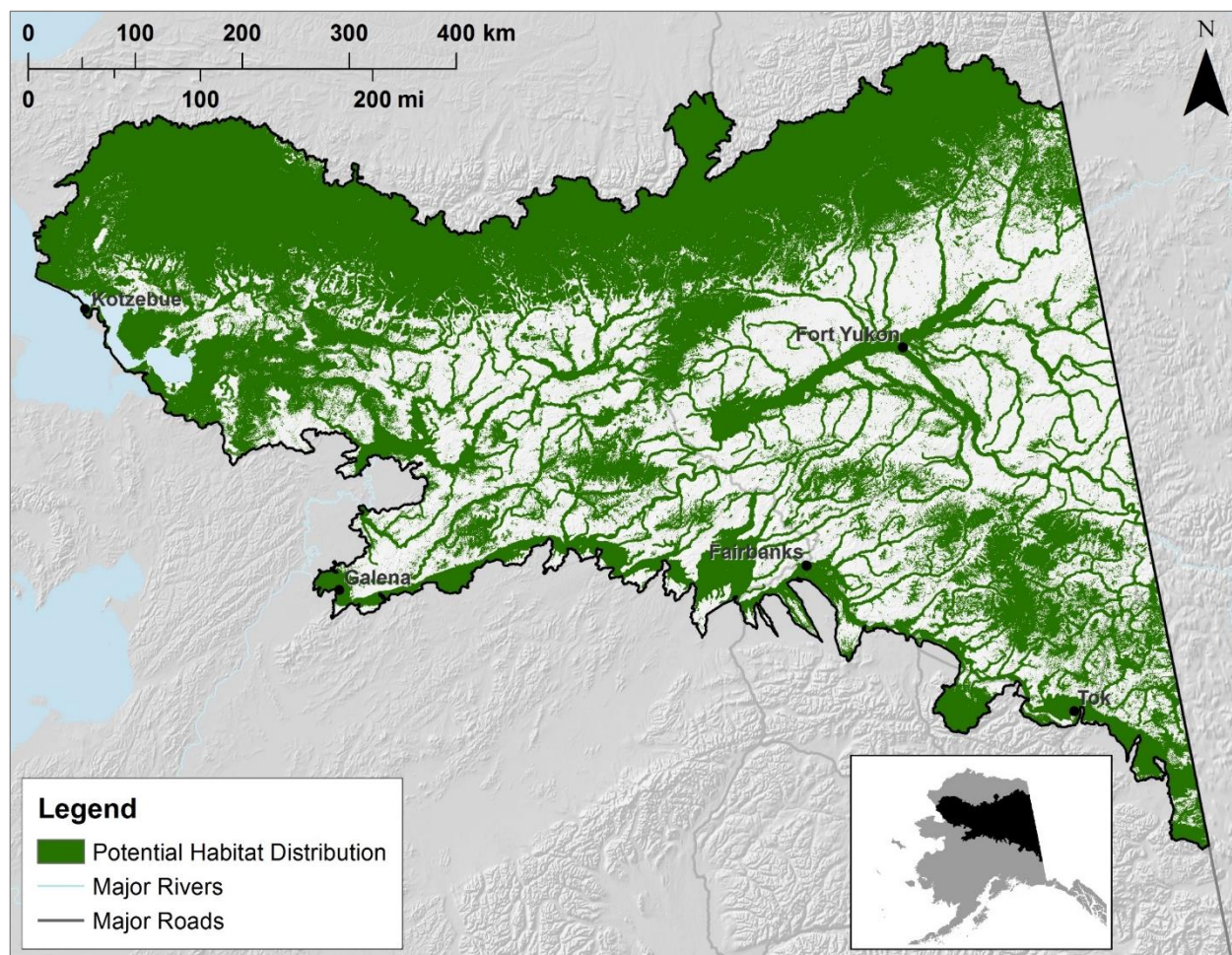


Figure H-39. Current potential habitat distribution of golden eagle in the CYR study area.

8.1 Introduction

In Alaska, golden eagles range from the Brooks Range south throughout much of the mainland, with limited distribution in Southeast, and rare occurrences in the Aleutian Islands and Alaska Peninsula (ADF&G 2015, Kochert et al. 2002). They inhabit areas that are open or barren, such as Arctic and alpine tundra, prairie, open forest, and hilly or mountainous regions (Figure H-39). Golden eagles typically breed in semi-open habitats such as tundra, grasslands, woodland, and coniferous forests (Kochert 1972). In Alaska, breeding occurs in areas of rugged topography or mountainous terrain near or above treeline and along riparian areas (Ritchie and Curatolo 1982, Petersen et al. 1991, Young, Jr. et al. 1995).

The breeding season occurs during late April through May. Individuals establish a nesting territory at approximately 4 years of age and are monogamous, remaining with their mate for several years. Typically, a clutch of two eggs is laid, which require 35–45 days of incubation. Nests are large (up to 3-m across and 1.2-m thick), and can be found on rugged alpine areas with bluffs or cliffs, but trees are also used (ADF&G 2015).

Golden eagles prey on a variety of animals, but in Alaska they mainly feed on hares and ground squirrels (Poole and Bromley 1988). They also prey on birds such ptarmigan, which have been identified as an important secondary prey item in central Alaska (McIntyre and Adams 1999). Though golden eagles are capable of killing larger prey (i.e., caribou calves, Dall sheep lambs, etc.), it has rarely been observed (ADF&G 2015).

Factors that influence golden eagle abundance include: food availability, severe weather, habitat availability, anthropogenic disturbances, and accidental poisoning (caused by ingesting poisoned meat intended for coyotes) (ADF&G 2015, Schweiger et al. 2015, Whitfield et al. 2006).

The golden eagle is under protection of the Bald and Golden Eagle Protection Act (BGEPA) of 1940, which is undergoing re-evaluation by the U.S. Fish and Wildlife Service (USFWS) so they can be more effectively managed (Katzner et al. 2012).

8.2 Conceptual Model

The conceptual model below (Figure H-40) is based on literature review and describes the relationship between the various CAs and natural drivers for golden eagle. The boxes and arrows represent the state of knowledge about the golden eagle and its relationships to each CA. The arrows and red text represent relationships between the CAs, natural drivers, and primary habitat for golden eagle. The primary CAs selected for this CE include: climate change, human uses such as land use change, and wildland fire.

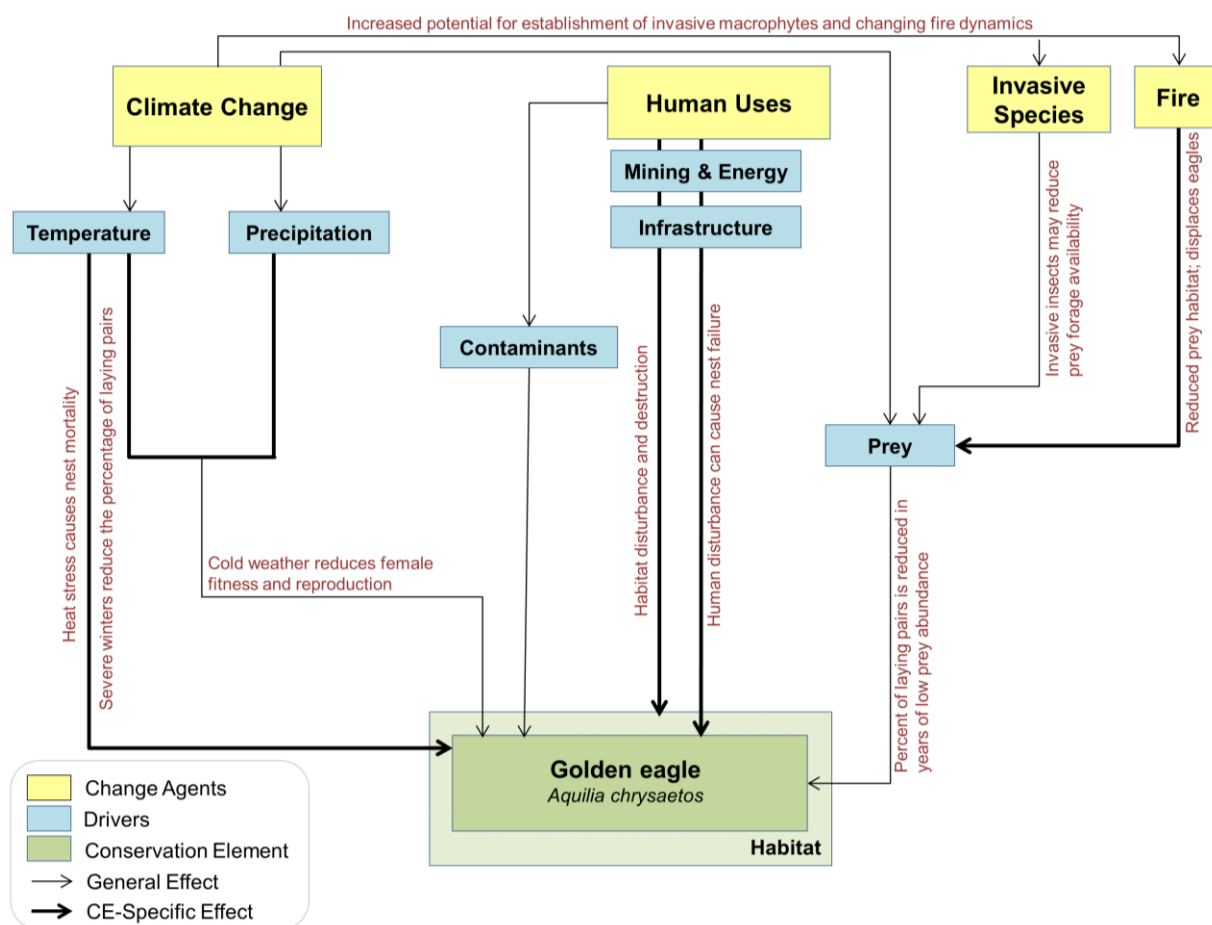


Figure H-40. Conceptual model describing the relationship between various CAs and natural drivers for golden eagle.

8.3 Attributes and Indicators

Attributes and indicators helped to define the relationships between CEs and CAs, and, where possible, the thresholds associated with these relationships. Based on the assessment of available indicators, spatial data used to assess the status of Golden eagle included: length of growing season, winter temperature and shrub/forest extent (Table H-29).

Table H-29. Attributes and Indicators for the potential effect of various CAs and natural drivers on golden eagle.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Temperature	Pre-egg laying temperature (15 Jan-15 Feb) ²⁵	Cold weather = lower female fitness = reduced production.	Lower than average temperatures			Higher than average temperatures
	Summer temperature	# of days > 32 °C between 15 May to 15 June. ²⁶	Heat stress during first 6 weeks after hatching causes nestling mortality.	Fewer days than average			More days than average
	Winter severity	# of days < -18 °C; # days with snow cover ²⁷	Winter severity preceding nesting season (in combination with low prey abundance) is negatively related to percentage of pairs laying eggs.	More days than average			Fewer days than average
		Growing season length ²⁷		Shorter growing season length			Longer growing season length

²⁵ Kochert et al. 2002, Steenhof et al. 1997

²⁶ Beecham and Kochert 1975, Steenhof et al. 1997

²⁷ Steenhof et al. 1997

Section H. Terrestrial Fine-filter Conservation Elements

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Fire	Fire frequency and extent ²⁸	Frequency/return interval	Fire destroys prey habitat; breeding pairs move location = smaller nesting population in area.	High frequency			Low frequency
	Prey abundance ²⁹	Hare populations	Many pairs don't lay eggs during times of low prey abundance.	Low hare abundance			High hare abundance
	Shrub habitat ³⁰	Shrubification	Need shrubby habitat for prey. Shrub communities should be protected within 3 km of nests.	Decrease in shrubby habitat			Increase in shrubby habitat
Anthropogenic Development	Human disturbance ³¹	Landscape condition model	Golden eagle often abandon habitat with intensive human activity and move to more remote areas; nest failure is often associated with human disturbance.	< .5 km from nest sites		> 3 km from nest sites	

²⁸ Kochert et al. 1999

²⁹ McIntyre and Adams 1999, Krebs et al. 2001, Martin et al. 2009b

³⁰ Kochert et al. 2002

³¹ Boeker and Ray 1971, Holmes et al. 1993

8.4 Abiotic Change Agents Analysis

We explored the relationship between golden eagle and three climate variables: length of growing season, mean summer temperature, and mean winter temperature at three time steps (current, near-term, and long-term). We also explored the potential for expansion of favored dwarf and low shrub habitats and fire return intervals through comparison with ALFRESCO model outputs.

Length of Growing Season

Growing season length is expected to increase across the CYR study area by the long-term future (see Section C. Abiotic Change Agents). Throughout the current golden eagle habitat distribution, increases are expected to be most prominent in the northwestern region, with increases of greater than 14 days predicted for some areas (Figure H-41, Table H-30). Longer growing season length is associated with greater prey success and abundance, which can be beneficial for golden eagle. Studies have shown that low prey abundance associated with short growing season length and severe winters are negatively related to the presence and number of egg laying golden eagle pairs in a given area (Steenhof et al. 1997). The projected warming trends are expected to be beneficial for golden eagle prey and thereby for golden eagle nesting success.

Table H-30. Percent of golden eagle potential habitat distribution affected by change in length of growing season for the near-term (2020s) and long-term (2060s) future.

Golden Eagle	Δ Length of Growing Season				
	No Change	0–6 Days	7–14 Days	> 14 Days	Range (Days)
Near-Term	32%	68%	0%	0%	-3 to 15
Long-Term	0%	0%	100%	0%	6 to 52

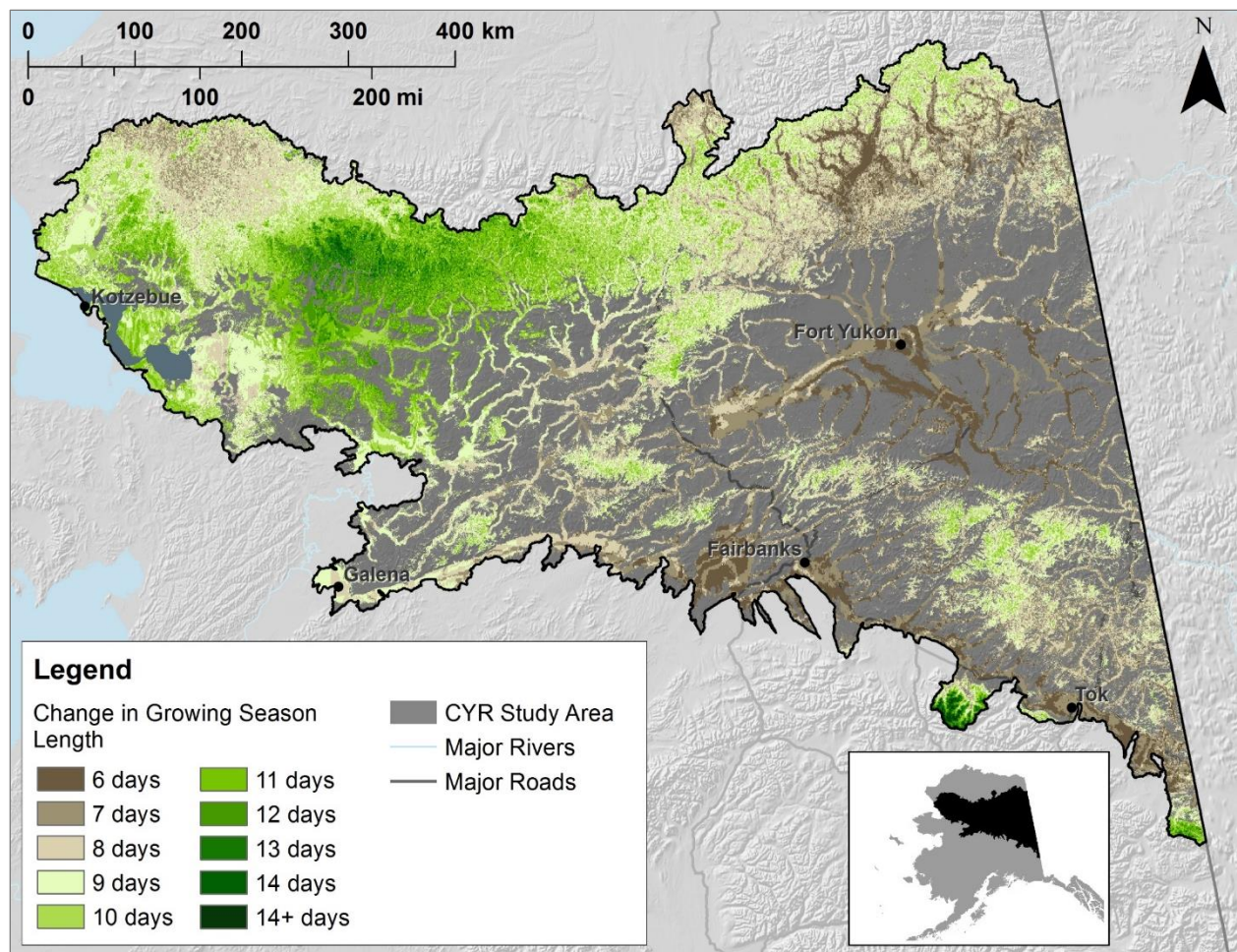


Figure H-41. Change in growing season length from the 2010s to the 2060s within the golden eagle potential habitat distribution.

Winter Temperature

Seasonal temperatures affect both reproductive timing and success of golden eagles. Steenhof et al. (1997) observed that reproductive success (nesting survival and brood size at fledging) of golden eagles in Idaho was inversely related to the number of 'extremely hot' days (temperature > 32 °C). With increasing temperatures, these 'hotter' days may become more frequent. They also found that winter severity affected both the timing of hatching and the percent of laying pairs. Cold weather has also been linked to decreased female fitness and reproductive success (Kochert et al. 2002, Steenhof et al. 1997).

Future climate projections predict a winter warming trend throughout all of the golden eagle habitat in the CYR study area (Table H-30, Figure H-42). Warmer winters may increase female fitness and reproductive success for Golden eagles in the area.

Table H-31. Percent of golden eagle potential habitat distribution affected by change in mean December-January-February temperature for the near-term (2020s) and long-term (2060s) future.

Golden Eagle	Δ Winter Temperature (December, January, February)		
	No Change	Significant Increase ³	Range (°C)
Near-Term	100%	0%	-0.30 to 0.80
Long-Term	0%	100%	2.30 to 3.90

³Based on a mean standard deviation of 1 (near-term: ± 2.17 °C; long-term: ± 1.7 °C)

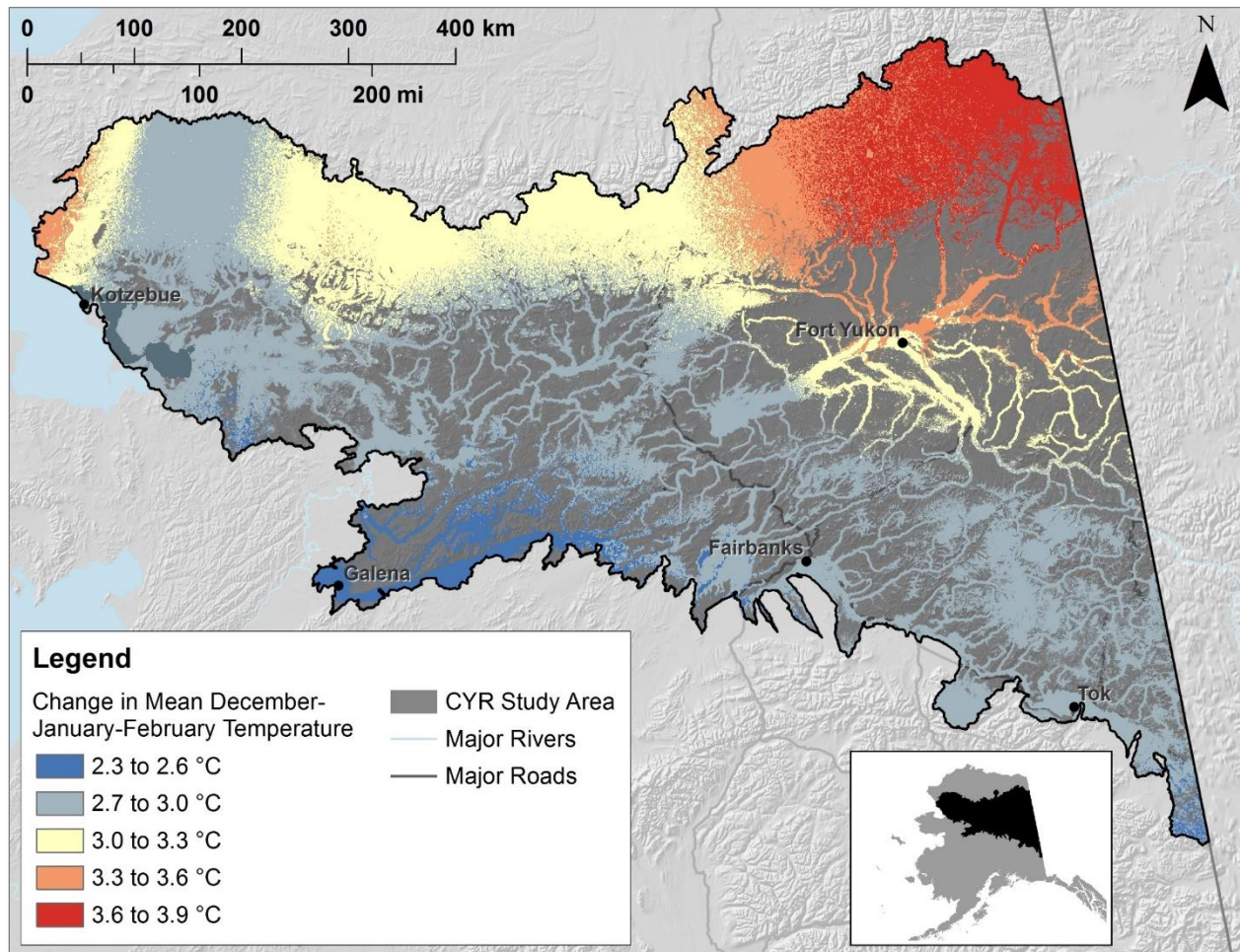


Figure H-42. Change in mean December-January-February temperature from the 2010s to the 2060s within golden eagle potential habitat distribution.

Shrub Expansion

Shrub habitat is essential for golden eagle prey (Kochert et al. 2002). An increase in low and tall shrub habitat may result in increased availability of prey species such as snowshoe hare while an increase in dwarf shrub habitat may result in increased availability of prey species such as Arctic ground squirrel. To assess future shrub expansion in the CYR study area, we compared the SNAP ALFRESCO model (see Section C. Abiotic Change Agents) to the current golden eagle habitat distribution. ALFRESCO classes do not correlate to Terrestrial Coarse-filter CEs or to traditional vegetation classifications used in Alaska. Therefore, an interpretation of how ALFRESCO

predictions relate to golden eagle habitat is tenuous. Because ALFRESCO classes were compiled to predict future fire behavior rather than vegetation change, many uncertainties remain regarding what ALFRESCO predictions mean in an ecological sense.

Golden eagle habitat includes areas of dwarf, low, and tall shrub tundra, which correlate indirectly to the ALFRESCO shrub tundra and forest classes. A 2.5% loss and 2.7% gain is predicted for the ALFRESCO shrub tundra class within golden eagle habitat, indicating that spatial shifting is likely to occur without a net change in total area. However, because the ALFRESCO shrub tundra class includes more than just dwarf shrub tundra, it is possible that changes within the ALFRESCO shrub tundra class will still affect golden eagle habitat. The ALFRESCO forest classes, which include low and tall shrub tundra, are predicted to gain 2.6% area within golden eagle habitat with no loss. However, the change that this value represents in low and tall shrub specifically is impossible to disentangle from possible changes in other forest classes included in the ALFRESCO forest classes. It is likely that the ALFRESCO prediction implies an overall gain in low and tall shrub tundra within golden eagle habitat, but it is not possible to determine where or to what extent (Figure H-43).

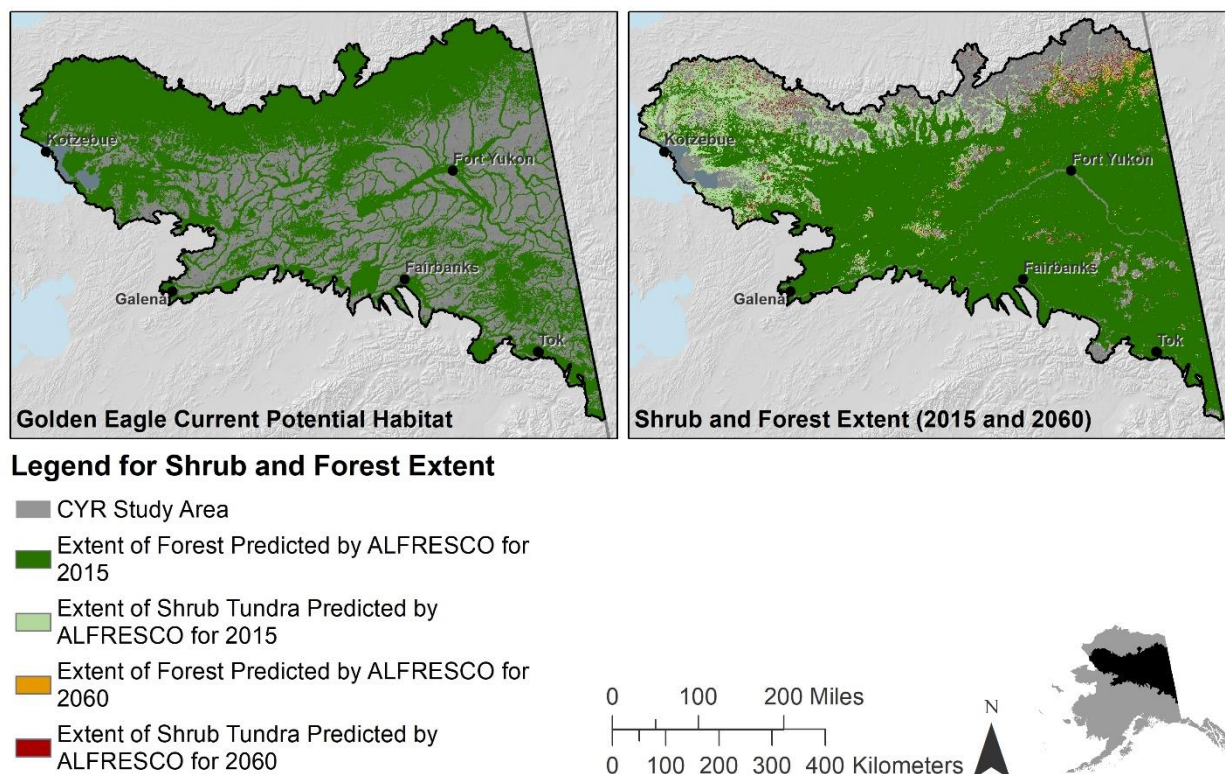


Figure H-43. Current (2015) and long-term future (2060) extent of ALFRESCO shrub tundra and forest classes and the potential habitat distribution of golden eagle.

Fire

Fire is a direct cause of habitat loss for gold eagle prey (snowshoe hare and ground squirrels). Decreased prey abundance can result in lower egg laying rates (McIntyre and Adams 1999, Krebs et al. 2001, Martin et al. 2009) and/or breeding pairs moving to more prey-abundant locations, thereby decreasing the nesting population in a given area (Kochert et al. 1999). With warming

temperatures, increasing fire frequency and area burned are predicted for the CYR study area (see Section C. Abiotic Change Agents).

Invasive Species

Direct impacts of invasive species on the Terrestrial Fine-filter CEs in these time periods seem unlikely. Increased establishment of the invasive *Melilotus albus* on early successional floodplains could impact snowshoe hares indirectly through reductions in willow browse, as *M. albus* has been shown to depress willow and native forb establishment (see Spellman and Wurtz 2011). Golden eagles in turn are highly reliant on snowshoe hare as prey; however, it seems unlikely that, based on the current and perceived future conditions of invasive plants, measurable impacts would occur.

8.5 Current Status and Future Landscape Condition

Human disturbance in an area can cause habitat abandonment (Boeker and Ray 1971) and nest failure for golden eagles (Holmes et al. 1993). The area associated with very high landscape condition is expected to decrease by 2.2% within the golden eagle potential habitat distribution in the CYR study area over the next 50 years (Figure H-44). These human disturbances may cause localized displacement of current breeding areas and/or reduction in golden eagle reproductive success.

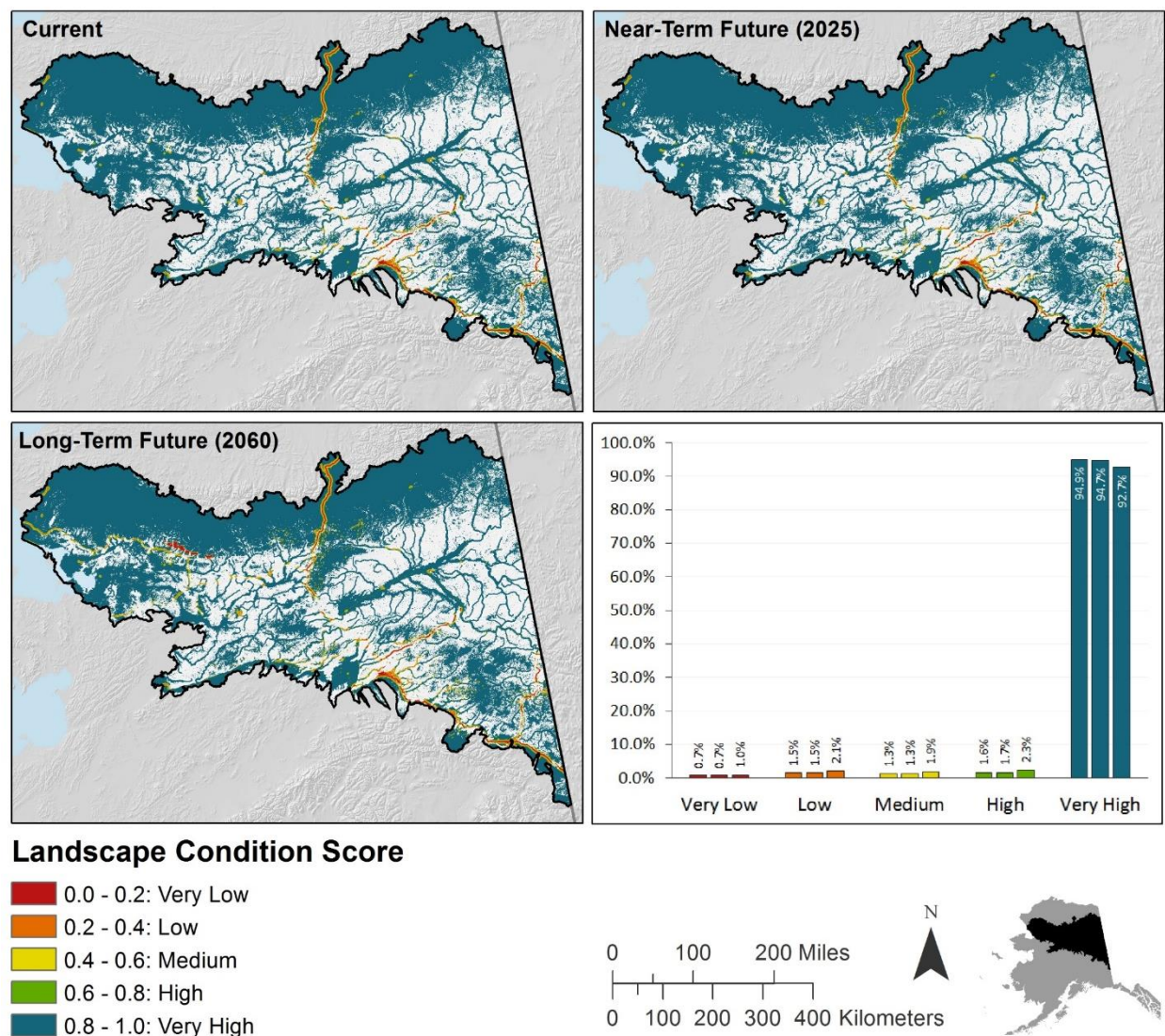


Figure H-44. Current, near-term, and long-term landscape condition within the potential habitat distribution of golden eagle.

8.6 Summary

Future projections suggest that throughout the golden eagle habitat distribution in CYR study area, there will be an increase in length of growing season and winter temperature, which may support increased prey abundance and increased golden eagle reproductive success. However, high flammability and increased human development in localized portions of the distribution may reduce available habitat and displace golden eagle nests. The probable expansion of low and tall shrub tundra and shifting of dwarf shrub tundra indicated by ALFRESCO results suggest that the distributions of prey species will shift in the future. Other variables considered in this analysis, such as invasive species, are not expected to have a significant impact on golden eagle in the next 50 years.

Table H-32. Summary and projected effects of change agents used in the assessment for Golden eagle in the CYR study area.

Indicator	Near-term change	Long-term change	Effect in CYR study area	Impact
Length of growing season	+	+	+	Increased prey abundance
Winter temperature	+	+	+	Reproductive success
Landscape condition	Minimal change	-	-	Reproductive success
Fire	Unknown	+	-	Decreased prey abundance
Shrub expansion	Minimal change	+	+	Prey habitat
Invasive species	N/A	N/A	None	None

8.7 Limitation and Data Gaps

The ALFRESCO outputs do not include fire severity or precise spatial/temporal predictions of future fires (see Section C. Abiotic Change Agents), therefore, identifying areas where increased wildfire may have a negative effect on golden eagle populations was not possible with these data.

ALFRESCO classes do not correlate to Terrestrial Coarse-filter CEs or to traditional vegetation classifications used in Alaska. Because ALFRESCO classes were compiled to predict future fire behavior rather than vegetation change, many uncertainties remain regarding what ALFRESCO predictions mean in an ecological sense. Interpretation of ALFRESCO predictions is more difficult because ALFRESCO classes do not correlate to golden eagle habitat. A finer scale and ecologically oriented vegetation prediction model would greatly enhance the ability to determine potential climate change impacts to golden eagle habitat within a 50-year time frame.

It is important to note that this study was limited to assessing the effect of specific CAs on CEs that we could spatially model and that had strong cause-and-effect linkages in the literature. There may be additional factors not addressed in this study that play an important role in determining the status of Golden eagle throughout the CYR study area.

8.8 Datasets and Literature Cited

Table H-33. Datasets used for analysis of Golden eagle in the CYR study area.

Dataset	Dataset Description	Dataset Provider	Data Type	Dataset Last Updated	Restrictions
Alaska GAP Analysis terrestrial vertebrate occurrence database- Golden eagle	This dataset contains 50-point occurrence records for golden eagle acquired from numerous data sources for the Alaska Gap Analysis Project	Alaska Center for Conservation Science	Point	2009	Not for publication and/or distribution
BISON Golden Eagle occurrence records	This dataset contains 1774- (135 in CYR study area) point occurrence records for golden eagle compiled by Biodiversity Information Serving Our Nation (BISON), an integrated and permanent resource for biological occurrence data from the United States. Date range of occurrence records is 1895 through 2013.	Biodiversity Information Serving Our Nation (BISON)	Point	2013	Use of data must be cited according to BISON data user agreement [†]

[†]Data user agreement available online: <http://bison.usgs.ornl.gov/#about>

Literature Cited

- Alaska Department of Fish and Game (ADF&G). 2015. Species profile: Golden eagle (*Aquila chrysaetos*). Available: <http://www.adfg.alaska.gov/index.cfm?adfg=goldeneagle.main>
- Beecham, J. J., and M. N. Kochert. 1975. Breeding biology of the golden eagle in southwestern Idaho. *Wilson Bulletin* 87:506-513.
- Boeker, E. L., and T. D. Ray. 1971. Golden eagle population studies in the Southwest. *Condor* 73:463-467.
- Holmes, T. L., R. L. Knight, L. Stegall, and G. R. Craig. 1993. Responses of wintering grassland raptors to human disturbance. *Wildlife Society Bulletin* 21:461-468.
- Katzner T., B. W. Smith, T. A. Miller, D. Brandes, J. Cooper, M. Lanzone, D. Brauning, C. Farmer, S. Harding, D. E. Kramar, and C. Koppie. 2012. Status, biology, and conservation priorities for North America's eastern golden eagle (*Aquila chrysaetos*) population. *The Auk* 129:168-76.
- Kochert, M. N. 1972. Population status and chemical contamination in golden eagles in southwestern Idaho. M.S. Thesis, University of Idaho, Moscow.
- Kochert, M. N., K. Steenhof, L. B. Carpenter, and J. M. Marzluff. 1999. Effects of fire on golden eagle territory occupancy and reproductive success. *Journal of Wildlife Management* 63:773-780.
- Kochert, M. N., K. Steenhof, C. L. McIntyre, and E. H. Craig. 2002. Golden eagle (*Aquila chrysaetos*), the birds of North America online (A. Poole, Ed.). Cornell Lab of Ornithology, Ithaca. Available: <http://bna.birds.cornell.edu/bna/species/684>
- Krebs, C. J., R. Boonstra, S. Boutin, and A. R. E. Sinclair. 2001. What drives the 10-year cycle of snowshoe hares? *BioScience* 51:25-35.
- Martin, J., C. L. McIntyre, J. E. Hines, J. D. Nichols, J. A. Schmutz, and M. C. MacCluskie. 2009. Dynamic multistate site occupancy models to evaluate hypotheses relevant to conservation of golden eagles in Denali National Park, Alaska. *Biological Conservation* 142:2726-2731.
- McIntyre, C. L., and L. G. Adams. 1999. Reproductive characteristics of migratory golden eagles in Denali National Park, Alaska. *Condor* 101:115-123.

- Petersen, M. R., D. N. Weir, and M. H. Dick. 1991. Birds of the Kilbuck and Ahklun Mountain region, Alaska. North American Fauna 76. U.S. Fish Wildlife Service, Washington, D.C.
- Poole, K. G., and R. G. Bromley. 1988. Interrelationships within a raptor guild in the central Canadian Arctic. Canadian Journal of Zoology 66:2275-2282.
- Ritchie, R. J., and J. A. Curatolo. 1982. Notes on golden eagle productivity and nest site characteristics, Porcupine River, Alaska, 1979-1982. Raptor Research 16:123-127.
- Schweiger A., H. J. Fünfstück, and C. Beierkuhnlein. 2015. Availability of optimal-sized prey affects global distribution patterns of the golden eagle *Aquila chrysaetos*. Journal of Avian Biology 46:81-88.
- 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.
- Steenhof, K., M. N. Kochert, and T. L. McDonald. 1997. Interactive effects of prey and weather on golden eagle reproduction. British Ecological Society 66:350-362.
- Whitfield D. P., A. H. Fielding, D. R. McLeod, P. F. Haworth, and J. Watson. 2006. A conservation framework for the golden eagle in Scotland: refining condition targets and assessment of constraint influences. Biological conservation 130:465-480.
- Young, Jr., D. D., C. L. McIntyre, P. J. Bente, T. R. McCabe, and R. E. Ambrose. 1995. Nesting by golden eagles on the North Slope of the Brooks Range in northeastern Alaska. Journal of Field Ornithology 66:373-379.

9. Swainson's Thrush (*Catharus ustulatus*)

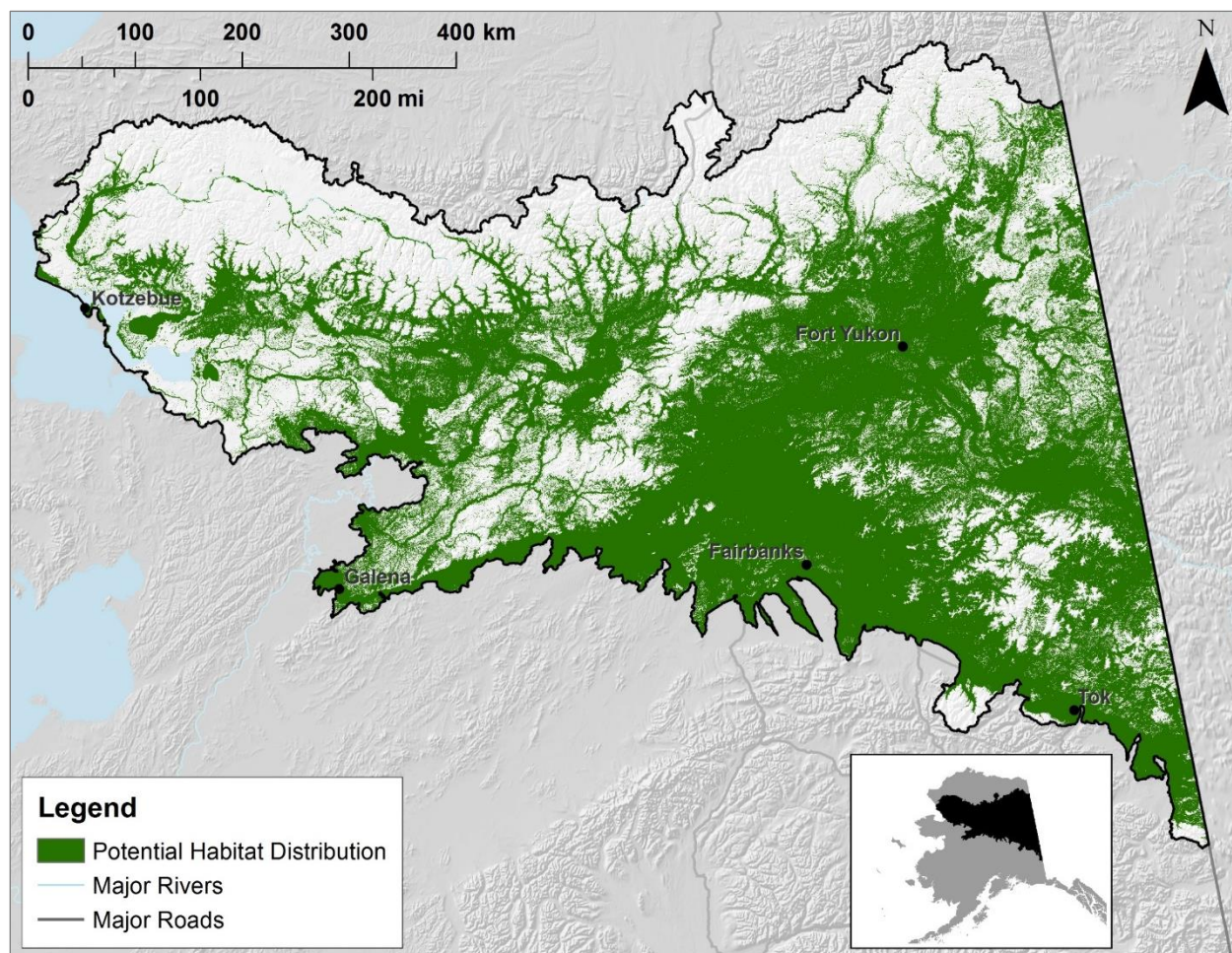


Figure H-45. Current potential habitat distribution for Swainson's thrush in the CYR study area.

9.1 Introduction

Swainson's thrush is a small aerial insectivore common throughout Alaska. It is a long-distant migrant that breeds in western to northern North America, and spends its winters from southern Mexico to northern Argentina (Mack and Yong 2000). In Yukon, Swainson's thrush inhabits willow shrub and various forest types (Theberge 1976). In the Alaska taiga, Swainson's thrush typically inhabits forested areas more than shrub thickets (Mack and Yong 2000; Figure H-45).

Swainson's thrush arrive in Southeast Alaska by mid-May and breed in pairs between June and early August (Mack and Yong 2000, Rogers 1994). Clutch sizes are typically 3–4 with incubation lasting approximately 10–14 days (Campbell et al. 1997). Young are tended by both parents until they leave the nest approximately 10–14 days after hatching (Mack and Yong 2000). Reproductive success is estimated at 18% to 50% of nests that rear at least one brood to independence and life spans of at least 10 years have been reported for adults (Mack and Yong 2000).

Swainson's thrush has a varied diet including insects and other invertebrates, small fruits, and seeds (Terres 1980). It is typically insectivorous during breeding and spring migration, with some populations converting to a more frugivorous diet during autumn migration and winter (Hilty and Brown 1986). Prior to migration, Swainson's thrush will deposit fat stores on their summer grounds and will replenish these fat stores during migration as well (Hicks 1967, Child 1969, Yong and Moore 1997).

While Swainson's thrush are common throughout Alaska, populations are reported as declining across their range, particularly in Alaska and the Northeast (Mack and Yong 2000).

9.2 Conceptual Model

The conceptual model below (Figure H-46) is based on literature review and describes the relationship between the various CAs and natural drivers for Swainson's thrush. The boxes and arrows represent the state of knowledge about the Swainson's thrush and its relationships to each CA. The arrows and red text represent/describe relationships between the CAs, natural drivers, and primary habitat for golden eagle. The primary CAs selected for this CE include: climate change, human uses, such as land use change, and wildland fire.

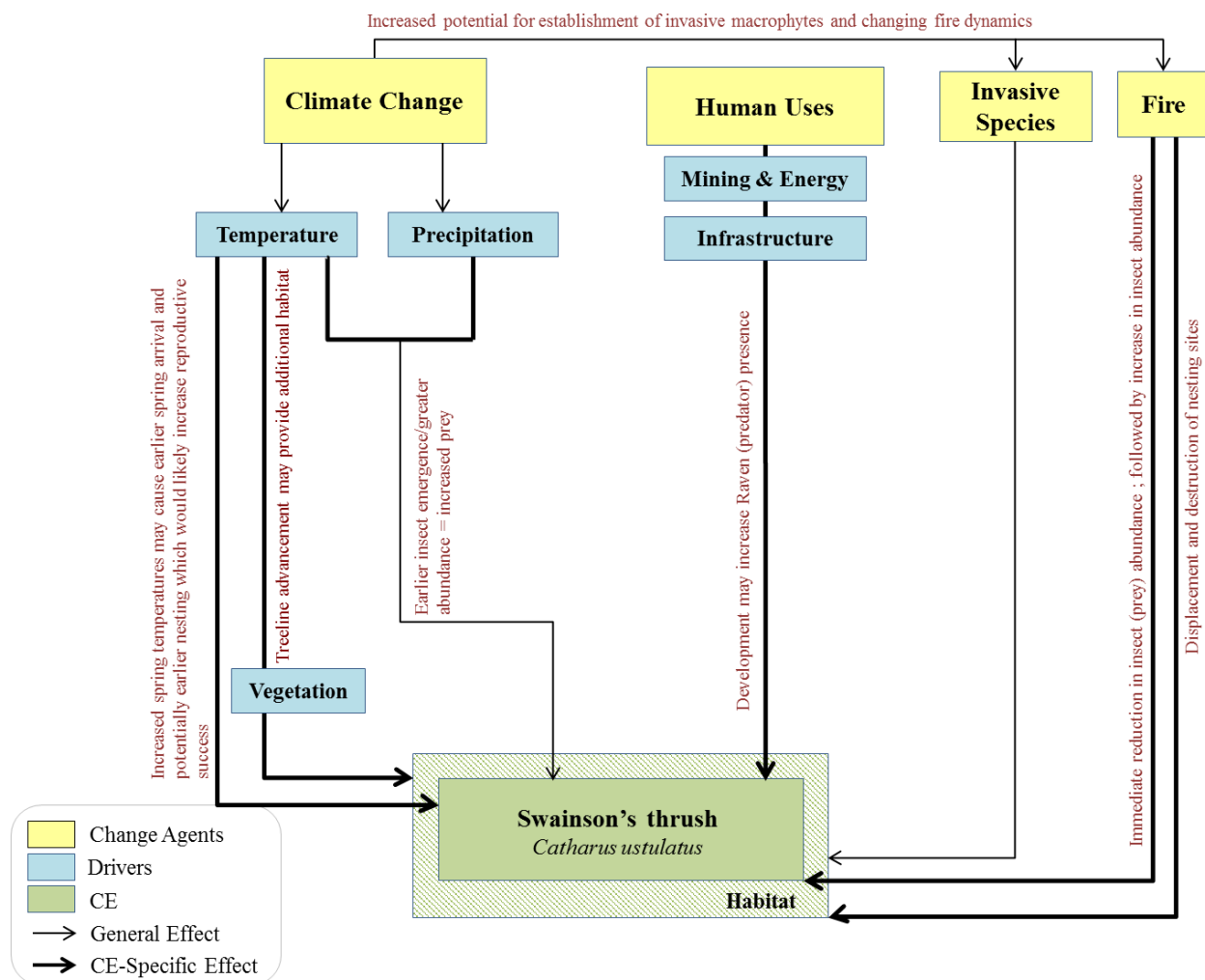


Figure H-46. Conceptual model describing the relationship between various CAs and natural drivers for Swainson's thrush.

9.3 Attributes and Indicators

Attributes and indicators helped to define the relationships between CEs and CAs, and, where possible, the thresholds associated with these relationships. Based on the assessment of available indicators, spatial data used to assess the status of Swainson's thrush included: length of growing season, spring temperature, treeline expansion and relative flammability (Table H-34).

Table H-34. Attributes and Indicators for the potential effect of various CAs and natural drivers on Swainson's thrush.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Spring temperature ³²	Mean monthly temp (April, May)	Earlier spring arrival of migratory bird species has been linked to warmer spring temperatures.	Colder than average			Warmer than average
	Insect abundance ³³	Length of growing (LOG) season	Insect emergence and abundance are directly influenced by mean ambient temperature and the number of frost-free days.	Shorter LOG			Longer LOG
Vegetation	Treeline expansion	ALFRESCO treeline	Treeline expansion may increase availability of forest habitat.	Treeline retreat			Treeline advancement
Fire	Fire ³⁴	Flammability	Wildfires directly reduces habitat, however, it indirectly increases prey availability.				

³² Based on Marra et al. 2005, Ward et al. 2016

³³ Based on Bolduc et al. 2013

³⁴ Based on Taylor and Barmore 1980

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CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Anthropogenic	Human activity ³⁵	Landscape condition	Human activity can cause nest abandonment around nest sites.	Low landscape condition			High landscape condition
	Fragmentation ³⁶	Landscape Intactness	Fragmentation decreases Swainson's thrush presence	Highly fragmented habitat			No fragmentation of habitat

³⁵ Based on Evans et al. 1998, Gardali et al. 1999

³⁶ Based on Hobson and Bayne 2000

9.4 Abiotic Change Agents Analysis

We explored the relationship between Swainson's thrush and two climate variables: mean April-May temperature and length of growing season at three time steps (current, near-term, and long-term).

Spring Temperature

Warmer spring temperatures have been associated with the earlier arrival of spring migrants on the breeding grounds (Marra et al. 2005, Ward et al. 2016). Increased temperatures are expected to promote a northward expansion of breeding distributions for numerous bird species, including Swainson's thrush; however, some studies show that Swainson's thrush may not be impacted as heavily as other bird species (Marra et al. 2005, Miller-Rushing et al. 2008, Mills 2005). Warmer spring and summer temperatures promote increased insect abundance (Bolduc et al. 2013), which increases food availability for Swainson's thrush and may positively affect reproductive success (Strong et al. 2004).

Spring temperature is expected to increase by the long-term future throughout the Swainson's thrush potential habitat distribution in the CYR study area (Table H-35). The greatest change is expected to occur in the northwest portion of the study area (Figure H-47). Little to no change (less than 1 °C) is expected through the central and eastern portions of the region.

Table H-35. Percent of Swainson's thrush potential habitat distribution affected by change in mean April-May temperature for the near-term (2020s) and long-term (2060s) future.

Swainson's thrush	Δ Spring Temperature (April, May)		
	No change	Significant Increase ¹	TOTAL RANGE (°C)
Near-Term	100%	0%	-0.15 to 0.45
Long-Term	0%	100%	0.75 to 1.75

¹Based on a mean standard deviation of 1 (near-term: ± 1.15 °C; long-term: ± 0.7 °C)

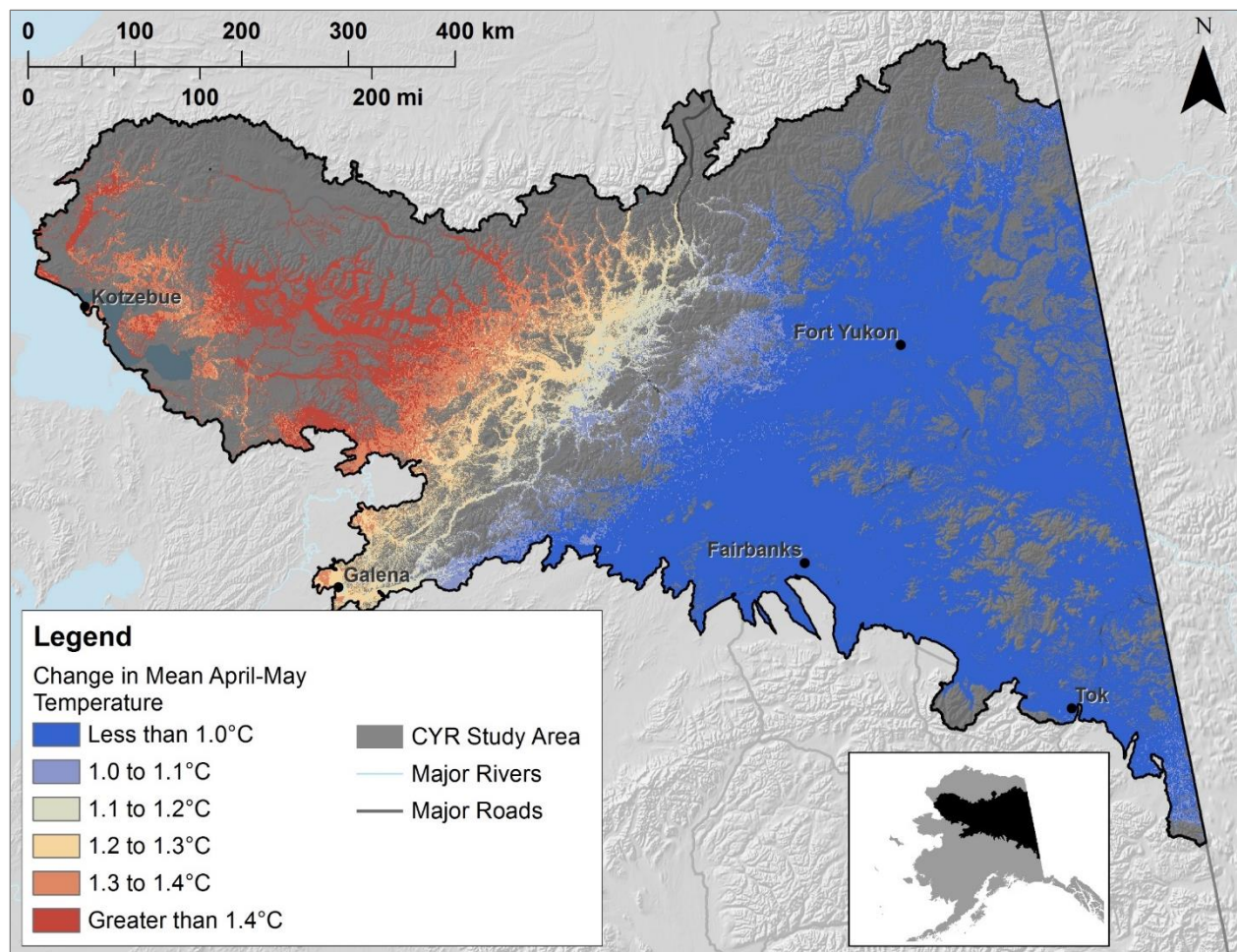


Figure H-47. Change in mean April-May temperature from the 2010s to the 2060s within the Swainson's thrush potential habitat distribution.

Length of growing season

Growing season length is positively correlated with daily availability of arthropods (Bolduc et al. 2013), which are a large part of the diet of Swainson's thrush (Mack and Yong 2000). Longer growing seasons have also been associated with increased reproductive success for migrants by allowing for a longer season on the breeding grounds, promoting earlier breeding phenology, increasing adult and chick fitness at time of autumn departure, and/or increasing amount of time to compensate for clutch failure (Gordo 2007). However, many climate variables are involved in determining the departure of a migrant passerine from their winter grounds, the arrival of a migrant passerine to their summer grounds, and the fitness of adults and chicks during the breeding season (Gordo 2007).

Growing season length is expected to increase for a portion of Swainson's thrush habitat in the near-term future and all Swainson's thrush habitat in the long-term future (Table H-36). These increases will be most pronounced in the western portion of the range (Figure H-48).

Table H-36. Percent of Swainson's thrush potential habitat distribution affected by change in growing season length for the near-term (2020s) and long-term (2060s) future.

Swainson's thrush	Δ Length of Growing Season				
	No Change	0–6 Days	7–14 Days	> 14 Days	Range (Days)
Near-Term	61%	39%	0%	0%	-3 to 4
Long-Term	0%	0%	100%	0%	6 to 16

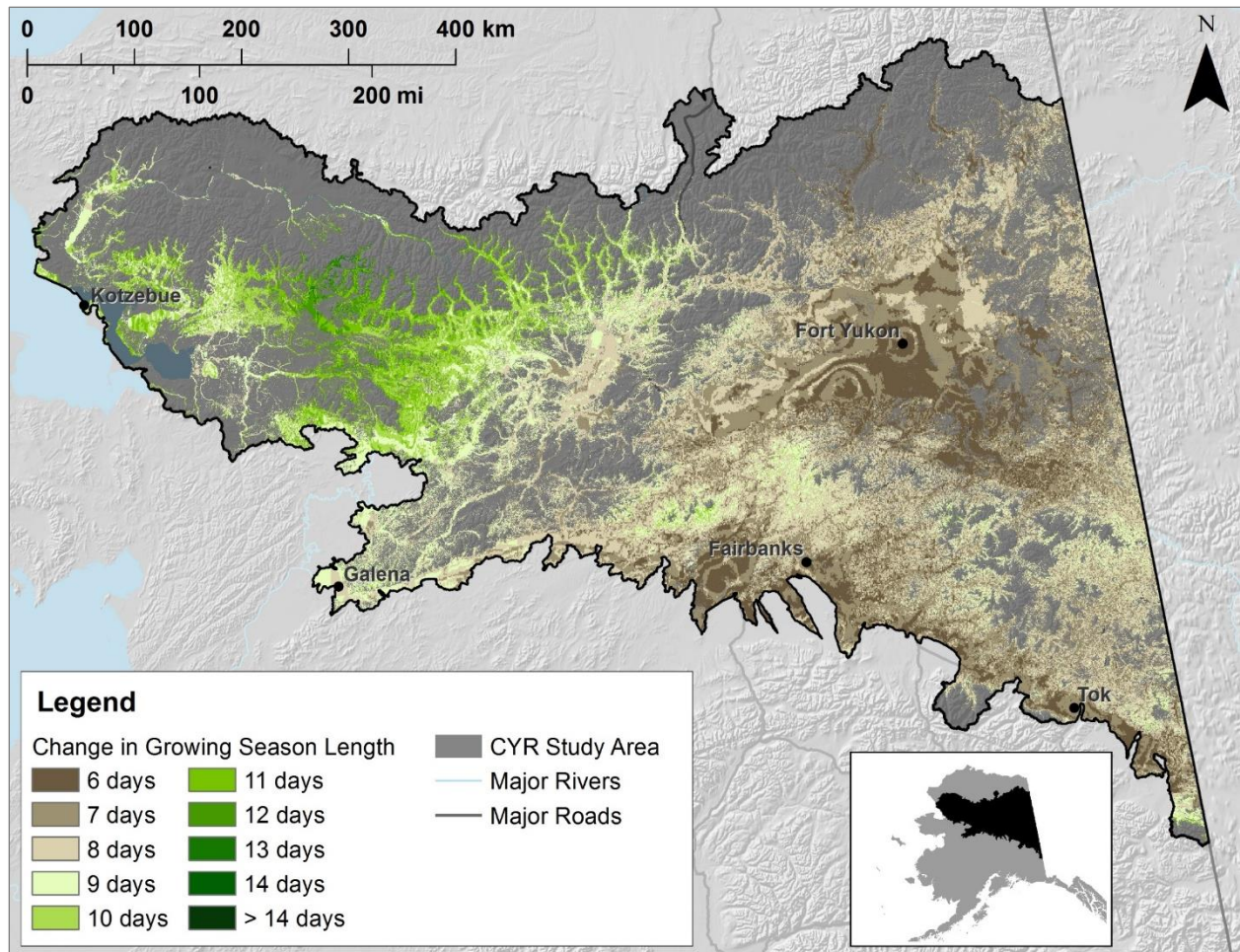


Figure H-48. Change in growing season length from the 2010s to the 2060s within the Swainson's thrush potential habitat distribution.

Treeline Expansion

In the Alaska taiga, Swainson's thrush inhabit forested areas (Mack and Yong 2000). The percent of forest cover is expected to increase by approximately 0.8% throughout the CYR study area and may provide more habitat for Swainson's thrush at the edge of its range (Figure H-49).

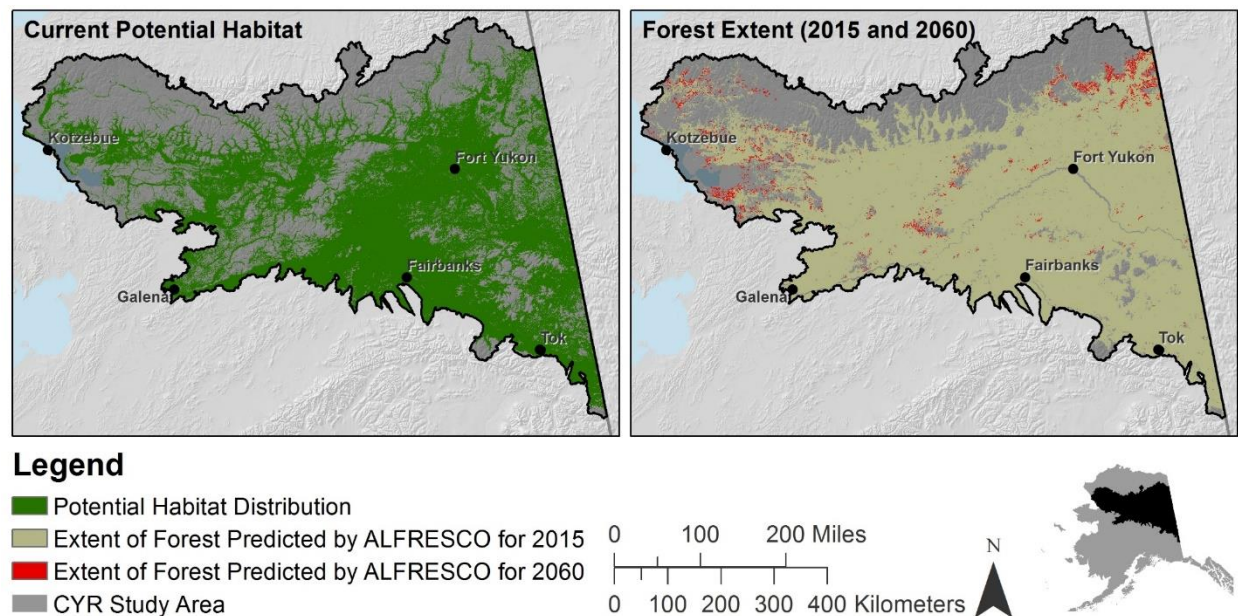


Figure H-49. Current (2015) and long-term future (2060) extent of ALFRESCO forest classes and the potential habitat distribution of Swainson's thrush.

Fire

Wildfires can cause direct destruction of Swainson's thrush habitat (forest), however, wildfires tend to increase bird species diversity immediately after the fire, with the greatest diversity occurring in the first five years and decreasing as the forest canopy closes (approx. 45 years; Taylor and Barmore, Jr. 1980). With warming temperatures, increasing fire frequency and area burned are predicted for the CYR study area (see Section C. Abiotic Change Agents).

Invasive Species

Invasive species such as spruce beetle can negatively impact breeding density of understory-nesting birds by reducing habitat availability (Matsuoka et al. 2001). Swainson's thrush however, does not seem to be significantly impacted by changes in forest stands due to spruce beetle outbreaks.

9.5 Current Status and Future Landscape Condition

Swainson's thrush can be sensitive to human activity around nest sites during the breeding season, causing nest abandonment (Evans et al. 1998, Gardali et al. 1999). In addition, fragmentation of the landscape may reduce (or eliminate) the presence of Swainson's thrush in an area (Hobson and Bayne 2000). The area associated with very high landscape condition is expected to decrease by 2% within Swainson's thrush habitat in the CYR study area (Figure H-50). This fragmentation of the landscape and increased human activity may have localized negative effects on Swainson's thrush.

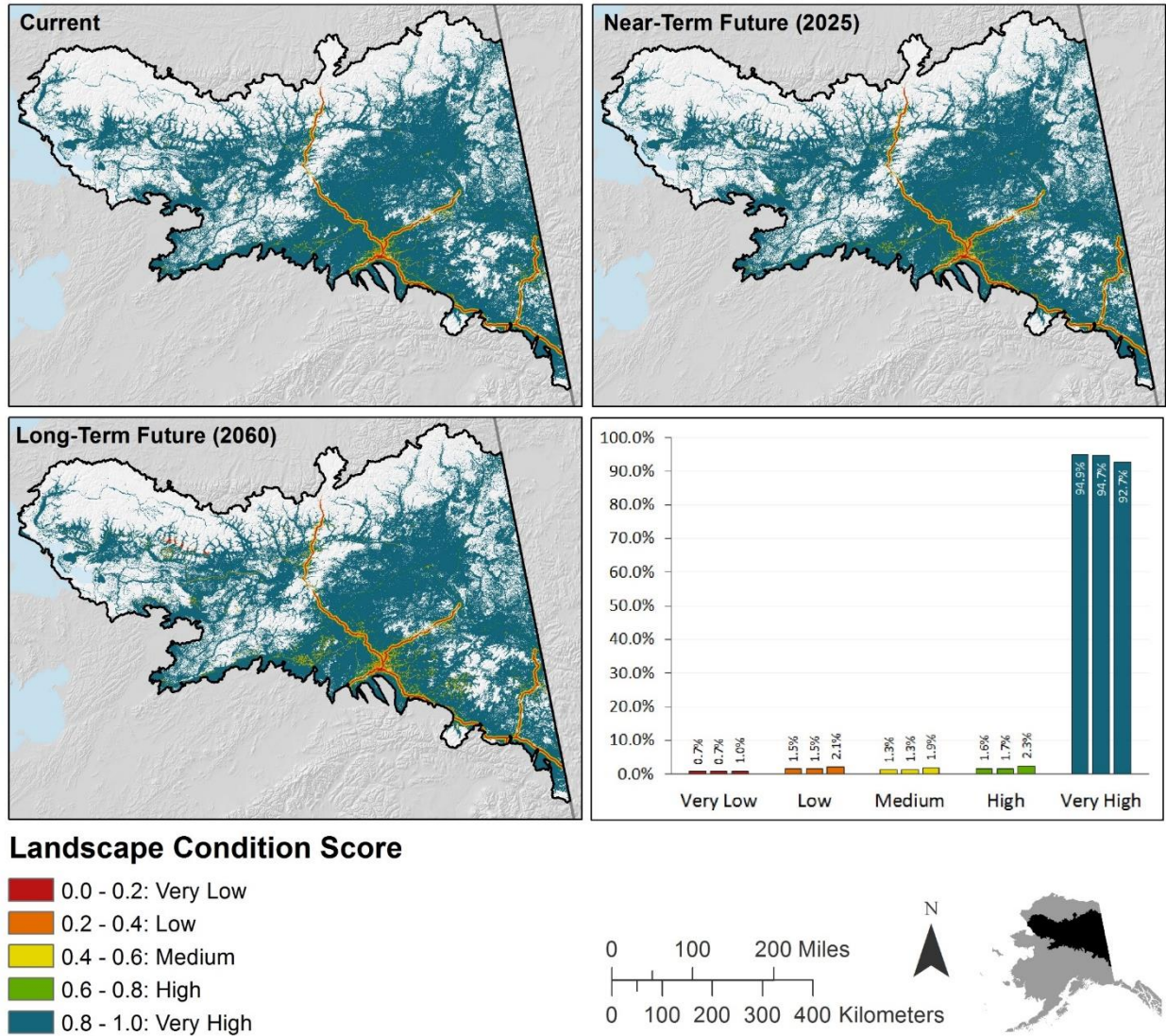


Figure H-50. Current, near-term, and long-term landscape condition within the potential habitat distribution of Swainson's thrush.

9.6 Summary

Future projections suggest a spring warming trend, an increase in the length of growing season, and treeline advancement throughout Swainson's thrush habitat that will likely promote increased prey and habitat availability, and positively influence survival and reproductive success in the CYR study area (Table H-37). Wildfires are expected to increase prey and habitat availability in the long-term future, while landscape condition may have localized negative effects on Swainson's thrush abundance and reproductive success. Invasive species are not expected to have a strong impact on Swainson's thrush.

Table H-37. Summary and projected effects of change agents used in the assessment for Swainson's thrush in the CYR study area.

Indicator	Near-term Change	Long-term Change	Effect in CYR Study Area	Impact
Length of growing season	+	+	+	Prey abundance, breeding season
Spring temperature	+	+	+	Spring arrival, Reproductive success
Treeline advancement	+	+	+	Prey habitat quality
Fire: Relative flammability	Unknown	+	+/-	Prey abundance, Habitat availability
Landscape condition	Minimal change	-	-	Reproductive success, Habitat availability
Invasive species	N/A	N/A	None	None

9.7 Limitation and Data Gaps

Grey-cheeked thrush was originally proposed as a Terrestrial Fine-filter CE; however, very little information or data were available to develop an accurate species distribution model, or perform a useful impact analysis. Therefore, Swainson's thrush was substituted into the study.

More Alaska-specific studies on the effect of climate and prey availability are needed to understand the effects of different variables on Swainson's thrush survival and reproductive success.

The ALFRESCO outputs do not include fire severity or precise spatial/temporal predictions of future fires (see Section C. Abiotic Change Agents), therefore, identifying areas where increased wildfire may impact prey abundance or habitat availability was not possible with these data.

ALFRESCO classes do not correlate to Terrestrial Coarse-filter CEs or to traditional vegetation classifications used in Alaska. Because ALFRESCO classes were compiled to predict future fire behavior rather than vegetation change, many uncertainties remain regarding what ALFRESCO predictions mean in an ecological sense. Interpretation of ALFRESCO predictions is more difficult because ALFRESCO classes do not correlate to Swainson's thrush habitat. A finer scale and ecologically oriented vegetation prediction model would greatly enhance the ability to determine potential climate change impacts to Swainson's thrush habitat within a 50-year time frame.

It is important to note that this study was limited to assessing the effect of specific CAs on CEs that we could spatially model and that had strong cause-and-effect linkages in the literature. There may be additional factors not addressed in this study that play an important role in determining the status of Swainson's thrush throughout the CYR study area.

9.8 Datasets and Literature Cited

Table H-38. Datasets used for analysis of Swainson's thrush in the CYR study area.

Dataset	Dataset Description	Dataset Provider	Data Type	Dataset Last Updated	Restrictions
Alaska GAP Analysis terrestrial vertebrate occurrence database—Swainson's thrush	This dataset contains 10312-point occurrence records for Swainson's thrush acquired from numerous data sources for the Alaska Gap Analysis Project.	Alaska Center for Conservation Science	Point	2009	Not for publication and/or distribution
BISON Swainson's thrush occurrence records	This dataset contains 9473-point occurrence records for Swainson's thrush compiled by Biodiversity Information Serving Our Nation (BISON), an integrated and permanent resource for biological occurrence data from the United States. Date range of occurrence records is 1867 through 2013.	Biodiversity Information Serving Our Nation (BISON)	Point	2013	Use of data must be cited according to BISON data user agreement [†]

[†]Data user agreement available online: <http://bison.usgs.ornl.gov/#about>

Literature Cited

- 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.
- Campbell, R. W., N. K. Dawe, I. McTaggart-Cowan, J. M. Cooper, and G. W. Kaiser. 1997. The birds of British Columbia, Vol. 3-Passerines: flycatchers through vireos. Royal British Columbia Museum, Victoria.
- Child, G. I. 1969. A study of nonfat weights in migrating Swainson's thrushes (*Hylocichla ustulata*). *Auk* 86:327-338.
- Evans, D. M., J. C. Bednarz, C. R. Davis, and J. C. Hovis. 1998. The effects of forest landscape modification and management on neotropical migratory songbird populations in west-central Idaho. Arkansas State University, Jonesboro, Arkansas.
- Gardali, T., S. E. Scoggin, and G. R. Geupel. 1999. Songbird use of Redwood and Lagunitas creeks: management and restoration recommendations. Prepared for: the Golden Gate National Recreation Area, January 1999. Point Reyes Bird Observatory, Stinson Beach, California. Available: <http://www.prbo.org/cms/docs/terre/Gardalireport98.pdf>
- Gordo, O. 2007. Why are bird migration dates shifting? A review of weather and climate effects on avian migratory phenology. *Climate Research* 35:37-58.
- Hicks, D. L. 1967. Adipose tissue composition and cell size in fall migration thrushes (Turdidae). *Condor* 69:38-39.
- Hilty, S. L., and B. Brown. 1986. A guide to the birds of Colombia. Princeton University Press.
- Hobson, K. A., and E. Bayne. 2000. Effects of forest fragmentation by agriculture on avian communities in the southern boreal mixedwoods of western Canada. *The Wilson Bulletin* 112:373-387.

Section H. Terrestrial Fine-filter Conservation Elements

- Mack, D. E., and W. Yong. 2000. Swainson's thrush (*Catharus ustulatus*). The birds of North America online (A. Poole, ed.). Cornell Lab of Ornithology, Ithaca. Available: <http://bna.birds.cornell.edu/bna/species/540>
- Marra, P. P., C. M. Francis, R. S. Mulvihill, and F. R. Moore. 2005. The influence of climate on the timing and rate of spring bird migration. *Oecologia* 142:307-315.
- Matsuoka, S. M., C. M. Handel, and D. R. Ruthrauff. 2001. Densities of breeding birds and changes in vegetation in an Alaskan boreal forest following a massive disturbance by spruce beetles. *Canadian Journal of Zoology* 79:1678-1690.
- Miller-Rushing, A. J., T. L. Lloyd-Evans, R. B. Primack, and P. Satzinger. 2008. Bird migration times, climate change, and changing population sizes. *Global Change Biology* 14:1959-1972.
- Mills, A. M. 2005. Changes in the timing of spring and autumn migration in North American migrant passerines during a period of global warming. *Ibis* 147:259-269.
- Rogers, C. M. 1994. Avian nest success, brood parasitism and edge-independent reproduction in an Alaskan wetland. *Journal of Field Ornithology* 65:433-440.
- Strong, A. M., C. C. Rimmer, and K. P. McFarland. 2004. Effect of prey biomass on reproductive success and mating strategy of Bicknell's thrush (*Catharus bicknelli*), a polygynandrous songbird. *The Auk* 121:446-451.
- Taylor, D. L., and W. J. Barmore, Jr. 1980. Post-fire succession of avifauna in coniferous forests of Yellowstone and Grand Teton National Parks, Wyoming. Pages 11-114 in Workshop proceedings of the management of western forests and grasslands for nongame birds.
- Terres, J. K. 1980. Audubon Society encyclopedia of North American birds. Distributed by Random House.
- Theberge, J. B. 1976. Bird populations in the Kluane Mountains, southwest Yukon, with special reference to vegetation and fire. *Canadian Journal of Zoology* 54:1346-1356.
- Ward, D. H., J. Helmericks, J. W. Hupp, L. McManus, M. Budde, D. C. Douglas, and K. D. Tape. 2016. Multi-decadal trends in spring arrival of avian migrants to the central Arctic coast of Alaska: effects of environmental and ecological factors. *Journal of Avian Biology* 47:197-207.
- Yong, W., and F. M. Moore. 1997. Spring stopover of the intercontinental migratory thrushes along the northern coast of the Gulf of Mexico. *Auk* 114:263-278.

10. Trumpeter Swan (*Cygnus buccinator*)

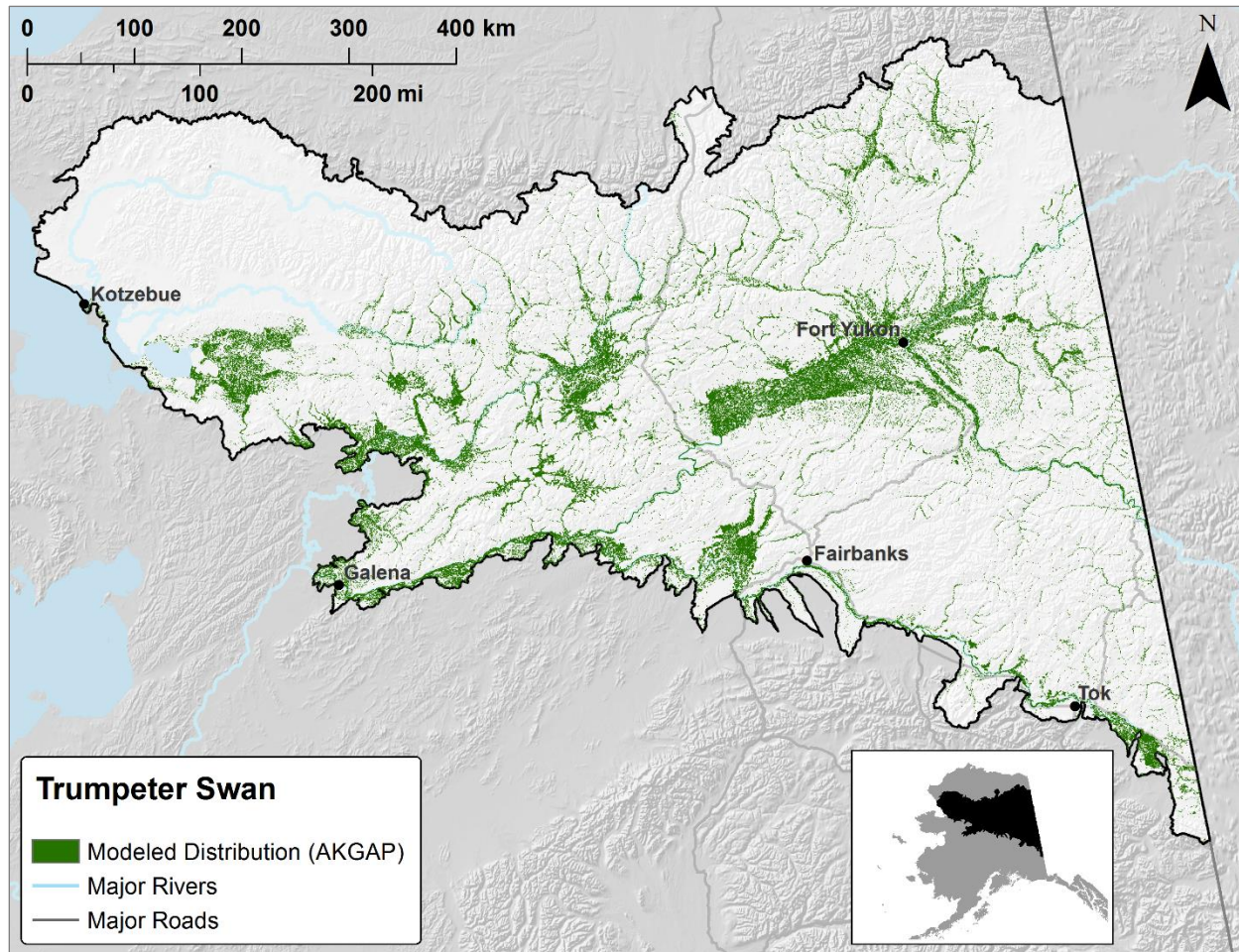


Figure H-51. Current potential habitat distribution for trumpeter swan in the CYR study area.

10.1 Introduction

The trumpeter swan is one of the largest waterfowl species in North America. Wetlands in Central and Southcentral Alaska provide the majority of the breeding habitat for the Pacific population of trumpeter swans. During autumn, trumpeter swans migrate south to wetland habitats in coastal British Columbia and western Washington where they spend the winter months (PFC 2006).

During summer, trumpeter swans use a variety of freshwater wetland habitats for breeding, including marshes, ponds, lakes, and occasionally rivers (Banko 1960, Hansen et al. 1971, Gale et al. 1987; Figure H-51). Suitable wetlands require adequate room to allow for take-off, available forage resources, shallow and stable water levels, emergent vegetation, and low levels of human disturbance for nesting (Mitchell and Eichholz 2010). Summer forage consists of various marsh plants including horsetails, pondweeds, sedges, bulrushes, water milfoil, widgeon grass, and pond lily. Young cygnets consume aquatic vertebrates during their first few weeks to acquire enough protein and energy for rapid growth (ADF&G).

Historically, the trumpeter swan was widespread and abundant; however, the early fur trade and European settlement nearly extirpated the entire population. Conservation and monitoring efforts have resulted in a steady increase in population size and breeding distribution in Alaska.

10.2 Conceptual Model

The conceptual model below (Figure H-52) is based on literature review and describes the relationship between the various CAs and natural drivers for trumpeter swan. The boxes and arrows represent the state of knowledge about the trumpeter swan and its relationships to each CA. The arrows and red text represent/describe relationships between the CAs, natural drivers, and primary habitat for trumpeter swan. The primary CAs selected for this CE include: climate change, human uses, such as land use change, and wildland fire.

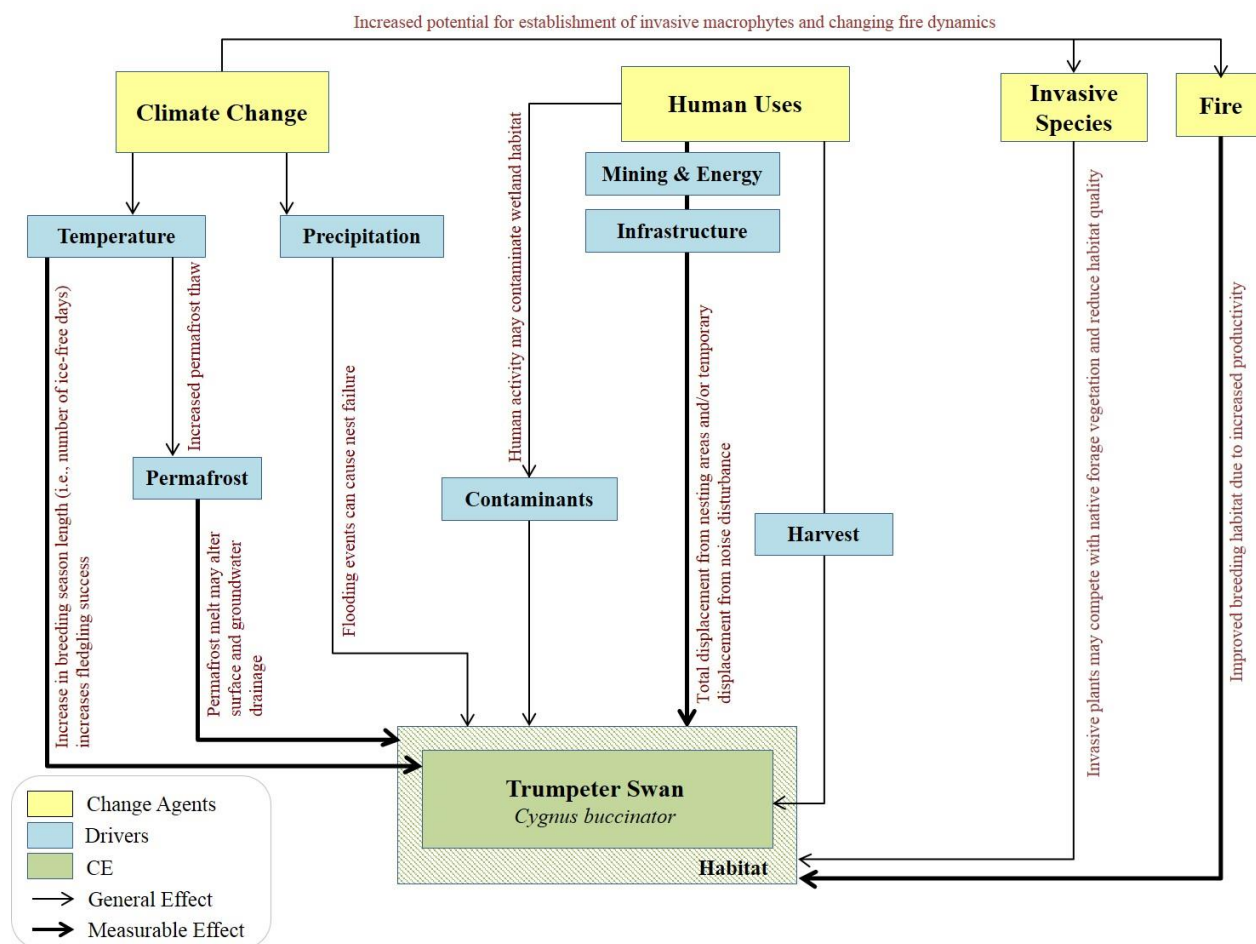


Figure H-52. Conceptual model describing the relationship between various CAs and natural drivers for trumpeter swan.

10.3 Attributes and Indicators

Attributes and indicators helped to define the relationships between CEs and CAs, and, where possible, the thresholds associated with these relationships. Based on the assessment of available indicators, spatial data used to assess the status of trumpeter swan included: spring flooding, breeding season, permafrost, relative flammability, and anthropogenic activity (Table H-39).

Table H-39. Attributes and Indicators for the potential effect of various CAs and natural drivers on trumpeter swan.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Spring flooding events ³⁷	April precipitation	Flooding events can cause nest failure and chick mortality during nesting (April).	Frequent flooding events			No flooding events
	Breeding season length ³⁸	Length of growing season	Breeding is limited by the number of ice-free days (i.e., 145-150 days; Hansen et al. 1971). In years with cold springs, pairs may not breed. Range expansion in Alaska has likely occurred as a result of climate warming (Schmidt et al. 2011).	< 145 ice-free days			145-150 ice-free days
	Permafrost ³⁹	Permafrost melt	Permafrost melt alters both surface water and groundwater systems, which may affect habitat availability.	Deep thaw (increased groundwater drainage)			Shallow melting (increased surface water)

³⁷ Based on RMCESU 2008

³⁸ Based on Hansen et al. 1971, Schmidt et al. 2009, Schmidt et al. 2011

³⁹ Based on Roach et al. 2013.

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CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Fire	Fire frequency ⁴⁰	Fire return interval	Schmidt et al. (2009) found wildfire improved the quality of brood-rearing habitat in the Minto Flats State Game Refuge and Tetlin National Wildlife Refuge, likely as a result of increased productivity.				
Anthropogenic Development	Habitat ⁴¹		Active transportation infrastructure increases human access and makes wetlands less suitable for nesting and brood rearing (Hanson and Grant 1991). Schmidt et al. (2009) suggest a buffer of at least 402 m from development for all lakes and ponds.	Development < 400m from wetland areas			Disturbance > 400 m from wetland areas
	Human presence/raven abundance ⁴²	Landscape condition model	Risk of predation on passerine bird nests increases within 5 km of human infrastructure. Ravens, a common predator associated with human infrastructure have a foraging range of approx. 5-7 km in diameter.	Human development < 5 km from nesting habitat	Human development sites 5-10 km from nesting habitat		Human development sites > 10 km from nesting habitat

⁴⁰ Based on Schmidt et al. 2009

⁴¹ Based on Henson and Grant 1991, Schmidt et al. 2009

⁴² Based on Leibezeit et al. 2009, Støen et al. 2010, RMCESU 2008

10.4 Abiotic Change Agents Analysis

We explored the relationship between Trumpeter swan and one climate and one permafrost variable: length of growing season and mean annual ground temperature at three time steps (current, near-term, and long-term).

Length of Growing Season

Trumpeter swan breeding is limited by the number of ice-free days per year (growing season length; RMCESU 2008). Trumpeter swans need 145–150 ice free days to breed and successfully fledge young. Earlier spring arrivals accelerate nesting and hatching and give cygnets more time for development before heading south (Hansen et al. 1971). The recent northerly expansion in distribution of trumpeter swans is likely a result of earlier spring thaw dates and overall warmer temperatures (Schmidt et al. 2011).

Throughout the CYR study area, the length of available breeding season is likely to increase, measured as the number of ice free days or length of growing season (see Section C. Abiotic Change Agents). Growing season length is projected to increase by one to two weeks in all trumpeter swan habitat in the study area by the long-term future (Table H-40). Increases are expected to be largest in western portion of the study area (Figure H-53).

Table H-40. Percent of trumpeter swan potential habitat distribution and of total study area affected by change in growing season length for the near-term (2020s) and long-term (2060s) future.

Trumpeter Swan Habitat Distribution	Δ Length of Growing Season				
	No Change	0–6 Days	7–14 Days	> 14 Days	Range (Days)
Near-term	57%	43%	0%	0%	-2 to 4
Long-term	0%	0%	100%	0%	6 to 15
Entire Central Yukon Study Area					
Near-term	44%	56%	0%	0%	-3 to 15
Long-term	0%	0%	100%	0%	6 to 52

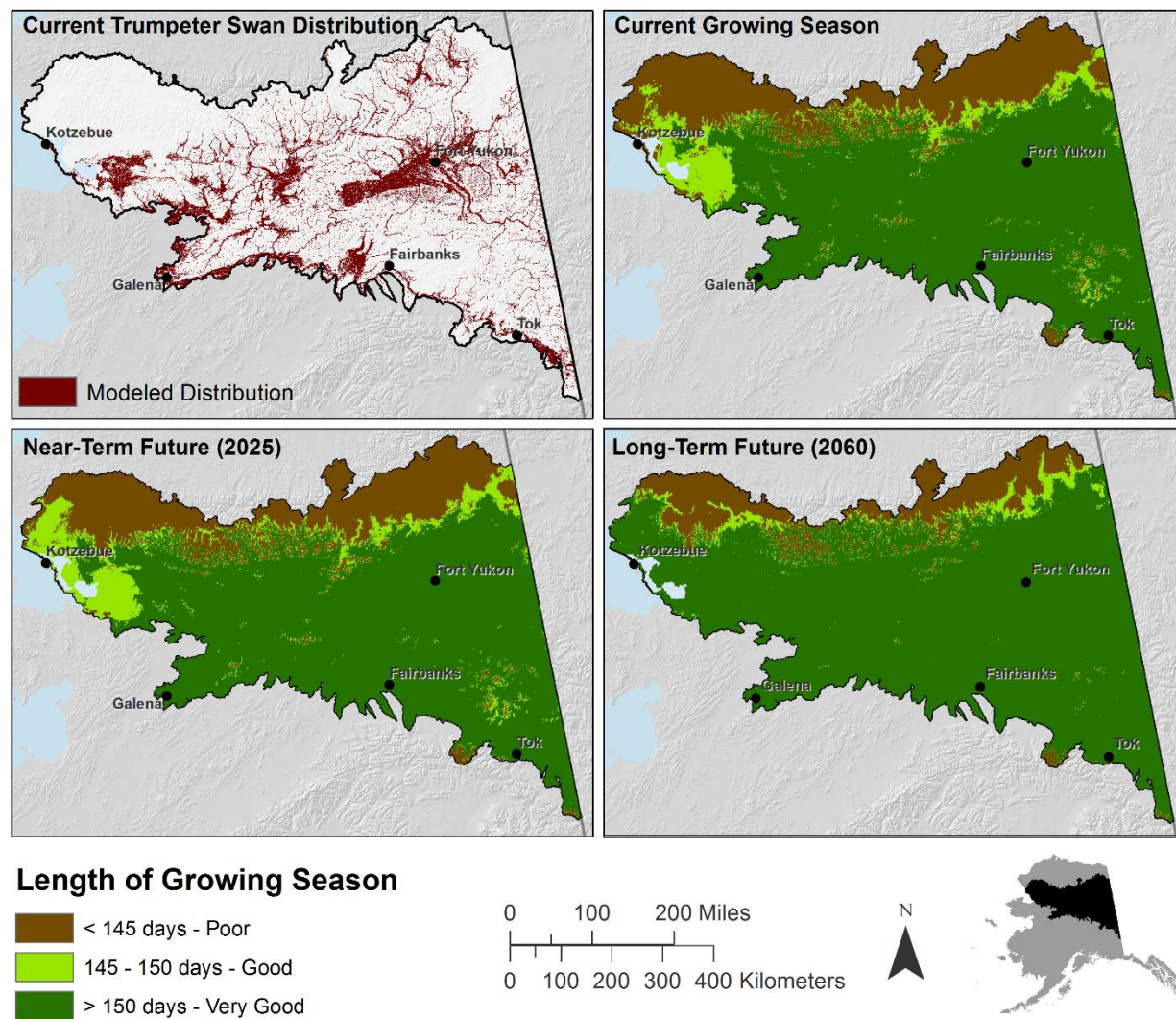


Figure H-53. Current (2010s), near-term future (2020s), and long-term future (2060s) growing season length and the potential habitat distribution of trumpeter swan.

Mean Annual Ground Temperature

Permafrost thaw has the potential to cause wetland drying and shrinkage. Some wetlands are likely to become less suitable as they shrink and become more shallow, but other deeper waters may become shallower and, thus, more suitable (Schmidt et al. 2011). Permafrost melt also alters both surface water and groundwater systems, which may affect trumpeter swan habitat (wetlands) availability (Roach et al. 2013).

Mean annual ground temperature (MAGT) is predicted to increase throughout the CYR study area, altering areas currently underlain by permafrost (see Section C. Abiotic Change Agents and Section G. Terrestrial Coarse-Filter Conservation Elements). These changes are predicted to occur in the southern portion of the CYR study area (Figure H-54).

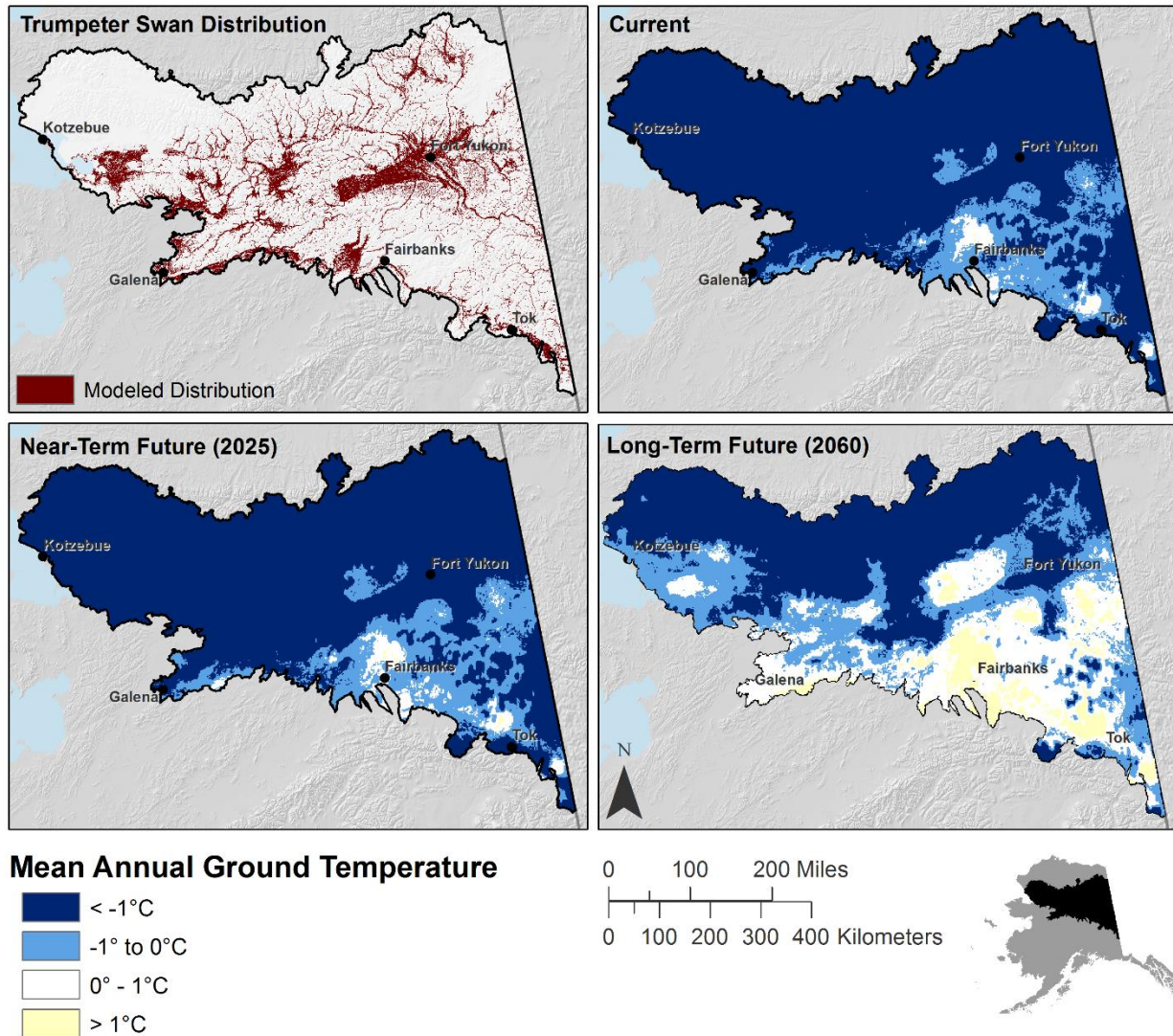


Figure H-54. Current (2010s), near-term future (2020s), and long-term future (2060s) mean annual ground temperature and the potential habitat distribution of trumpeter swan.

Fire

Increased post-fire levels of phosphorous, nitrogen, and potassium in the environment can increase the productivity of swan forage and brood-rearing habitat (Schmidt et al. 2009). These increases in quality of brood-rearing habitat have been observed in places such as Minto Flats State Game Refuge and Tetlin National Wildlife Refuge (Henson and Grant 1991). With warming temperatures, increasing fire frequency and area burned are predicted for the CYR study area (see Section C. Abiotic Change Agents).

Invasive Species

Invasive plant species have the potential to change the habitat structure, biodiversity, productivity, nutrient cycling, and trophic ecology of wetlands ecosystems. This may result in habitat loss for trumpeter swans (Zedler and Kercher 2004). In addition, it is unclear how the establishment of *Eloidea* may impact trumpeter swans or beavers. The movement of trumpeter swans and other

waterfowl may result in increased spread of *Elodea* in the CYR study area (see Section D. Biotic Change Agents).

10.5 Current Status and Future Landscape Condition

Changes in land use, including infrastructure, transportation, and natural resource development, can often result in partial or complete loss of wetland habitat for trumpeter swans. Human activity and disturbance, such as recreation, vehicle traffic, and wildlife viewing, cause noise disturbance that often results in female displacement from nesting sites (Henson and Grant 1991, Schmidt et al. 2009). The establishment of human infrastructure can also increase raven presence and predation on trumpeter swan nests (Leibzeit et al. 2009, Støen et al. 2010).

Landscape condition throughout the majority of the trumpeter swan habitat distribution in the CYR study area is considered high to very high (Figure H-55). The area associated with very high landscape condition is expected to decrease by 0.5% within the trumpeter swan potential habitat distribution.

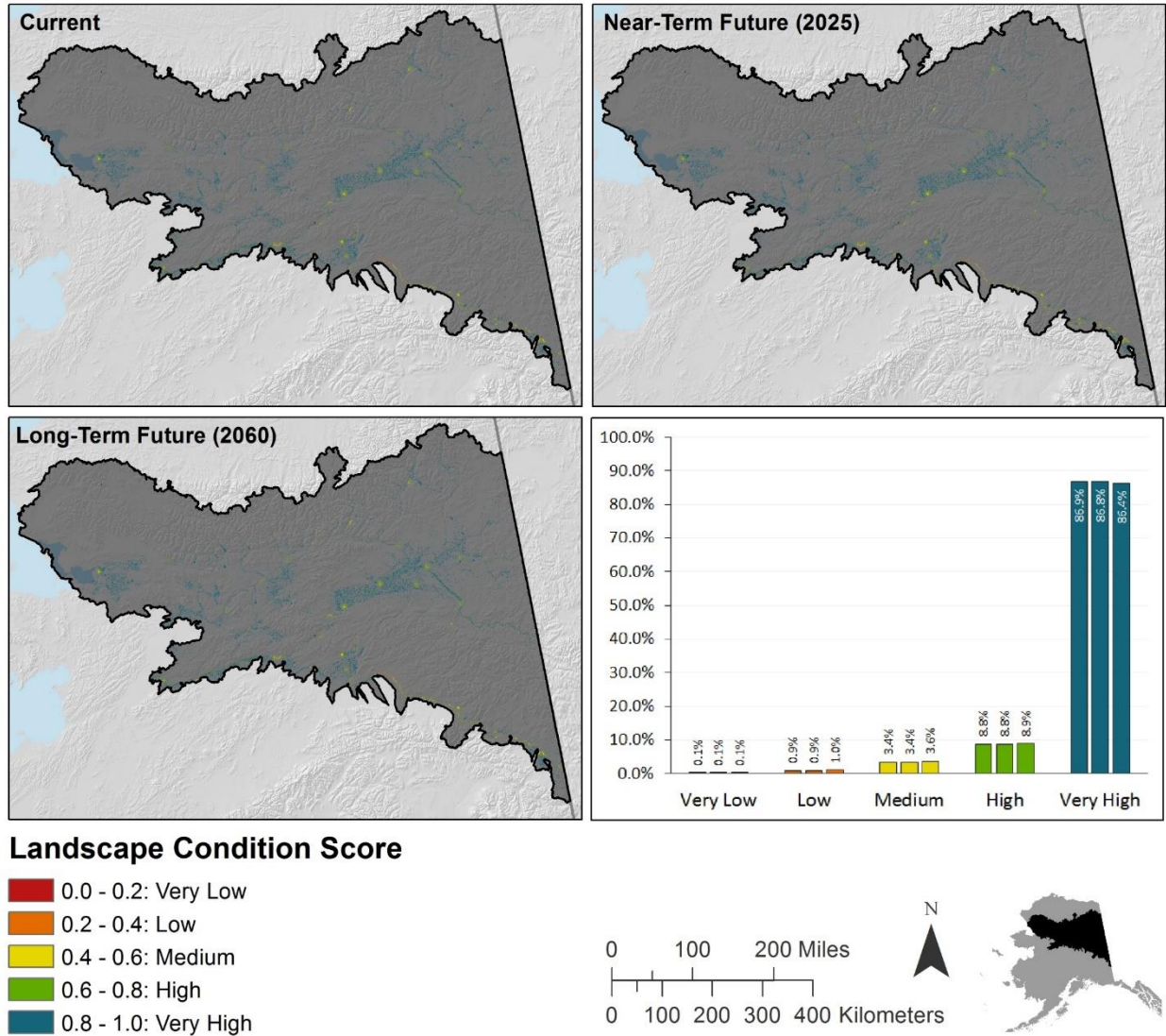


Figure H-55. Current, near-term, and long-term landscape condition within the potential habitat distribution of trumpeter swan.

10.6 Summary

Future projections relevant to trumpeter swan suggest that throughout the CYR study area, there will be an increase in length of growing season and an increase in permafrost melt (Table H-41). In addition, an increase in fire frequency and area burned are predicted for the CYR study area in general. These changes may support increased fledging success through a longer breeding season and increased habitat quality and availability. Other variables considered in this analysis, such as invasive species and landscape condition, are not expected to have a significant impact on trumpeter swan in the next fifty years.

Table H-41. Summary and projected effects of CAs used in the assessment for Trumpeter swan in the CYR study area.

Indicator	Near-term Change	Long-term Change	Effect in CYR Study Area	Impact
Length of growing season	+	+	+	Reproductive success
Fire: Relative flammability	+	+	+	Habitat quality
Mean annual ground temperature	Minimal change	+	+/-	Habitat availability
Invasive species	N/A	N/A	None	Habitat quality

10.7 Limitation and Data Gaps

Permafrost melt alters both surface water and groundwater systems and is an important variable in predicted changes to habitat availability. We have used mean annual ground temperature as a proxy for permafrost melt; however, obtaining a better measure/predictive model of permafrost melt may allow for more accurate predictions for impacts to trumpeter swan habitat.

The ALFRESCO) outputs do not include fire severity or precise spatial/temporal predictions of future fires (see Section C. Abiotic Change Agents), therefore, identifying areas where wildfire cycling may increase habitat and forage productivity for Trumpeter Swan was not possible with these data.

It is important to note that this study was limited to assessing the effect of specific CAs on CEs that we could spatially model and that had strong cause-and-effect linkages in the literature. There may be additional factors not addressed in this study that play an important role in determining the status of Trumpeter swan throughout the CYR study area.

10.8 Datasets and Literature Cited

Table H-42. Datasets used for analysis of trumpeter swan in the CYR study area.

Dataset	Dataset Description	Dataset Provider	Data Type	Dataset Last Updated	Restrictions
Alaska GAP Analysis terrestrial vertebrate occurrence database—Trumpeter swan	This dataset contains 1366-point occurrence records for trumpeter swan acquired from numerous data sources for the Alaska Gap Analysis Project.	Alaska Center for Conservation Science	Point	2009	Not for publication and/or distribution
Alaska GAP Analysis final distribution model—Trumpeter swan	GAP habitat distribution models represent the areas where species are predicted to occur based on habitat associations. Models have a 60 meter resolution and are delimited by GAP species range.	Alaska Gap Analysis Project	Raster	2009	None
BISON Trumpeter swan occurrence records	This dataset contains 339-point occurrence records for golden eagle compiled by Biodiversity Information Serving Our Nation (BISON), an integrated and permanent resource for biological occurrence data from the United States. Date range of occurrence records is 1895 through 2013.	Biodiversity Information Serving Our Nation (BISON)	Point	2013	Data must be cited according to BISON data user agreement [†]
National Hydrography Dataset	The NHD represents the drainage network with features such as rivers, streams, canals, lakes, ponds, coastline, dams, and stream gages.	U.S. Geological Survey	Digital vector dataset	2014	None

[†]Data user agreement available online: <http://bison.usgs.ornl.gov/#about>

Literature Cited

- Alaska Department of Fish and Game (ADF&G). Species bulletin: swans. Available: <http://www.adfg.alaska.gov/static/education/wns/swans.pdf>
- Banko, W. E. 1960. The trumpeter swan: its history, habits, and population in the United States. *North American Fauna* 63:1-214.
- 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 & Wildlife Service, Montana Cooperative Wildlife Research Unit, Missoula, Montana.
- Hansen, H. A., P. E. K. Shepard, J. G. King, and W. A. Troyer. 1971. The trumpeter swan in Alaska. *Wildlife Monographs* 26:3-83.
- Henson, P., and T. A. Grant. 1991. The effects of human disturbance on trumpeter swan breeding behavior. *Wildlife Society Bulletin* 19:248-257.
- Liebezeit, J., S. Kendall, S. Brown, C. Johnson, P. Martin, T. McDonald, D. Payer, C. Rea, A. Streever, A. Wildman, and S. Zack. 2009. Influence of human development and predators on nest survival of tundra birds, Arctic Coastal Plain, Alaska. *Ecological Applications* 19:1628-1644.

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- Mitchell, C. D., and M. W. Eichholz. 2010. Trumpeter swan (*Cygnus buccinator*). The birds of North America online (A. Poole, ed.). Cornell Lab of Ornithology, Ithaca. Available: <http://bna.birds.cornell.edu/bna/species/>
- 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.
- Roach, J. K., B. Griffith, and D. Verbyla. 2013. Landscape influences on climate-related lake shrinkage at high latitudes. *Global Change Biology* 19:2276-2284.
- Rocky Mountains Cooperative Ecosystems Studies Unit (RMCESU). 2008. Yellowstone National Park trumpeter swan conservation assessment. Prepared for: Yellowstone National Park, Cooperative Agreement Number: H1200040001.
- 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.
- Støen, O., P. Wegge, S. Hied, O. Hjeljord, and C. Nellemann. 2010. The effect of recreational homes on willow ptarmigan (*Lagopus lagopus*) in a mountain area of Norway. *European Journal of Wildlife Research* 56:789-795.
- 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.

11. MQ AE1: Waterfowl Habitat

MQ AE1: Where is primary waterfowl habitat located?

11.1 Introduction

Alaska's wetlands provide nesting habitat for approximately 20% of waterfowl species that occur in the U.S. (USFWS 2010). Species richness has been one of the most frequently used indicators of habitat quality for waterfowl, along with relative density of birds (Murphy et al. 1984). Because this Management Question (MQ) focuses on species habitat distribution rather than species distribution, richness of predicted species habitat was selected as the most appropriate measure for assessing the spatial distribution of primary waterfowl habitat. An analysis of relative density of birds would be a useful addition to species habitat richness, but such an analysis was not possible because of lack of data. Although wetlands are important to waterfowl, this assessment did not include any direct correlation of wetland status with primary waterfowl habitat.

11.2 Methods

Waterfowl are defined for purposes of this MQ to include only species belonging to the family Anatidae. Although MQ AE1 does not specifically mention breeding habitat, the treatment in this assessment assumes 'primary' correlates to 'breeding' for breeding habitat:

- 1.) is the most biologically definable habitat type for waterfowl species;
- 2.) is the most biologically sensitive habitat type for waterfowl species; and
- 3.) has been modeled for waterfowl species in Alaska through the Alaska Gap Analysis Project while other seasonal distributions have not.

Breeding Distribution models produced for the Alaska Gap Analysis Project for all waterfowl (Anatidae) species known to occur in Alaska were extracted to the CYR study area. Each distribution model consisted of values of predicted presence of suitable breeding habitat with "0" representing absence and "1" representing presence. Species with breeding habitat within the study area were preliminarily selected for this assessment. Summer range polygons developed by NatureServe and the Alaska Center for Conservation Science were overlapped with the study area to produce a final list of selected species. The distribution models for all selected species were summed to produce an estimate of habitat importance based on percent of total species habitats predicted as suitable per cell.

To determine areas of important waterfowl habitat, an arbitrary overlap threshold of 25% was selected to remove habitat suitable only for one or a few species from consideration. Because model performance was low for most included species (see Limitations and Data Gaps), areas of important waterfowl habitat were summarized per hydrologic unit. Important Bird Areas designated by Audubon Alaska were then compared to hydrologic units selected as important habitat on the basis of 25% mean habitat overlap. Important waterfowl habitat could also be determined from relative density of waterfowl. A relative density approach was considered for this assessment in addition to the species habitat richness approach; however, waterfowl species

populations were not available across the study area. Table H-43 provides a list of the datasets selected for MQ AE1.

Table H-43. Source datasets used to determine distribution of primary waterfowl habitat in CYR study area.

Dataset Name	Data Source
Breeding Habitat Distribution Models	Alaska Gap Analysis Project
Important Bird Areas	Audubon Alaska

11.3 Results and Discussion

The CYR study area provides breeding habitat for 28 waterfowl species (Table H-44). Waterfowl habitat is not uniform within the study area and is not limited to any particular vegetation classes, including those classified as wetland or aquatic habitats. Presence of predicted breeding habitat for at least one waterfowl species covers 89% of the CYR study area (Figure H-56), indicating that waterfowl species use a variety of habitat types for breeding. Low average model performance may partially contribute to the ubiquity of predicted breeding habitat in the study area (see Limitations and Data Gaps). However, literature review of species habitat also indicates that waterfowl breeding habitat is varied and not always located immediately adjacent to lakes, streams, and wetlands (Gotthardt et al. 2013).

Table H-44. Percent of study area predicted as suitable breeding habitat for 28 waterfowl species with predicted breeding habitat within the CYR study area.

Scientific Name	Common Name	Percent of Study Area Predicted as Suitable Breeding Habitat
<i>Aythya collaris</i>	Ring-Necked Duck	55%
<i>Bucephala clangula</i>	Common Goldeneye	52%
<i>Aythya marila</i>	Greater Scaup	31%
<i>Bucephala albeola</i>	Bufflehead	31%
<i>Aythya americana</i>	Redhead	31%
<i>Anas platyrhynchos</i>	Mallard	29%
<i>Clangula hyemalis</i>	Long-Tailed Duck	26%
<i>Melanitta americana</i>	Black Scoter	26%
<i>Anas acuta</i>	Northern Pintail	25%
<i>Mergus serrator</i>	Red-Breasted Merganser	22%
<i>Melanitta perspicillata</i>	Surf Scoter	22%
<i>Anas crecca</i>	Green-Winged Teal	22%
<i>Melanitta fusca</i>	White-Winged Scoter	21%
<i>Anas americana</i>	American Wigeon	18%
<i>Anser albifrons</i>	Greater White-Fronted Goose	16%
<i>Aythya valisineria</i>	Canvasback	12%
<i>Branta canadensis</i>	Canada Goose	11%
<i>Histrionicus histrionicus</i>	Harlequin Duck	10%

Scientific Name	Common Name	Percent of Study Area Predicted as Suitable Breeding Habitat
<i>Anas clypeata</i>	Northern Shoveler	7%
<i>Mergus merganser</i>	Common Merganser	6%
<i>Aythya affinis</i>	Lesser Scaup	6%
<i>Branta hutchinsii</i>	Cackling Goose	4%
<i>Anas discors</i>	Blue-Winged Teal	4%
<i>Cygnus buccinator</i>	Trumpeter Swan	3%
<i>Cygnus columbianus</i>	Tundra Swan	2%
<i>Somateria mollissima</i>	Common Eider	1%
<i>Branta bernicla</i>	Brant	< 1%
<i>Bucephala islandica</i>	Barrow's Goldeneye	< 1%

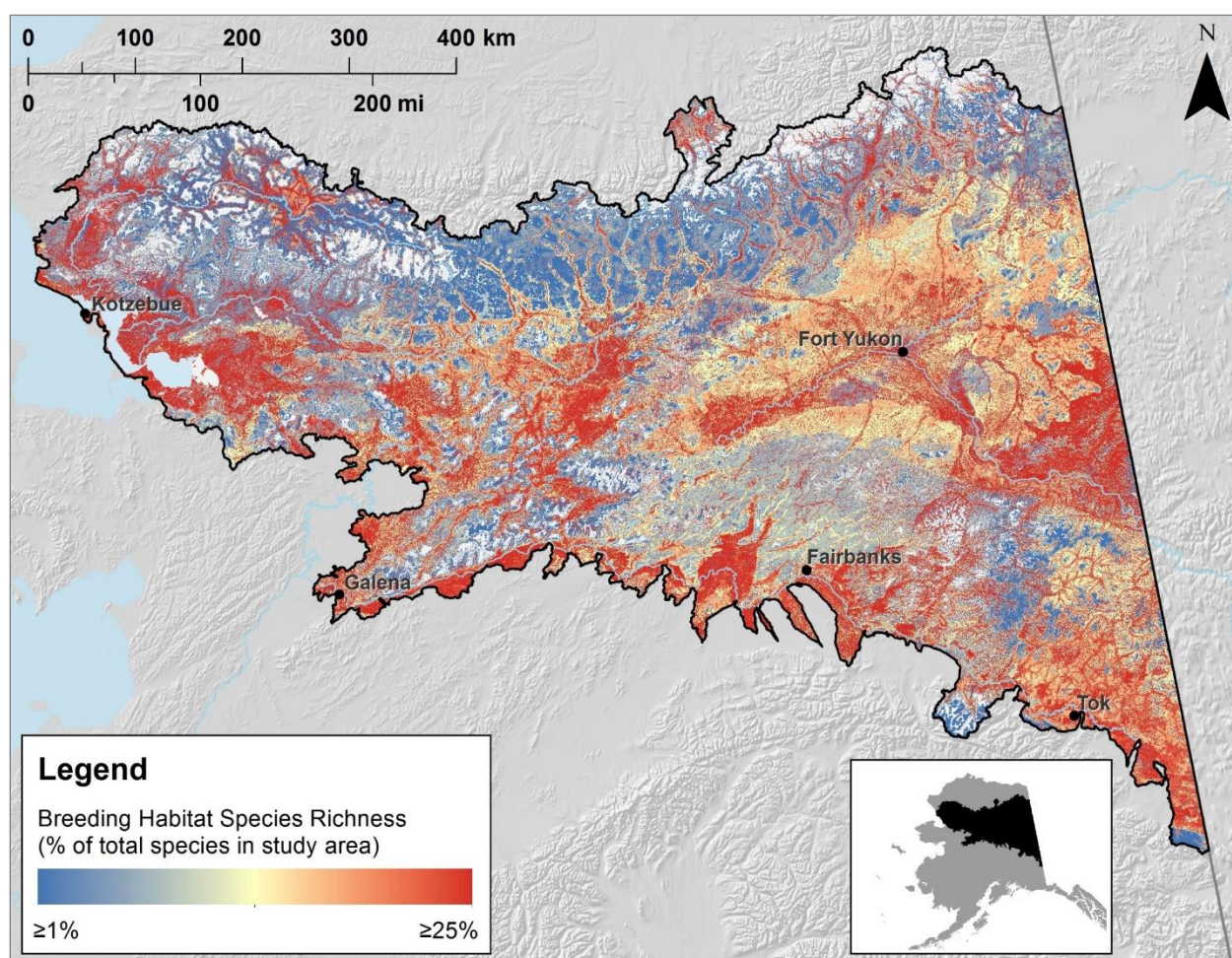


Figure H-56. Waterfowl species breeding habitat richness throughout the CYR study area.

Predicted breeding habitat for 25% or more of waterfowl species (i.e., areas where breeding habitat overlaps for at least seven species) covered 27% of the study area. Most of the habitat for

25% of waterfowl species occurred south of the Brooks Range ecoregion, and was widespread but heterogeneous. Within the southern Brooks Range, habitat for 25% of waterfowl species was narrowly limited to riparian corridors. The Important Bird Areas designated by Audubon Alaska generally coincided with hydrologic units in which the mean overlap in species habitat was at least 25% (Figure H-57). However, no hydrologic units with 25% mean overlap coincided with the two Important Bird Areas north of Kotzebue, likely an artifact of the shape and size of hydrologic units. Hydrologic units with 25% mean overlap also existed outside of designated Important Bird Areas within the study area.

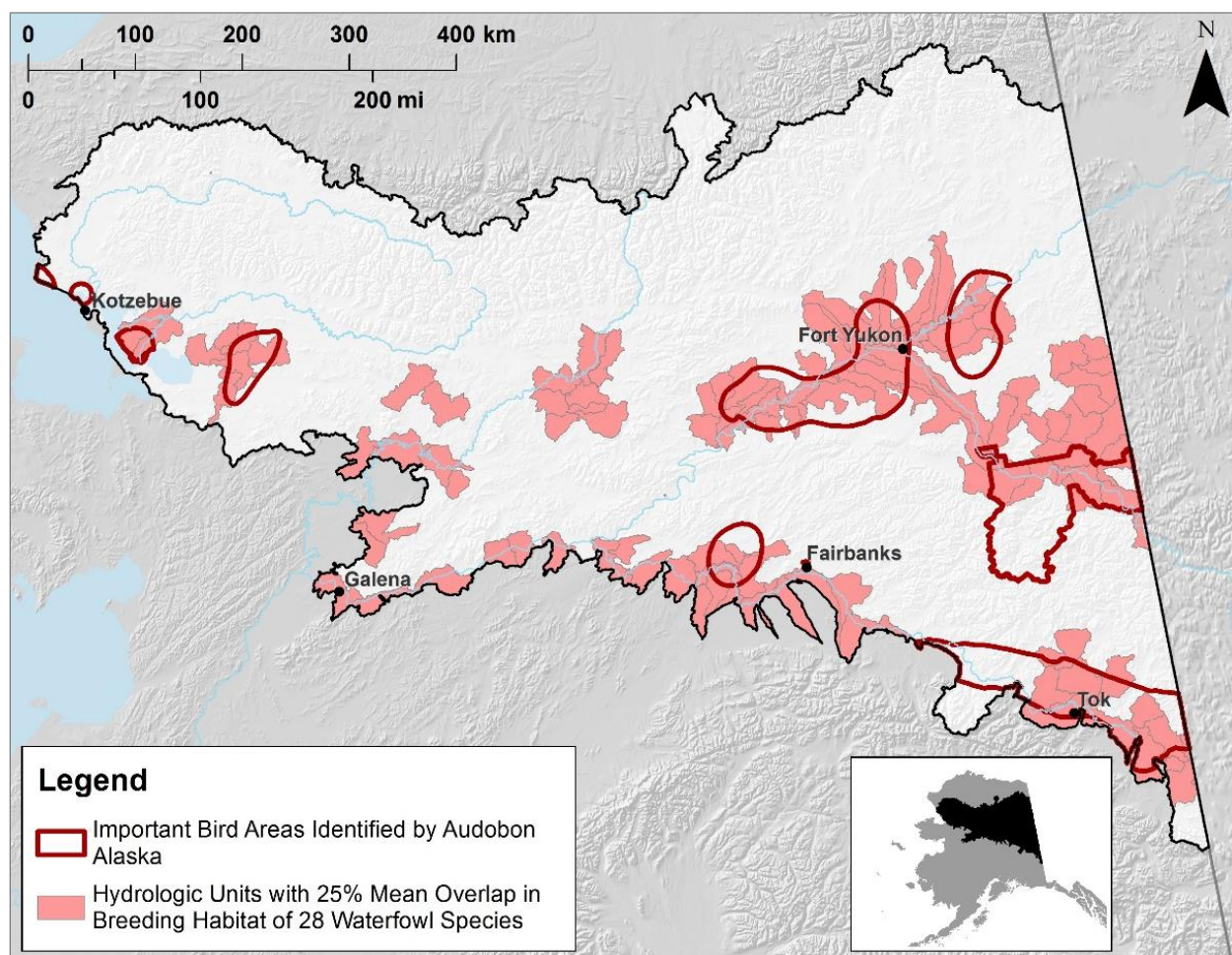


Figure H-57. 5th-level hydrologic units with 25% mean overlap in breeding habitat of 28 waterfowl species and Important Bird Areas designated by Audubon Alaska.

Habitat Descriptions by Species

The habitat descriptions provided per species below are taken from the *Alaska Gap Analysis Project Terrestrial Vertebrate Species Atlas* (Gotthardt et al. 2013).

Ring-necked duck:

Breeds in freshwater wetlands, especially marshes, fens, and bogs that are generally shallow (< 1.5-m deep), with fringes of flooded or floating emergents, predominantly sedges interspersed with other herbaceous vegetation and shrubs. Also utilizes open water zones vegetated with

abundant submerged or floating aquatic plants (Hohman and Eberhardt 1998). In British Columbia, breeds from 300 to 1,200 m in elevation, primarily in freshwater lakes (Campbell et al. 1990).

Common goldeneye

Nests usually near ponds, lakes, or rivers, but may nest in woodlands up to a mile from water (NatureServe 2007). Both coniferous and deciduous trees are used for nesting, and birds typically prefer lakes with clear water that lack emergent or submerged vegetation (Nummi and Pöysä 1993, Wayland and McNicol 1994). In British Columbia, breeds from 180 to 1,550-m elevation (Campbell et al. 1990).

Greater Scaup

Breeds near shores of ponds and lakes, in marshes, or on islands, primarily in forested tundra and northern borders of the taiga; among grass or shrubs, or under spruce boughs (NatureServe 2007). In the northern Yukon, nests in wet sedge and on floating mats of sedge and buckbean (Alexander et al. 2003).

Bufflehead

Breeds near freshwater, permanent ponds with no outlet or only seasonal outflow, and small lakes with only a small fringe of emergent vegetation along the shoreline. Ponds with extensive emergent or submergent vegetation are avoided. Nests in cavities in conifer forest mixed with poplar (Gauthier 1993). In British Columbia, breeds from 300 to 1,430 m in elevation (Campbell et al. 1990).

Redhead

According to Custer (1993), nests in large freshwater marshes (semi-permanently and seasonally flooded palustrine wetlands with persistent emergent vegetation). Optimum nesting conditions are wetlands that are 2 ha or more and not more than 0.4 km from a large permanent or semi-permanent lake. Nests usually are placed in dense bulrush or cattail stands that are interspersed with small areas of open water; nests usually are within 3 to 4 m of open water. Broods use shallow ponds if emergent vegetation is available for escape cover; later, access to deeper water with ample pondweeds is important. After nesting, many move to large lakes to molt (Custer 1993). In British Columbia, breeds from 330 to 1,000 m in shallow freshwater lakes, marshes, ponds, and sloughs (Campbell et al. 1990).

Mallard

Nests usually within 800 m of water (Palmer 1976). In the Yukon, this species nests among shrubs and other low vegetation associated with lakes, rivers, and wetlands; females and young use marshy areas (Alexander et al. 2003). In British Columbia, breeds from sea level to 1,300 m in sloughs, marshes, lakes, swamps, islands, riparian woodlands, city parks, agricultural fields, and private yards (Campbell et al. 1990).

Long-tailed duck

Sub-Arctic and Arctic wetlands, rarely to treeline; occasionally found in tundra habitats at higher latitudes. Nests near and raises broods on freshwater (including offshore islands with freshwater ponds and tundra vegetation). Often nests on islands or peninsulas in lakes. In Alaska, breeding

birds use shallow ponds and braided streams dominated by sedge (*Carex* spp.) or pendant grass (*Arctophila fulva*) (Robertson and Savard 2002). Nests are often concealed by vegetation, low-growing shrubs, or spruce (*Picea* spp.). Broods are usually reared on ponds with emergent vegetation (Todd 1996). In the Arctic National Wildlife Refuge, the highest density of breeding long-tailed ducks was found in an area characterized by a flooded pond complex with vegetation dominated by sedges and willows (*Salix* spp.) (Spindler and Miller 1983).

Black scoter

Nests near lakes and pools on grassy or brushy tundra and in northern taiga (AOU 1983). Usually nests close to water. In Quebec, black scoters used shallow (< 5 m) lakes, generally with till or rock substrate (Bordage and Savard 1995). They preferred lakes < 10 ha in area, but also used lakes up to 100 ha. On the Yukon-Kuskokwim Delta, black scoters used disturbed areas such as river banks and sloughs, preferring areas of tall grass used to conceal nests (C. Dau, pers. comm. in Bordage and Savard 1995).

Northern Pintail

In British Columbia, breeding habitat is in sparse or low vegetation, not necessarily near water. Specific habitats include drier margins of lakes, sloughs, ponds, lagoons, dry grasslands, shrubby fields, edges of mixed forests, damp meadows, and subalpine bogs (Campbell et al. 1990). Often associated with seasonal and semi-permanent wetlands (Suchy and Anderson 1987). In boreal forests, birds are found in meadows with low sedge and herbaceous growth, and, in Alaska, birds are often found on coastal barrier islands (Austin and Miller 1995). In the Yukon-Kuskokwim Delta, broods use 1 to 5 ha wetlands with abundant emergent and submergent aquatic vegetation (J. B. Grand, pers. comm. in Austin and Miller 1995). In Yukon, birds are found in low willow and birch shrubs and tussock tundra (Alexander et al. 2003).

Red-breasted merganser

Tundra and boreal forest zones on fresh, brackish, and saltwater wetlands with sheltered bays, typically not far from sea coast (Titman 1999). Nests along inland waters, generally on ground on small islands with low vegetative cover, and also near seacoast and occasionally on shores of ocean or on coastal islands (NatureServe 2007). In British Columbia, breeding sites were heavily vegetated with shrubs and trees and ranged from sea level to 770 m in elevation (Campbell et al. 1990). Nests on islets in British Columbia were situated among dune wild rye, Nootka rose, coastal strawberry, Nootka lupine, or salal (M. Rodway, pers. comm. in Campbell et al. 1990).

Surf scoter

Nests in brushy tundra, in freshwater marsh, or in wooded area near pond, bog, or stream. Nests on the ground in an area protected by vegetative cover (NatureServe 2007). Also uses rocky-shored lakes and ponds within boreal forests and tundra zones (Goudie et al. 1994). In Quebec, breeding habitat includes shallow lakes < 10 ha (Decarie et al. 1995, Bergeron et al. 1996).

Green-winged teal

In British Columbia, breeds from sea level to 1,525 m in grassy, brushy, or lightly wooded upland habitat near freshwater marshes in the Interior and in sloughs and ponds associated with estuaries in coastal areas (Campbell et al. 1990). Nests in areas with dense emergent vegetation

on islands and lake edges (NatureServe 2007), and, in Yukon, nests among shrubs, grasses, and other low vegetation in wooded and open areas (Alexander et al. 2003).

White-winged scoter

Nests on large, shallow, freshwater lakes and wetlands. Also nests on slow-moving streams in sites with dense shrub or tree cover, or, less commonly, in concealed or bare sites in open tundra (NatureServe 2007). Lakes with islands densely covered by shrubs support high density of nesting sites. Lakes and rivers within boreal forest zone support high density of nesting sites in Alaska.

American wigeon

In British Columbia, breeds from sea level to 1,200-m elevation in the vicinity of freshwater sloughs, lakes, ponds, marshes, and rivers, but can breed far from water. Nests have been found in brushy, upland habitats, often near lakes or marshy sloughs (Campbell et al. 1990, Mowbray 1999). In Yukon, breeds in coastal plains near major river deltas that are underlain by continuous permafrost with polygonal ground and other permafrost-related features. Vegetation is a mosaic of dry tussock, wet sedge, and low shrub tundra with tall brush (> 3 m) in drainage courses and around lakeshores (Salter et al. 1980). In Alaska, breeds as far north as the Beaufort Coastal Plain (Bellrose 1980).

Greater white-fronted goose

Pre-nesting birds on the Yukon-Kuskokwim Delta concentrate on meltwater areas, slough banks, and river edges within 30 km of the Bering Sea (Campbell et al. 1990). Nests are located in moderate to dense cover of grasses and sedges or dwarf shrubs (Mickelson 1975, Ely and Raveling 1984) in meltwater areas and lower edges of pingos (Campbell et al. 1990). Interior populations breed in alluvium lowlands on stream deltas, low sedge–cotton grass (*Eriophorum* spp.)—moss meadows, tussock lowlands, tundra ponds with *Carex aquatilis*–*Arctophila fulva* emergent ecotone, taiga forests and bogs, raised polygon edges, hummocky ground, inland tributary stream edges, dwarf shrub and occasionally tall shrub tundra of birch and willow. To a lesser extent, Interior nest sites also include ericaceous tundra, drier rock fields, eskers, hill slopes with *Dryas* spp., grasses and lichens (Bird 1980, Chapin et al. 1992).

Canvasback

Occurs in boreal and montane coniferous forests or mixed forests with thick undergrowth. May also forage in open forest, rocky areas, and tundra during periods of prey scarcity (auxiliary habitat). Den sites in mature or old growth forest with high density of downed logs. Requires a mosaic of habitat types, including old growth for denning and younger stands for foraging (Koehler 1990, Koehler and Britnell 1990).

Canada goose

In British Columbia, breeds from sea level to 1,250 m in inland and coastal marshes, islands in lakes, ponds, sloughs, rivers, tundra, muskeg, and man-made environments with water nearby. Most nests are within 60 m of water (Campbell et al. 1990). Broods are typically seen along gently sloping pond or river shorelines, with mudflats or mud barrens, and abundant short prostrate grasses, sedges, or semiaquatic plants (MacInnes 1962, O'Neil 1988, Babcock and Ely 1994, Conover 1998).

Harlequin duck

Nests along fast-moving rivers and mountain streams on rocky islands or banks. Streams are braided to reticulate with many riffles and rapids (Cassirer et al. 1993). Requires relatively undisturbed, low gradient, meandering mountain streams with dense shrubby riparian areas (greater than 50% streamside shrub cover), and woody debris for nesting and brood rearing; also needs mid-stream boulders or log jams and overhanging vegetation for cover and loafing (Spahr et al. 1991). Sometimes nests beside mountain lakes and lake outlets. Nests in a hollow, usually under the cover of shrubs within about 30 m of water; also in rock crevice among boulders, in rock cavity in cliff face, in a tree cavity (Cassirer et al. 1993), in a puffin burrow, or similar hidden site; occasionally on open tundra (Ehrlich et al. 1992). In coastal Alaska, uses streams with larger discharges, widths, estuary areas, and riparian zones (Crowley 1994, Crowley and Patten, Jr. 1996).

Northern shoveler

Shallow, often muddy, fresh-water areas with surrounding cover. Ponds, marshes, sloughs, and creeks. Nests near shallow freshwater lakes, ponds, marshes, etc. (AOU 1983). In British Columbia, breeds from sea level to 1,100-m elevation in open and semi-open habitats (Campbell et al. 1990).

Common merganser

Lakes and rivers bordered by coniferous or mixed forests mature enough to provide nesting cavities (Mallory and Metz 1999) and mountainous terrain (AOU 1983, Terres 1980). Northern limit of breeding range follows limit of open boreal forest (Palmer 1976, Haapanen and Nilsson 1979, Bellrose 1980). Females move broods downstream to larger rivers, lakes, or bays (White 1957, Erskine 1972, Wood 1985, McNicol et al. 1995). In British Columbia, breeds on marine shores at sea level to mountainous regions up to 1,000 m in elevation (Campbell et al. 1990).

Lesser scaup

Usually nests near small ponds and lakes, sedge meadows, creeks; in cover 1- to 2-ft high, within 46 m of water (NatureServe 2007). Nests around semi-permanent (< 1 ha) waterbodies with emergent vegetation, but will also nest in sparse shrub patches (Austin et al. 1998). In Interior Alaska, broods use semi-permanent and permanent wetlands greater than 1 ha in area dominated by cattail and sedge (Van Horn 1991).

Cackling goose

Breeds in low tundra vegetation along the shorelines of major rivers and small braided streams, shorelines of small tundra ponds, and on islands in tundra ponds and lakes of the Yukon-Kuskokwim Delta (Mowbray et al. 2002). Restricted to inland areas beyond the influence of tides, populations extend inland up to the North Slope (Johnson et al. 1979, Jarvis and Bromley 1998).

Blue-winged teal

Optimal nesting habitats include semi-permanent wetlands, ponds, and seasonal wetlands surrounded by grassland (Brewer et al. 1991). Nests usually on the ground among tall grasses or sedges, usually near water; seems to prefer to nest in native grass communities in good range condition (Gammonley and Fredrickson 1995). Stock ponds with well-developed emergent vegetation provide locally important brood habitat (Gammonley and Fredrickson 1995). In British

Columbia, breeds from sea level to 1,200 m, and nests are found as far as 50 m from small water bodies (most within 23 m of water) including fresh and brackish water marshes, bogs, swamps, and sloughs (Campbell et al. 1990).

Trumpeter swan

Inhabits ponds, lakes, and marshes, and breeds in areas of reeds, sedges or similar emergent vegetation, primarily on freshwater, occasionally in brackish situations (AOU 1983). Prefer water bodies with ample room for take-off and structures (such as islands) for nesting (Mitchell 1994).

Tundra swan

Breeds on tundra lakes, ponds, and pools, primarily in coastal deltas and less frequently inland to treeline. Prefers lakes with pondweed (*Potamogeton* spp.) (Monda 1991, Spindler and Hall 1991). In Bristol Bay lowlands, breeds along coast and in broad drainage basins with little relief, wet meadows, and shallow lakes with littoral emergent vegetation (Wilk 1988). On the Colville River Delta, prefers large lakes that are connected to a river channel or are partially drained, and utilize polygon lakes and moist tundra near edges of waterbodies (Earnst 1992). Primary emergent vegetation includes *Carex aquatilis* and *Arctophila fulva*; and primary moist tundra vegetation includes *Carex* spp., *Puccinellia phryganodes*, *Dupontia fisheri*, and *Stellaria humifusa* (Limpert and Earnst 1994).

Common eider

Prefers small islands, islets, and low-lying points of land. Sometimes nests on islands or islets in freshwater lakes, ponds, and lagoons near outlet to the sea (Nakashima 1986, Cornish and Dickson 1997). Vegetation at nest sites variable and can range from rocky substrate to coniferous forests (Goudie et al. 2000). Most productive nests occur in driftwood on high elevation islands in flood plumes of large rivers (Johnson 2000).

Brant

In low Arctic, nests near upper edge of salt marshes along gently sloping seacoasts or broad estuarine deltas with abundant low graminoid vegetation. Breeds on coastal tundra, in low and barren terrain; on islands, deltas, lakes, and sandy areas among puddles and shallows; and in vegetated uplands. Often nest on islands in small ponds or river deltas, on small offshore islands, or on gravel spits. In mid and high Arctic, nests near braided river valleys, deltas, and inland lakes up to 30 km inland (Reed et al. 1998). Typically rears broods in salt marshes less than 1 km from tidal areas (Sedinger and Flint 1991, Stickney and Ritchie 1996).

11.4 Summary

Waterfowl breed in a variety of habitats throughout the CYR study area. Hotspots of waterfowl species diversity exist in the central region around Fort Yukon, along the southern border around Tok and west of Fairbanks, and around Kotzebue. Important Bird Areas identified by Audubon correspond with areas of high richness in modeled breeding habitats. However, species habitat richness identified additional areas of importance not noted by Audubon.

11.5 Limitations and Data Gaps

The accuracy of breeding distribution models was not assessed within the CYR study area as part of this assessment. However, model accuracy for the entire state of Alaska was assessed using area-under-curve (AUC) as part of the Alaska Gap Analysis Project. Values larger than 0.5 indicated a performance better than random. Model performance for each species is provided in Table H-45 below.

Table H-45. Model performance measured as area-under-curve (AUC) for breeding distribution models of 28 waterfowl species from the Alaska Gap Analysis Project.

Scientific Name	Common Name	AUC	Interpreted Model Performance
<i>Branta bernicla</i>	Brant	0.972	High
<i>Branta canadensis</i>	Canada Goose	0.952	High
<i>Branta hutchinsii</i>	Cackling Goose	0.952	High
<i>Somateria mollissima</i>	Common Eider	0.865	Moderate
<i>Aythya collaris</i>	Ring-Necked Duck	0.8	Moderate
<i>Aythya americana</i>	Redhead	0.781	Moderate
<i>Anser albifrons</i>	Greater White-Fronted Goose	0.777	Moderate
<i>Anas acuta</i>	Northern Pintail	0.76	Moderate
<i>Cygnus columbianus</i>	Tundra Swan	0.738	Moderate
<i>Bucephala clangula</i>	Common Goldeneye	0.737	Moderate
<i>Clangula hyemalis</i>	Long-Tailed Duck	0.722	Moderate
<i>Melanitta americana</i>	Black Scoter	0.679	Low
<i>Anas clypeata</i>	Northern Shoveler	0.677	Low
<i>Anas americana</i>	American Wigeon	0.664	Low
<i>Mergus merganser</i>	Common Merganser	0.632	Low
<i>Aythya valisineria</i>	Canvasback	0.624	Low
<i>Anas crecca</i>	Green-Winged Teal	0.617	Low
<i>Anas platyrhynchos</i>	Mallard	0.616	Low
<i>Bucephala albeola</i>	Bufflehead	0.61	Low
<i>Aythya affinis</i>	Lesser Scaup	0.61	Low
<i>Anas discors</i>	Blue-Winged Teal	0.564	Low
<i>Melanitta perspicillata</i>	Surf Scoter	0.559	Low
<i>Cygnus buccinator</i>	Trumpeter Swan	0.546	Low
<i>Histrionicus histrionicus</i>	Harlequin Duck	0.544	Low
<i>Aythya marila</i>	Greater Scaup	0.523	Low
<i>Melanitta fusca</i>	White-Winged Scoter	0.521	Low
<i>Bucephala islandica</i>	Barrow's Goldeneye	0.502	Low
<i>Mergus serrator</i>	Red-Breasted Merganser	--	Model Not Validated

Average model performance for the 27 waterfowl species with AUC values was 0.686 (Low). Statewide input data layers that were available at the time the Alaska Gap Analysis Project was conducted likely did not have the specificity, detail, or accuracy necessary to accurately classify most waterfowl species breeding habitat. For example, the LANDFIRE Existing Vegetation Type was an input data layer for all distribution models, but has relatively low accuracy within Alaska (Boggs et al. 2014).

Additionally, the Alaska Gap Analysis Project was a generalized effort to produce the first statewide distribution models for all terrestrial vertebrate species in Alaska. Therefore, input data layers were not selected specifically for relevance to waterfowl. Some datasets that would potentially have helped to better classify waterfowl habitat in Alaska did not and still do not exist, such as an aquatic habitat classification and a detailed, accurate, statewide existing vegetation classification produced using standardized methods.

Waterfowl species population estimates are not available across the study area, preventing the assessment of relative waterfowl density. Determining relative waterfowl density in the future would provide an additional way to delineate important bird areas. Species habitat richness lacks a population component and relative waterfowl density lacks a diversity component. In combination, the two metrics provide a holistic representation of important waterfowl areas. The important waterfowl areas presented in this section are based on species habitat richness only and should, therefore, be viewed as only partially complete.

11.6 Literature Cited

- Alexander, S., F. Doyle, C. Ecker, H. Grünberg, N. Hughes, M. Jensen, I. Johnson, D. Mossop, W. Nixon, and P. Sinclair. 2003. Birds of the Yukon Territory. UBC Press, Vancouver, British Columbia.
- AOU. 1983. Check-list of North American birds. 6th ed. American Ornithologists' Union, Washington D.C.
- Austin, J., and M. Miller. 1995. Northern pintail (*Anas acuta*). In A. Poole, and F. Gill, eds. 1995. The birds of North America, Vol. 5, No. 163. Philadelphia: The Academy of Natural Sciences; Washington, D.C. The American Ornithologists' Union.
- Austin, J., C. Custer, and A. Afton. 1998. Lesser scaup (*Aythya affinis*). In: Poole, A., and F. Gill, eds. 1998. The Birds of North America, Vol. 9, No. 338. Philadelphia: The Academy of Natural Sciences; Washington, D.C. The American Ornithologists' Union.
- Babcock, C., and C. Ely. 1994. Classification of vegetation communities in which geese rear broods on the Yukon-Kuskokwim Delta, Alaska. Canadian Journal of Botany 72:1294-1301.
- Bellrose, F. 1980. Ducks, geese and swans of North America. Stackpole Books, Harrisburg, Pennsylvania.
- Bergeron, R., R. Hughes, and A. Reed. 1996. Projet de Laforge-1. Etude de la sauvagine et caractérisation de ses habitats-été 1995. Final report. Direction Ingenierie et Environnement, Societe d'energie de la Baie James and Groupe Dryade Ltee, QC.
- Bird, B. 1980. The natural landscape of Canada, 2nd ed. John Wiley and Sons, Toronto, Ontario.
- Boggs, K., T. V. Boucher, T. T. Kuo, D. Fehringier, and S. Guyer. 2014. Vegetation map and classification: Northern, Western and Interior Alaska. Alaska Natural Heritage Program, University of Alaska Anchorage, Anchorage, Alaska. 88 pp.
- Bordage, D., and J. Savard. 1995. Black scoter (*Melanitta nigra*). In A. Poole, and F. Gill, eds. 1980. The birds of North America, Vol. 5, No. 177. Philadelphia: The Academy of Natural Sciences; Washington, D.C. The American Ornithologists' Union.
- Brewer, R., G. McPeck, and R. Adams, Jr. 1991. The atlas of breeding birds of Michigan. Michigan State University Press, East Lansing, Michigan.
- Campbell, R., N. Dawe, I. McTaggart-Cowan, J. Cooper, G. Kaiser, and M. McNall. 1990. The birds of British Columbia. Vol. 1 and 2, Nonpasserines. UBC Press, Vancouver, British Columbia.
- Cassirer, E., A. Breault, P. Clarkson, D. Genter, R. Goudie, B. Hunt, S. Latta, G. Mittelhauser, M. McCollough, G. Schirato, and R. Wallen. 1993. Status of harlequin ducks (*Histrionicus histrionicus*) in North America. Report of the Harlequin Duck Working Group. 83 pp.
- Chapin, F., R. Reynolds, J. Shaver, and G. Svoboda (eds.). 1992. Arctic ecosystems in a changing climate: an ecophysiological perspective. Academic Press, San Diego, California.
- Conover, M. 1998. Reproductive biology of an urban population of Canada geese. 1998. Pages 67-70 in D. Rusch, M. Samuel, D. Humburg, and B. Sullivan, eds. Biology and management of Canada geese. Proceedings of the International Canada Goose Symposium. Milwaukee, Wisconsin.
- Cornish, B., and D. Dickson. 1997. Common eiders nesting in the western Canadian Arctic. Pages 40-50 in D. Dickson, ed. King and common eiders of the western Canadian Arctic. Canadian Wildlife Service Occasional No. 94.
- Crowley, D. 1994. Breeding habitat of Harlequin ducks in Prince William Sound, Alaska. M.S. Thesis, Oregon State University. Corvallis, Oregon.
- Crowley, D., and S. Patten, Jr. 1996. Breeding ecology of Harlequin ducks in Prince William Sound, Alaska. Exxon Valdez Oil Spill/ Federal Natural Resources Damage Assessment Final Report (Restoration Study no. 71), Alaska Department of Fish and Game. Anchorage, Alaska.
- Custer, C. 1993. Life history traits and habitat needs of the redhead. Part 13.1.11 of Waterfowl management handbook. 7 pp.
- Decarie, R., F. Morneau, D. Lambert, S. Carriere, and J. Savard. 1995. Habitat use by brood-rearing waterfowl in sub-Arctic Quebec. Arctic 48:383-390.

- Earnst, S. 1992. Behavior and ecology of tundra swans during summer, autumn, and winter. Ph. D. dissertation, Ohio State University, Columbus, Ohio.
- Ehrlich, P., D. Dobkin, and D. Wheye. 1992. Birds in jeopardy: the imperiled and extinct birds of the United States and Canada, including Hawaii and Puerto Rico. Stanford University Press. Stanford, California. 259 pp.
- Ely, C., and D. Raveling. 1984. Breeding biology of pacific white-fronted geese. *Journal of Wildlife Management* 48:823-837.
- Erskine, A. 1972. Buffleheads. Canadian Wildlife Service Monograph Series Number 4.
- Gammonley, J., and L. Fredrickson. 1995. Life history and management of the blue-winged teal. USDI National Biological Service. Waterfowl Management Handbook 13.1.8. 7 pp.
- Gauthier, G. 1993. Bufflehead (*Bucephala albeola*). In A. Poole, and F. Gill, eds. The birds of North America, Vol. 2, No. 67. Philadelphia: The Academy of Natural Sciences; Washington, D.C. The American Ornithologists' Union.
- Gotthardt, T., S. Pyare, F. Huettmann, K. Walton, M. Spathelf, K. Nesvacil, A. Baltensperger, G. Humphries, and T. Fields. 2013. Alaska gap analysis project terrestrial vertebrate species atlas. Alaska Natural Heritage Program, Anchorage, Alaska. 766 pp.
- Goudie, R., S. Brault, B. Conant, A. Kondratyev, M. Petersen, and K. Vermeer. 1994. The status of sea ducks in the north Pacific Rim: toward their conservation and management. *Transactions of the North American Wildlife and Natural Resources* 59:27-49.
- Goudie, R., G. Robertson, and A. Reed. 2000. Common Eider (*Somateria mollissima*). In A. Poole, and F. Gill, eds. 2000. The birds of North America. Vol. 7, No. 546. Philadelphia: The Academy of Natural Sciences; Washington, D.C. The American Ornithologists' Union.
- Haapanen, A., and L. Nilsson. 1979. Breeding waterfowl populations in northern Fennoscandia. *Ornis Scandinavica* 10:145-219.
- Hohman, W., and R. Eberhardt. 1998. Ring-necked duck (*Aythya collaris*). In A. Poole, and F. Gill, eds. 1998. The birds of North America. Vol. 9, No. 329. Philadelphia: The Academy of Natural Sciences; Washington, D.C. The American Ornithologists' Union.
- Jarvis, R., and R. Bromley. 1998. Managing racially mixed flocks of Canada Geese. Pages 413-423 in D. Rusch, M. Samuel, D. Humburg, and B. Sullivan, eds. Biology and management of Canada Geese. Proceedings of the International Goose Symposium, Milwaukee, Wisconsin.
- Johnson, D., D. Timm, and P. Springer. 1979. Morphological characteristics of Canada geese in the Pacific Flyway. Pages 56-80 in R. Jarvis, and J. Bartonek, eds. Management and biology of Pacific Flyway geese. Oregon State University, Corvallis, Oregon.
- Johnson, S. 2000. Pacific eider. Pages 259-272 in J. Truett, and S. Johnson, eds. Natural history of an Arctic oil field: development and the biota. Academic Press, San Diego, California.
- Koehler, G. 1990. Population and habitat characteristics of lynx and snowshoe hares in north central Washington. *Canadian Journal of Zoology* 68:845-851.
- Koehler, G., and J. Brittell. 1990. Managing spruce-fir habitat for lynx and snowshoe hares. *Journal of Forestry* 88:10.
- Limpert, R., and S. Earnst. 1994. Tundra swan (*Cygnus columbianus*). In A. Poole, and F. Gill, eds. The birds of North America. Vol. 3, No. 89. Philadelphia: The Academy of Natural Sciences; Washington, D.C. The American Ornithologists' Union.
- MacInnes, C. 1962. Nesting of small Canada geese near Eskimo Point, Northwest Territories. *Journal of Wildlife Management* 26:247-256.
- Mallory, M., and K. Metz. 1999. Common merganser (*Mergus merganser*). In A. Poole, and F. Gill, eds. The birds of North America. Vol. 12, No. 442. Philadelphia: The Academy of Natural Sciences; Washington, D.C. The American Ornithologists' Union.

Section H. Terrestrial Fine-filter Conservation Elements

- McNicol, D., R. Ross, M. Mallory, and L. Brisebois. 1995. Trends in waterfowl populations: evidence of recovery from acidification. Ch. 16. pages 203-217 in J. Gunn, ed. Environmental restoration and recovery of an industrial region. Springer-Verlag, New York.
- Mickelson, P. 1975. Breeding biology of cackling geese and associated species on the Yukon-Kuskokwim Delta, Alaska. Wildlife Monographs 45:3-35.
- Mitchell, C. 1994. Trumpeter swan (*Cygnus buccinator*). In A. Poole, and F. Gill, eds. The birds of North America. Vol. 3, No. 105. Philadelphia: The Academy of Natural Sciences; Washington, D.C. The American Ornithologists' Union.
- Monda, M. 1991. Reproductive ecology of tundra swans on the Arctic National Wildlife Refuge, Alaska. Ph. D. Dissertation, University of Idaho, Moscow.
- Mowbray, T. 1999. American Wigeon (*Anas americana*). In A. Poole, and F. Gill, eds. The birds of North America. Vol. 11, No. 401. Philadelphia: The Academy of Natural Sciences; Washington, D.C. The American Ornithologists' Union.
- Mowbray, T., C. Ely, J. Sedinger, and R. Trost. 2002. Canada goose (*Branta canadensis*). In A. Poole, and F. Gill, eds. 2002. The Birds of North America. Vol. 18, No. 682. Philadelphia: The Academy of Natural Sciences, Washington, D.C. The American Ornithologists' Union.
- Murphy, S., B. Kessel, and L. Vining. 1984. Waterfowl populations and limnologic characteristics of taiga ponds. Journal of Wildlife Management 48:1156-1163.
- Nakashima, D. 1986. Inuit knowledge of the ecology of the common eider in north Quebec. Pages 102-113 in A. Reed, ed. Eider ducks in Canada. Rep. Ser. No. 47. Canadian Wildlife Service. Ottawa, Ontario.
- NatureServe. 2007. NatureServe Explorer: an online encyclopedia of life [web application]. Version 6.2. NatureServe, Arlington, Virginia. Available <http://www.natureserve.org/explorer>
- Nummi, P., and H. Pöysä. 1993. Habitat associations of ducks during different phases of the breeding season. Ecography 16:319-328.
- O'Neil, T. 1988. Effects of removal and replacement of brood-rearing habitats on a Canada goose flock. Murrelet 69:41-45.
- Palmer, R. (ed.) 1976. Handbook of North American birds. Vol. 2. Waterfowl (first part). Whistling ducks, swans, geese, sheld-ducks, dabbling ducks. Yale Univ. Press, New Haven. 521 pp.
- Reed, A., D. Ward, D. Derksen, and J. Sedinger. 1998. Brant (*Branta bernicla*). In A. Poole, and F. Gill, eds. 1998. The birds of North America, Vol. 9, No. 337. Philadelphia: The Academy of Natural Sciences, Washington, D.C. The American Ornithologists' Union.
- Robertson, G., and J. Savard. 2002. Long-tailed duck (*Clangula hyemalis*). In A. Poole, and F. Gill, eds. 2002. The birds of North America. Vol. 18, No. 682. Philadelphia: The Academy of Natural Sciences, Washington, D.C. The American Ornithologists' Union.
- Salter, R., M. Gollop, S. Johnson, W. Koski, and C. Tull. 1980. Distribution and abundance of birds on the Arctic coastal plains of the Northern Yukon and adjacent Northwest Territories, 1971-1976. Canadian Field Naturalist 94:219-238.
- Sedinger, J., and P. Flint. 1991. Growth rate is negatively correlated with hatch date in Black Brant. Ecology 72:496-502.
- Spahr, R., L. Armstrong, D. Atwood, and M. Rath. 1991. Threatened, endangered, and sensitive species of the Intermountain Region. USDA USFS, Ogden, Utah.
- Spindler, M., and K. Hall. 1991. Local movements and habitat use of tundra or whistling swans *Cygnus columbianus* in the Kobuk-Selawik lowlands of northwest Alaska. Wildfowl 42:17-32.
- Spindler, M., and P. Miller. 1983. Terrestrial bird populations and habitat use on coastal plain tundra of the Arctic National Wildlife Refuge. ANWR Progress Report Number FY83-5. Arctic NWR Coastal Plain Resource Assessment, USFWS, Fairbanks, AK. Pages 108-200 in 1982 Update report baseline study of the fish, wildlife, and their habitats. Section 1002C, ANILCA, USDI, USFWS, Reg. 7, Anchorage, Alaska.

- Stickney, A., and R. Ritchie. 1996. Distribution and abundance of brant (*Branta bernicla*) on the central Arctic Coastal Plain of Alaska. *Arctic* 49:44-52.
- Suchy, W., and S. Anderson. 1987. Habitat suitability index models: northern pintail. U.S. Fish and Wildlife Service Biological Report 82(10.145). Fish and Wildlife Service, U.S. Department of the Interior. 23 pp.
- Terres, J. 1980. The Audubon Society encyclopedia of North American birds. Alfred A. Knopf. New York, New York.
- Titman, R. 1999. Red-breasted merganser (*Mergus serrator*). In A. Poole, and F. Gill, eds. 1999. The birds of North America. Vol. 12, No. 443. Philadelphia: The Academy of Natural Sciences, Washington, D.C. The American Ornithologists' Union.
- Todd, F. 1996. Natural history of the waterfowl. San Diego Natural History Museum, San Diego, California. Ibis Publishing Company, California. 490 pp.
- U.S. Fish and Wildlife Service (USFWS). 2011. Waterfowl fact sheet. Migratory Bird Management. Available: <https://www.fws.gov/alaska/mbmp/mbm/waterfowl/waterfowl.htm>
- Van Horn, K. 1991. Habitat use and activity patterns of Interior Alaskan waterbirds. M.S. Thesis, University of Missouri, Columbia.
- Wayland, M., and D. McNicol. 1994. Movements and survival of common goldeneye broods near Sudbury, Ontario, Canada. *Canadian Journal of Zoology* 72:1252-1259.
- White, H. 1957. Food and natural history of mergansers on salmon waters in the maritime provinces of Canada. Fish Research Board Canada Bulletin No. 116.
- Wilk, R. 1988. Distribution, abundance, population structure, and productivity of tundra swans in Bristol Bay, Alaska. *Arctic* 41:288-292.
- Wood, C. 1985. Aggregative response of common mergansers (*Mergus merganser*): predicting flock size and abundance on Vancouver Island salmon streams. *Canadian Journal of Fisheries and Aquatic Sciences* 42:1259-1271.

12. MQ T1: Biological Potential for Reindeer Herding

MQ T1: What areas would be most likely to biologically support a reindeer herd?

12.1 Introduction

In 1892, the first reindeer were shipped from Siberia to the Seward Peninsula (Swanson and Barker 1992, Dau 2000). At the time, caribou herds were not present on the Seward Peninsula or in Northwest Alaska south of the Brooks Range (Dau 2000), so importing reindeer did not conflict with native caribou herd ranges. Originally, reindeer were intended to provide a supplemental food source for Alaska Natives, but reindeer herding flourished and gained regional commercial importance. By the late 1920s, exported reindeer meat totaled over 1,000,000 pounds annually (Palmer 1934). By the early 1930s, reindeer herds in the region totaled approximately 640,000 individuals (Beach 1985). By the mid-1930s, disease epidemics had depleted the local pool of skilled reindeer herders and reindeer populations began to decline (Dau 2000). Herds were reduced to approximately 24,000 reindeer by the late 1970's (Beach 1985), with continued declines throughout the 1980s (Finstad et al. 1999, Dau 2000).

Herds were intensively managed after reindeer were first introduced to Alaska until the 1930s (Beach 1985, Swanson and Barker 1992). However, with disease epidemics in Alaska and decreased demand for reindeer meat from the contiguous U.S., management efforts waned. For the past 75 years, reindeer herds have been allowed to roam their ranges with little interference from the herders (Beach 1985).

Biologically, Siberian reindeer and Alaskan caribou are the same species (*Rangifer tarandus*) and have very similar requirements for forage and habitat. *Rangifer tarandus* have adapted a life cycle that favors nutrient and energy conservation in the winter months and rapid growth and energy/nutrient storage in summer months. Seasonal forage preferences of caribou correlate to the plants species, plant parts, and plant growth stage that contain the highest available nutrients and digestible energy at the time. Vegetation communities preferred by *R. tarandus* are, thus, seasonally dependent.

While reindeer herds and caribou ranges did not initially overlap on the Seward Peninsula when reindeer were first introduced, caribou ranges expanded in Northwest Alaska south of the Brooks Range and into the Seward Peninsula over time. Interactions between reindeer and caribou increased (Finstad et al. 2002). When reindeer and large groups of caribou come into contact, reindeer will often join the caribou herd and leave their domestic range (Beach 1985, Dau 2000). On the Seward Peninsula, numerous reindeer, and occasionally entire herds, have been lost after caribou of the Western Arctic herd migrated through reindeer range (Finstad et al. 1999, Dau 2000). Similarly, reindeer owned by NANA Regional Corporation have been lost in Northwest Alaska (Beach 1985). Additionally, small numbers of caribou that come into contact with reindeer may join the reindeer herd, resulting in the reindeer becoming more difficult for herders to control (Beach 1985, Finstad et al. 1999, Dau 2000). Similar conflicts with caribou or wild reindeer have been encountered by reindeer herders in Russia, Canada, and Greenland (Klein 1980).

To assess the biological potential for reindeer herds in the CYR study area, we investigated the spatial distribution of forage availability in relation to the current distribution of caribou ranges throughout the region.

12.2 Methods

The names reindeer and caribou refer to *Rangifer tarandus* native to Eurasia and North America respectively. For this assessment, the term "caribou" was applied to barren-ground caribou native to Alaska and the term "reindeer" was applied to semi-domestic strains of *Rangifer tarandus* that were transported to Alaska from Siberia.

Seasonal Forage Quality

To assess forage availability for potential reindeer herds, we related seasonal caribou forage quality to existing vegetation landcover classes using the Vegetation Map of Northern, Western, and Interior Alaska (Boggs et al. 2014). The Vegetation Map of Northern, Western, and Interior Alaska (Boggs et al. 2014) was the best available existing vegetation classification because it was the only landcover map available that provided full coverage of the study area with detail and accuracy sufficient to delineate caribou forage. The Boggs et al. 2014 map was developed by mosaicking the best available regional landcover datasets by priority of accuracy and detail (Figure H-58). Because the Boggs et al. (2014) map was developed by mosaicking regional landcover datasets, detailed landcover classes were not consistently applied throughout the study area. The standardized coarse landcover classes were considered for caribou forage classes but were too generalized to assign forage quality values. Detailed landcover classes from the Boggs et al. (2014) map were, therefore, assigned a score of low, moderate, or high for each season based on prevalence of preferred caribou forage.

We developed seasonal forage distributions for summer and winter to illustrate the spatial extent of potential caribou habitat. Based on similarities in preferred forage specific to the study area, we combined calving season and summer in the summer seasonal forage distribution and late fall, winter, and early spring in the winter seasonal forage distribution. We identified caribou diet and forage preferences with a thorough literature review of peer-reviewed papers and management reports.

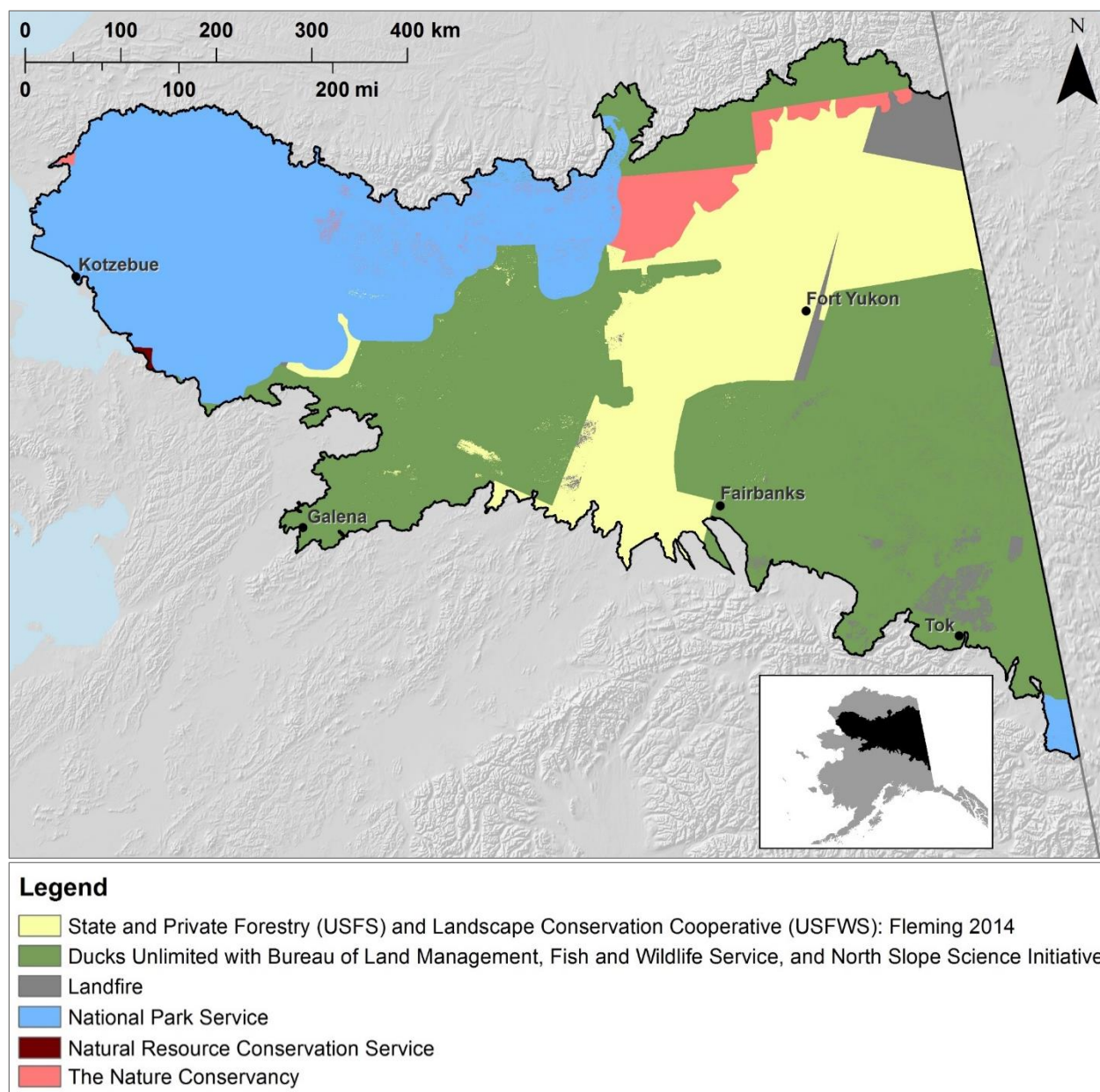


Figure H-58. Source dataset coverage for the Vegetation Map of Northern, Western, and Interior Alaska (Boggs et al. 2014) layered in order of mosaicking priority.

Biological Potential for Reindeer Herding

Calving season and summer forage quality was compared to the summer ranges for all caribou herds that used summer habitat within the CYR study area. Summer ranges for the Western Arctic herd, Teshekpuk herd, and Central Arctic herd were developed for the North Slope REA (Gotthardt et al. 2015) based on a variety of datasets and management reports and were reconciled with the annual kernel densities for each herd. Summer herd ranges for other herds were based on seasonal range polygons digitized from Alaska Habitat Management Guide (ADF&G 1985-1986) and modified in 2015 based on opinion of ADF&G herd biologists. Areas of

moderate and good forage quality were split and quantified based on the boundary of herd summer ranges (Figure H-59).

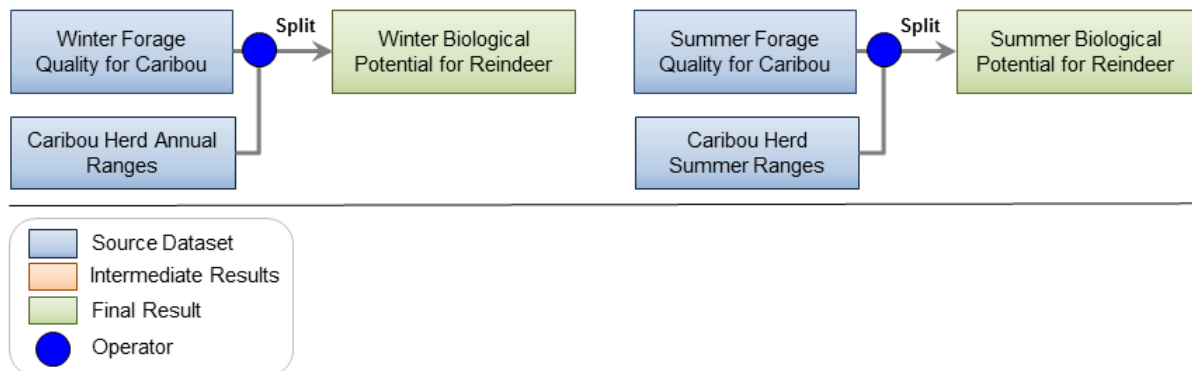


Figure H-59. Process model for assessment of biological potential for reindeer herding within the CYR study area.

Late fall, winter, and early spring forage quality was compared to annual ranges for all caribou herds that used habitat within the CYR study area. Annual range was selected instead of winter range because annual range more adequately covered the large areas that caribou migrate through during fall and early spring, especially for the Western Arctic herd. Annual kernel densities from 2004 to 2014 (or 2013 for Teshekpuk Herd) provided by Alaska Department of Fish and Game represented the annual ranges of the Western Arctic herd, Teshekpuk herd, and Central Arctic herd. Annual herd ranges for other herds were based on seasonal range polygons digitized from Alaska Habitat Management Guide (ADF&G 1985-1986) and modified in 2015 based on opinion of ADF&G herd biologists. Areas of moderate and good forage quality were split and quantified based on the boundary of herd annual ranges (Figure H-59).

12.3 Results and Discussion

Seasonal Forage Quality

Forage quality for late autumn to early spring (approximately October to mid-May) was assessed as a single unit because fruticose lichens contribute a large, often majority, portion of caribou diet during this part of the year (Thomas and McCourt 1981, Boertje 1984, Thomas and Hervieux 1986, Joly et al. 2010). Especially important lichen species are *Cladina mitis*, *Cladina rangiferina*, *Cladina stellaris*, and *Cladonia uncialis*; additional frequently foraged lichen species are *Flavocetraria cucullata*, *Cetraria ericetorum*, *Cetraria islandica*, *Flavocetraria nivalis*, *Cladonia amaurocraea*, and *Cladonia gracilis* (Joly et al. 2010). Good quality winter forage was, therefore, assigned to detailed landcover classes that are likely to have relatively high cover of lichens. Detailed landcover classes sometimes containing lichens or containing moderate cover of lichens were assigned a quality of moderate.

Sedge (*Carex* spp.) bases and some other graminoids are also consumed in winter (Boertje 1984). In some years and areas, mosses contribute over 20% of the winter diet (Gustine et al. 2012), and some evidence suggests that caribou in Alaska ingest moss independently of lichen availability rather than purely as a result of low lichen availability (Ihl and Barboza 2007, Ihl 2010). However, in regions where lichen is generally unavailable, wild reindeer and Peary caribou

consume large and sometimes dominant amounts of moss (Parker 1978, Staalnd et al. 1993). Evergreen dwarf shrubs, especially lingonberry (*Vaccinium vitis-idaea*), and winter-green forbs are also consumed in winter (Boertje 1984, Klein 1990, Gustine et al. 2012). Moderate forage quality was assigned to detailed landcover classes lacking lichens if they had high availability of sedges and high availability of at least one of the following: *Equisetum variegatum*, *Equisetum arvense*, *Stellaria longipes*, *Vaccinium vitis-idaea*, and mosses (i.e., wet to mesic sedge or graminoid classes).

Moderate and good quality winter forage was most dense west of the Koyukuk River and in the southern Brooks Range (Figure H-60). Localized areas of dense forage occurred in upland areas in the eastern and central portions of the study area, except for the stretch just west of Fort Yukon south to just west of Fairbanks where most cells were classified as open to closed spruce, deciduous, or mixed forest. Lowland areas of high quality forage were spruce woodlands or open spruce forests classified as having lichen dominant in the understory. Spruce woodlands with lower lichen covers were classified as moderate quality.

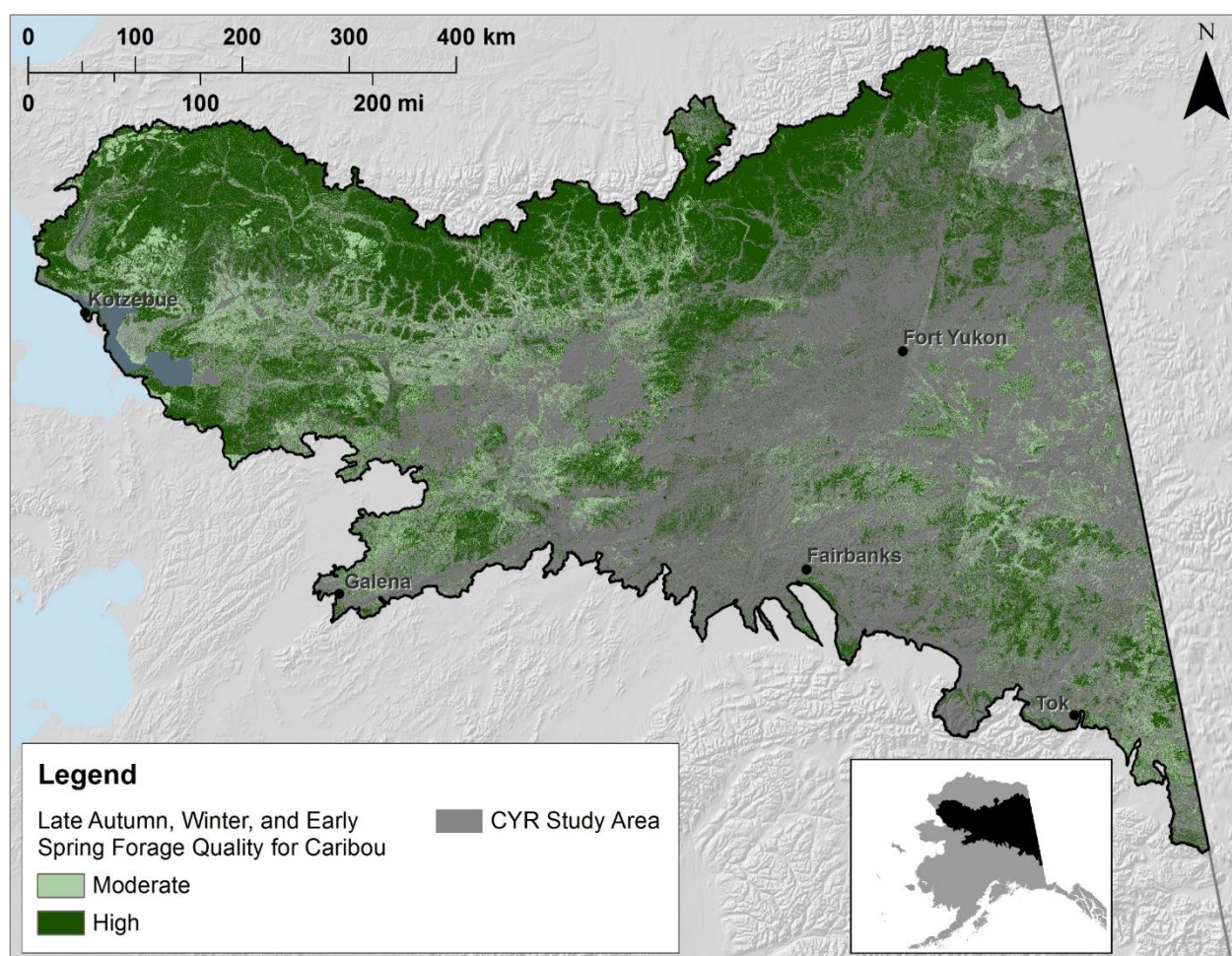


Figure H-60. Areas of moderate and good quality late fall to early spring (October to mid-May) forage for caribou.

Forage quality for calving season through summer was assessed as a single unit because caribou with calving and summer ranges within the CYR study area primarily consume willow (*Salix* spp.) during this part of the year (Boertje 1984). The summer ranges of the Western Arctic, Teshekpuk, and Central Arctic herds did not overlap with or barely overlapped with the CYR study area. Therefore, the selection of detailed landcover classes representing calving season and summer forage was tailored to the diets of caribou herds of Central Alaska. The calving season and summer diets of caribou on the North Slope differ from what is reported here (see Gotthardt et al. 2015).

The catkins, buds, and leaves of prostrate, low, and tall shrub willows contribute the largest and sometimes majority portion of caribou diet during calving season and summer (Boertje 1984). Female caribou and calves avoid tall willow stands, likely because they associate tall shrub with increased predation risk (Boertje 1984, Jakimchuk et al. 1987). However, males will browse tall willow, such as riparian stands of felt-leaf willow (*Salix alaxensis*) (White and Trudell 1980, Boertje 1984, Klein 1990). All detailed landcover classes containing high cover of prostrate or low willow were assigned high quality. Tall willow landcover classes were assigned moderate quality because they are browsed only by males. Landcover classes containing moderate cover of prostrate willow were assigned moderate quality.

Additionally, lichen remains a non-majority component of the diet in summer (Boertje 1984). Landcover classes containing high lichen cover were assigned moderate forage quality. Sedges, grasses, and forbs are consumed as well. Forbs are consumed in the highest amount during calving season and in late-melting patches of snow as new growth emerges (Boertje 1984). Landcover classes that contain high availability of commonly foraged sedges, grasses, or forbs were assigned moderate forage quality.

Good quality summer forage was primarily restricted to uplands and mountains covered by low and dwarf shrub tundra dominated by willow (Figure H-61). In the southern Brooks Range and west of the Koyukuk River, moderate quality forage was common because of the large amount of dwarf shrub tundra where prostrate willows, lichens, and upland sedges are available. Similar to the distribution of winter forage quality, the stretch just west of Fort Yukon south to just west of Fairbanks was primarily low forage quality because most cells were classified as open to closed spruce, deciduous, or mixed forest.

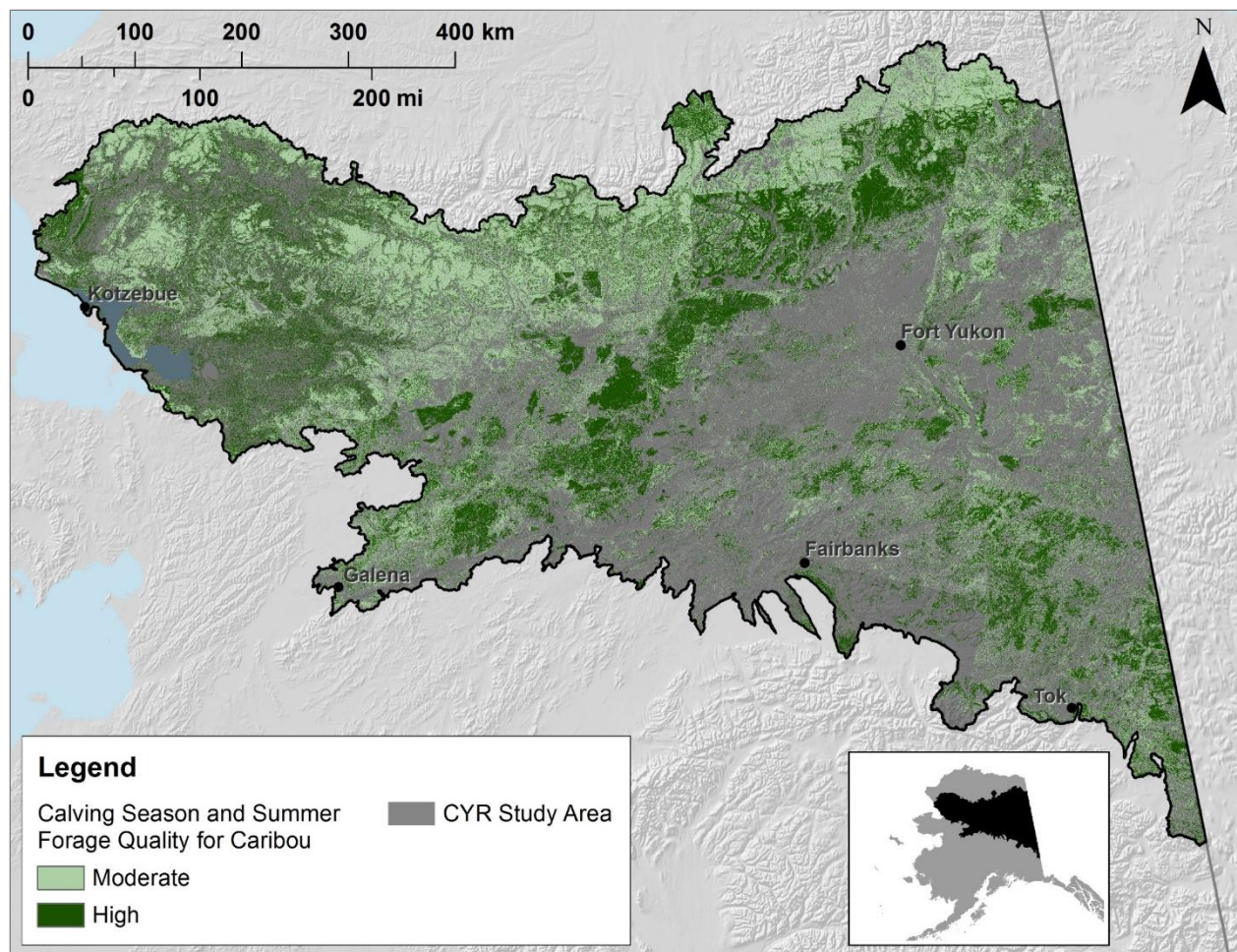


Figure H-61. Areas of moderate and good quality calving season and summer forage for caribou.

Areas that were consistently classified as either low or high forage quality in both calving season and summer and late autumn, winter, and early spring were much more common in the eastern and central portions of the study area than the western or northern portions of the study area (Figure H-62). Detailed landcover classes with little value as caribou forage in any season included those dominated by alder, open forest lacking high lichen cover in the understory, closed forest, aquatic herbaceous, marsh, or open water. Mountains and uplands in the eastern and central portions of the study area consistently provided good quality forage for caribou year-round. The pattern of annual forage quality was consistent with herd spatial trends in the study area: herds use the western and northern portions of the study area seasonally while herds in the eastern and central portions of the study area are relatively stationary around upland and mountain regions. However, many factors unrelated to or indirectly related to forage quality drive herd range distributions and seasonal movements. The existence of localized high or moderate quality seasonal forage outside of herd seasonal ranges emphasizes that factors in addition to forage availability drive caribou distributions and movements.

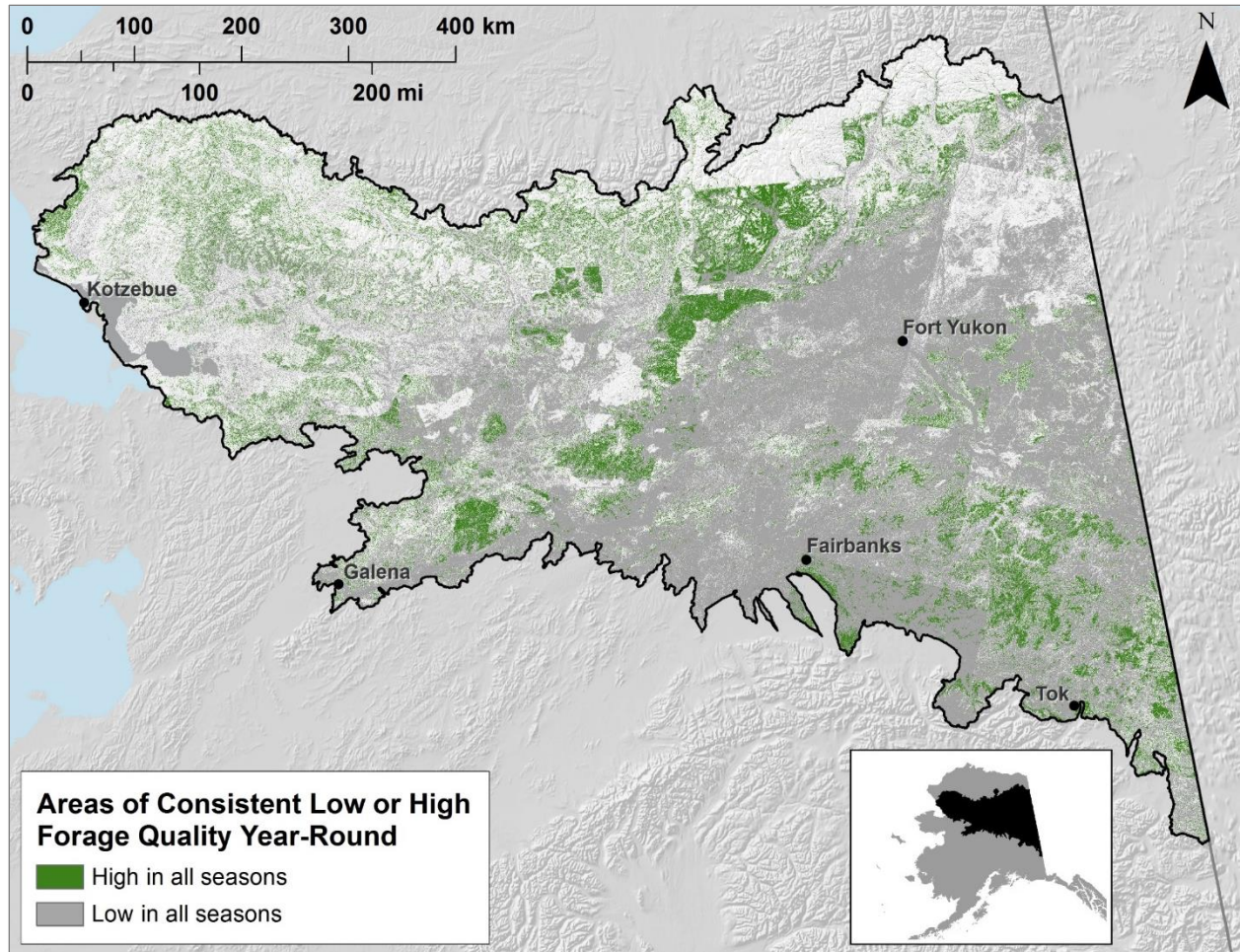


Figure H-62. Areas consistently classified as low or high forage quality in both calving season and summer and late fall, winter, and early spring.

Biological Potential for Reindeer Herding

Because of the potential for reindeer to commingle into caribou herds when the two occupy the same range or when caribou migrate through reindeer range (Finstad et al. 1999), areas within current caribou herd summer ranges were considered to have low biological potential to support reindeer herding for calving season and summer. Similarly, areas within the current herd annual ranges were considered to have low biological potential to support reindeer herding for late fall, winter, and early spring. Areas of moderate and good quality forage occurred both within and outside of caribou herd ranges for both assessed seasons within the CYR study area but to widely differing extents.

The summer ranges of all caribou herds covered only 17% of the CYR study area. A large amount of the study area was, therefore, theoretically available for reindeer in calving season and summer. Moderate or high quality summer forage occurred at a lower rate outside of herd summer ranges than within herd summer ranges but was still common: 44% of the study area outside of herd summer ranges contained good or moderate quality forage, compared to 65% within herd summer ranges (Figure H-63). However, the portions of the study area west of the Koyukuk River

and in the southern Brooks Range east of the Koyukuk River contained high concentrations of moderate and good quality forage despite falling outside of current herd summer ranges. More localized patches of moderate and good quality forage were available east of Fort Yukon and east of Tok near the Yukon border.

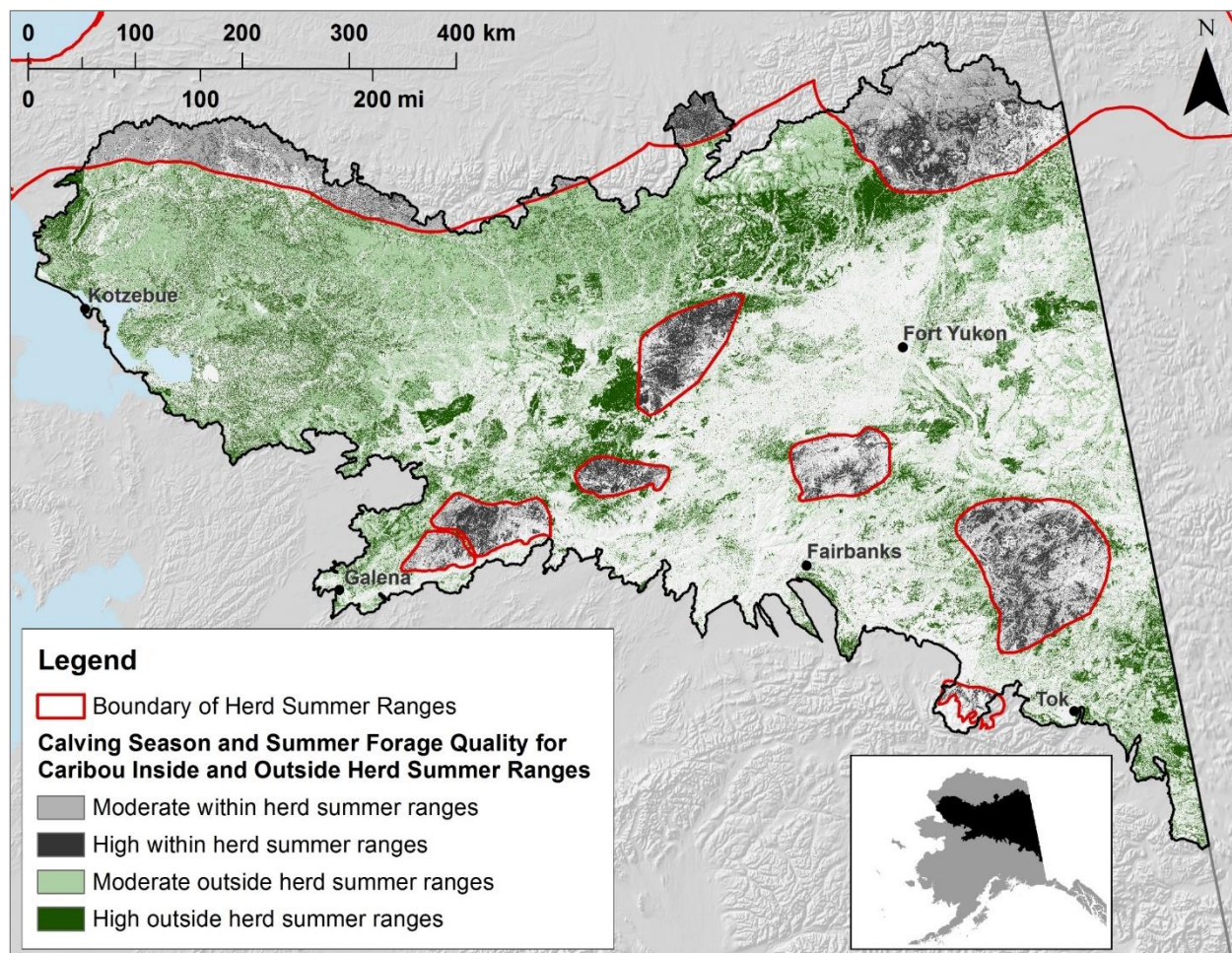


Figure H-63. Forage quality for caribou during calving season and summer within and outside of herd summer ranges in the CYR study area.

Annual ranges of caribou herds covered nearly 80% of the study area. The availability of high and moderate quality forage outside of herd ranges was relatively low: 20% of the study area outside of caribou annual ranges contained good or moderate quality forage, compared to 55% within caribou annual ranges (Figure H-64). The areas west of the Koyukuk River and in the southern Brooks Range, which contained high concentrations of summer forage and did not overlap caribou summer ranges, fell within important migration routes and winter ranges for the Western Arctic, Teshekpuk, Central Arctic, and Porcupine herds. The areas east of Fort Yukon and east of Tok were within the annual ranges of the Porcupine, Fortymile, Mentasta, and Nelchina herds.

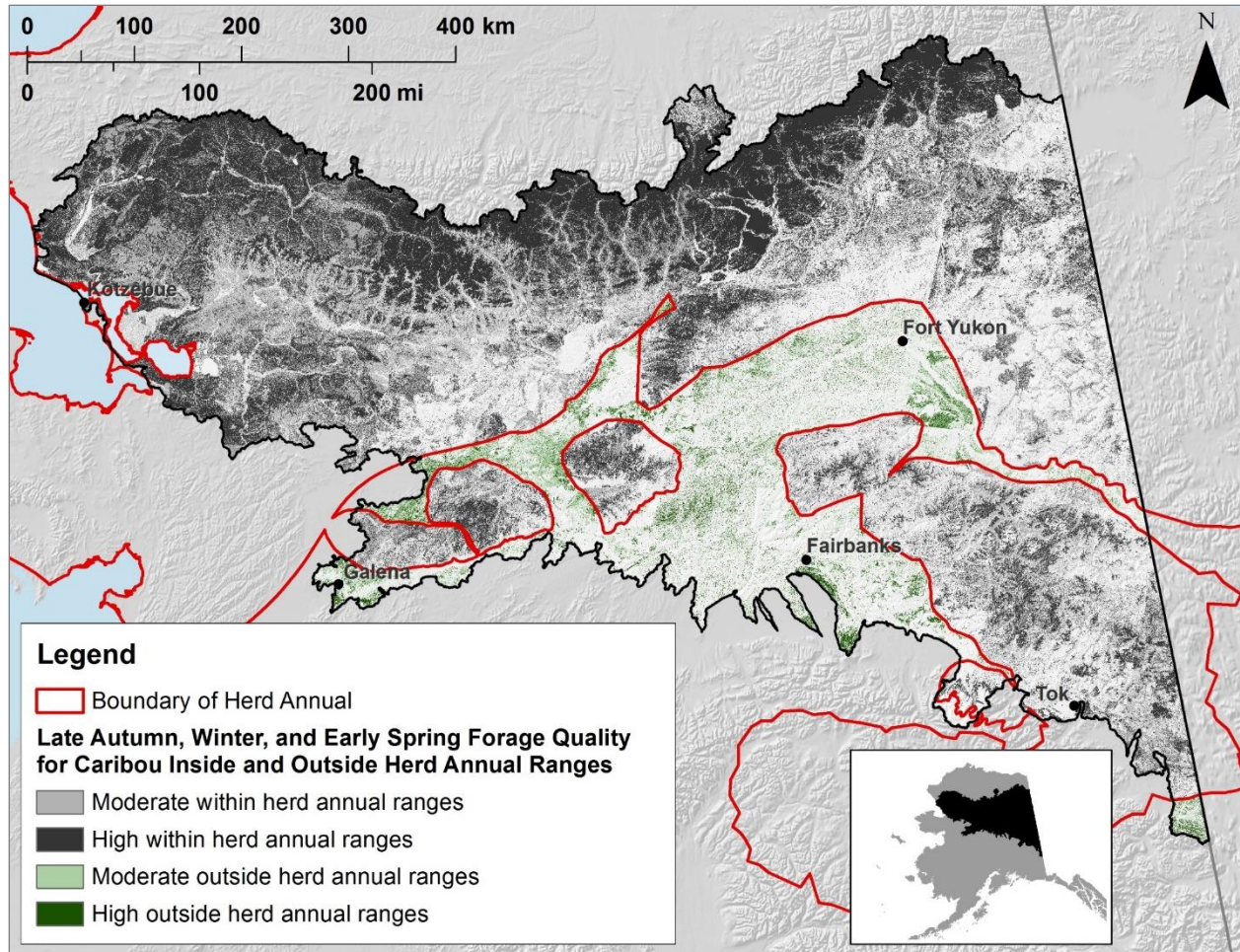


Figure H-64. Forage quality for caribou during late fall, winter, and early spring within and outside of herd annual ranges in the CYR study area.

12.4 Summary

In general, summer forage was plentiful for reindeer but winter forage was highly limited in areas not already occupied by caribou. The low availability of winter forage outside of herd annual ranges may cause reindeer and caribou to conflict in late fall, winter, and early spring if reindeer are introduced in the future, especially because localized areas of available forage bordered on or fell in narrow margins between caribou herds. The bulk of the region available year-round for reindeer herds within the study area was characterized by a large proportion of open-closed spruce, mixed, and deciduous forests. Based on the lack of available winter forage, reindeer herds in the CYR study area would likely be limited to small numbers and could require intensive management.

In 1934, Palmer concluded in a study for the U.S. Department of Agriculture that eastern Alaska was unfeasible for reindeer herding compared to the Seward Peninsula and western Alaska. Since then, herd ranges have changed, but the overall trends noted by Palmer have remained, at least in terms of biological potential. The practicality and economic feasibility of reindeer herding in the CYR study area was not considered in this assessment. However, management intensity

and methods and socioeconomic factors would likely strongly influence the biological potential of the study area if reindeer are introduced in the future.

12.5 Limitations and Data Gaps

Seasonal Forage Quality

The Vegetation Map of Northern, Western, and Interior Alaska (Boggs et al. 2014) was produced by mosaicking the best available (prioritized by detail and accuracy) regional landcover maps into a single spatial coverage. The regional landcover maps were produced using different imagery and classification schema. Although regional landcover maps were assessed for accuracy within their coverages, no accuracy assessment has been conducted for the mosaicked dataset. Regional differences in seasonal forage may, therefore, partially be artifacts of inconsistent classification. More reliable seasonal forage quality datasets could be developed if an existing vegetation classification dataset were produced for the entire state of Alaska using consistent and standardized methodology with landcover defined at the association, alliance, or group level as defined by the National Vegetation Classification Standard.

Diet varies between calves, adult females, and adult males. The approach in this section has been to combine forage preferences for calves, adult females, and adult males to produce generalized forage quality datasets for calving season and summer and late fall, winter, and early spring. However, this generalized approach prevented any insights into sexual segregation within herds. Diet also varies by region and herd. Diet studies are not available for all herds so information was generalized to all herds of Central Alaska. Most previous diet studies have focused on large caribou herds with calving grounds on the North Slope. Less information is available regarding diet of caribou herds that do not use habitat north of the Brooks Range.

Biological Potential for Reindeer Herding

Herd ranges constantly change depending on many factors. It was not possible to predict future herd ranges. Additionally, herd ranges for all herds within the study area except for the annual ranges of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine herds are estimates. Herd ranges selected for this assessment, excluding the four North Slope herds, were digitized from the Alaska Habitat Management Guides (ADF&G 1985-1986). Although they were updated based on expert opinion in 2015, they do not reflect recent telemetry data. Telemetry data are not available for all caribou herds.

To enable a more detailed and accurate assessment of biological potential for reindeer herding, caribou herd annual and seasonal ranges for the most recent 10–15 years should be delineated using standardized kernel density estimation or similar suitable methodology. Standardized methodology applied to all herds in Alaska would first require increased collaring effort for many herds that do not use habitat on the North Slope. Future biological potential for reindeer herding is dependent on current and future changes in caribou herd ranges. Therefore, the biological potential for reindeer herding will not remain constant into the future.

The biological potential for reindeer herding in the CYR study area is influenced by the intensity and methods of herd management. Herd management in turn is determined by, among other factors, economy and local culture, practicality dictated by terrain, and the intents and goals of the herder (e.g., produce meat for export, commercial velvet antler production, provide community

with a supplement to meat from subsistence hunting, increase social status by controlling local resources). Herd management factors and socioeconomic factors were not included in this assessment of biological potential. The results for biological potential for reindeer herding should be interpreted only as the quality of forage and the current presence or absence of caribou herds.

12.6 Literature Cited

- Alaska Department of Fish and Game (ADF&G). 1985-1986. Alaska habitat management guide.
Available: <http://www.arlis.org/docs/vol1/C/AHMG/>
- Beach, H. 1985. The reindeer-caribou conflict in NANA region of Alaska: a case study for native minority rights issues. *Nomadic Peoples* 17:2-22.
- Boertje, R. 1984. Seasonal diets of the Denali caribou herd, Alaska. *Arctic* 37:161-165.
- Boggs, K., T. Boucher, T. Kuo, D. Fehring, and S. Guyer. 2014. Vegetation map and classification: Northern, Western, and Interior Alaska, 2014 Update. Alaska Natural Heritage Program, Anchorage, Alaska. 80 pp.
- Dau, J. 2000. Managing reindeer and wildlife on Alaska's Seward Peninsula. *Polar Research* 19:57-62.
- Finstad, G. L., H. R. Bader, and A. K. Prichard. 1999. Conflicts between reindeer herding and an expanding caribou herd in Alaska. Final report to fulfill partial requirements for contracted project, Bureau of Indian Affairs; Kawerak Inc.: Legal implications concerning reindeer-caribou interactions on the Seward Peninsula. Reindeer Research Program, University of Alaska Fairbanks. 12 pp.
- Finstad, G., H. Bader, and A. Prichard. 2002. Conflicts between reindeer herding and an expanding caribou herd in Alaska. *Rangifer* 13:33-37.
- Gotthardt, T., T. Nawrocki, and N. Fresco. 2015. Section H. Terrestrial fine-filter Conservation elements. In E. Trammell, M. Carlson, N. Fresco, T. Gotthardt, M. McTeague, and D. Vadapalli, eds. North Slope rapid ecoregional assessment. Prepared for: the Bureau of Land Management, U.S. Department of the Interior.
- Gustine, D., P. Barboza, J. Lawler, L. Adams, K. Parker, S. Arthur, and B. Shults. 2012. Diversity of nitrogen isotopes and protein status in caribou: implications for monitoring northern ungulates. *Journal of Mammalogy* 93:778-790.
- Ihl, C. 2010. Percentage of fecal moss in Arctic ungulates as an indicator of wintering area quality. *Journal of Wildlife Management* 74:690-697.
- Ihl, C., and P. Barboza. 2007. Nutritional value of moss for Arctic ruminants: a test with muskoxen. *Journal of Wildlife Management* 71:752-758.
- Jakimchuk, R., S. Ferguson, and L. Sopuck. 1987. Differential habitat use and sexual segregation in the central Arctic caribou herd. *Canadian Journal of Zoology* 65:534-541.
- Joly, K., F. Chapin, III, and D. Klein. 2010. Winter habitat selection by caribou in relation to lichen abundance, wildfires, grazing, and landscape characteristics in northwest Alaska. *Ecoscience* 17:321-333.
- Klein, D. 1980. Conflicts between domestic reindeer and their wild counterparts: a review of Eurasian and North American experience. *Arctic* 33:739-756.
- Klein, D. 1990. Variation in quality of caribou and reindeer forage plants associated with season, plant part, and phenology. *Rangifer* 10:123-130.
- Palmer, L. 1934. Raising reindeer in Alaska. Miscellaneous Publication Number 207. U.S. Department of Agriculture. Washington, D.C. 41 pp.
- Parker, G. 1978. The diets of muskoxen and Peary caribou on some islands in the Canadian High Arctic. Canadian Wildlife Service Occasional Paper 35. Ottawa, Ontario.
- Staaland, H., J. Schleie, F. Grøndahl, E. Persen, A. Leifseth, and Ø. Holand. 1993. The introduction of reindeer to Broggerhalvøya, Svalbard: grazing preferences and effects on vegetation. *Rangifer* 13:15-19.
- Swanson, J., and M. Barker. 1992. Assessment of Alaska reindeer populations and range conditions. *Rangifer* 12:33-43.
- Thomas, D., and D. Hervieux. 1986. The late winter diets of barren-ground caribou in North-Central Canada. *Rangifer Special Issue No. 1*:305-310.

Section H. Terrestrial Fine-filter Conservation Elements

- Thompson, D., and K. McCourt. 1981. Seasonal diets of the porcupine caribou herd. *American Midland Naturalist* 105:70-76.
- White, R., and J. Trudell. 1980. Habitat preference and forage consumption by reindeer and caribou near Atkasook, Alaska. *Arctic and Alpine Research* 12:511-529.

13. MQs X1 and X2: Historical and Future Cumulative Impacts of Roads and Mineral Extraction

MQ X1: What have the past cumulative impacts of road construction and mineral extraction been on terrestrial CE habitat and population dynamics?

MQ X2: How might future road construction and mineral extraction infrastructure (e.g., both temporary and permanent roads [Umiat, Ambler, Stevens Village], pads, pipeline, both permanent and temporary) affect species habitat, distribution, movements and population dynamics (especially caribou, moose, sheep)?

13.1 Introduction

Many studies have investigated the interaction between human development and animal habitat and behavior (Bergerund et al. 1984, Dyer et al. 2001, Eldegard et al. 2012, Laurian et al. 2008, Liebezeit et al. 2009). As development increases throughout Alaska, understanding how these human activities and structures impact animal habitat, distribution, movements, and population dynamics is important for developing management strategies for particular species.

13.2 Methods

Management questions X1 and X2 were combined because they refer to past and future impacts of the same anthropogenic variables: transportation and mining infrastructure. Although MQ X1 was phrased to include all Terrestrial Coarse-filter and Fine-filter CEs, the analysis was focused only on caribou, Dall sheep, and moose. Moose was not included in the CYR REA as a Terrestrial Fine-filter CE but was included for the analysis of MQ X1 and X2 by request of the AMT. We provided an analysis of landscape intactness within species habitat and a literature review of documented impacts of transportation and mineral extraction infrastructure both within and outside the study area for caribou, moose, and Dall sheep.

Landscape intactness is a classification of patch size of land in the very high landscape condition category and provides a non-species-specific representation of habitat fragmentation (see Section F. Landscape and Ecological Integrity). Landscape intactness was classified as highest integrity for patches greater than 200 km², high integrity for patches between 200 and 40 km², and vulnerable for patches less than 40 km². Habitat fragmentation also occurs within condition classes less than very high, so an additional non-intact category was included to represent the combined area of high, medium, low, and very low condition classes. A visual comparison of long-term future (2060) landscape intactness with the combined annual ranges of caribou, the GAP modeled distribution of moose habitat, and the modeled distribution of Dall sheep habitat was provided.

The percent of caribou, moose, and Dall sheep habitat impacted by current (2015) and long-term future (2060) landscape intactness was calculated and provided as a tabular output. Although high integrity represents some of the least fragmented habitats in the contiguous U.S., areas classified as high integrity are heavily influenced by proximity to surrounding human infrastructure relative to most of Alaska. Therefore, habitat in the high integrity category was considered

fragmented in addition to habitat in the vulnerable and non-intact categories. Change was assessed from 2015 to 2060 by percent change in area and by percent increase according to the equations below. Both metrics were provided because the amount of habitat fragmentation is and will likely remain low compared to total available habitat but the projected increase in fragmented habitat is high.

$$\text{Percent Change in Area} = \frac{\text{Future Impacted Area} - \text{Current Impacted Area}}{\text{Current Total Area}}$$

$$\text{Percent Increase} = \frac{\text{Future Impacted Area} - \text{Current Impacted Area}}{\text{Current Impacted Area}}$$

Although numerous additional spatially explicit methods were investigated for MQ X1 and X2, none were selected as feasible. MQ X1 and X2 were limited to a literature review. However, the LCM was designed to identify the spatial distribution of impacts of infrastructure on habitat. Intersections of current, near-term future, and long-term future landscape condition were included in the core REA analysis for caribou and Dall sheep.

13.3 Results and Discussion

Caribou

Summary: *Individual or groups of caribou can be deflected from their movement and migration courses by linear infrastructure, resulting in additional energetic costs, less time spent foraging, delays in migration, and, sometimes, unsuccessful migration leading to starvation. Additionally, caribou, especially parturient females during calving season, avoid both linear and point infrastructure, using habitat within 4 km to 14 km of infrastructure at rates lower than similar habitat further from infrastructure. At the herd scale, because linear infrastructure is functionally a semi-permeable barrier, the presence of linear infrastructure within or adjacent to herd ranges does not prevent migration or range extensions associated with population increase. Population dynamics are likely indirectly influenced by roads by the introduction of additional human predators from common access points.*

Resource extraction and infrastructure development have caused the fragmentation of caribou habitat throughout Alaska, and fragmentation is likely to increase in the future. Recent studies have found that caribou generally avoid areas of human activity (up to 50–95% reduced presence; Vistnes and Nellemann 2008) and can be displaced from preferred calving grounds by human disturbance (Joly and Klein 2011, Wolfe et al. 2000). In addition, human activities can result in increased vigilance and avoidance behaviors which increase energy expenditure of individuals (Fancy 1983, Wolfe et al. 2000). Human activity causes a redistribution of animals on the landscape (Wolfe et al. 2000).

Evidence from Scandinavia suggested that reindeer avoid linear infrastructure by 4–5 km. Vistness and Nellemann (2001) found that in northern Norway mean reindeer density was 73% lower within 4 km of a powerline than within comparable habitat greater than 4 km from infrastructure despite relatively low human traffic. Maternal females were less likely to be within 4 km of the powerline than males (Vistness and Nellemann 2001). Research by Nellemann et al. (2001) in western Norway showed that reindeer avoided roads and powerlines in combination by

5 km during winter. Reindeer density was highest in the undisturbed fragments cordoned by roads, and lichen abundance was lowest in those fragments because of the concentration of foraging (Nellemann et al. 2001). Avoidance behavior has in some cases caused caribou to shift into areas of less favorable habitat (Vistnes and Nellemann 2008). The impact of roads expands far beyond the road corridor itself because of caribou avoidance behavior at a multi-kilometer scale, an associated increase in concentration of foraging in remaining available habitat, and, sometimes, a shift away from the most suitable habitat.

Studies in northern Alberta showed that woodland caribou were able to cross roads but that road avoidance resulted in reduced travel compared to roadless areas. Woodland caribou avoided linear infrastructure associated with oil extraction, and the intensity of avoidance was strongest during late winter, which was correlated to the level of human activity (Dyer et al. 2001). Roads in northern Alberta functioned as semi-permeable barriers: female woodland caribou crossed roads up to six times less frequently than non-road control lines (Dyer et al. 2002). Additionally, Dyer et al. (2001) conjectured that infrastructure avoidance behavior has the potential to decrease predator avoidance if caribou densities increase in areas away from infrastructure, especially because wolves similarly avoid infrastructure (Dyer et al. 2001).

In Alaska, many of the studies of impacts of linear infrastructure on caribou have concentrated on oil field development on the North Slope. Although major differences exist between caribou habitat on the North Slope and within the CYR study area, the impact of roads is likely to be similar in both regions based on agreement of results from the North Slope with results from Scandinavia and northern Canada. Parturient females were displaced by 4–6 km by the Milne Point Road in the North Slope Borough compared to pre-construction distribution (Dau and Cameron 1986, Cameron et al. 1992). Road density in the Milne Point area subsequently increased with construction of well sites. Using data collected by Noel et al. (2004), Joly et al. (2006) showed that from 1991 to 2001 caribou density decreased in the Milne Point area, despite the overall concurrent population growth of the Central Arctic herd. The construction of roads passed a density threshold such that little habitat further than 4 km from any road remained, resulting in the gradual abandonment of the area by maternal caribou (Joly et al. 2006).

No evidence suggests that the presence of a single road causes general habitat abandonment, but, similar to results from Scandinavia and northern Canada, roads in Alaska have acted as semi-permeable barriers buffered by low-use areas. Groups of caribou including calves avoided the Trans-Alaska Pipeline and associated haul road (now the Dalton Highway) during fall migration from 1976 to 1978 (Cameron and Whitten 1980). Adult males crossed the pipeline and haul-road corridor more frequently than females and calves (Cameron and Whitten 1980). Caribou are more tolerant of oil infrastructure when insect harassment causes them to seek relief features (Murphy and Curatolo 1986, Joly et al. 2006). Therefore, although linear infrastructure is avoided, crossing frequency varies based on seasonal variations in environment.

In a study of caribou telemetry data from the Western Arctic herd, Dau (2013) observed that caribou that came into contact with the Red Dog Mine Road during fall migration were diverted by that road such that, subsequent to eventually passing the road, they doubled their movement speed to catch up with the rest of the herd. During 2011, caribou that came into contact with the road took an average of 44 days before crossing the road, first traveling 100 miles to the north or

northwest. A small subset of caribou did not successfully cross the road and turned back to the north. Although data from other years suggested that caribou are not strongly diverted by the road during every migration season (Dau 2013), the diversion and delay caused by the Red Dog Mine Road suggests that the semi-permeable barrier effect of roads is temporal in addition to spatial.

Scale, both spatial and temporal, has been an important factor influencing the results of studies on impact of infrastructure on reindeer and caribou. According to Vistnes and Nellemann (2008), scale accounts for at least some of the variability reported in peer-reviewed articles on reindeer and caribou responses to infrastructure. Studies focused at local scales concluded that individual animals made only short-term behavioral adjustments and movements of less than 1 km after encountering human activity. While these studies implied that impact of infrastructure on reindeer or caribou was low, the study areas did not extend beyond the low-use area surrounding infrastructure (Vistnes and Nellemann 2008). The term avoidance indicates that caribou use habitat near infrastructure at rates lower than habitat far from infrastructure, not that habitat within a certain distance from infrastructure becomes non-functional or abandoned. While reindeer and caribou generally avoid linear infrastructure, the results of studies at local scales have shown that, when they do encounter human activity within a low-use area, their reactions and associated stress impacts are short-term (see Vistnes and Nellemann 2008).

Avoidance behavior is a long-term impact of infrastructure; little evidence suggests that caribou habituate to the presence of infrastructure (Vistnes and Nellemann 2008). Although some studies have suggested habituation, the animals studied were primarily males during periods of heavy insect harassment (Vistnes and Nellemann 2008). Infrastructure can delay or redirect caribou moving between different types of habitat, such as caribou of North Slope herds moving to coastal areas to seek mosquito relief, rather than solely during seasonal migrations. If displacement from breeding, foraging, and relief habitats causes energetic stress, then affected cows will likely respond with lower fecundity (Murphy and Lawhead 2000, Vistnes and Nellemann 2008). Birth rates for female caribou in the Central Arctic herd exposed to areas of oil development were 10–20% lower than those not exposed to oil development (Cameron et al. 2005). A reduction of overall herd fitness is a possible effect of future increases in linear infrastructure.

Bergerud et al. (1984) hypothesized that caribou move in paths of least energetic resistance aligned with their learned seasonal directional orientation. Roads and other linear features alter the energetic costs of travel across the landscape, making caribou likely to divert from their course to travel along linear infrastructure. However, reindeer and caribou have only stopped crossing linear infrastructure during times of population decline when herd ranges have contracted, a phenomenon that has sometimes been interpreted in the past as evidence of linear infrastructure preventing migration. The range of the Nelchina herd expanded across the Richardson Highway in the early 1960s following population increase. Similarly, the Fortymile herd overlapped the Steese and Taylor highways without range abandonment from these transportation corridors. Lastly, the construction of the Dempster Highway in Yukon did not subsequently alter the range of the Porcupine herd (Bergerud et al. 1984). Although linear infrastructure impacts the movement, migration, and habitat use of individuals and groups, linear infrastructure does not prevent migration or range expansion at the herd level, at least in cases of a single road with or without associated pipelines or powerlines.

Another type of impact of transportation corridors through or adjacent to herd ranges is potential increased sport and subsistence hunting pressure. The overlap of highways with herd ranges caused heavy sport hunting pressure on the Nelchina and Fortymile herds in the late 1960s and 1970s (Bergerud et al. 1984). Harvest rates of the Fortymile herd greatly exceeded yearling recruitment from 1970 to 1972 (Davis et al. 1978). The intensity of hunting pressure varies with game management. The presence of a road alone does not result in overhunting. For example, the construction of the Dempster Highway in Yukon corresponded with changes in game management to compensate for the new presence of the road, and the population of the Porcupine herd remained relatively stable through 1980 (Bergerud et al. 1984).

The effects of point infrastructure have received less attention than the effects of linear infrastructure. By nature of being points at the landscape scale, point infrastructure has much lower potential to cause habitat fragmentation than linear infrastructure. However, evidence from throughout the range of reindeer and caribou still indicates that reindeer and caribou avoid point infrastructure. Aerial surveys in the Canadian Arctic showed that migratory caribou of the Bathurst Herd were less likely to select foraging habitat within 14 km of mine sites (Boulanger et al. 2012). Air quality within 2 km of mines was low because of high total suspended particles, which correlated with the lowest habitat selection by caribou (Boulanger et al. 2012). A resort in Norway caused caribou avoidance of 10 km in females and 5 km in males during winter, despite similarities in vegetation composition, snow hardness, and snow depth with increasing distance from the resort (Nellemann et al. 2000). Available lichen biomass decreased with increasing distance from the resort, probably as a result in differential foraging pressure (Nellemann et al. 2000). In northern Norway, mean reindeer density was 78% lower within 4 km of a resort with females less likely to be within that 4 km than males (Vistnes and Nellemann 2001). Avoidance of point infrastructure associated with oil extraction in northern Alberta was strongest during late winter and calving season, which corresponded to seasons of highest human activity in the study area (Dyer et al. 2001). The impact of point infrastructure extends far beyond the developed area because of caribou avoidance at a multi-kilometer scale, an associated increase in concentration of foraging in remaining available habitat, and, sometimes, a shift away from the most suitable habitat.

Moose

Summary: *Although some moose habitat is lost by direct conversion to infrastructure, moose habitat quality can increase following low intensity/density development because of increased patch heterogeneity and increased edge habitat with associated increase in abundance of forage species (primarily willows, Salix spp.). In ecosystems where humans are the dominant predators, moose perceive increased predation risk as their distance to areas of human activity decreases. However, in ecosystems where wolves and bears are dominant predators in addition to human sport and subsistence hunters, such as within the CYR study area, moose likely perceive decreased predation risk as their distance to areas of human activity decreases because wolves and bears are displaced by infrastructure and human activity, resulting in an overall decrease in predator density. Population dynamics are indirectly influenced by roads by altering predator relationships by introduction of additional human predators from common access points.*

The impacts of human infrastructure on habitat, movement, and population dynamics of moose in Alaska have received little research effort. However, numerous related studies have been conducted in Scandinavia. We reviewed the available research from Scandinavia, northern Alberta, and Alaska. The density and nature of infrastructure and the ecosystem relationships involving moose in Scandinavia are different from those of northern Alberta or Alaska, and therefore, impacts of infrastructure on moose in Scandinavia and northern Alberta or Alaska are not likely to be similar, as is reviewed in detail below. Roads and mines impact various aspects of moose habitat differentially: for example, a high density of roads may create increased forest edge habitat with good forage quality and simultaneously increase perceived (or actual) predation risk.

The impacts of infrastructure can vary daily or seasonally depending on which aspects of moose habitat are most important at the time. Bjørneraas et al. (2011) concluded that moose in central Norway benefited from mosaics of varied habitat both on a daily scale and a seasonal scale. During summer, spring, and autumn, moose selected areas with good forage at night and moved into habitats with better cover from predators, humans, and weather but less suitable forage in the day. Moose transitioned to selecting higher cover habitats in autumn and winter. Males and females without young made use of edge habitat created by human infrastructure and agriculture while females with young avoided human infrastructure and agriculture (Bjørneraas et al. 2011). Areas of high forage quality were often associated with human infrastructure in central Norway (Lykkja et al. 2009).

Linear infrastructure has been shown to alter the movements of moose in central Norway; however, the effects of linear infrastructure were minor compared to topography and forest cover (Bartzke et al. 2015). Moose were not deterred from crossing powerlines but were frequently diverted by roads so that direction of travel turned parallel to the road (Bartzke et al. 2015). According to a geospatial analysis by Krisp et al. (2004), new roads in southern Finland have altered moose behavior. The roads included in the analysis were accompanied by wildlife fences designed to prevent car-moose collisions, and they, therefore, posed actual physical barriers to movement. When moving inland to winter habitat from the coast in Finland, some moose were diverted by highways, travelling parallel to them instead of maintaining their course across them. The observed impacts of linear infrastructure on moose range developed gradually over a timespan of decades where changes were not immediately obvious (Krisp et al. 2004).

The intensity of human activity influences the degree to which moose may avoid (or not avoid) infrastructure such as roads and mines. Lykkja et al. (2009) found in central Norway that males were more likely to use habitat adjacent to intense human activity than were females with calves. The overall response of moose associated with human disturbance was similar to that of perceived predation risk, such that intensive human activity reduced the use of favorable habitat for females with calves (Lykkja et al. 2009). Increases in perceived predation risk reduce the amount of time animals spend on other fitness-enhancing activities and have the potential to displace animals from good foraging areas. Additionally, moose tolerate higher intensity human activity when available food is low overall (Strand et al. 2006 in Lykkja et al. 2009). Female moose are more likely to select areas of low human activity even in spite of less suitable forage than males (Ramsrud 2007 in Lykkja et al. 2009).

The results from Scandinavia are based on ecosystems where natural predators are very infrequent and humans are the dominant cause of moose mortality from hunting and vehicle collisions. The situation in Alaska and northern Canada, where wolves and bears are common and are dominant predators of moose in addition to human sport and subsistence hunters, is therefore, not analogous to Scandinavia. Although forage quality, habitat availability, and migration corridors are likely influenced in similar ways in Alaska compared to Scandinavia, the difference in predators may drive a different outcome for moose in Alaska.

Where moose range overlaps with ranges of both wolves and bear in North America, moose densities are regulated to a relatively low 0.1 to 0.4 individuals per square kilometer (Messier 1994, Crête and Courtois 1997). Wolf predation is density dependent, but brown bears kill calves opportunistically. Black bears are also a predator of moose calves for 4 weeks after calving (Franzmann et al. 1980 in Gasaway et al. 1983). The combination of predators reduces moose to densities lower than would be likely in a system with predation only by wolves and much lower than would be likely if moose were resource limited (Messier 1994). Additionally, human predation and wolf / bear predation are additive, not compensatory (Gasaway et al. 1983), so predation by humans further limits moose to low densities. Low densities of moose across the landscape may indicate that there is a less pronounced difference between moose densities near infrastructure compared to undeveloped areas.

In an analysis of early winter distribution and density of female moose in Interior Alaska, Maier et al. (2005) concluded that moose density was higher in riparian corridors, areas of moderate elevation, and near towns. Moose density was also linked to areas of high habitat heterogeneity, which can be an outcome of the fragmentation and edge habitat created by human infrastructure. The influence of elevation found in the study was likely a result of the timing of the study in late autumn when moose generally move from higher elevations to lowlands (Maier et al. 2005). Dominant predators, wolves and bears, have low use of habitat adjacent to human infrastructure (Weaver et al. 1996, Sidorovich et al. 2003, Theuerkauf et al. 2003). Predation risk, perceived and actual, for moose is likely reduced near towns in Alaska and northern Canada because of the reduced occurrence of wolves and bears, even though predation by humans may be high in those areas.

Schneider and Wasel (2000) observed similar results in northern Alberta: moose density increased as road density increased. Hunting pressure was also highest in areas near settlements or high density of roads, but, because sport hunting was concentrated on adult males only and females continued to be impregnated by the remaining males, the population level effects were likely low. As observed in Scandinavia, areas of good forage quality were associated with human infrastructure. Although settlements, roads, and agricultural fields result in some direct loss of habitat, the subsequent increase in habitat heterogeneity and available forest edge and early successional habitat may increase overall carrying capacity (Schneider and Wasel 2000). While roads and towns may still displace moose at the local scale, at the regional scale it is possible that high road density is causal of high moose density in ecosystems where dominant predators are wolves and bears.

Currently, few roads are fenced in Alaska, however, future wildlife fences are possible and have the potential to negatively impact moose populations by restricting movement and migration.

Fenced road corridors in Sweden posed effective barriers to moose; wildlife underpasses were used only occasionally and were largely ineffective (Seiler et al. 2003). Wilson et al. (2015) detected a small but significant genetic subdivision in moose in Anchorage corresponding to the fenced Glenn Highway. Moose in Anchorage were not observed avoiding other roads (Farley et al. 2012 in Wilson et al. 2015), and no genetic subdivisions were identified along roads other than the Glenn Highway (Wilson et al. 2015). Any future construction of wildlife fences along roads within the CYR study area in the future is likely to cause a similar barrier effect.

Dall Sheep

Summary: *Dall sheep generally avoid linear infrastructure that overlaps their range. Sheep are not prevented from migrating between summer and winter range when a road bisects the two, but they cross infrequently or during a limited time frame and increase movement speed. Although sheep habitat is generally restricted to rugged, mountainous terrain away from populated places, sheep habitat overlaps with mines and associated infrastructure. Several highway corridors in the CYR study area also directly overlap Dall sheep habitat. Future increases in fragmentation of Dall sheep habitat are likely because of probable future mining activity.*

Direct overlap of populated places with Dall sheep habitat is relatively low compared to other ungulates because Dall sheep are restricted to rugged or mountainous terrain where village and urban development has been limited. Major highways are also often confined to lowland terrain that sheep are likely to avoid regardless of the presence of a road. Impacts to Dall sheep populations from populated places and lowland highways are still possible indirectly: increased hunting pressure may occur where Dall sheep habitat is adjacent to a highway or close to a town. However, hunting pressure is highly dependent on game management within each area.

Within the CYR study area, four state highways traverse Dall sheep habitat: the Dalton, Steese, Taylor, and Top of the World highways. The length of highway over 800-m elevation in the CYR study area is relatively low at 16% of total highway length (Table H-46), although the Top of the World Highway does not traverse Dall sheep habitat despite being above 800 m. A small amount of Dall sheep habitat is directly lost to highways. However, sheep may have to cross additional stretches of highway below 800 m if highway separates areas of sheep habitat, which is likely along the Dalton, Taylor, and Steese Highways.

Table H-46. State highways above 800-m elevation in the CYR study area.

Highway	Total Length (km)	Length Above 800-m Elevation (km)	Percent Above 800 m
Dalton	474	108	23%
Taylor	238	91	38%
Steese	243	37	15%
Top of the World	21	21	100%
Total Highway	1580	257	16%

Unlike populated places and highways, mines and mining infrastructure often occur in or adjacent to areas that are favorable Dall sheep habitat. Therefore, although Dall sheep habitat is removed from most populated places within the study area, it is fragmented to a degree similar to the

habitat of caribou and moose (Table H-35). Mining activity is often concentrated and future mining activity and associated roads have the potential to fragment previously contiguous habitat in some areas at a local scale.

When roads do overlap sheep habitat, avoidance is likely to be correlated to gender and traffic levels. For example, traffic on the Denali National Park Road restricted Dall sheep movements between summer and winter range (Dalle-Molle and Van Horn 1991 in Phillips et al. 2010). Phillips et al. (2010) found that male Dall sheep crossed the road an average of four times more often than female Dall sheep. However, male sheep crossed only in spring while migrating from winter to summer range while female sheep crossed throughout the study period of May 15 to September 20. Sheep of both sexes shifted away from the road as traffic volume increased, although a small proportion of sheep locations were within 300 m of the road even at the highest traffic levels. Additionally, Dall sheep increased their rates of movement when approaching the road (Phillips et al. 2010). In southern Utah, desert bighorn sheep (*Ovis canadensis nelsoni*) avoided a road corridor resulting in a 15% reduction in potential suitable habitat within a high human use area compared to a low human use area (Papouchis et al. 2001). Roads in the CYR study area may have greater impacts on Dall sheep because, unlike in Denali National Park, traffic is not controlled. Additionally, the Dalton Highway and Steese Highway are trafficked year-round, and impacts are not likely seasonal.

Current and Future Fragmentation of CYR Study Area

Despite being predominantly classified as very high landscape condition (see Section F. Landscape and Ecological Integrity), the CYR study area does contain regions of fragmented habitat (Figure H-65). Relatively few roads are required to fragment habitat in areas of widespread but low density infrastructure development, and even localized fragmentation can have regional impacts. Future landscape fragmentation is primarily concentrated in Fairbanks North Star Borough and along the road to Ambler Mining District.

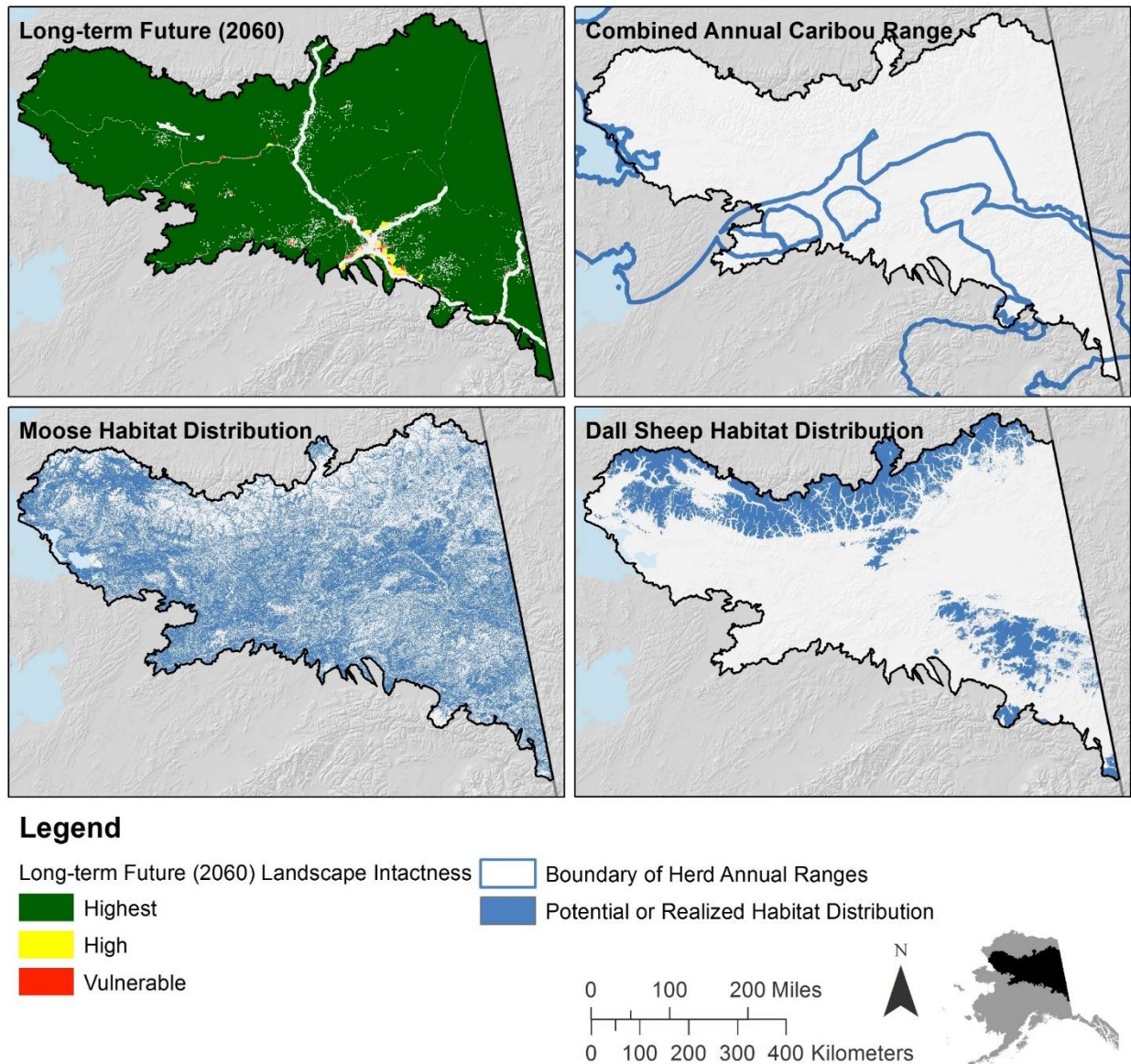


Figure H-65. Long-term future (2060) landscape integrity compared to the combined annual range of caribou herds that use habitat within the CYR study area and the modeled habitat distributions of moose and Dall sheep in the CYR study area.

Fragmentation of currently intact habitat is projected to increase by 1.8% to 2.0% by the long-term future for caribou, moose, and Dall sheep (Table H-47).

Table H-47. Percent of caribou, moose, and Dall sheep habitat per current (2015) and long-term future (2060) landscape intactness categories of high integrity, vulnerable, and non-intact. Percent change in area and percent increase indicate amount of expected change. Values have been rounded to two significant digits or to the nearest hundredth of a percent.

Species	Landscape Intactness	Current	Long-term Future	Change in Area	Relative Change in Fragmentation
Caribou	Not Fragmented	97%	95%	-1.8%	-
	High Integrity	0.06%	0.07%	0.01%	12%
	Vulnerable	0.05%	0.11%	0.05%	> 100%
	Non-intact	2.9%	4.7%	1.7%	59%
Moose	Not Fragmented	95%	93%	-1.8%	-
	High Integrity	0.47%	0.38%	-0.10%	-20%
	Vulnerable	0.28%	0.35%	0.07%	25%
	Non-intact	4.4%	6.2%	1.9%	43%
Dall Sheep	Not Fragmented	97%	95%	-1.9%	-
	High Integrity	0.04%	0.04%	< 0.01%	0.67%
	Vulnerable	0.01%	0.01%	< 0.01%	33%
	Non-intact	2.8%	4.6%	1.9%	40%

The highest integrity class, referred to in the tables as "not fragmented," indicates species habitat unaffected by fragmentation. The 'high integrity' and 'vulnerable' classes reflect influences of large-scale habitat fragmentation, which occurs at a scale larger than the predicted impacts of infrastructure on habitat. The 'non-intact' class reflects direct impacts of infrastructure on habitat and habitat fragmentation (see Methods section for more details).

Of the three species considered here, moose habitat is most influenced by fragmentation because it occurs throughout the Fairbanks North Star Borough and in heavily mined areas in the southern portion of the study area. Dall sheep habitat is the least influenced by large-scale fragmentation, likely because it occurs in mountain areas and rugged terrain that have not been developed as populated places. For all species habitats, the percent change in area of fragmentation is small. Species are likely to continue to have access to primarily unfragmented habitats in the long-term future. However, the influence of roads on species movements (small and large-scale) may have local impacts in targeted areas.

The fragmentation of caribou habitat varies widely per herd (Table H-48). In general, the four large Arctic herd annual ranges are relatively less impacted by fragmentation than the smaller non-Arctic herd annual ranges, largely because the Arctic herds cover large, remote areas. The non-Arctic herd ranges cover less territory in total so infrastructure of the same size has a larger relative fragmentation impact on non-Arctic herds than on Arctic herds. The projected percent increase in fragmentation by the long-term future also varies widely by herd. Overall projected increases in fragmentation of over 100% are likely for the annual ranges of the Galena Mountain, Ray Mountains, Teshekpuk, Western Arctic, White Mountain, and Wolf Mountain herds within the

CYR study area. Future development outside of the CYR study area will also impact the annual ranges of many caribou herds but is not accounted for here.

Table H-48. Percent of caribou herd annual ranges per current (2015) and long-term future (2060) landscape intactness categories of high integrity, vulnerable, and non-intact. Percent change in area and percent increase indicate amount of expected change. Values have been rounded to two significant digits or to the nearest hundredth of a percent.

Herd	Landscape Intactness	Current	Long-term Future	Change in Area	Relative Change in Fragmentation
Central Arctic	Not Fragmented	96%	95%	-1.5%	-
	High Integrity	0.0%	0.0%	0.0%	0.0%
	Vulnerable	0.0%	0.0%	0.0%	0.0%
	Non-intact	3.7%	5.2%	1.5%	39%
Fortymile	Not Fragmented	93%	90%	-2.4%	-
	High Integrity	0.0%	0.0%	0.0%	0.0%
	Vulnerable	0.07%	0.08%	0.01%	4.9%
	Non-intact	7.4%	9.8%	2.4%	32%
Galena Mountain	Not Fragmented	100%	98%	-1.7%	-
	High Integrity	0.0%	0.0%	0.0%	0.0%
	Vulnerable	0.0%	0.0%	0.0%	0.0%
	Non-intact	0.03%	1.7%	1.7%	> 100%
Hodzana Hills	Not Fragmented	88%	83%	-4.8%	-
	High Integrity	0.0%	0.0%	0.0%	0.0%
	Vulnerable	0.0%	0.0%	0.0%	0.0%
	Non-intact	12%	17%	4.8%	40%
Macomb	Not Fragmented	79%	72%	-6.7%	-
	High Integrity	0.0%	0.0%	0.0%	0.0%
	Vulnerable	0.18%	0.19%	0.01%	2.9%
	Non-intact	21%	28%	6.7%	31%
Mentasta	Not Fragmented	82%	82%	-0.04%	-
	High Integrity	0.41%	0.41%	0.0%	0.0%
	Vulnerable	0.42%	0.42%	0.0%	0.0%
	Non-intact	18%	18%	0.04%	0.23%
Nelchina	Not Fragmented	83%	83%	0.03%	-
	High Integrity	0.31%	0.31%	0.0%	0.0%
	Vulnerable	0.46%	0.46%	0.0%	0.0%
	Non-intact	17%	17%	-0.02%	-0.15%
Porcupine	Not Fragmented	100%	99%	-0.29%	-
	High Integrity	0.0%	0.0%	0.0%	0.0%
	Vulnerable	0.02%	0.02%	0.0%	0.0%
	Non-intact	0.32%	0.61%	0.29%	91%

Herd	Landscape Intactness	Current	Long-term Future	Change in Area	Relative Change in Fragmentation
Ray Mountains	Not Fragmented	100%	98%	-1.4%	-
	High Integrity	0.0%	0.0%	0.0%	0.0%
	Vulnerable	0.0%	0.0%	0.0%	0.0%
	Non-intact	0.43%	1.8%	1.4%	> 100%
Teshekpuk	Not Fragmented	93%	91%	-2.3%	-
	High Integrity	0.0%	0.0%	0.0%	0.0%
	Vulnerable	0.0%	0.04%	0.04%	> 100%
	Non-intact	7.1%	9.4%	2.3%	32%
Western Arctic	Not Fragmented	98%	96%	-2.3%	-
	High Integrity	0.03%	0.07%	0.04%	> 100%
	Vulnerable	0.04%	0.18%	0.13%	> 100%
	Non-intact	1.5%	3.6%	2.1%	> 100%
White Mountains	Not Fragmented	97%	91%	-5.8%	-
	High Integrity	1.3%	0.95%	-0.32%	-25%
	Vulnerable	0.0%	0.03%	0.03%	> 100%
	Non-intact	1.7%	7.8%	6.1%	> 100%
Wolf Mountain	Not Fragmented	99%	96%	-3.2%	-
	High Integrity	0.0%	0.0%	0.0%	0.0%
	Vulnerable	0.07%	0.05%	0.02%	-39%
	Non-intact	0.69%	3.9%	3.2%	> 100%

Landscape intactness indicates where fragmentation and direct impacts of infrastructure on habitat occur. No component of landscape intactness indicates how species respond to or are influenced by habitat fragmentation or human activity.

13.4 Summary

Future roads and mining will increase fragmentation of the landscape throughout the CYR study area, but most species habitat will remain highest integrity. Road development may cause shifts or interruptions to movements of caribou, moose, and sheep. In addition, roads may increase hunting access, although hunting pressure is highly dependent on management.

Table H-49. Summary and projected effects of human development on caribou, moose and Dall sheep habitat and behavior.

Human Development	Caribou	Moose	Dall sheep
Line Infrastructure	-	+/-	-
Roads–hunting access	-	-	-
Point Infrastructure	-	+/-	-
Fragmentation	-	+/-	-

13.5 Limitations and Data Gaps

Although an analysis of the association of roads with sport harvests was proposed for MQs X1 and X2, the resolution of sport harvest data prevented any meaningful comparisons. Sport harvest data are maintained by GMU subunit. Although this resolution is appropriate and practical for the purpose of game management, it does not make spatial analysis with landscape features possible. In the absence of collecting sport and subsistence harvest data as individual points at the coordinates of the kill, determination of association of roads with harvest levels would require a focused study with collection of new data.

The impacts of mineral extraction on caribou, moose, and sheep are not well studied. In this assessment, impacts on mines were generalized to a broader discussion of impacts of point infrastructure of various types. Furthermore, the impacts of infrastructure in general are not well studied for Dall sheep, likely because major impacts have not been suspected based on little overlap between Dall sheep habitat and distribution of infrastructure.

13.6 Literature Cited

- Bartzke, G., R. May, E. Solberg, C. Rolandsen, and E. Røskaft. 2015. Differential barrier and corridor effects of power lines, roads, and rivers on moose (*Alces alces*) movements. *Ecosphere* 6:1-17.
- Bergerud A. T., R. D. Jakimchuk, and D. R. Carruthers. 1984. The buffalo of the north: caribou (*Rangifer tarandus*) and human developments. *Arctic* 1:7-22.
- Bjørneraas, K., E. Solberg, I. Herfindal, B. van Moorter, C. Rolandsen, J. Tremblay, C. Skarpe, B. Sæther, R. Eriksen, and R. Astrup. 2011. Moose *Alces alces* habitat use at multiple temporal scales in a human-altered landscape. *Wildlife Biology* 17:44-54.
- Boulanger, J., K. Poole, A. Gunn, and J. Wierzchowski. 2012. Estimating the zone of influence of industrial developments on wildlife: a migratory caribou *Rangifer tarandus groenlandicus* and diamond mine case study. *Wildlife Biology* 18:164-179.
- Cameron, R., and K. Whitten. 1980. Influence of the Trans-Alaska Pipeline corridor on the local distribution of caribou. Pages 475-484 in E. Reimers, E. Gaare, and S. Skjenneberg, eds. *Proceedings of the 2nd International Reindeer/Caribou Symposium*. Røros, Norway.
- Cameron, R. D., D. J. Reed, J. R. Dau, and W. T. Smith. 1992. Redistribution of calving caribou in response to oil field development on the Arctic Slope of Alaska. *Arctic* 1:338-42.
- Cameron, R., W. Smith, R. White, and B. Griffith. 2005. Central Arctic caribou and petroleum development: distributional, nutritional, and reproductive implications. *Arctic* 58:1-9.
- Crête, M., and R. Courtois. 1997. Limiting factors might obscure population regulation of moose (*Cervidae: Alces alces*) in unproductive boreal forests. *Journal of Zoology* 242:765-781.
- Dalle-Molle, J., and J. Van Horn. 1991. Observations of vehicle traffic interfering with migration of Dall's sheep (*Ovis dalli dalli*), in Denali National Park, Alaska. *Canadian Field Naturalist* 105:409-411.
- Dau, J. 2013. Units 21D, 22A, 22B, 22C, 22D, 22E, 23, 24, and 26A. Pages 201-280 in P. Harper, ed. *Caribou management report of survey-inventory activities 1 July 2010 – 30 June 2012*. Species Management Report ADF&G/DWC/SMR-2013-3. Alaska Department of Fish and Game. Juneau, Alaska.
- Dau, J., and R. Cameron. 1986. Effects of a road system on caribou distribution during calving. *Rangifer Special Issue No. 1*:95-101.
- Davis, J., R. Shideler, and R. LeResche. 1978. Fortymile caribou herd studies. Alaska Department of Fish and Game, Pittman Robertson Projects W-17-6 and W-17-7. 153 pp.
- Dyer, S., J. O'Neill, S. Wasel, and S. Boutin. 2001. Avoidance of industrial development by woodland caribou. *Journal of Wildlife Management* 65:531-542.
- Dyer, S., J. O'Neill, S. Wasel, and S. Boutin. 2002. Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. *Canadian Journal of Zoology* 80:839-845.
- Eldegard, K., J. T. Lyngved, and O. Hjeljord. 2012. Coping in a human-dominated landscape: trade-off between foraging and keeping away from roads by moose (*Alces alces*). *European journal of wildlife research* 58:969-979.
- Fancy, S. 1983. Movements and activity budgets of caribou near oil drilling sites in the Sagavanirktok River floodplain, Alaska. *Arctic* 36:193-197.
- Farley, S., P. Barboza, H. Griesse, and C. Gardner. 2012. Characterization of moose movement patterns, movement of black bears in relation to anthropogenic food sources, and wolf distribution and movement on JBER lands, of Elmendorf AFB and Ft. Richardson AP. Alaska Department of Fish and Game Report, Juneau.
- Franzmann, A. W., C. C. Schwartz, and R. O. Peterson. 1980. Moose calf mortality in summer on the Kenai Peninsula, Alaska. *Journal of Wildlife Management* 44:764-768.
- Gasaway, W., R. Stephenson, J. Davis, P. Shepherd, and O. Burris. 1983. Interrelationships of wolves, prey, and man in Interior Alaska. *Wildlife Monographs* 84:1-50.

- Joly, K., and D. Klein. 2011. Complexity of caribou population dynamics in a changing climate. *Alaska Park Science* 10:27-31.
- Joly, K., C. Nellemann, and I. Vistnes. 2006. A reevaluation of caribou distribution near an oilfield road on Alaska's North Slope. *Wildlife Society Bulletin* 34:866-869.
- Krisp J. M., S. Väre, J. Dame, and K. Virrantaus. 2004. Visualizing moose habitat changes due to infrastructure construction in southern Finland. *Proceedings on the 20th ISPRS congress 2004 July* 12-23.
- Laurian, C., C. Dussault, J. P. Ouellet, R. Courtois, M. Poulin, and L. Breton. 2008. Behavior of moose relative to a road network. *The Journal of Wildlife Management* 72:1550-7.
- Liebezeit, J. R., S. J. Kendall, S. Brown, C. B. Johnson, P. Martin, T. L. McDonald, D. C. Payer, C. L. Rea, B. Streever, A. M. Wildman, and S. Zack. 2009. Influence of human development and predators on nest survival of tundra birds, Arctic Coastal Plain, Alaska. *Ecological Applications* 19:1628-44.
- Lykkja, O., E. Solberg, I. Herfindal, J. Wright, C. Rolandsen, and M. Hanssen. 2009. The effects of human activity on summer habitat use by moose. *Alces* 45:109-124.
- Maier, J., J. ver Hoef, A. McGuire, R. Bowyer, L. Saperstein, and H. Maier. 2005. Distribution and density of moose in relation to landscape characteristics: effects of scale. *Canadian Journal of Forest Research* 35:2233-2243.
- Messier, F. 1994. Ungulate population models with predation: a case study with the North American moose. *Ecology* 75:478-488.
- Murphy, S., and J. Curatolo. 1986. Activity budgets and movement rates of caribou encountering pipelines, roads, and traffic in northern Alaska. *Canadian Journal of Zoology* 65:2483-2490.
- Murphy, S., and B. Lawhead. 2000. Caribou. *In* J. Truett, and S. Johnson, eds. *The natural history of an Arctic oil field: development and the biota*. Academic Press, San Diego, California. 422 pp.
- Nellemann, C., P. Jordhøy, O. Støen, and O. Strand. 2000. Cumulative impacts of tourist resorts on wild reindeer (*Rangifer tarandus tarandus*) during winter. *Arctic* 53:9-17.
- Nellemann, C., I. Vistnes, P. Jordhøy, and O. Strand. 2001. Winter distribution of wild reindeer in relation to power lines, roads, and resorts. *Biological Conservation* 101:351-360.
- Noel, L., K. Parker, and M. Cronin. 2004. Caribou distribution near an oilfield road on Alaska's North Slope, 1978-2001. *Wildlife Society Bulletin* 32:757-771.
- Papouchis, C., F. Singer, and W. Sloan. 2001. Responses of desert bighorn sheep to increased human recreation. *The Journal of Wildlife Management* 65:573-582.
- Phillips, L., R. Mace, and T. Meier. 2010. Assessing impacts of traffic on large mammals in Denali National Park and Preserve. *Park Science* 27:60-65.
- Ramsrud, J. 2007. Calving site selection by moose: anti-predation versus feeding conditions. Norwegian University of Science and Technology, Trondheim, Norway.
- Schneider, R., and S. Wasel. 2000. The effect of human settlement on the density of moose in northern Alberta. *Journal of Wildlife Management* 64:513-520.
- Seiler, A., G. Cederlund, H. Jernelid, P. Grängstedt, and E. Ringaby. 2003. The barrier effect of highway E4 on migratory moose (*Alces alces*) in the High Coast area, Sweden. *In* *Habitat Fragmentation due to Transportation Infrastructure*. IENE.
- Sidorovich V. E., L. L. Tikhomirova, and B. Jedrzejewska. 2003. Wolf *Canis lupus* numbers, diet and damage to livestock in relation to hunting and ungulate abundance in northeastern Belarus during 1990-2000. *Wildlife Biology* 9:103-11.
- Strand, O., K. Bevinger, and T. Falldorf. 2006. Reinens bruk av Hardangervidda. Sluttrapport fra Rv7-prosjektet. (Wild reindeer habitat use at Hardangervidda. Final Report from the Hw7 Project). NINA Rapport 131, Trondheim, Norway. (In Norwegian.) 67 pp.
- Theuerkauf J., W. Jedrzejewski, K. Schmidt, and R. Gula. 2003. Spatiotemporal segregation of wolves from humans in the Białowieża Forest (Poland). *Journal of Wildlife Management* 1:06-16.

Section H. Terrestrial Fine-filter Conservation Elements

- Vistnes, I., and C. Nellemann. 2001. Avoidance of cabins, roads, and power lines by reindeer during calving.
- Vistnes, I., and C. Nellemann. 2008. The matter of spatial and temporal scales: a review of reindeer and caribou response to human activity. *Polar Biology* 31:399-407.
- Weaver, J. L., P. C. Paquet, and L. F. Ruggiero. 1996. Resilience and conservation of large carnivores in the Rocky Mountains. *Conservation Biology* 10:964-976.
- Wilson, R., S. Farley, T. McDonough, S. Talbot, and P. Barboza. 2015. A genetic discontinuity in moose (*Alces alces*) in Alaska corresponds with fenced transportation infrastructure. *Conservation Genetics* 16:791-800.
- Wolfe, S., B. Griffith, and C. Wolfe. 2000. Response of reindeer and caribou to human activities. *Polar Research* 19:63-73.

I. Aquatic Coarse-filter Conservation Elements

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Summary

Section I. *Aquatic Coarse-filter Conservation Elements* provides the detailed descriptions, methods, datasets, results, and limitations for the assessments of four habitats considered to be of high ecological importance in the region and potential impacts of Change Agents on these habitats.

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1. Introduction to Aquatic Habitats (Coarse-filter Elements)

Four aquatic habitats were selected as Coarse-filter Conservation Elements (CEs) that represent the dominant ecological patterns across the Central Yukon (CYR) study area and are summarized in Table I-1 with the criteria used for selecting them.

Table I-1. List of Aquatic Coarse-filter CEs.

Conservation Element	Selection Criteria
Rivers and large streams	Provide fish and invertebrate habitat; important spawning, rearing, and overwintering habitat for all fish CEs; essential migration corridors for many populations.
Small streams (including headwater streams)	Provide fish and invertebrate habitat, export of nutrients and organic matter downstream, important rearing habitat for Chinook and Dolly Varden.
Large, freshwater connected lakes	Provide fish, invertebrate, and bird habitat; both fish and birds are important for subsistence and recreational use.
Small, freshwater connected lakes	Provide fish, invertebrate, and bird habitat; both fish and birds are important for subsistence and recreational use.

2. Methods

For each Coarse-filter CE, we evaluated the potential impacts by individual Change Agents (CAs). The process of intersecting the current distribution of the individual CEs with CAs is considered the core analysis of the REA. Due to lack of spatial data relating many of the CAs (e.g., climate change and stream temperatures) to aquatic habitats, relationships between the Aquatic Coarse-filter CEs and CAs were mostly based on literature review. Below we summarize the methods and results of the core analysis for all Aquatic Coarse-filter CEs, followed by individual CE accounts where we present a more in-depth explanation of our findings.

We also answered two Management Questions (MQs) that broadly inquired about anthropogenic impacts to aquatic habitat and species, which are included in Section J. Aquatic Fine-filter Conservation Elements (MQs W2 and V1):

MQ W2: How might future road construction and mineral extraction infrastructure (e.g., both temporary and permanent roads, pads, pipeline) affect fish habitat, fish distribution, and fish movements (especially Chinook salmon, chum salmon, and inconnu)?

MQ V1: How does human activity (e.g., mineral extraction, gravel extraction) alter stream ecology and watershed health (i.e., water quantity, water quality, outflow/stream connectivity, fish habitat, and riparian habitat)?

The following steps were completed for the four Aquatic Coarse-filter CEs:

1. Mapped or modeled the **current distribution** of each CE.
2. Created a **conceptual model** for each CE based on its relationship to CAs.
3. **Intersected the mapped/modeled distribution of each CE with those CAs** identified as having significant impacts to aquatic habitats or species.
4. **Conducted a literature review** summarizing the effects of CAs on each CE when spatial data were not available.
5. Assessed current and long-term future (2060) **status** by intersecting the mapped distribution of each CE with the **Landscape Condition Model** (LCM)—modified for aquatic habitats.

2.1 Distribution Modeling

Our goal was to generate a distribution map for each CE using existing datasets. The best available spatial dataset for streams and lakes in the CYR study area was the National Hydrography Dataset (NHD). The NHD was used to create the distribution maps for the large and small connected lakes. A lake size cutoff of 0.1 km² was used to differentiate between large and small lakes and connectivity was based on having inlets and/or outlets included in the NHD flow lines. No attributes existed for the NHD flow lines that could be used to differentiate streams by size (e.g., Strahler stream order, stream width, or watershed area). For this reason, a synthetic stream network was built using the best available digital elevation model (DEM) for the CYR study area, which was the National Elevation Dataset 60-m DEM. The synthetic stream network was created using TauDEM tools in ArcGIS and enabled attribution of Strahler stream order to the stream network. Small streams were differentiated from large streams and rivers

based on stream orders of 1 or 2 and 3 or higher, respectively. The total length/area of streams and connected lakes in the CYR study area is shown in Table I-2; Figure I-1 provides an example of how the habitats are spatially distributed in the Minto Flats Lake District.

Table I-2. Distribution of Coarse-filter CEs in CYR study area.

Coarse-filter CE	Total Length (km)	Total Area (km ²)
small streams	140,310	---
large streams or rivers	47,810	---
connected small lakes	---	761
connected large lakes	---	3,967

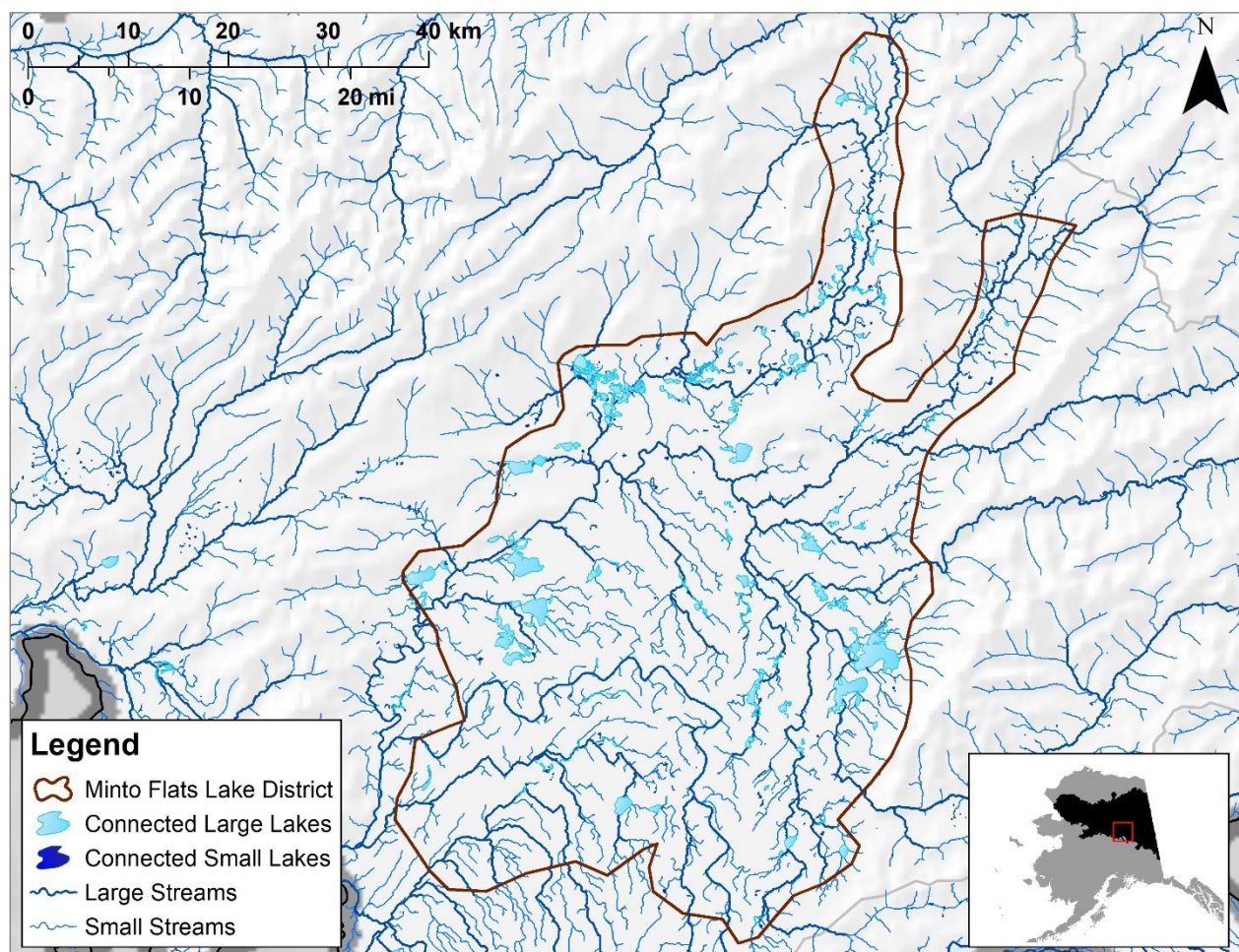


Figure I-1. Distribution of Coarse-filter CEs in Minto Flats Lake District, CYR study area. Lakes shown on the map are connected to the NHD stream network. The NHD stream network is not shown because it does not match the synthetic stream network used to map the distribution of stream habitats.

2.2 Conceptual Models and Attributes and Indicators

Conceptual models were developed for each Aquatic Coarse-filter CE and are essentially “stressor” models that depict the effects that environmental stressors (i.e., CAs) impose on key ecological components. The CE-specific conceptual models represent the state of knowledge between the CE, CAs, and other resources. Conceptual models for the Aquatic Coarse-filter CEs are presented within the individual CE sections.

Ecological attributes are defined as traits or factors necessary for maintaining a fully functioning population, assemblage, community, or ecosystem. During the methods phase, we identified a number of attributes derived from the conceptual model, and assigned indicators based on potential spatial data layers. Categories were generalized based on published threshold values, where available, or otherwise the best available information (e.g., average, greater than average, or lower than average).

The attributes and indicator tables originally proposed in the methods document are not included in this report for the reasons described below, although their effects have been addressed in other sections of this report (Table I-3). The anthropogenic indicators originally listed in the attributes and indicators tables were moved to the core analysis because we were unable to find published information on indicator levels that triggered an effect on aquatic habitat attributes applicable to streams in Alaska (e.g., road density and sedimentation). In the core analysis results, we reviewed the literature to describe the likely impacts of CAs on aquatic habitats and summarized the results quantitatively (e.g., kilometers of habitat impacted by impassable culverts). Several of the climate change datasets originally listed in the attributes and indicators tables were not included in the core analysis because spatial data were not available (e.g., cumulative degree-days or stream temperature). Climate change effects on aquatic habitats have been summarized using a literature review in the individual CE accounts. Two climate change datasets were included in the core analysis (e.g., permafrost thaw and thermokarst potential in areas projected to thaw to at least 1-m depth by the 2060s) because spatial data were available. More details on data limitations for aquatic habitats are described in the Limitations and Data Gaps section (I.2.6) of this report.

Table I-3. Method used to address Coarse-filter CE attributes originally identified in the methods document.

Attribute	Method Used
Frost-free days/season length	Literature review in individual CE sections
Fire frequency	Literature review in individual CE sections
Summer temperature	Literature review in individual CE sections
Contaminated sites	Core analysis
Riparian invasive species	Literature review in individual CE sections and included in Section D. Biotic Change Agents

2.3 CE × CA Intersections

The CE × CA assessment was based on the availability of spatial datasets expected to have meaningful impacts to aquatic habitats or species. These included: water quality and habitat impacts, future roads, future mineral potential, long-term future (2060s) permafrost thaw, and thermokarst potential in areas projected to thaw to at least 1-m depth by the 2060s. Datasets

selected for the analysis of water quality and habitat impacts were: Alaska Department of Environmental Conservation (ADEC) impaired waters, ADEC contaminated sites, Alaska Department of Natural Resources (ADNR) active placer mines, and Alaska Department of Fish and Game (ADF&G) culvert inventory. Results from the core analyses are summarized in tables and presented in Section I.3. Maps of all CE × CA intersections are not included in this report; however, we included those maps that provided meaningful information in the core analysis results or individual CE accounts. All GIS data are provided as a final product and will be made publicly available through the BLM online data portal for future analyses.

2.4 Status Assessment

The current (2015) and long-term future (2060) landscape condition model (LCM) was modified for Aquatic Coarse-filter CEs to develop condition scores for both the stream network and individual 6th-level hydrologic units. Landscape condition is a measurement of the impact of the human footprint on a landscape. Human modifications were categorized into different levels of impact (site impact scores) based on the current state of knowledge about the impacts of specific human land uses (see Section F. Landscape and Ecological Integrity).

The flow direction grid and LCM grids were used to create a condition-weighted contributing area grid that summed condition scores upstream of each cell in the synthetic stream network. The resulting sums were divided by the total accumulation (number of upstream cells per individual cell) of each cell to create mean watershed condition scores along the stream network. Mean watershed condition scores only represented those parts of the watershed within the CYR study area since the extent of input data ended at the boundary. Mean watershed LCM scores were intersected with the synthetic stream network to assign scores to the small streams and large streams aquatic habitats. Mean watershed condition scores were averaged for all 6th-level hydrologic units in the study area and intersected with the small and large connected lake habitats. Current and long-term future (2060) condition scores for all four Aquatic Coarse-filter CEs were classified into five equal intervals and summarized across the study area.

Section I. Aquatic Coarse-filter Conservation Elements

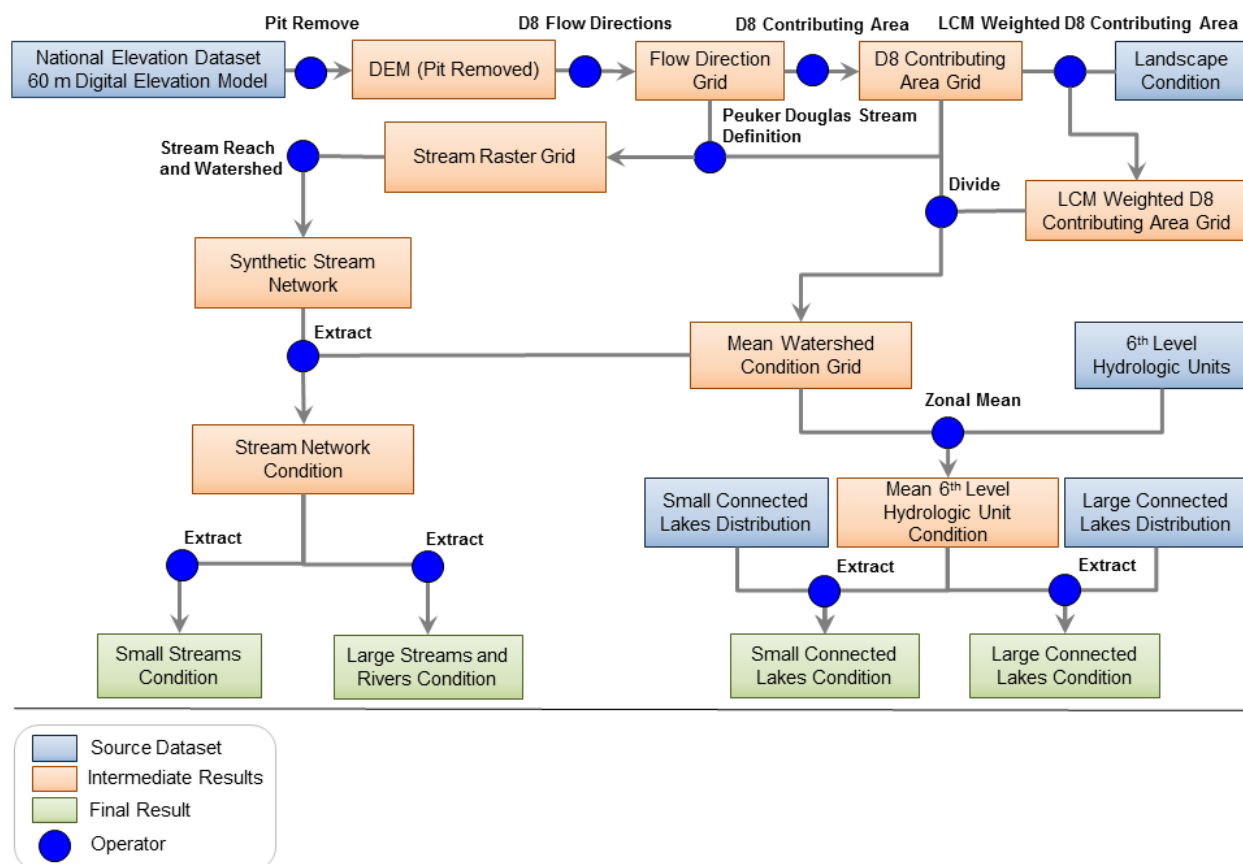


Figure I-2. Process model for analysis of landscape condition in aquatic habitats based on generation of stream network condition and mean 6th-level hydrologic unit condition.

2.5 Relative Management Responsibility

The relative amount of management responsibility on public lands for each CE was assessed by intersecting the CE-specific distributions with general land management status for 2015. Although each state and federal agency has different management mandates and responsibilities for specific fish and wildlife species, this assessment provides an estimate of the proportion of a species distribution that occurs within the boundaries of areas managed by public agencies. This type of information may be useful to managers to promote better collaboration and increase effectiveness of public lands managed for species that migrate across political boundaries.

3. Core Analysis Results

The core analysis focuses on impacts from climate change and human uses on aquatic habitats. A separate analysis of *Elodea*, an invasive aquatic plant, is in Section D. Biotic Change Agents. The effects of other CAs that lack spatial data, such as wildfire and water temperature, are included as literature reviews in the individual CE sections.

3.1 Climate Change

The effects of permafrost thaw and resulting thermokarst in the long-term future were compared to the distributions of aquatic habitats in the CYR study area. Due to lack of data or models representing the complex interactions between thawing permafrost, increasing temperatures, and changes in the amount and form of precipitation on stream temperatures or discharge, these climate change impacts are considered data gaps and are summarized based on a literature review in the individual CE sections.

Thawing permafrost in Interior Alaska will lead to dramatic changes in stream discharge, bank stability, and water chemistry. Stream discharge will change from surface- to groundwater-dominated flow, resulting in increased baseflows (including winter flows) and declining annual flows (Walvoord and Striegl 2007, Brabets and Walvoord 2009, Jones and Rinehard 2010, Bennett et al. 2015). Thawing permafrost along streams and rivers will decrease bank stability, which could lead to erosion and alteration of the stream channel (Nilsson et al. 2015). Shifts to deeper flow paths will result in altered stream chemistry, depending upon the soil types intersected and residence times. Observations in Alaska show that flow paths will interact with organic-rich soils and result in increased concentrations of dissolved organic carbon and nitrogen, although over longer time periods deeper flow paths through mineral soils may result in adsorption and mineralization of organic matter and decreased export to streams (Striegl et al. 2007). Increased mineralization and weathering after permafrost thaw will lead to higher export of inorganic nutrients and major ions to streams (Frey and McClelland 2009). Increases in nutrient export and groundwater flow will likely have positive effects on aquatic habitats, such as increased productivity and increased overwintering habitats, respectively.

Lakes will likely experience similar changes to water chemistry as streams. Permafrost thaw effects on lake area may be positive or negative for fish populations, depending upon surrounding thermokarst potential and hydraulic gradients. Thermokarsting (lateral permafrost degradation) tends to increase lake area, whereas lake area may increase or decrease when permafrost melts vertically and surface water reconnects with groundwater systems (Roach et al. 2011). Observations of lake area trends in National Wildlife Refuges since the 1980s indicate that lake area has: 1) decreased in the Selawik and Kanuti refuges; 2) not changed significantly in the Koyukok and Tetlin refuges; 3) and not changed significantly, increased, or decreased in the Yukon Flats refuge (Roach et al. 2013). The measured rates indicate the potential for 33%, 53%, and 77% decreases in lake area for the Selawik, Kanuti, and Yukon Flats refuges, respectively, by 2060. These reductions may have important impacts to both fishes and waterfowl that use these areas for summer feeding and rearing.

Streams are evenly distributed throughout the study area, whereas lakes predominantly occur in lowland areas along the Yukon River and also in the Noatak, Kobuk, and Selawik watersheds in the western portion of the study area. The largest of these lake districts is the Yukon Flats; others that are partly or entirely in the study area include Tetlin, Minto Flats, Kanuti, Koyukuk,

Selawik, Kobuk Delta, and Noatak. Permafrost was defined spatially for this assessment as 2-km grid cells where mean annual ground temperature was projected to be less than or equal to 0 °C at 1-m depth (see Section C. Abiotic Change Agents). Lake districts projected to experience the greatest reductions in permafrost are Minto Flats, Yukon Flats, and the lower Selawik River (Figure I-3). The aquatic habitat most affected by permafrost thaw will be large lakes, half of which may no longer be underlain by permafrost by the 2060s (Table I-4). Almost a third of small lakes will no longer be associated with permafrost.

Table I-4. Permafrost thaw effects on lakes.

Coarse-filter CE	Current Permafrost (2010s)		Long-Term Future Permafrost (2060s)	
	Present (%)	Absent (%)	Present (%)	Absent (%)
small connected lakes	99%	1%	72%	28%
large connected lakes	99%	1%	46%	54%

Currently, permafrost covers most of the study area, resulting in high watershed cover for both small and large streams. By the 2060s, almost a quarter of small streams and over 10% of large streams will no longer have permafrost in their watersheds (Table I-5). The watersheds most affected by permafrost thaw include tributaries of the Tanana River, such as the Tolovana, Chena, and Salcha rivers in addition to upper Yukon tributaries, such as Beaver and Birch creeks (Figure I-3).

Table I-5. Permafrost thaw effects on streams and rivers.

Stream Type	Watershed Permafrost Cover Classes (%)	Current Permafrost (2010s)	Long-Term Future Permafrost (2060s)
Small streams	0	3%	24%
	1–30	1%	4%
	31–60	1%	3%
	61–90	1%	4%
	91–100	95%	64%
Large streams or rivers	0	2%	12%
	1–30	0%	12%
	31–60	2%	10%
	61–90	5%	11%
	91–100	91%	55%

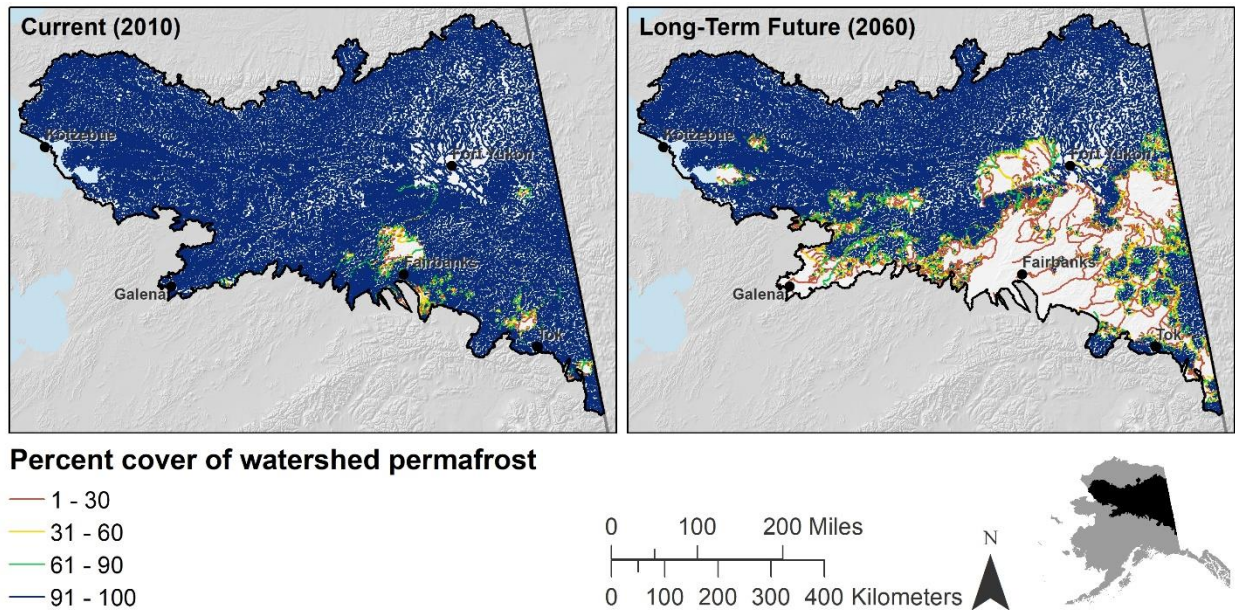


Figure I-3. Current and long-term future percent cover of watershed permafrost along stream network.

The development of thermokarst features after permafrost thaw will contribute both sediment and nutrients to streams and lakes. Water chemistry observations on the north side of the Brooks Range indicated that thermokarst features were associated with suspended sediment concentrations two orders of magnitude and inorganic nutrient concentrations (nitrate, phosphate, and ammonium) 4–40 times higher than background (Bowden et al. 2008). A larger study of water chemistry impacts from mega-slump thermokarst features (> 5 hectares in area with headwalls > 4-meters high) in northwestern Canada also recorded suspended sediment concentrations two orders of magnitude higher than in unimpacted watersheds (Kokelj et al. 2009). Increased nutrient delivery to streams and lakes in the CYR study area may stimulate aquatic productivity. Sediment delivery could also have a negative effect, increasing substrate embeddedness and smothering benthic biofilms that form the base of aquatic food webs.

A large retrogressive thaw slump (RTS) in the Selawik River that initiated in 2004 contributed large amounts of sediment to the river and likely impacted an inconnu spawning habitat approximately 40 km downstream (U.S. Fish and Wildlife Service No Date). The RTS retreated approximately 20 m/yr and, by 2011, had a headwall of 15 m and a width of 250 m (Barnhart and Crosby 2013). By 2013, the slump had stabilized, although some erosion to the river was still observable (Figure I-4).



Figure I-4. Selawik retrogressive thaw slump in 2013. Photo by U.S. Fish and Wildlife Service.

Medium and high thermokarst potential in areas projected to thaw to at least 1-m depth by the 2060s occurs mostly in the southern portion of the study area, although there is an additional area of high thermokarst potential along the lower Selawik River (Figure I-5). Lakes tend to be distributed in areas of high thermokarst potential, making them more vulnerable to sedimentation impacts in the long-term future, although the total percentage of lake and stream habitats affected by thermokarst are roughly the same (21–23%; Table I-6). Lake districts with the greatest thermokarst potential in areas projected to thaw to at least 1-m depth by the 2060s are Minto Flats, Yukon Flats, and the lower Selawik River (Figure I-5).

Table I-6. Thermokarst potential in areas projected to thaw to at least 1-m depth by the 2060s and effects on Aquatic Coarse-filter CEs.

Coarse-filter CE	Percent of current habitat in areas of medium thermokarst potential	Percent of current habitat in areas of high thermokarst potential
small streams	15%	8%
large streams or rivers	13%	9%
small connected lakes	3%	18%
large connected lakes	2%	20%

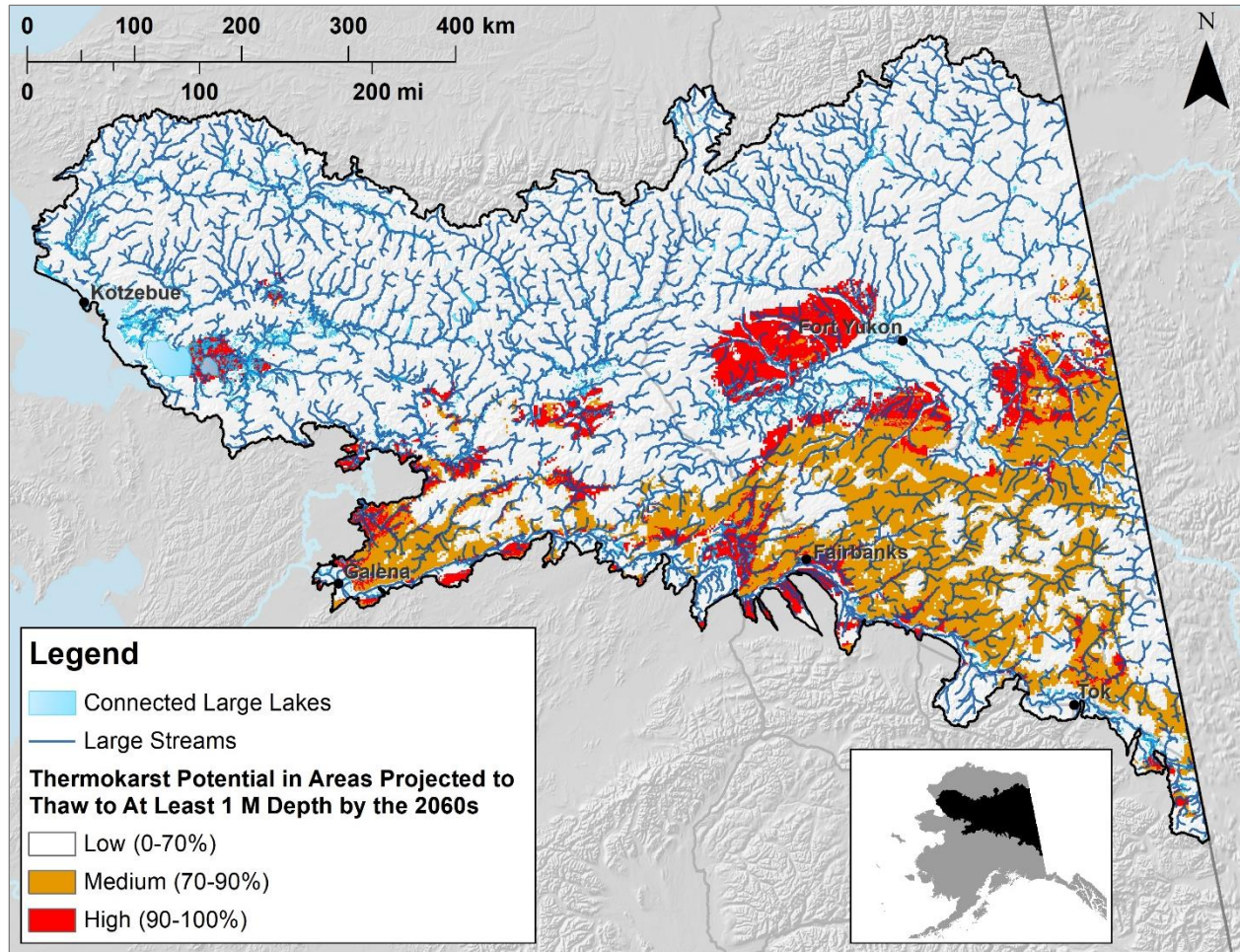


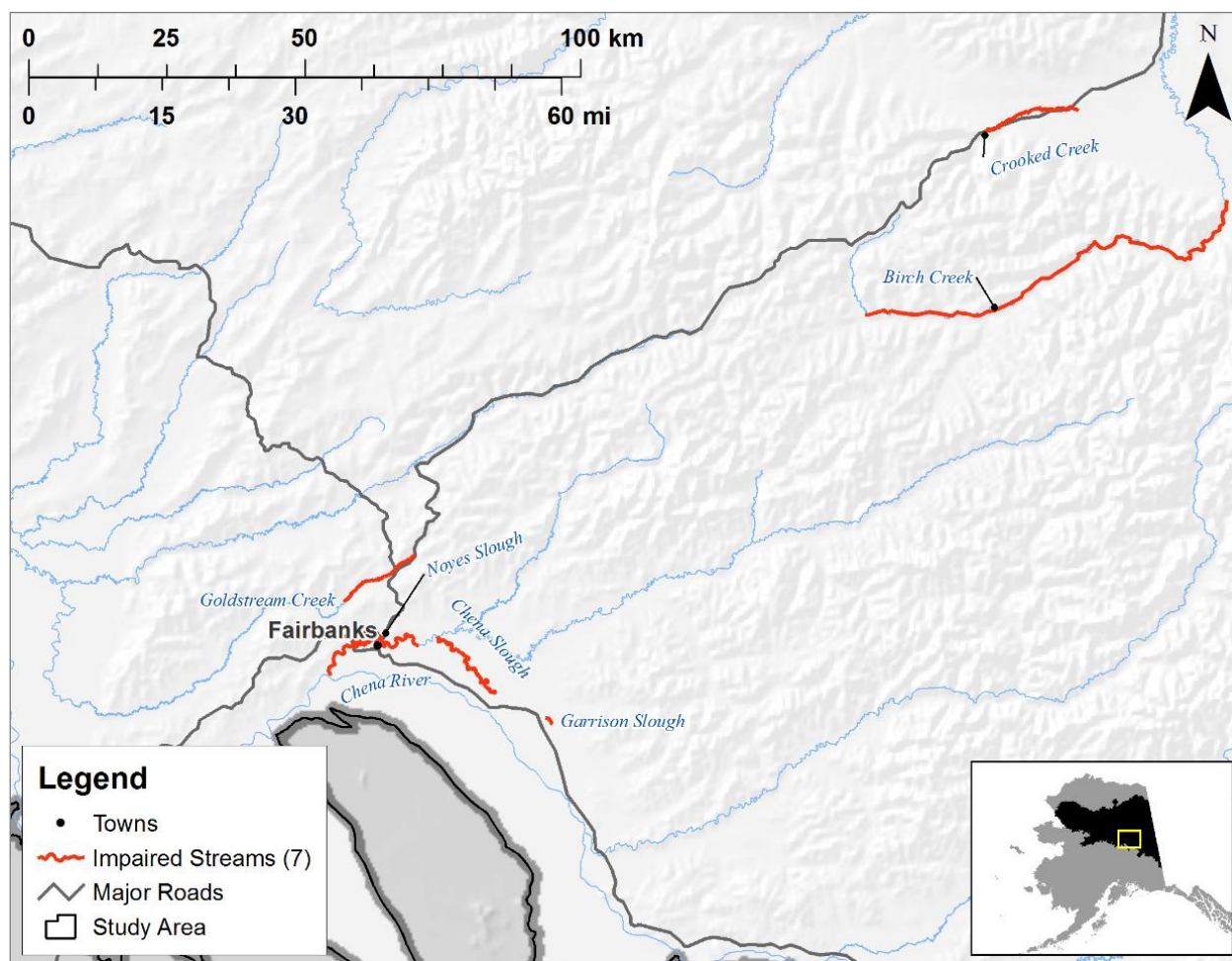
Figure I-5. Large streams and large connected lakes compared to areas of medium and high thermokarst potential projected to thaw to at least 1-m depth by the 2060s in the CYR study area.

3.2 Human Uses

Several anthropogenic CA datasets were used to evaluate potential water quality or physical habitat impacts to Aquatic Coarse-filter CEs. The ADEC impaired waters dataset showed all streams and lakes that did not meet State Water Quality Standards approved by EPA as of 2010. There were seven impaired streams and no impaired lakes within the CYR study area (Table I-7 and Figure I-6). Birch, Crooked, and Goldstream creeks were listed for turbidity due to placer mining activities. Garrison Slough was listed for PCBs from military activities. Chena River, Chena Slough, and Noyes Slough were listed for sedimentation in addition to other contaminants from urban runoff in Fairbanks. The total length of impaired streams in the CYR study area was 187 km, all of which was located on large streams or rivers.

Table I-7. ADEC impaired waters and impacts to Coarse-filter CEs.

Stream name	Water quality impact(s)	Length (km)	Coarse-filter CE
Birch Creek	Turbidity	84	large stream
Crooked Creek	Turbidity	22	large stream
Goldstream Creek	Turbidity	17	large stream
Garrison Slough	PCBs	2	large stream
Chena River	Turbidity, petroleum hydrocarbons, oils and grease, sediment	31	large stream
Chena Slough	Sediment	22	large stream
Noyes Slough	Debris, petroleum hydrocarbons, sediment	9	large stream
Total length of impaired streams		187	


Figure I-6. ADEC impaired streams in the CYR study area.

The ADEC open contaminated sites layer showed contaminated sites that still require cleanup in the CYR study area. Contaminated sites were located within a variety of land management jurisdictions. There were 419 open contaminated sites in the study area, and 199 were within 0.5 km of one or more Aquatic Coarse-filter CEs (Table I-8 and Figure I-7). Some contaminated sites were close to multiple aquatic habitats: the 199 sites have the potential to affect 284 aquatic habitats in the study area. The majority of open contaminated sites were near small streams (130).

Table I-8. ADEC contaminated sites within 0.5 km of Aquatic Coarse-filter CEs.

Coarse-filter CE	Open contaminated sites (count)
small streams	130
large streams or rivers	92
small connected lakes	37
large connected lakes	25
Total aquatic habitats potentially impacted by open contaminated sites	284

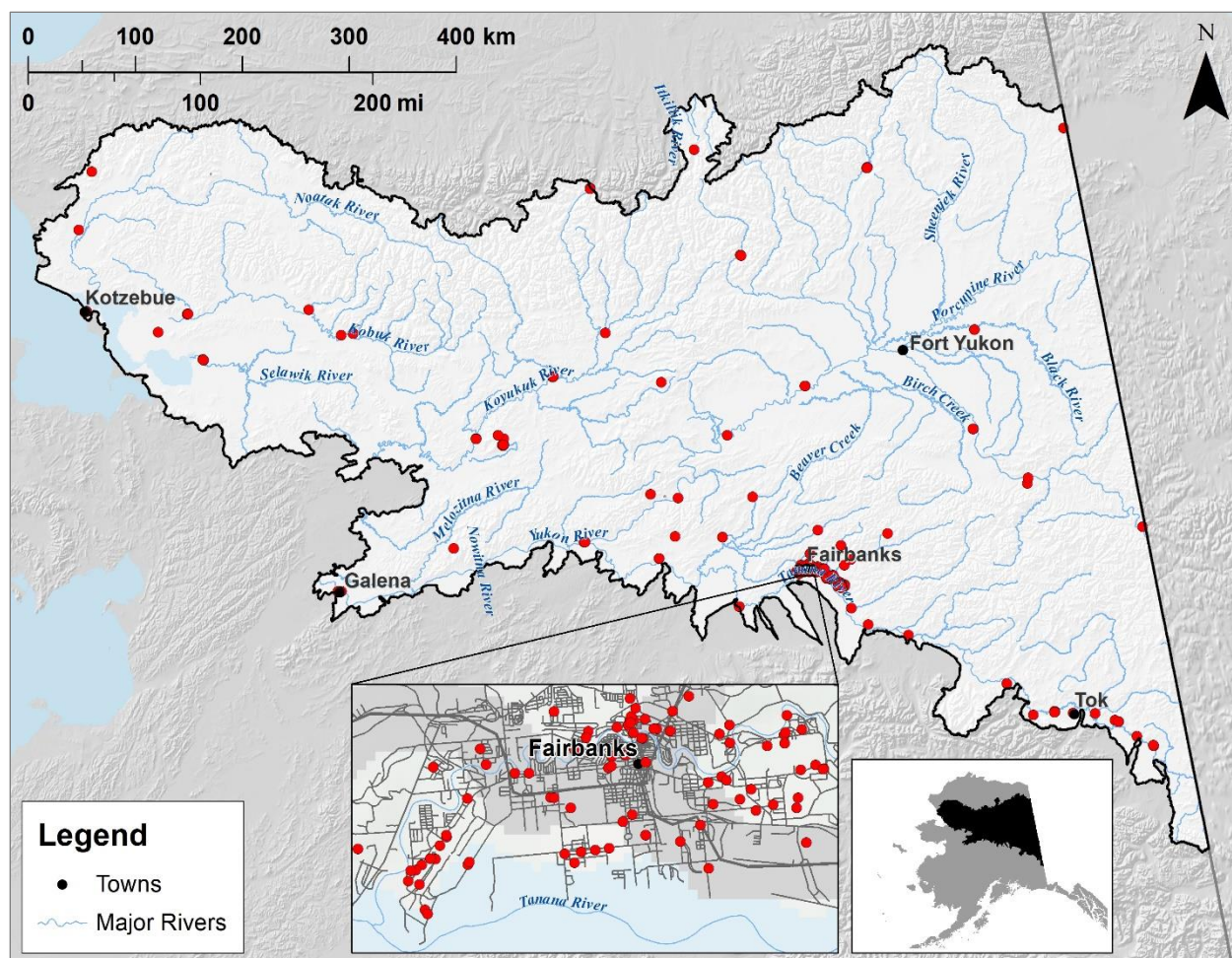


Figure I-7. Open contaminated sites within 0.5 km of Aquatic Coarse-filter CEs in the CYR study area.

Placer mining in streams affects water quality and physical habitat. Water quality impacts include increased turbidity and heavy metal concentrations (LaPerriere and Reynolds 1997, Brabets and Ourso 2013). Physical habitat impacts include removal of riparian vegetation (Van Haveren and Cooper 1992), channelization of the streambed resulting in loss of instream habitat diversity, such as deep pools or riffles (Gilvear et al. 1995), and sedimentation of substrates (Wagener and LaPerriere 1985, Van Nieuwenhuysse and LaPerriere 1986).

ADNR provided a dataset of the number of active placer mines per 5th-level hydrologic unit in the study area, which we used to indicate aquatic habitats potentially affected by placer mining. Mine density was classified as low, medium, and high defined, respectively, as 1–5, 6–12, and 13–45 mines per hydrologic unit. However, impacts from individual mines likely vary depending on the size of the operation, the location of the mining activity in relation to the waterbody (e.g., inside versus outside the floodplain), and the surrounding topography. The total distribution of aquatic habitats in 5th-level hydrologic units of low, medium, and high mining density were summed by area or length (Table I-9 and Figure I-8). The impacts to small streams may be overestimated since some may occur upstream of any mining activity. Likewise, connected lakes that lack inlets may also be protected from upstream placer mining activity.

Table I-9. Number of 5th-level hydrologic units and percent of total length or area for four Aquatic Coarse-filter CEs impacted by low, medium, and high numbers of mines per 5th-level hydrologic unit in the CYR study area.

Coarse-filter CE	Low mine density (1-5 mines)	Medium mine density (6-12 mines)	High mine density (13-45 mines)	Total habitat affected by placer mining
5 th -level hydrologic units (count)	7	32	11	50
small streams	6%	2%	1%	9%
large streams or rivers	6%	2%	1%	9%
small connected lakes	3%	1%	0%	4%
large connected lakes	2%	1%	0%	3%

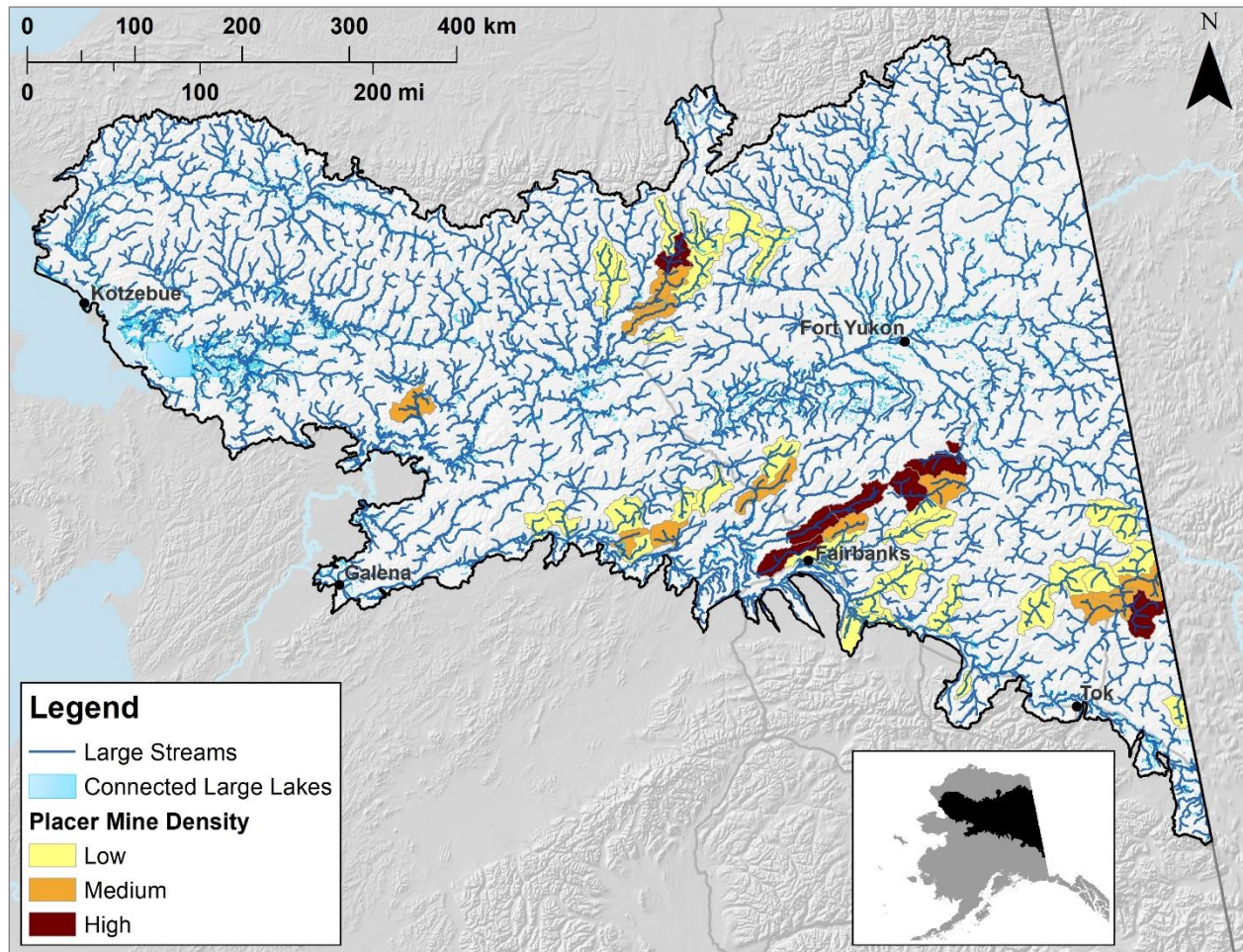


Figure I-8. Distribution of large streams and large connected lakes compared to density of placer mines in the CYR study area. Mine density was classified as low (1–5), medium (6–12), or high (13–45) mines per 5th-level hydrologic unit.

Culverts that are sized or installed inappropriately can have several detrimental impacts to stream physical and chemical habitat, in addition to preventing fish passage (discussed in

Section J. Aquatic Fine-filter Conservation Elements). Water quality impairments from road crossings include increased sedimentation and delivery of toxic compounds from the road surface (Forman and Alexander 1998). Types of toxic compounds contributed by roads to streams include heavy metals and organic pollutants (e.g., PCBs or hydrocarbons) from vehicles, ozone from vehicle exhaust, and deicing salts (Trombulak and Frissell 2000). Physical habitat impairments are numerous and include stream channelization; scouring or erosion downstream of perched culverts; ponding and sedimentation upstream; decreased transport of water, sediments, and wood downstream; and partial to complete blockage, which may lead to failure during flood events (Wheeler et al. 2005). Finally, roads are also an important pathway transporting invasive species to aquatic habitats (Trombulak and Frissell 2000).

ADF&G inventoried 374 culverts within the study area for juvenile fish passage. Culvert conditions that prevent passage to fish include perched outlets, steep gradients, or constricted culverts (Table 7 in Eisenman and O'Doherty 2014). These same failures lead to physical habitat impacts both upstream and downstream. Roads assessed included the Dalton, Elliott, Steese, Alaska, Richardson, and Taylor highways, in addition to Chena Hot Springs Road and multiple secondary roads in Fairbanks. Culverts were rated red when conditions were inadequate for fish passage, gray when conditions were unlikely to allow for fish passage, green when conditions allowed for fish passage, and black when more information was needed. Approximately 60% ($n = 224$) of inventoried culverts were rated red or gray in the CYR study area.

We shifted culvert locations to the National Hydrography Dataset (NHD) to utilize geometric network tracing tools and calculated the total amount of stream habitat unavailable to juvenile salmonids by tracing all stream reaches upstream of red or gray culverts. Some culverts could not be used in the analysis: 65 were associated with small streams not included in the NHD and 19 were associated with sloughs. Approximately 1,555 km of stream habitat in the study area were impacted by culverts that were unlikely to allow for fish passage (Figure I-9). This total underestimated stream habitat impacts because the streams associated with 40 culverts rated red or gray were not included in the NHD. The blocked streams were predominantly small stream habitats.

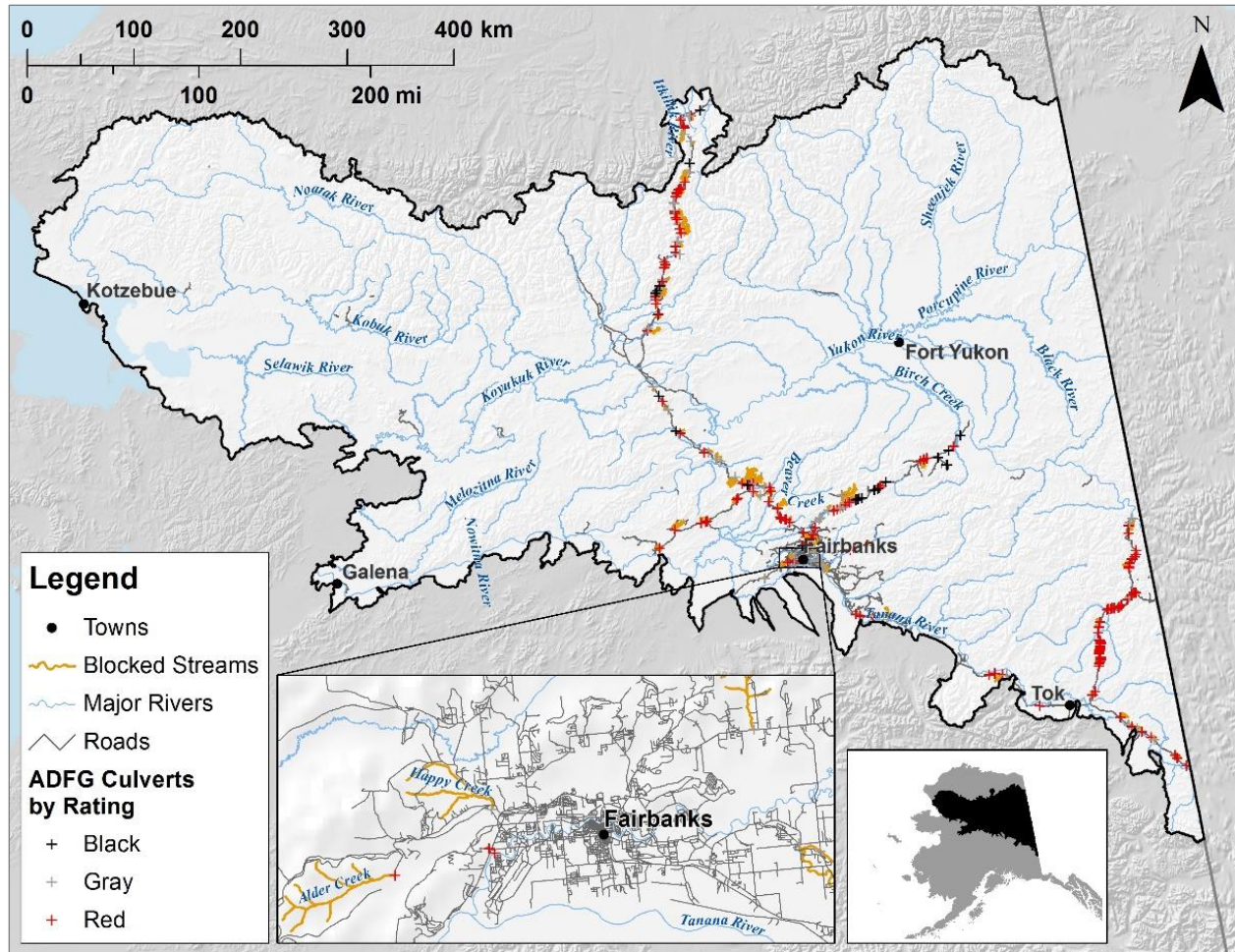


Figure I-9. Culverts inventoried by ADF&G for fish passage in the CYR study area and analysis of streams inaccessible to juvenile salmonids. Ratings of red or gray indicate culverts that are inadequate or likely inadequate for fish passage, respectively.

3.3 Status Assessment

The status of aquatic habitats was based on mean watershed landscape condition scores, which integrated the effects of roads, urban development, and altered vegetation on aquatic habitats. A complete list of all inputs to the LCM is provided in Section F. Landscape and Ecological Integrity. Stream and river habitats reflect modifications throughout their watershed due to their topographic position and the downstream flow of materials in stream networks. There is a long history of utilizing watershed metrics to predict impacts to stream water chemistry, physical habitat, and biological communities (see reviews in Gergel et al. 2002, Allan 2004, Johnson and Host 2010).

The landscape modification variables used in the LCM have been tied to stream habitat degradation in many monitoring studies, both in Alaska and elsewhere. Impervious surface cover has been tied to changes in water quality and benthic communities (Ourso and Frenzel 2003, Cuffney et al. 2010) and cultivated land cover has been tied to changes in water chemistry (King et al. 2005).

Section I. Aquatic Coarse-filter Conservation Elements

We calculated mean watershed condition scores to assign status to small streams and large streams and rivers across the CYR study area, collectively referred to as stream network condition (Figure I-10). We aggregated these same scores to create averages for each 6th-level hydrologic unit across the CYR study area so they could be intersected with the distributions of small and large connected lakes and classified habitat status into five equal intervals (Figure I-11). The majority of current and long-term future (2060) condition for all four Aquatic Coarse-filter CEs was classified as very high, indicating that aquatic habitats were and will likely remain relatively pristine (Figure I-11 and Table I-10).

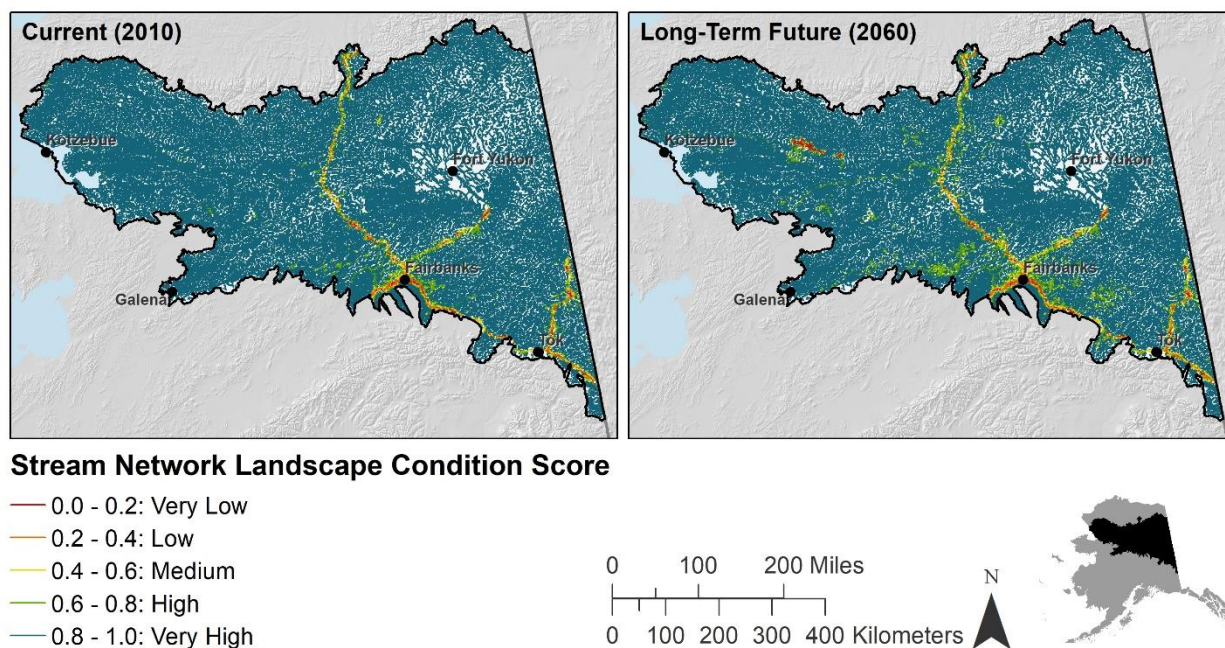


Figure I-10. Current and long-term future stream network landscape condition in the CYR study area.

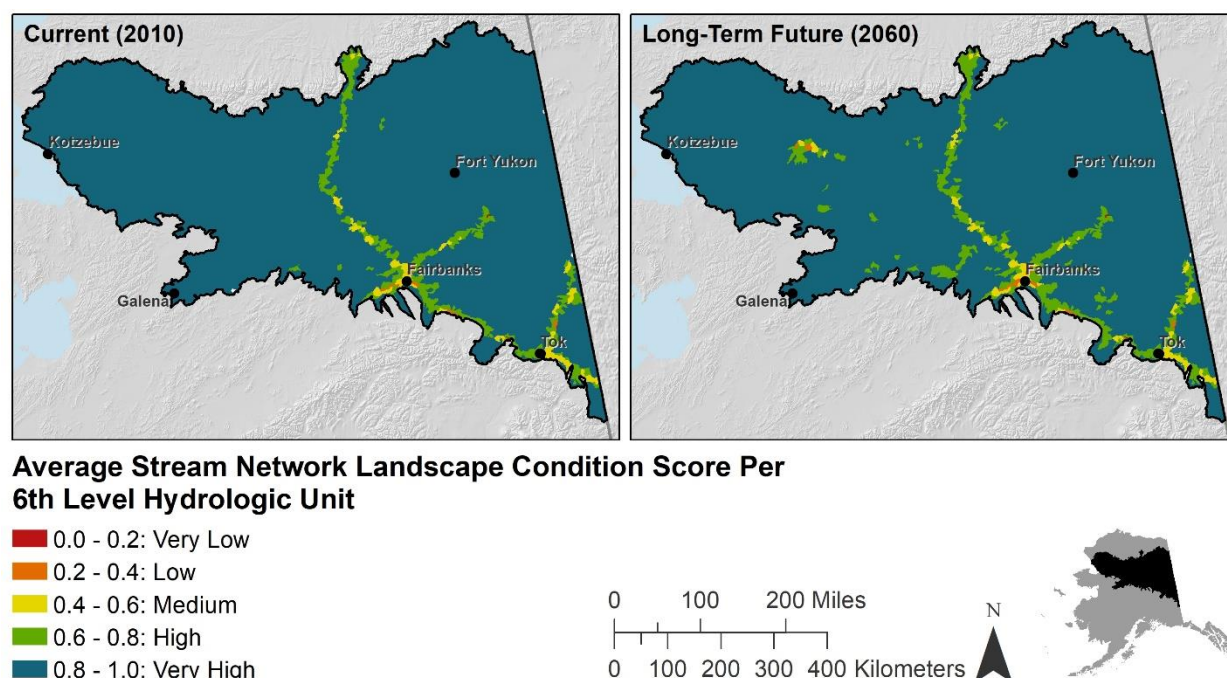


Figure I-11. Current and long-term future average stream network landscape condition per 6th-level hydrologic unit in the CYR study area.

Table I-10. Percent total area of connected lake Coarse-filter CEs by mean watershed condition score in the CYR study area. No hydrologic units received stream network condition score of very low.

Coarse-filter CE	Time period	Percent CE area per watershed condition category			
		Low	Medium	High	Very High
small connected lakes	Current (2015)	0.1	0.7	1.5	97.7
	Long-term future (2060)	0.1	0.9	1.9	97.0
large connected lakes	Current (2015)	0.0	0.3	1.2	98.5
	Long-term future (2060)	0.0	0.4	1.3	98.4

3.4 Distribution on Public and Private Lands

Federal and state agencies are faced with the challenge of balancing needs for resource extraction, energy development, recreation, and other uses with the growing urgency to conserve wildlife. Better collaboration among agencies can increase the effectiveness of public land management for habitats that occur across jurisdictions. We used the relative proportion of habitats falling within agency boundaries as a proxy for relative amount of management responsibility per Aquatic Coarse-filter CE.

Habitat distributions in relation to areas managed both publicly and privately reflect the overall ratio of land ownership within the CYR study area, with the highest percentages of habitat distributions occurring on native patent land, state patent land, and USFWS land (Table I-11, Figure I-12).

Table I-11. Land management status during 2015 in the CYR study area per Aquatic Coarse-filter CE.

Land Management Status	Coarse-filter CEs			
	small streams	large streams or rivers	small connected lakes	large connected lakes
BLM	13%	11%	9%	3%
FWS	26%	26%	41%	27%
Military	1%	1%	0%	0%
NPS	18%	17%	12%	10%
Native Patent or IC	12%	16%	17%	22%
Native Selected	2%	1%	2%	1%
Private	0%	0%	0%	0%
State Patent or TA	24%	23%	15%	35%
State Selected	5%	4%	4%	1%

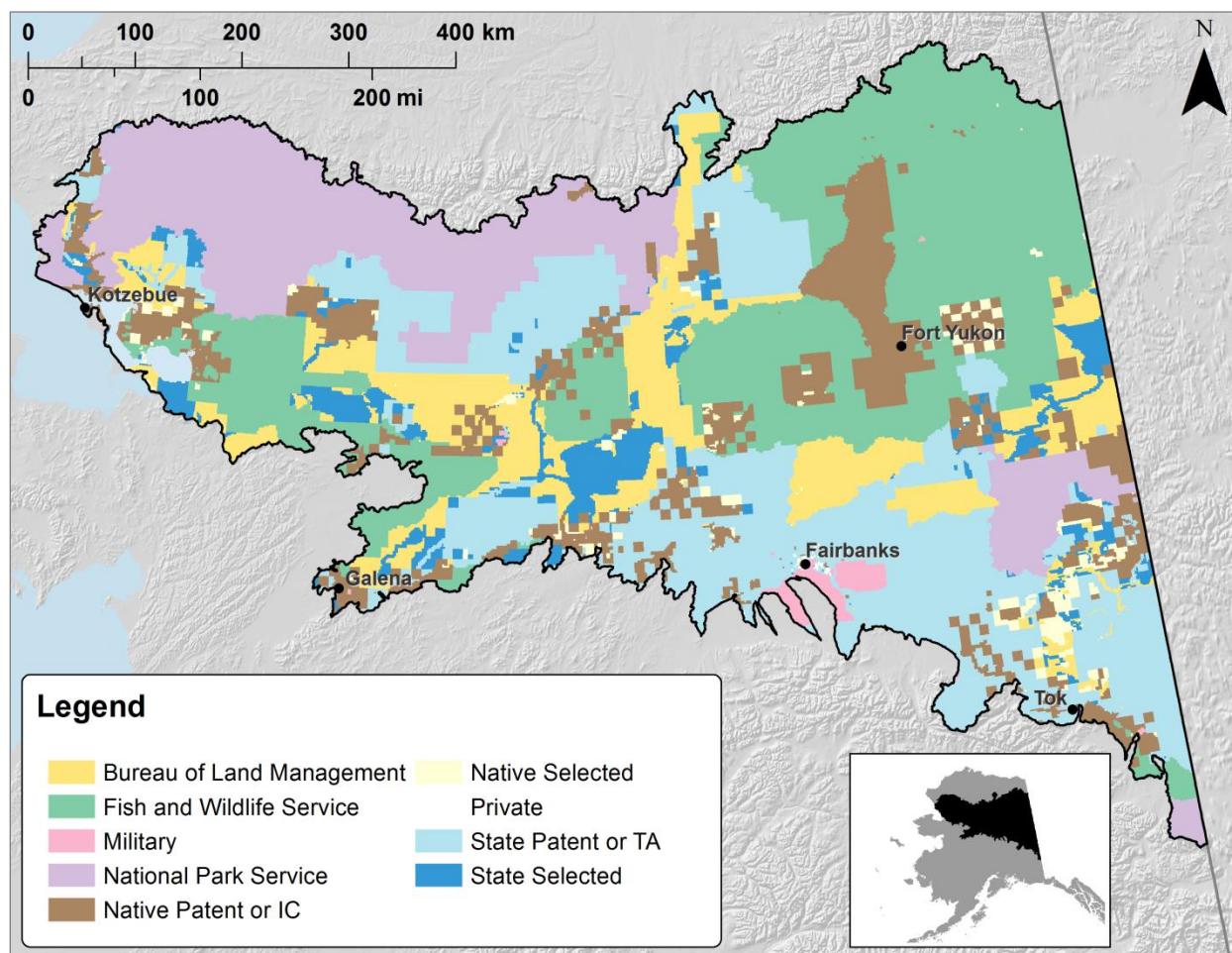


Figure I-12. Land management status in 2015 in the CYR study area.

4. Large Streams (Rivers) and Small Streams

Within the CYR study area, small and large stream ecosystems provide important habitat for aquatic invertebrates, fish, and waterbirds. Large streams are important migratory corridors for anadromous and resident fishes and the associated deep pools serve as overwintering habitat. Small streams typically freeze completely during the winter, however some springs and deep pools may provide overwintering habitat. Both large and small streams support extensive spawning and rearing habitat for numerous fish species. Additionally, headwater streams provide important spawning and rearing habitat for salmonids. Large and small streams within the CYR study area also provide important transportation and recreational uses for local residents.

4.1 Conceptual Models

Conceptual models for the rivers and large streams CE (Figure I-13) and the small streams CE (Figure I-14) are illustrated below.

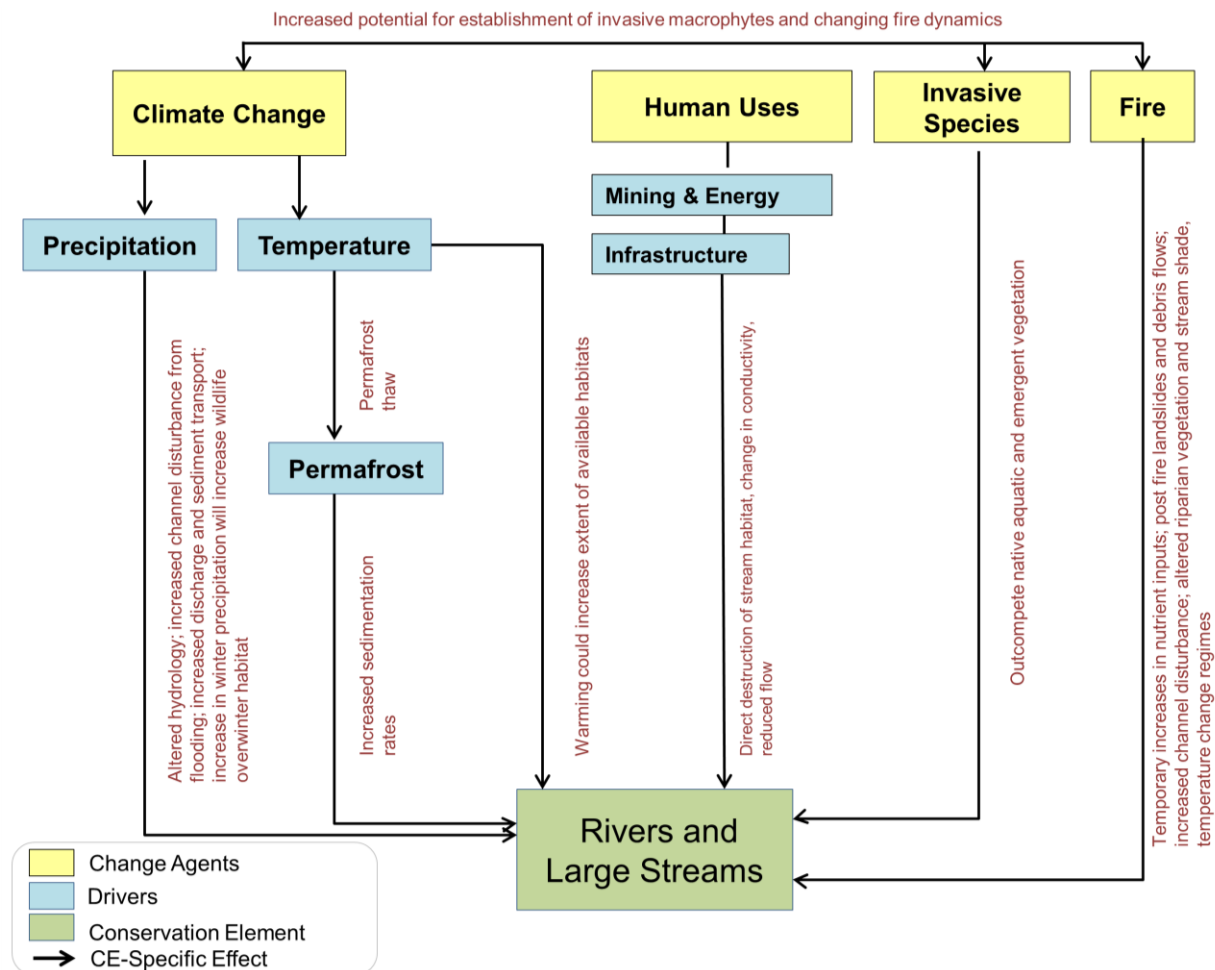


Figure I-13. Conceptual model for rivers and large streams.

Section I. Aquatic Coarse-filter Conservation Elements

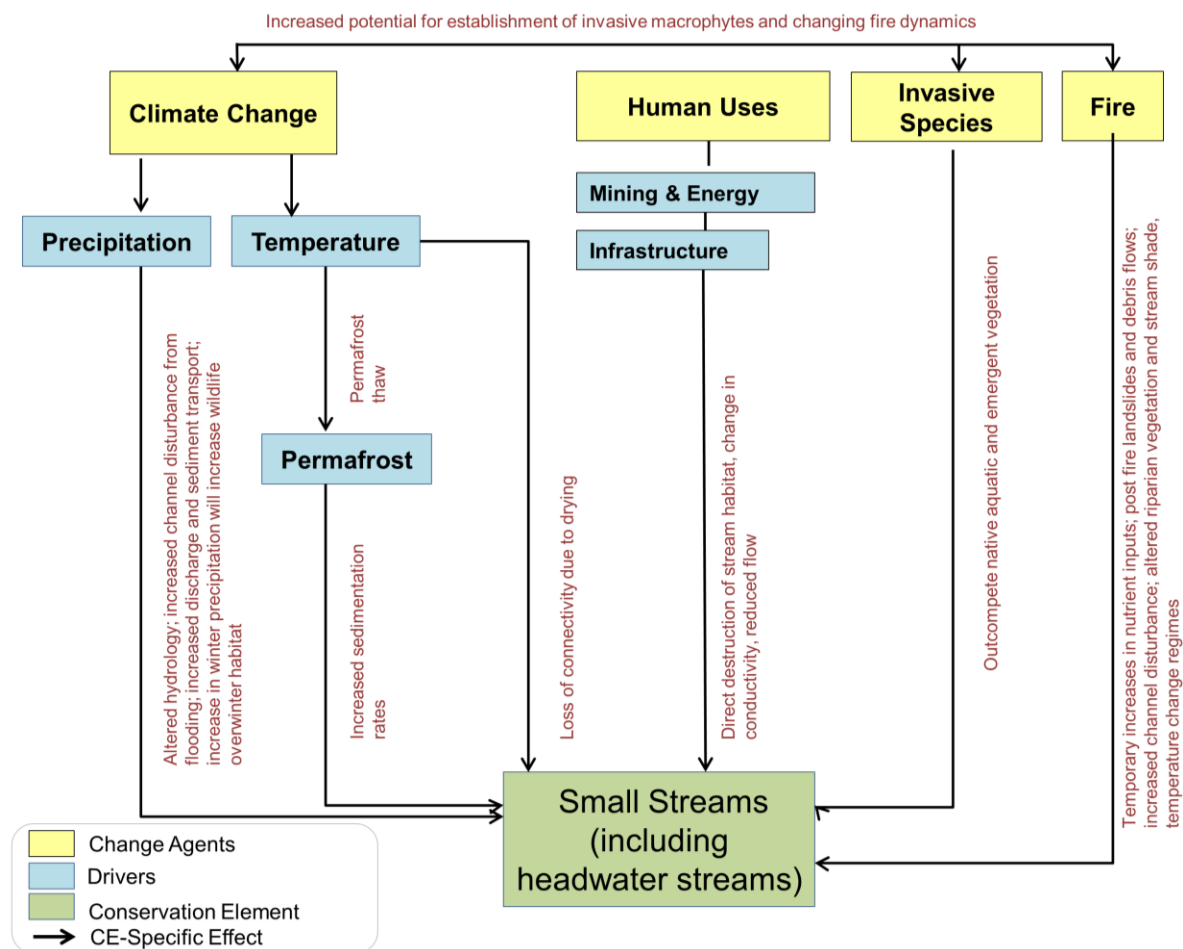


Figure I-14. Conceptual model for small streams.

4.2 Change Agent Analysis

Climate Change

Two climate change responses were intersected with aquatic habitats as part of the core analysis: permafrost thaw and thermokarst potential in areas projected to thaw to at least 1-m depth by the 2060s. Lack of data or models relating changes in air temperature and precipitation to stream temperature and flow precluded spatial analyses relating these key CAs to aquatic habitats. This section is devoted to a summary of expected climate change impacts in streams of the CYR study area based on results in Section C. Abiotic Change Agents. A literature review describing how these changes will affect aquatic habitats in the CYR study area is provided.

Long-term future projections for the CYR study area (i.e., to the 2060s) suggest that winter and summer precipitation will each increase 7–16 mm across the nine ecoregions. Projected long-term future temperature indicates ~1.5 °C increase in mean July temperature and ~4 °C increase in mean January temperature.

It is difficult to predict how the modest increase in precipitation projected for the CYR study area will affect stream hydrographs between the 2010s and 2060s. Streamflow will be influenced by many factors, including the timing and intensity of precipitation, the proportion of precipitation falling as rain vs. snow, the degree to which evaporation and evapotranspiration increase with warming air (not to mention changes related to increasing deciduous forest cover and changing cloud cover), the extent to which base flows increase in response to thawing permafrost, and year-to-year variation in air temperature regimes. Data from the CYR study area generally show increasing average and maximum streamflow during winter and during spring snowmelt, followed by increased summer base flows and lower summer maximum flows (Brabets and Walvoord 2009, Bennett et al. 2015). These changes appear to be driven by increasing base flows related to thawing permafrost, increasing winter precipitation, and advancing spring snowmelt attributable to climate change and shifting phases of the Pacific Decadal Oscillation (Brabets and Walvoord 2009, Bennett et al. 2015).

Increasing air temperatures for the CYR study area will likely translate to longer ice-free seasons and warmer summer temperatures for many streams. However, streams vary substantially in their sensitivity to increasing air temperature due to variation in watershed geomorphology and hydrology (Lisi et al. 2015, Mauger et al. 2016) and we lack the data necessary for site-specific predictions. While increasing stream temperature can be inferred from increasing air temperature, we do not know of any data sets that characterize long-term changes in water temperature in or near the CYR study area. The length of the ice-free season is a reasonable proxy for growing season length and a trend toward later freeze and earlier ice breakup has been observed for streams across northern North America (Magnuson et al. 2000, Burn 2008). Pertinent to the CYR study area, spring breakup on the Yukon River (at Dawson City) and Tanana River (at Nenana) has advanced by approximately one week over the past century (Brabets and Walvoord 2009).

Fire

Increasing wildfire extent and severity could have important compounding effects on stream ecosystems. Research within the CYR study area has shown increased concentrations of nitrate, decreased concentrations of dissolved organic carbon and organic nitrogen, and elevated rates of primary production and ecosystem respiration in the years immediately following wildfires (Betts and Jones 2009). The burning of organic soils during wildfire also

accelerates permafrost degradation (Yoshikawa et al. 2002) and, presumably, the associated impacts to stream habitats. However, research on wildfire effects to stream ecosystems within the CYR study area and comparable ecosystems is scarce. To the extent that research from other regions can be generalized to CYR streams, we can expect wildfire impacts to include warmer stream temperatures (Dunham et al. 2007, Isaak et al. 2010), increased nutrient loads (Bayley et al. 1992), and increased erosion and sediment transport (Benda et al. 2003, Ice et al. 2004). These impacts will persist over varying time scales and will likely be strongest in small streams.

Invasive Species

Few aquatic and riparian invasive plant species have been documented within the CYR study area. However, invasive aquatic plants of the *Elodea* genus have become established in the Chena River system near Fairbanks (Chena River, Chena Slough, and Chena Lake). It is reasonable to expect gradual dispersal of *Elodea* to suitable habitats downstream within the Tanana River and beyond. *Elodea* spp. can invade and outcompete other aquatic plant species in slow-moving streams or small, shallow lakes and ponds. Thus, small streams with slow moving waters, small connected lakes, and edges of large connected lakes would be most susceptible to invasion by *Elodea*. Boat and float plane traffic and proximity to roads and boat launches increase the likelihood of *Elodea* spp. dispersal from the Chena River to other waters within the CYR study area (see Section D. Biotic Change Agents).

5. Large and Small Connected Lakes

Large and small connected lakes throughout the CYR study area support a rich biodiversity of aquatic organisms and represent important foraging and breeding habitat for fish, waterfowl, and shorebirds. Additionally, lakes provide important recreational opportunities and food resources for local residents (e.g., subsistence harvest of fish and wildlife).

Small and large lakes were identified based on the definition used in Arp and Jones (2009) to differentiate small (< 0.1 km²) from medium and large lakes (> 0.1 km²). Lake connections, especially for smaller lakes, can vary greatly and change throughout the open-water season, with ephemeral connections commonly occurring during high flows in the spring.

5.1 Conceptual Models

Conceptual models for the large connected lakes CE (Figure I-15) and the small connected lakes CE (Figure I-16) are illustrated below.

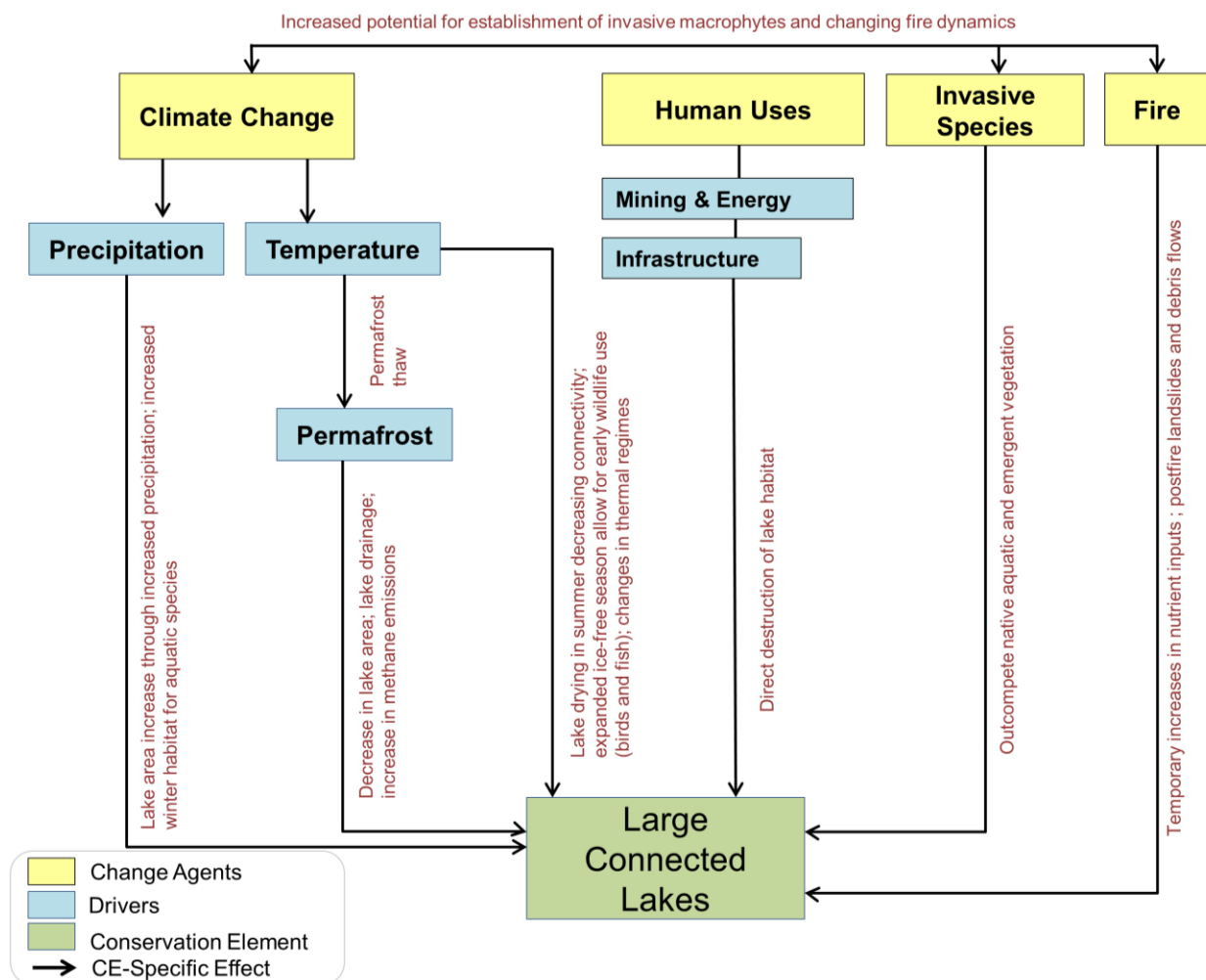


Figure I-15. Conceptual model for large connected lakes.

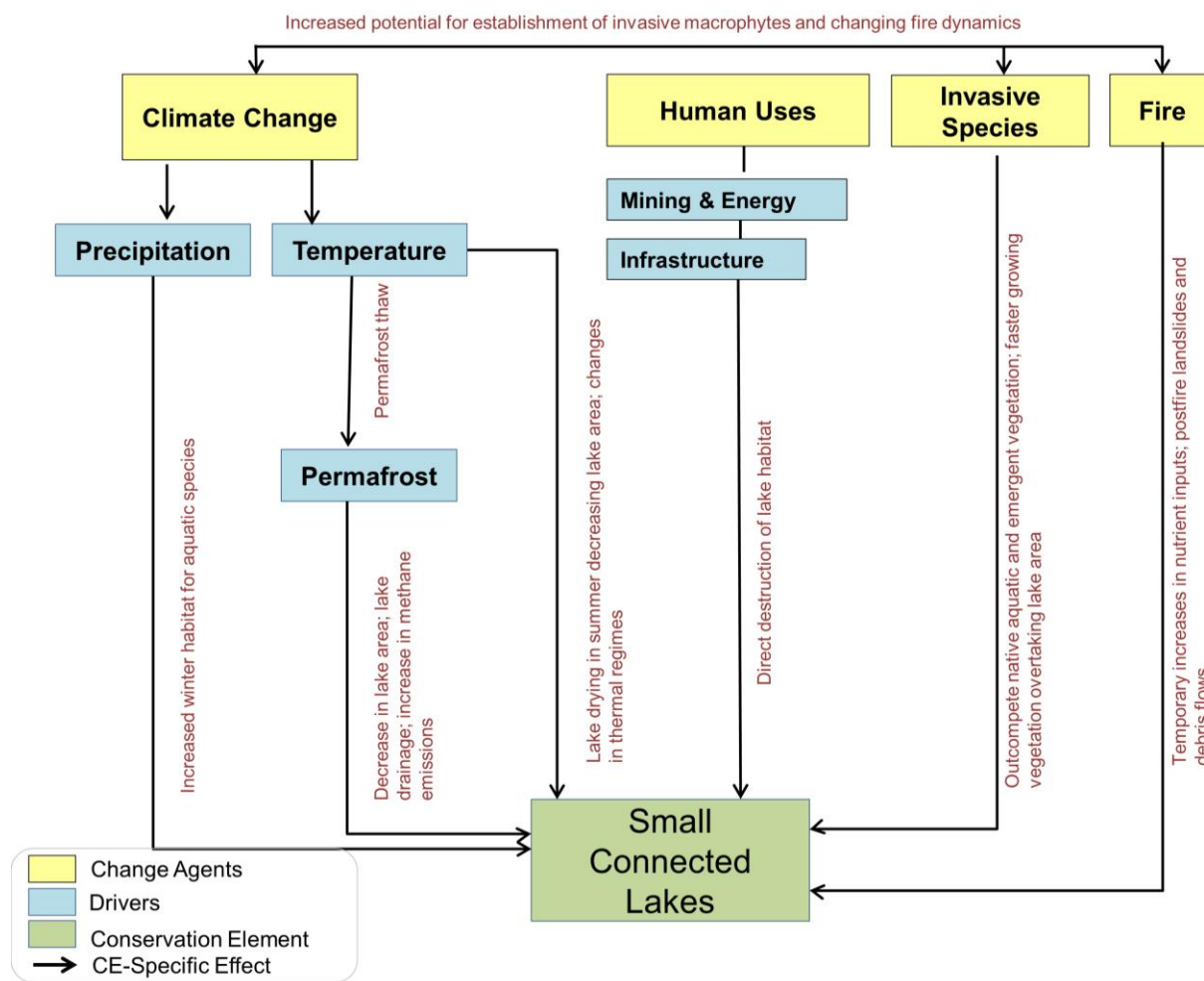


Figure I-16. Conceptual model for small connected lakes.

5.2 Change Agent Analysis

Climate Change

Two climate change responses were intersected with aquatic habitats as part of the core analysis: permafrost thaw and thermokarst potential in areas projected to thaw to at least 1-m depth by the 2060s. This section is devoted to a summary of expected climate change impacts on connected lakes of the CYR study area based on results in Section C. Abiotic Change Agents. A literature review describing how these changes will affect aquatic habitats in the CYR study area is provided. Abiotic changes addressed here are relatively minor increases in summer and winter precipitation and mean temperature increases of $\sim 1.5^{\circ}\text{C}$ for July and $\sim 4^{\circ}\text{C}$ for January by the 2060s.

Increasing temperatures will likely amplify the trend toward later freeze and earlier ice breakup observed in lakes across northern North America (Magnuson et al. 2000, Rühland et al. 2003, Schindler et al. 2005). Increased snow cover, which can insulate lakes and reduce ice thickness, may further contribute to this trend. These changes would result in an earlier seasonal rise in water temperature, longer growing seasons, and higher maximum summer temperatures.

Increased evapotranspiration and evaporation related to warming may further contribute to declines in lake area associated with thawing permafrost (Roach et al. 2013) and could lead to a lack of connectivity between streams and lakes. This lack of connectivity could limit access to spawning areas, affect the amount of available overwintering habitat, and potentially disrupt the timing of annual migrations for fish species.

Fire

Research into wildfire effects on lakes is virtually nonexistent, but increased nutrient loads (Bayley et al. 1992) and increased erosion and sediment transport (Benda et al. 2003, Ice et al. 2004) associated with streams will likely apply to lakes. In addition, wildfire activity is associated with declines in lake area through removal of the insulating organic layer and subsequent permafrost degradation (Roach et al. 2013).

Invasive Species

Impacts from invasive species are the same as for streams (see above).

6. Limitations and Data Gaps

The critical data gaps for managing aquatic resources in Alaska include the lack of seamless, high resolution digital elevation models and an accurate stream network spatial dataset. High quality IfSAR-derived DEM data are currently being collected across Alaska (<http://ifsar.gina.alaska.edu/>). In addition, the Alaska Hydrography Database is a collaborative effort to update spatial hydrography datasets across Alaska through partnerships among different agencies and entities (http://seakgis.alaska.edu/projects/ak_hydro.html). Neither of these datasets are currently available across the CYR study area.

The National Hydrography Dataset (NHD) is the best available spatial data depicting aquatic resources across the CYR study area. The current version provides a digital representation of streams and lakes shown on USGS topographic maps, which were created from historic aerial photos. It 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 very outdated (most topographic maps were created in the 50's and 60's), and stream locations and lake areas have likely changed due to natural hydrologic disturbances and climate change.
- 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.

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 were mapped by creating a synthetic 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 are 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 study area, this relationship will vary.

Once better topographic and hydrologic information exists for Alaska, management agencies may be interested in mapping aquatic habitats for specific watersheds or regions. The lack of an aquatic habitat classification for the study area represents a data gap preventing more effective management of aquatic resources.

As far as we know, there are no climate change predictions specific to aquatic habitats, such as changes to water temperature or hydrologic regime, available for the study area. This precludes the ability to make accurate predictions of climate change impacts to aquatic species (Al-Chokhachy et al. 2013).

7. Literature Cited

- Al-Chokhachy, R., S. J. Wenger, D. J. Isaak, and J. L. Kershner. 2013. Characterizing the thermal suitability of instream habitat for salmonids: a cautionary example from the Rocky Mountains. *Transactions of the American Fisheries Society* 142:793–801.
- Allan, J. D. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annual Review of Ecology, Evolution, and Systematics* 35:257–284.
- Arp, C. D., and B. M. Jones. 2009. Geography of Alaska lake districts: identification, description, and analysis of lake-rich regions of a diverse and dynamic state. U.S. Geological Survey Scientific Investigations Report 2008–5215. 40 pp.
- Barnhart, T. B., and B. T. Crosby. 2013. Comparing two methods of surface change detection on an evolving thermokarst using high-temporal-frequency terrestrial laser scanning, Selawik River, Alaska. *Remote Sensing* 5:2813–2837.
- Bayley, S. E., D. W. Schindler, K. C. Beaty, B. R. Parker, and M. P. Stainton. 1992. Effects of fires on nutrient yields from streams draining boreal forest and fen watersheds: nitrogen and phosphorus. *Canadian Journal of Fisheries and Aquatic Sciences* 49:584–596.
- Benda, L., D. Miller, P. Bigelow, and K. Andras. 2003. Effects of post-wildfire erosion on channel environments, Boise River, Idaho. *Forest Ecology and Management* 178:105–119.
- Bennett, K. E., A. J. Cannon, and L. Hinzman. 2015. Historical trends and extremes in boreal Alaska river basins. *Journal of Hydrology* 527:590–607.
- Betts, E. F., and J. B. Jones Jr. 2009. Impact of wildfire on stream nutrient chemistry and ecosystem metabolism in boreal forest catchments of interior Alaska. *Arctic, Antarctic, and Alpine Research* 41:407–417.
- Bowden, W., Gooseff, M., Balser, A., Green, A., Peterson, B. J., and J. Bradford. 2008. Sediment and nutrient delivery from thermokarst features in the foothills of the CYR, Alaska: potential impacts on headwater stream ecosystems. *Journal of Geophysical Research* 113: G02026. doi:10.1029/2007JG000470.
- Brabets, T. P., and R. T. Ourso. 2013. Water quality of streams draining abandoned and reclaimed mined lands in the Kantishna Hills area, Denali National Park and Preserve, Alaska, 2008 – 11. U.S. Geological Survey Scientific Investigations Report 2013–5048, Anchorage, Alaska. 72 pp.
- Brabets, T. P., and M. A. Walvoord. 2009. Trends in streamflow in the Yukon River Basin from 1944 to 2005 and the influence of the Pacific Decadal Oscillation. *Journal of Hydrology* 371:108–119.
- Burn, D. H. 2008. Climatic influences on streamflow timing in the headwaters of the Mackenzie River Basin. *Journal of Hydrology* 352:225–238.
- Cuffney, T. F., R. A. Brightbill, J. T. May, and I. R. Waite. 2010. Responses of benthic macroinvertebrates to environmental changes associated with urbanization in nine metropolitan areas. *Ecological Applications* 20:1384–1401.
- Dunham, J. B., A. E. Rosenberger, C. H. Luce, and B. E. Rieman. 2007. Influences of wildfire and channel reorganization on spatial and temporal variation in stream temperature and the distribution of fish and amphibians. *Ecosystems* 10:335–346.
- Eisenman, M., and G. O'Doherty. 2014. Culvert inventory and assessment for fish passage in the state of Alaska : a guide to the procedures and techniques used to inventory and assess stream crossings 2009-2014. Alaska Department of Fish and Game, Special Publication No. 14-08, Anchorage, Alaska.
- Forman, R. T. T., and L. E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics* 29:207–231.
- Frey, K. E., and J. W. McClelland. 2009. Impacts of permafrost degradation on arctic river biogeochemistry. *Hydrological Processes* 23:169-182. doi:10.1002/hyp.7196.

Section I. Aquatic Coarse-filter Conservation Elements

- Gergel, S. E., M. G. Turner, J. R. Miller, J. M. Melack, and E. H. Stanley. 2002. Landscape indicators of human impacts to riverine systems. *Aquatic Sciences* 64:118–128.
- Gilvear, D. J., T. M. Waters, and A. M. Milner. 1995. Image analysis of aerial photography to quantify changes in channel morphology and instream habitat following placer mining in interior Alaska. *Freshwater Biology* 34:389–398.
- Ice, G. G., D. G. Neary, and P. W. Adams. 2004. Effects of wildfire on processes. *Journal of Forestry* 102:16–20.
- Isaak, D., C. Luce, B. Rieman, D. Nagel, E. Peterson, D. Horan, S. Parkes, and G. Chandler. 2010. Effects of climate change and recent wildfires on stream temperature and thermal habitat for two salmonids in a mountain river network. *Ecological Applications* 20:100319061507001.
- Johnson, L. B., and G. E. Host. 2010. Recent developments in landscape approaches for the study of aquatic ecosystems. *Journal of the North American Benthological Society* 29:41–66.
- Jones, J. B., and A. J. Rinehard. 2010. The long-term responses of stream flow to climatic warming in headwater streams of interior Alaska. *Canadian Journal of Forest Research* 40:1210–1218.
- King, R. S., M. E. Baker, D. F. Whigham, D. E. Weller, T. E. Jordon, P. F. Kazyak, and M. K. Hurd. 2005. Spatial considerations for linking watershed land cover to ecological indicators in streams. *Ecological Applications* 15:137–153.
- Kokelj, S. V., T. C. Lantz, S. L. Smith, J. C. N. Kanigan, and R. Coutts. 2009. Origin and polycyclic behaviour of tundra thaw slumps, Mackenzie Delta Region, Northwest Territories, Canada. *Permafrost and Periglacial Processes* 20:173–184.
- LaPerriere, J. D., and J. B. Reynolds. 1997. Gold placer mining and stream ecosystems of Interior Alaska. Pages 265–280 in A. M. Milner and M. W. Oswood, eds. *Freshwaters of Alaska*. Springer, New York.
- Lisi, P. J., D. E. Schindler, T. J. Cline, M. D. Scheuerell, and P. B. Walsh. 2015. Watershed geomorphology and snowmelt control stream thermal sensitivity to air temperature. *Geophysical Research Letters* 42:3380–3388.
- Magnuson, J. J., D. Robertson, and B. Benson. 2000. Historical trends in lake and river ice cover in the northern hemisphere. *Science* 289:1743–1747.
- Mauger, S., R. Shaftel, J. Leppi, and D. Rinella. 2016. Summer temperature regimes in southcentral Alaska streams: watershed drivers of variation and potential implications for Pacific salmon. *Canadian Journal of Fisheries and Aquatic Sciences*. DOI: 10.1139/cjfas-2016-0076.
- Nilsson, C., L. E. Polvi, and L. Lind. 2015. Extreme events in streams and rivers in arctic and subarctic regions in an uncertain future. *Freshwater Biology* 60:2535–2546.
- Ourso, R. T., and S. A. Frenzel. 2003. Identification of linear and threshold responses in streams along a gradient of urbanization in Anchorage, Alaska. *Hydrobiologia* 501:117–131.
- Roach, J., B. Griffith, D. Verbyla, and J. Jones. 2011. Mechanisms influencing changes in lake area in Alaskan boreal forest. *Global Change Biology* 17:2567–2583.
- Roach, J. K., B. Griffith, and D. Verbyla. 2013. Landscape influences on climate-related lake shrinkage at high latitudes. *Global change biology* 19:2276–84.
- Rühland, K., A. Priesnitz, and J. P. Smol. 2003. Paleolimnological evidence from diatoms for recent environmental changes in 50 lakes across Canadian Arctic treeline. *Arctic, Antarctic, and Alpine Research* 35:110–123.
- Schindler, D. E., D. E. Rogers, M. D. Scheuerell, C. A. Abrey. 2005. Effects of changing climate on zooplankton and juvenile sockeye salmon growth in southwestern Alaska. *Ecology* 86:198–209.
- 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.
- Striegl, R. G., M. M. Dornblaser, G. R. Aiken, K. P. Wickland, and P. A. Raymond. 2007. Carbon export and cycling by the Yukon, Tanana, and Porcupine rivers, Alaska, 2001–2005. *Water Resources Research* 43:2001–2005.

- Trombulak, S. C., and C. A. Frissell. 2000. Review of ecological effects of roads on terrestrial and aquatic communities. *Conservation Biology* 14:18–30.
- U.S. Fish and Wildlife Service. (n.d.). Preliminary studies of a permafrost thaw slump impacting sheefish spawning Habitat in the Selawik River. Fairbanks, Alaska.
- Van Haveren, B. P., and D. J. Cooper. 1992. Rehabilitation potential of riparian systems disturbed by placer mining in interior Alaska. Page 7 *in* National Meeting of the American Society for Surface Mining and Reclamation. Duluth, Minnesota.
- Van Nieuwenhuysse, E. E., and J. D. LaPerriere. 1986. Effects of placer gold mining on primary production in subarctic streams of Alaska. *Water Resources Bulletin* 22:91–99.
- Wagener, S. M., and J. D. LaPerriere. 1985. Effects of placer mining on the invertebrate communities of interior Alaska streams. *Freshwater Invertebrate Biology* 4:208–214.
- Walvoord, M. A., and R. G. Striegl. 2007. Increased groundwater to stream discharge from permafrost thawing in the Yukon River basin: potential impacts on lateral export of carbon and nitrogen. *Geophysical Research Letters* 34:L12402. doi:10.1029/2007GL030216.
- Wheeler, A. P., P. L. Angermeier, and A. E. Rosenberger. 2005. Impacts of new highways and subsequent landscape urbanization on stream habitat and biota. *Reviews in Fisheries Science* 13:141–164.
- Yoshikawa, K., W. R. Bolton, V. E. Romanovsky, M. Fukuda, and L. D. Hinzman. 2002. Impacts of wildfire on the permafrost in the boreal forests of Interior Alaska. *Journal of Geophysical Research* 108:16–17.

J. Aquatic Fine-filter Conservation Elements

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Summary

Section J. *Aquatic Fine-filter Conservation Elements* provides the detailed descriptions, conceptual models, and limitations for the assessments of six fish species considered to be of high ecological importance in the region.

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1. Introduction to Aquatic Species (Fine-filter Elements)

Six species were selected as Aquatic Fine-filter Conservation Elements (CEs) for the Central Yukon (CYR) REA. An effort was made to select a variety of fish species of conservation concern or subsistence importance within the study area in addition to identifying species that fill different ecological niches.

- Chinook salmon (*Oncorhynchus tshawytscha*)
- Chum salmon (*Oncorhynchus keta*)
- Northern pike (*Esox lucius*)
- Inconnu (*Stenodus leucichthys*)
- Humpback whitefish (*Coregonus pidschian*)
- Dolly Varden (*Salvelinus malma*)

Table J-1 describes life history strategies and reasoning for inclusion in the REA for the six CEs.

Table J-1. Aquatic Fine-filter CEs selected for the CYR REA.

Conservation Element	Life History	Selection Criteria
Chinook salmon	Juveniles resident in streams for 1+ years	Provide nutrient inputs to both aquatic and terrestrial ecosystems, food resource for large predators, important subsistence species, and stock of yield concern since 2000. Proposed by BLM.
Chum salmon	Short juvenile residency period (2–3 weeks)	Provide nutrient inputs to both aquatic and terrestrial ecosystems, food resource for large predators, important subsistence species. Proposed by BLM.
Northern pike	Resident	Long-lived resident species that are mostly found in deep lakes and large, slow-moving rivers; piscivorous, making them susceptible to bioaccumulation of contaminants; important subsistence species, especially during the winter months. Proposed by BLM.
Inconnu (sheefish)	Anadromous and resident populations	Mostly piscivorous; anadromous and resident populations, both of which tend to migrate over long distances. Proposed by BLM.
Humpback whitefish	Anadromous	USGS suggested an additional whitefish species be included that is important to subsistence users. Humpback whitefish are harvested in high numbers in Interior Alaska.
Dolly Varden	Anadromous and resident populations	Important subsistence species and well-distributed throughout the stream network. Resident life history typically uses small streams. Proposed by BLM.

2. Methods

For each Aquatic Fine-filter CE, we evaluated the potential impacts from individual Change Agents (CAs). The process of intersecting the current distribution of the individual CEs with CAs is considered the core analysis of the REA. Due to lack of spatial data relating many of the CAs to stream networks (e.g., climate change and water temperature), relationships between the Aquatic Fine-filter CEs and CAs were mostly based on literature review. Below we summarize the methods and results of the core analysis for all Aquatic Fine-filter CEs, followed by individual species accounts where we present a more in-depth explanation of our findings.

We also answered two Management Questions (MQs) that broadly inquired about anthropogenic impacts to aquatic habitat and species, which are addressed at the end of this section (MQs W2 and V1):

MQ W2: How might future road construction and mineral extraction infrastructure (e.g., both temporary and permanent roads, pads, pipeline) affect fish habitat, fish distribution, and fish movements (especially Chinook salmon, chum salmon, and inconnu)?

MQ V1: How does human activity (e.g., mineral extraction, gravel extraction) alter stream ecology and watershed health (i.e., water quantity, water quality, outflow/stream connectivity, fish habitat, and riparian habitat)?

The following steps were completed for the four Aquatic Fine-filter CEs with distribution maps or models. There were not enough data to model the distributions of northern pike or humpback whitefish so we created a conceptual model for these two CEs.

1. Mapped or modeled the **current distribution** of each CE.
2. Created a **conceptual model** for each CE based on its relationship to CAs.
3. **Intersected the mapped/modeled distribution of each CE with those CAs** identified as having significant impacts to aquatic habitats or species.
4. **Conducted a literature review** summarizing the effects of CAs on each CE when spatial data were not available.
5. Assessed current and long-term future (2060) **status** by intersecting the mapped distribution of each CE with the **Landscape Condition Model (LCM)**—modified for aquatic habitats.

2.1 Distribution

Our goal was to generate a distribution map for each CE using existing datasets. For four of the fish species that exhibit anadromy (i.e., Chinook and chum salmon, inconnu, and some populations of Dolly Varden), distributions were available from the Alaska Department of Fish and Game's (ADF&G) Anadromous Waters Catalog (AWC). Inconnu distribution shown in the AWC was expanded by adding additional distributions and spawning reaches from published reports (Alt 1987, Brown et al. 2012). The AWC distribution of inconnu included the Kobuk, Selawik, Koyukuk, and Yukon River drainages and some associated tributaries. The AWC also included spawning habitats in the Yukon Flats and in reaches of the Alatna and Koyukuk rivers. Additional habitats added from published reports are described in detail below:

- The Chatanika spawning reach was added based on the description in Alt (1987, pg. 31): 7 km upstream of the Elliott Highway Bridge in a 3.2-km area of swift pool-like areas.
- Distribution was extended up the Tanana River to the mouth of the Delta River (Brown et al. 2012, pg. 125).
- A spawning reach in the mainstem Tanana River was added from the mouth of the Chena River to the mouth of the Salcha River (Brown et al. 2012, pg. 217).
- Distribution was extended up the Yukon River to the Canadian border (Brown et al. 2012, pg. 217; Alt 1987, pg. 39).
- Distribution was extended up the Porcupine River to the Canadian border (Alt 1987, pg. 32).
- Distribution was extended 32 km up the Chena River (Alt 1987, pg. 30).

Anadromous populations of Dolly Varden were documented in the Kobuk and Noatak drainages in the western part of the study area. For the resident populations of Dolly Varden, presence points from the ADF&G Alaska Freshwater Fish Inventory (AFFI) were combined with other fish observation data to create a distribution model. Distributions for northern pike and humpback whitefish were considered **data gaps** as no spatial datasets were available for these species and very limited fish observation data precluded the possibility of modeling their distributions.

Random Forest Habitat Distribution Model

We used a random forest approach to model the distribution of resident Dolly Varden habitat for the current and long-term future (2060s) time periods. An advantage of machine learning techniques in modeling species distributions is the ability to explore potential non-linear or non-intuitive interactions between species and environmental factors and generate resulting predictions (Evans et al. 2011). Random forest is a collection of non-parametric, weak learning trees that converge on an optimal solution (Breiman et al. 2001).

Presence points were derived from AFFI points that documented Dolly Varden as present and from BLM fish biologists. Absences for Dolly Varden were selected from points where Dolly Varden were not recorded as present, and the project objectives included sampling of the entire fish community. In areas with lots of field data points, the AFFI points were randomly resampled to match the lower sampling intensity of other hydrologic units (5th level hydrologic units were used for comparing field data density). Presence and absence points were shifted onto the artificial stream network generated from the USGS National Elevation Dataset (NED) 2 Arc-second Digital Elevation Model (DEM). Points were checked manually to ensure consistency of shifted locations with original locations, and in some cases points were re-shifted manually.

Unbalanced samples in Random Forest models introduce bias when the minority class has much less representation in the sample dataset than the majority class (Kubat and Matwin 1997, Drummond and Holte 2003). Biased classification accuracy is introduced as the probability of drawing the minority class per bootstrap becomes low. Highly unbalanced samples therefore lead to unreliable classification accuracy (Evans et al. 2011). A 1:1 sample ratio can also become problematic because of the potential to overfit the model in data structures where the minority class has little variation (Evans, pers. comm.). One technique to mitigate sample bias is to down-sample the majority class (Evans et al. 2011). Absence points were therefore downsampled to approximately match the number of presence points. A total of 81 presence points and 111 absence points were selected as training data for the model.

We selected a suite of 17 predictor raster datasets representing abiotic environmental factors (topography, hydrography, and climatic averages for the 2010s and 2060s decades). All predictor variables were calculated along an artificial stream network developed from the USGS NED 2 Arc-second DEM using TauDEM. The 2 Arc-second DEM was selected because that was the only available resolution of elevation data providing continuous coverage over the study area. When converted to a projected coordinate system, the 2 Arc-second resolution was resampled to a 60 m grid, which is approximately equivalent to 2 Arc-second within the study area. Climate variables included seasonal and monthly temperatures, annual precipitation, and extent of permafrost.

Input presences and absences and predictor datasets were pre-processed in ArcGIS 10.3.1 and passed via python as inputs into the random forest implementation in R (Breiman 2001, Liaw and Wiener 2002). A subset of the 17 predictor datasets was selected by following methods implemented in the R package rfUtilities by Jeffrey Evans: random forest assigns importance (I) to variables based on the number of times each variable reduces mean squared error. An initial random forest model run calculated I for all variables, and a model improvement ratio (MIR) was calculated per variable (I/I_{\max}). Progressive random forest models were run for iterations of variables subset from the initial run based on MIR thresholds at intervals of 0.05 from 0.05 to 1. The variable set with fewest retained metrics, lowest model mean squared error, and largest percentage of variation explained was selected (see Murphy et al. 2010 for further details). Random forest was run with the selected variable set and 5,000 bootstraps to obtain a model kappa. This process was repeated 100 times to ensure that all possible optimized variable sets were considered in the selection of a final model.

The three resulting random forest models with the highest kappa values were cross-validated with 1,000 permutations and 10% of data withheld per permutation. The model with the highest mean cross-validation kappa was selected as the final model, and a potential habitat distribution raster was predicted using the final model and selected predictor datasets as inputs. The initial prediction output was a continuous dataset of values between 0 and 1. Although the continuous dataset is a useful product for some applications and better represents the natural variability in habitat quality, a presence-absence distribution is much easier to interpret, standardized between models, more applicable to management considerations, and better suited for comparison with changing environmental and anthropogenic factors. Continuous potential habitat datasets were converted to presence-absence by identifying the lowest probability threshold that minimized the absolute value of the difference between sensitivity and specificity, a technique that has been shown to perform better than other common methods, especially compared to the a priori assumption of 0.5 as a threshold (Liu et al. 2005, Jiménez-Valverde and Lobo 2007). The resulting distribution is a representation of potential habitat: the distribution the species could have in the absence of historical, biotic, and other restrictive factors not considered in the model.

Dolly Varden Distribution Model

The potential habitat distribution performed well when cross-validated against subsets of training data. Model kappa was 0.629 and area under curve (AUC) was 0.884. Kappa values greater than 0.6 indicate good model performance (Manel et al. 2001). Because the threshold for conversion to presence-absence was derived from minimizing the absolute value of the difference between sensitivity and specificity, the sensitivity and specificity of the model compared to the training data are both 100%. Not enough data were available to perform

assessments of kappa, AUC, sensitivity, and specificity independent from the training data beyond cross-validation.

Twelve variables out of 17 were selected into the final random forest model, indicating that, of the variables tested, this subset had the strongest explanatory power for the Dolly Varden occurrences: **a.) Climate:** watershed annual precipitation, watershed annual temperature, watershed December-January-February temperature, watershed January temperature, watershed June-July-August temperature, and watershed July temperature; **b.) Topographic:** elevation, gradient, watershed area, watershed elevation, watershed slope over area ratio, and watershed slope.

The model was used to predict resident Dolly Varden habitat across the stream network for the long-term future (2060s) by replacing the 2010s climate data used to train the model with 2060s climate data. Data were not available to either temporally train the model or test the error resulting from a hindcast of the same amount of time as the forecast. Therefore, the errors introduced by applying the spatially trained Dolly Varden model to temporal variation are unknowable. We provide the forecast of Dolly Varden habitat because it may give an indication of possible habitat shifts resulting from climate change with the caveat that the accuracy of the forecast is wholly unknown.

2.2 Conceptual Models

Conceptual models were developed for each Aquatic Fine-filter CE and are essentially “stressor” models, which depict the effects that environmental stress (i.e., CAs) imposes on key ecological components. Conceptual models for the Aquatic Fine-filter CEs are presented within the individual CE sections.

2.3 Attributes and Indicators

Ecological attributes are defined as traits or factors necessary for maintaining a fully functioning population, assemblage, community, or ecosystem. For each Aquatic Fine-filter CE, we identified a number of attributes derived from the conceptual model, and assigned indicators based on spatial data layers. Categories were generalized based on published threshold values, where available, or best available information (e.g., average, greater than average, or lower than average).

The attributes and indicator tables originally proposed in the methods document are not included in this report for the reasons described below, although their effects have been addressed in other sections of this report (Table J-2). The anthropogenic indicators originally listed in the attributes and indicators tables were moved to the core analysis because we were unable to find published information on indicator levels that triggered an effect on attributes applicable to the Fine-filter CEs (e.g., a road density that leads to a decline in salmon productivity). In the core analysis results, we reviewed the literature to describe the likely impacts of CAs on Fine-filter CEs and summarized the results quantitatively (e.g., kilometers of fish habitat impacted by impassable culverts). Several of the climate change datasets originally listed in the attributes and indicators tables were not included in the core analysis because spatial data were not available (e.g., cumulative degree-days or stream temperature). Climate change effects on aquatic habitats have been summarized using a literature review in the individual CE accounts. Two climate change datasets were included in the core analysis (permafrost thaw and thermokarst potential in areas projected to thaw to at least 1-m depth by

the 2060s) because spatial data were available. More details on data limitations for fishes are described in the Limitations and Data Gaps section (Section J.12) of this report.

Table J-2. Method used to address Aquatic Fine-filter CE attributes originally identified in the methods document.

Attribute	Method Used
Frost-free days/season length	Literature review in individual CE sections
Summer temperature	Literature review in individual CE sections
Fall temperature	Literature review in individual CE sections
Winter precipitation	Literature review in individual CE sections
Permafrost thaw	Part of core analysis
Habitat fragmentation from roads	Part of core analysis
Habitat impacts from mineral/gravel extraction	Part of core analysis; status assessment based on LCM includes current mining activity
Water quality impacts from development	Part of core analysis

2.4 CE × CA Intersections

The CE × CA assessment was based on the availability of spatial datasets expected to have meaningful impacts to aquatic habitats or species. These included: water quality and habitat impacts, future roads, future mineral potential, long-term future (2060s) permafrost thaw, and thermokarst potential in areas projected to thaw to at least 1-m depth by the 2060s. Datasets selected for the analysis of water quality and habitat impacts were: Alaska Department of Environmental Conservation (ADEC) impaired waters, ADEC contaminated sites, Alaska Department of Natural Resources (ADNR) active placer mines per 5th-level hydrologic unit, and ADF&G culvert inventory. Results from the core analyses are summarized in tables and presented in Section J.3. Maps of all CE × CA intersections are not included in this report, however, we included those maps that provided meaningful information in the core analysis results or individual CE species accounts. All GIS data are provided as a final product and will be made publicly available through the BLM online data portal for future analyses.

2.5 Status Assessment

The current (2015) and long-term future (2060) landscape condition model (LCM) was modified for Aquatic Coarse- and Fine- Filter CEs to develop condition scores for both the stream network and individual 6th-level hydrologic units. Landscape condition is a measurement of the impact of the human footprint on a landscape. Human modifications were categorized into different levels of impact (site impact scores) based on the current state of knowledge about the impacts of specific human land uses (see Section F. Landscape and Ecological Integrity).

The flow direction and LCM grids were used to create a condition weighted contributing area grid that summed condition scores upstream of each cell in the synthetic stream network. The resulting sums were divided by the total accumulation number of upstream cells per individual cell to create mean watershed condition scores along the stream network. Mean watershed condition scores only represented those parts of the watershed within the study area since the extent of input data ended at the study area boundary. Mean watershed condition scores were used to evaluate resident Dolly Varden habitat because it was modeled using the same synthetic stream network and, therefore, the spatial datasets could be intersected. Dolly Varden

distribution was summarized across the study area by five equal interval classes of mean watershed LCM scores for both the current and long-term time periods.

The mean watershed condition scores along the synthetic stream network did not overlap the stream line representations of habitat from the Anadromous Waters Catalog. Therefore, the mean watershed condition scores for anadromous fishes were averaged for all 6th-level hydrologic units in the study area and extracted to the CE distributions (Figure J-1). Current and long-term future (2060) condition scores for all four spatially explicit Aquatic Fine-filter CEs were classified into five equal intervals and summarized across the study area.

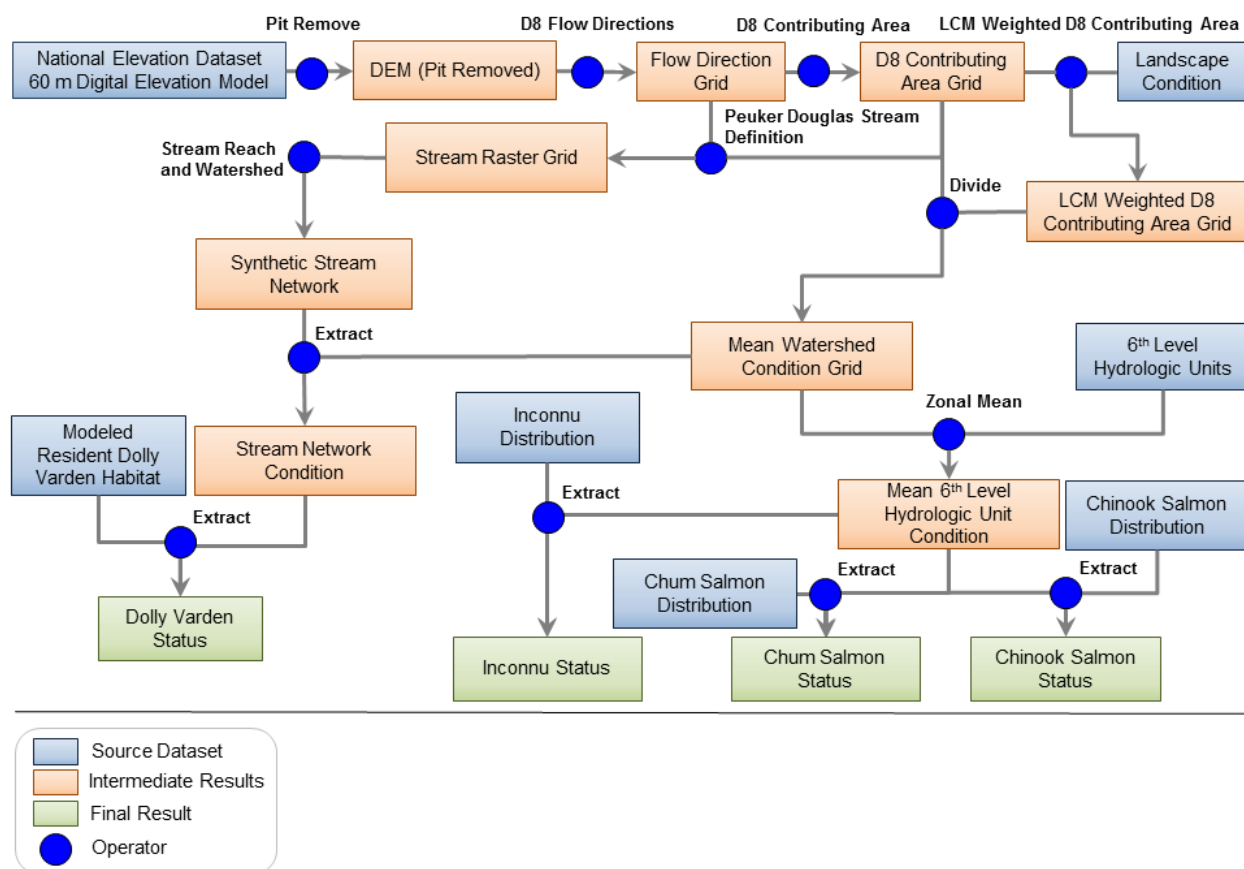


Figure J-1. Process model for analysis of landscape condition for four spatially explicit Aquatic Fine-filter CEs based on generation of stream network condition and mean 6th-level hydrologic unit condition.

2.6 Relative Management Responsibility

The relative amount of management responsibility on public lands for each CE was assessed by intersecting the CE-specific distributions with general land management status for 2015. Although each state and federal agency has different management mandates and responsibilities for specific fish and wildlife species, this assessment provides an estimate of the proportion of a species distribution that occurs within the boundaries of areas managed by public agencies. This type of information may be useful to managers to promote better collaboration and increase effectiveness of public lands managed for species that migrate across political boundaries.

3. Core Analysis Results

The total distribution for each Aquatic Fine-filter CE in the CYR study area is summarized in Table J-3. Dolly Varden had the most widespread distribution for the current time period, over two times greater than the total distribution for chum salmon. Chum salmon and Chinook salmon both had over 10,000 km of habitat in the CYR study area, and inconnu had almost 5,000 km of habitat. Chum salmon had the largest amount of documented spawning habitat in the study area. Maps of species distributions are included in the individual CE sections.

Table J-3. Total habitat and spawning habitat length in km for four spatially explicit Aquatic Fine-filter CEs in CYR study area.

Species	Total Habitat (km)	Spawning Habitats Only (km) ¹
Chinook salmon	11,707	2,824
Chum salmon	13,506	4,105
Inconnu	4,901	255
Dolly Varden ²	27,278	240
Dolly Varden 2060s ²	39,338	NA

¹ Spawning habitats are from the AWC for anadromous populations only.

² Dolly Varden habitat in the current time period includes anadromous habitat from the AWC and modeled resident habitat. Where anadromous and resident habitats overlapped, they were only counted once. Dolly Varden habitat in the long-term future time period (2060s) only includes modeled resident habitat.

3.1 Climate Change

Two climate change datasets were evaluated for long-term future impacts to Aquatic Fine-filter CEs: permafrost thaw and thermokarst potential in areas projected to thaw to at least 1-m depth by the 2060s. Climate impacts to habitats were reviewed in Section I. Aquatic Coarse-filter Conservation Elements. The habitat impacts are briefly summarized here in order to provide context for how these habitat changes may affect fish species.

Permafrost thaw will lead to increases in groundwater, decreased bank stability, and higher export of nutrients and major ions to streams. Dissolved organic matter may increase during initial phases of thaw and then stabilize once subsurface flow paths no longer intersect organic rich soils. Increased groundwater inputs may increase the availability of spawning and overwintering habitats, both of which require stable winter baseflows (Cunjak 1996, Huusko et al. 2007).

The increases in stream nutrients and organic matter will increase primary and secondary productivity, indirectly benefiting resident fishes. Long-term nutrient additions to two streams on the North Slope of Alaska led to increases in primary production, macroinvertebrate densities, and growth of Arctic grayling (Harvey et al. 1998, Slavik et al. 2004). Phosphorus additions to the Kuparuk River also resulted in a 10-fold increase in moss cover, dramatically altering physical habitat and the related algal and macroinvertebrate communities (Slavik et al. 2004). Additions of dissolved organic carbon to a headwater stream on the Kenai Peninsula over one growing season resulted in increased nitrogen uptake, macroinvertebrate densities, and Dolly Varden densities and growth, especially for fry (King et al. 2014). Through increased water temperature, climate change will also increase the metabolic demand and physiological growth

potential of fishes, yet the combined effect of increased nutrients and temperature on fish growth and productivity are not yet known.

Permafrost was defined spatially for this assessment as 2-km grid cells where mean annual ground temperature was projected to be less than or equal to 0 °C at 1-m depth (see Section C. Abiotic Change Agents). Currently, almost all fish habitat is underlain by permafrost (Table J-4). About one third of the habitat for the four fish species is projected to become permafrost-free by the 2060s (decreases of 28%–39%, depending on species). These results are similar to changes in percent watershed permafrost cover across the stream network (see Section I. Aquatic Coarse-filter Conservation Elements); 31% of small streams and 35% of large streams or rivers shift from being mostly underlain by permafrost (91%–100% permafrost cover) to having low to moderate permafrost cover in their watersheds.

Table J-4. Current and projected permafrost extent by Aquatic Fine-filter CE habitat.

Fine-filter CE	Habitat Underlain by Permafrost (2010s)	Habitat Underlain by Permafrost (2060s)
Chinook salmon	97%	57%
Chum salmon	98%	66%
Inconnu	98%	63%
Dolly Varden*	98%	70%

*Includes current anadromous habitat and current modeled resident habitat.

Changes to stream and river bank stability from either permafrost thaw or thermokarst features will negatively impact stream habitats, productivity, and fish species (Durand et al. 2011). A large retrogressive thaw slump on the Selawik River that developed in 2004 is being monitored by U.S. Fish and Wildlife Service (USFWS) for effects on a downstream spawning habitat for inconnu. Sedimentation of the gravel substrate in the inconnu spawning habitat (Figure J-2) has been observed during the open water season and will negatively affect egg survival (Brown et al. 2012). The effect on the impacted brood years is still unknown. Thermokarst features near to spawning habitats may degrade them for many years by burying stream gravels in fine sediment.



Figure J-2. Sediment in Selawik River in 2006 just downstream of an inconnu spawning habitat and 40 km downstream of a retrogressive thaw slump that initiated in 2004. Photo by USFWS.

Habitats of the four spatially explicit Aquatic Coarse-filter CEs are likely to be adversely affected by thermokarst development in areas projected to thaw to at least 1-m depth by the 2060s (Table J-5 and Figure J-3). Inconnu will be the least affected (9% of habitat) and Dolly Varden and Chinook salmon will be the most affected (> 20% of habitat).

Table J-5. Thermokarst potential in areas projected to thaw to at least 1-m depth by the 2060s by Aquatic Fine-filter CE habitat.

CE	Habitat in Areas of Medium Thermokarst Potential	Habitat in Areas of High Thermokarst Potential
Chinook salmon	12%	10%
Chum salmon	5%	10%
Inconnu	2%	7%
Dolly Varden*	21%	4%

*Includes current anadromous habitat and long-term future (2060) modeled resident habitat.

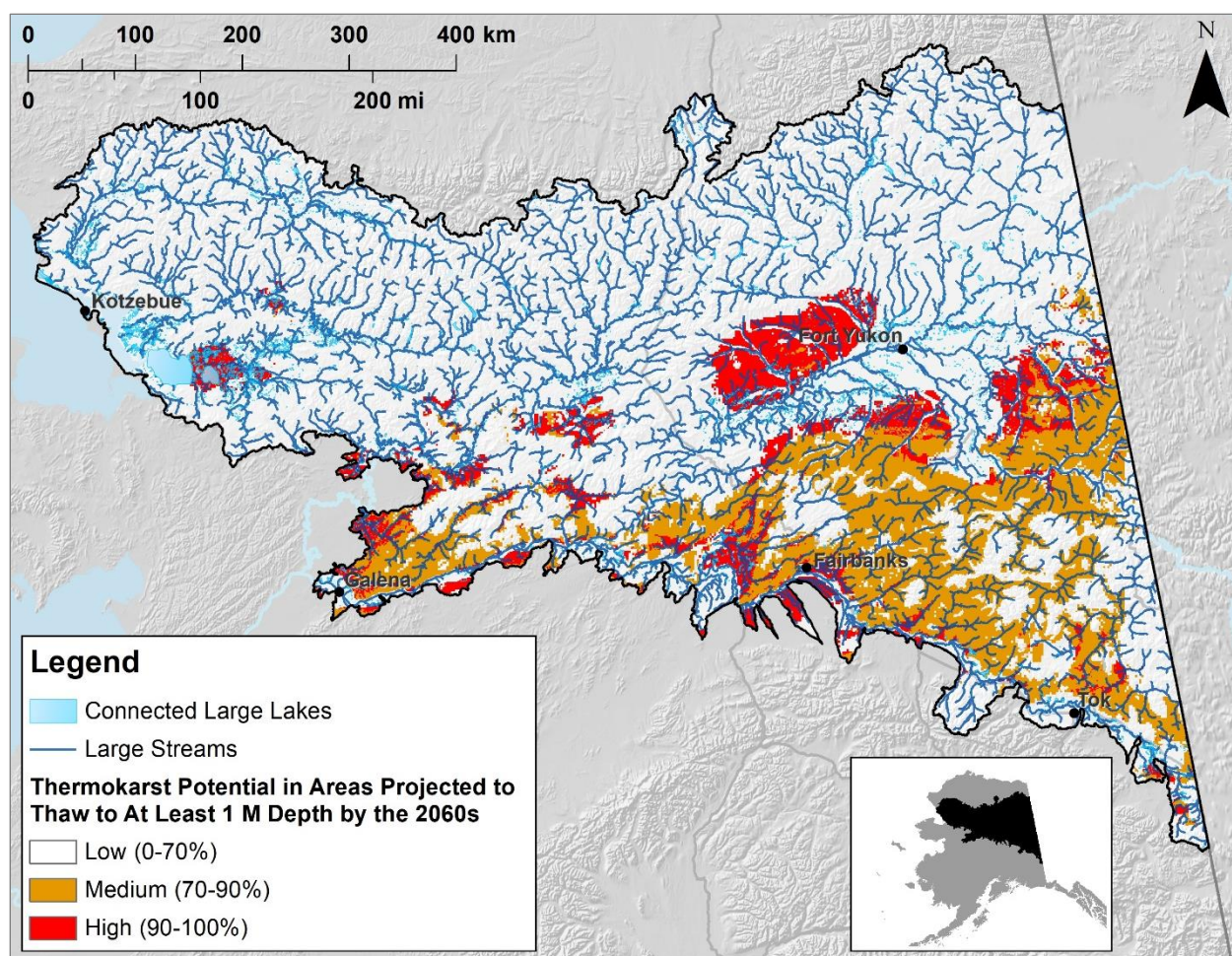


Figure J-3. Large streams and large connected lakes compared to areas of medium and high thermokarst potential projected to thaw to at least 1-m depth by the 2060s in the CYR study area.

3.2 Human Uses

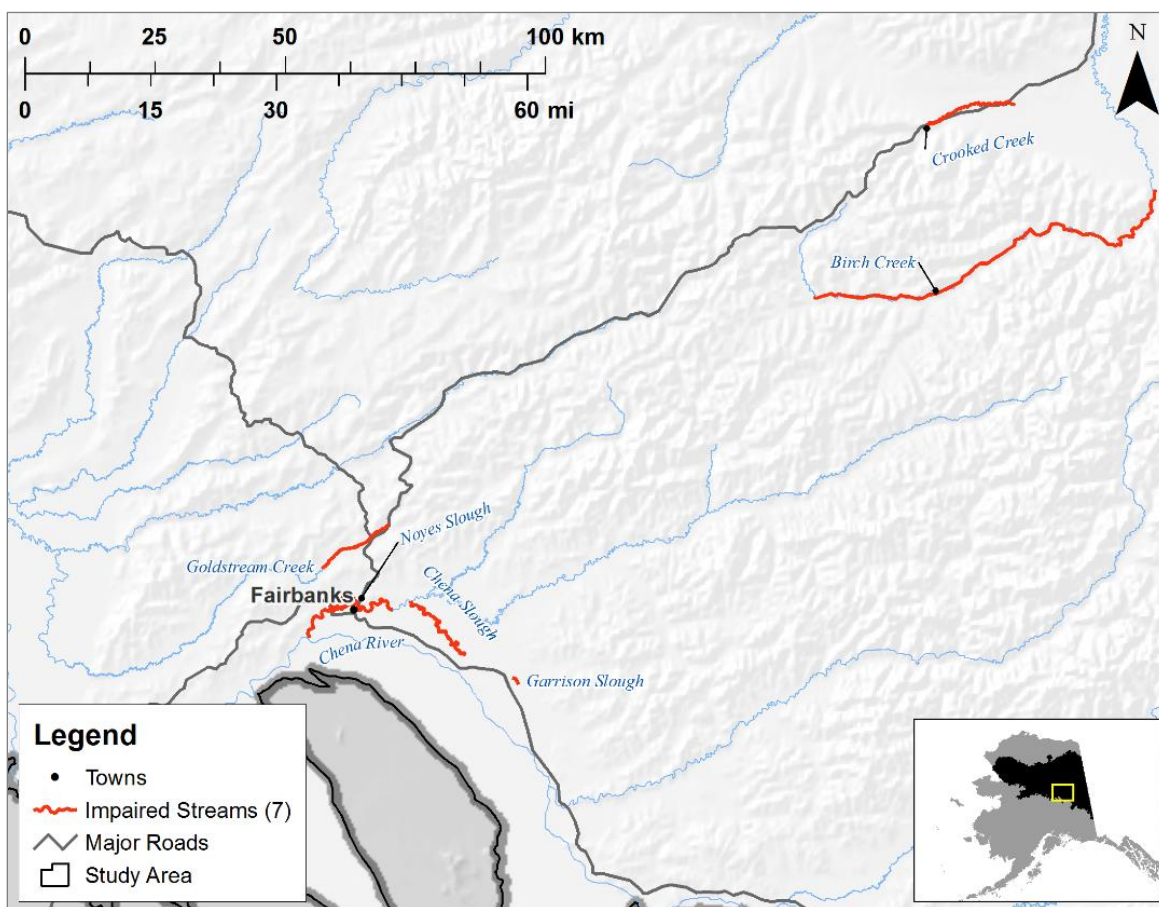
Several anthropogenic datasets were used to evaluate water quality and physical habitat impacts on the Aquatic Fine-filter CEs. Three anthropogenic CA datasets were used to indicate water quality impacts to fish. The ADEC impaired waters dataset showed all streams and lakes that did not meet EPA-approved state water quality standards as of 2010. There were seven impaired streams and no impaired lakes within the CYR study area (Table J-6 and Figure J-4). Birch, Crooked, and Goldstream creeks were listed for turbidity due to placer mining activities. Garrison Slough was listed for PCBs from military activities. Chena River, Chena Slough, and Noyes Slough were listed for sedimentation in addition to other contaminants from urban runoff in Fairbanks. The total length of impaired streams in the CYR study area was 187 km. Chinook salmon and Dolly Varden had the highest frequency of occurrence at these sites (4 and 3, respectively; Table J-6).

Table J-6. ADEC impaired waters and impacts to Aquatic Fine-filter CEs. Fish species documented in each stream are noted.

Stream Name	Water Quality Impact(s)	Length (km)	Chinook Salmon	Chum Salmon	Inconnu	Dolly Varden
Birch Creek	Turbidity	84	Yes	No ¹	No ¹	Yes
Crooked Creek	Turbidity	22	No	No	No	Yes
Goldstream Creek	Turbidity	17	No	No	No	Yes
Garrison Slough	PCBs	2	No	No	No	No
Chena River	Turbidity, petroleum hydrocarbons, oils and grease, sediment	31	Yes	Yes	Yes	No
Chena Slough	Sediment	22	Yes	No	No	No
Noyes Slough	Debris, petroleum hydrocarbons, sediment	9	Yes	No ²	No ²	No

¹ Chum salmon occur immediately downstream of the impaired section of Birch Creek.

² Both chum salmon and inconnu occur in the Chena River past its upstream connection to Noyes Slough.

**Figure J-4.** ADEC impaired streams in the CYR study area.

The ADEC open contaminated sites layer showed contaminated sites that still require cleanup in the CYR study area. Contaminated sites were located within a variety of land management jurisdictions. There were 419 open contaminated sites in the study area and Table J-7 summarizes the number of these sites that affect Aquatic CE species. The four spatially explicit Aquatic Fine-filter CEs had numerous open contaminated sites within 0.5 km of habitat, although Chinook salmon, chum salmon, and inconnu may have had greater exposure than Dolly Varden.

Table J-7. ADEC contaminated sites within 0.5 km of Aquatic Fine-filter CEs.

Fine-filter CE	Open Contaminated Sites (Count)
Chinook salmon	83
Chum salmon	83
Inconnu	73
Dolly Varden	39

Placer mining affects stream habitats by degrading water quality, reducing habitat diversity, removing riparian vegetation, and increasing sedimentation (see Section I. Aquatic Coarse-filter Conservation Elements). These habitat changes can directly impact fish communities both at the mining operation and downstream. Direct effects may include mortality during mining or sedimentation of spawning gravels suffocating eggs (Harvey and Lisle 1998), while indirect effects include changes to stream food webs. Primary productivity and algal biomass were completely undetected in heavily mined streams (10–12 active mines) and 50% less in moderately mined streams (3–4 active mines) than in unmined streams (Van Nieuwenhuysse and LaPerriere 1986). Decreases in macroinvertebrate abundance and biomass have also been documented in streams affected by placer mining (Wagener and LaPerriere 1985), with significant changes persisting many years after mining (12–50 years, Milner and Piorkowski 2004).

Studies have documented increased heavy metal exposure (e.g., mercury, arsenic, and antimony) in macroinvertebrate tissues from mining practices in other parts of Alaska (Matz 2012). Juvenile fishes eat macroinvertebrates, so heavy metal accumulation in their prey could have negative health impacts on Aquatic Fine-filter CEs. Adult fish could accumulate high levels of mercury and other contaminants in their tissues.

Using ADNR data, we classified placer mine density as low, medium, and high, respectively defined as 1–5, 6–12, or 13–45 mines per 5th-level hydrologic unit. However, impacts from individual mines likely vary depending on the size of the operation. Summing the total length of fish habitats by mine density indicated that Chinook and chum salmon spawning habitats had the greatest exposure to placer mining and associated impacts (Table J-8 and Figure J-5). Impacts on Dolly Varden spawning habitats were likely underestimated because they were only documented for anadromous populations in the western portion of the study area, where very little placer mining occurred. Spawning habitats for resident Dolly Varden populations were not identified, but were probably affected in similar proportions to total habitats.

Table J-8. Number of 5th-level hydrologic units and percent of total habitat length for four spatially explicit Aquatic Fine-filter CEs impacted by low, medium, and high placer mine density per 5th-level hydrologic unit in the CYR study area.

Fine-filter CE		Low Mine Density (1–5)	Medium Mine Density (6–12)	High Mine Density (13–45)	Total Habitat Affected by Placer Mining
5 th -level hydrologic units (count)		7	32	11	50
Chinook salmon	total habitat	8%	3%	2%	13%
	spawning habitat	15%	4%	5%	24%
Chum salmon	total habitat	5%	3%	1%	9%
	spawning habitat	11%	6%	3%	20%
Inconnu	total habitat	4%	1%	1%	7%
	spawning habitat	0%	0%	4%	4%
Dolly Varden	total habitat	7%	2%	2%	11%
	spawning habitat	0%	0%	0%	0%

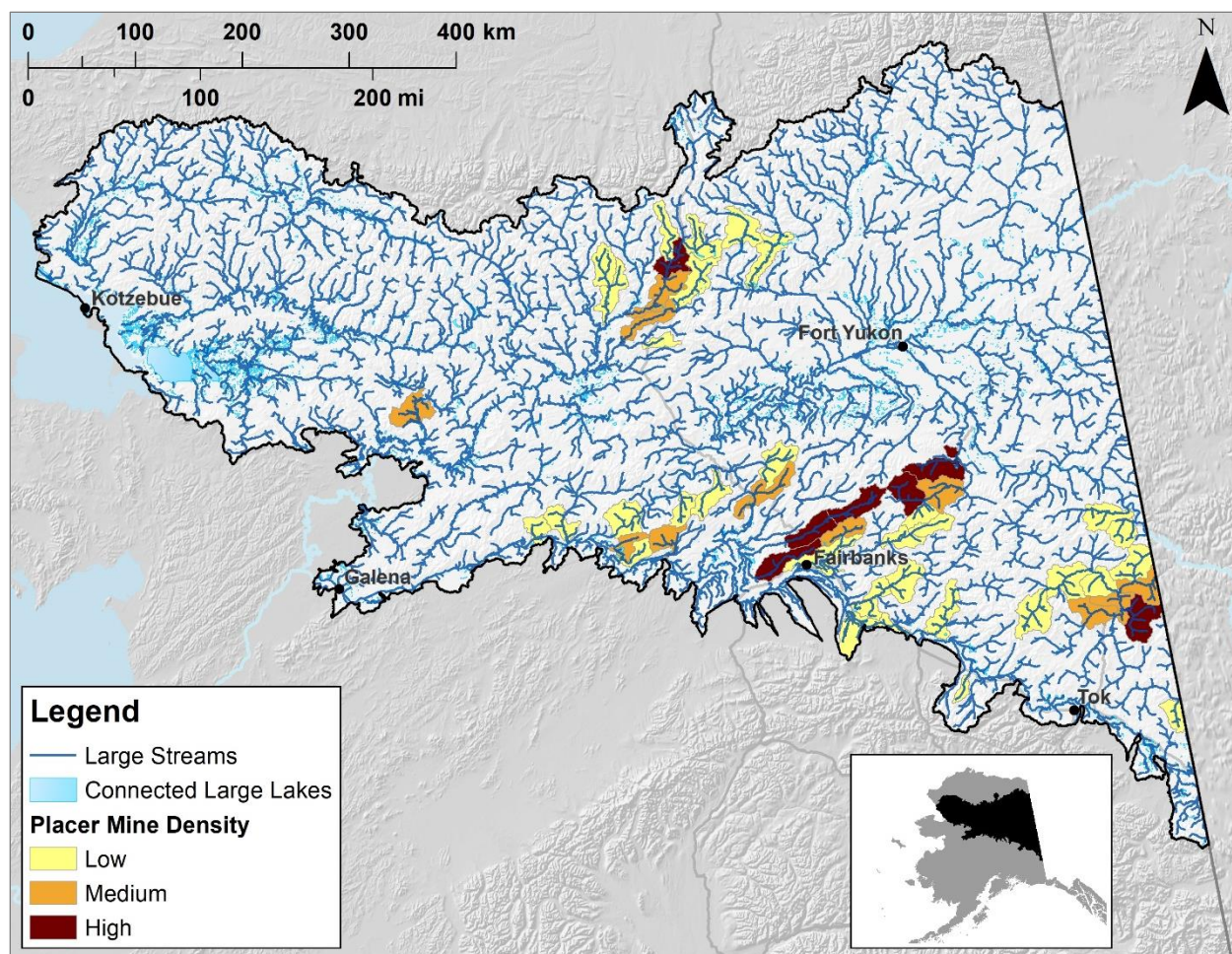


Figure J-5. Distribution of large streams and large connected lakes compared to density of placer mines in the CYR study area. Mine density was classified as low (1–5), medium (6–12), or high (13–45) mines per 5th-level hydrologic unit.

Road crossings can have severe physical and chemical impacts to stream habitats, in addition to blocking fish passage. Habitat impacts include sedimentation, delivery of toxic compounds, channelization, ponding, scouring and erosion, partial to complete blockage, and introduction of invasive species (see Section I. Aquatic Coarse-filter Conservation Elements). Impediments to fish passage caused by culverts result in differences between upstream and downstream fish communities and densities (Evans et al. 2015, Maitland et al. 2015). Juvenile salmon were blocked by culverts from both downstream and upstream migrations in streams in Southcentral Alaska (Davis and Davis 2011).

ADF&G inventoried 374 culverts in the CYR study area for fish passage adequacy, and 224 were rated red or gray, indicating that conditions were inadequate or likely inadequate (respectively) for passage of juvenile salmonids. A total of 1,555 km of stream habitat was upstream of culverts that were rated red or gray. We intersected the locations of these culverts with fish distributions: four were blocking documented habitat for Chinook salmon and 23 were blocking potential habitat for resident Dolly Varden (see Section I. Aquatic Coarse-filter Conservation Elements, Figure I-9).

3.3 Status Assessment

The status of aquatic habitats was based on mean watershed landscape condition scores, which integrated the effects of roads, urban development, and altered vegetation on aquatic habitats. A complete list of all inputs to the LCM is provided in Section F. Landscape and Ecological Integrity. Stream and river habitats reflect modifications throughout their watershed due to their topographic position and the downstream flow of materials in stream networks. There is a long history of utilizing watershed metrics to predict impacts to stream water chemistry, physical habitat, and biological communities (see reviews in Gergel et al. 2002, Allan 2004, Johnson and Host 2010).

The landscape modification variables used in the LCM have been tied to stream habitat degradation in many monitoring studies, both in Alaska and elsewhere. Impervious surface has been tied to changes in water quality and benthic communities (Ourso and Frenzel 2003, Cuffney et al. 2010). Percent cover of cultivated land has been tied to changes in water chemistry (King et al. 2005).

We calculated mean watershed condition scores to assign status to small streams and large streams and rivers across the CYR study area, collectively referred to as stream network condition (see Section I. Aquatic Coarse-filter Conservation Elements). We aggregated these same scores to create averages for each 6th-level hydrologic unit. The resulting average stream network condition was extracted to the distributions of Chinook salmon, chum salmon, and inconnu. The status for each spatially explicit Aquatic Fine-filter CE was classified into five equal intervals, representing categories of condition to aid interpretation (Table J-9).

Over 90% of current and long-term future (2060) condition for the four spatially explicit Aquatic Fine-filter CEs was very high, indicating that CE habitats were and will likely remain relatively pristine (Table J-9). Predicted changes in status between current condition and long-term future condition were very small. The LCM has not been directly linked to stream habitat condition in Alaska or elsewhere, but several studies have shown that relatively low levels of watershed disturbance lead to stream habitat impairment that directly and indirectly affect fish (Wang et al. 2001, Pess et al. 2002, Baker and King 2010).

Table J-9. Percent of total habitat length for four spatially explicit Aquatic Fine-filter CEs by mean watershed condition score in the CYR study area.

Fine-filter CE	Time Period	Percent CE Habitat Length per Watershed Condition Category			
		Low	Medium	High	Very High
Chinook salmon	Current (2015)	0.3	3.8	3.6	92.3
	Long-term future (2060)	0.5	4.2	3.9	91.4
Chum salmon	Current (2015)	0.2	3.7	4.7	91.4
	Long-term future (2060)	0.3	3.9	4.7	91.1
Inconnu	Current (2015)	0.5	4.3	1.4	93.9
	Long-term future (2060)	0.6	4.1	1.4	93.9
Dolly Varden	Current (2015)	0.2	1.2	2.3	96.3
	Long-term future (2060)	0.4	1.9	2.7	94.9

3.4 Distribution on Public and Private Lands

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

Species distributions in relation to areas managed both publicly and privately reflect the overall ratio of land ownership within the CYR study area, with the highest percentages of species distributions occurring on native patent land, state patent land, USFWS land, and National Park Service (NPS) land (Table J-10).

Table J-10. Land management status in the CYR study area per Aquatic Fine-filter CE.

Land Management Status	Fine-filter CEs			
	Chinook Salmon	Chum Salmon	Dolly Varden	Inconnu
BLM	8%	7%	16%	1%
FWS	17%	19%	12%	21%
Military	2%	2%	1%	2%
NPS	7%	12%	21%	8%
Native Patent or IC	33%	32%	12%	47%
Native Selected	2%	2%	1%	3%
Private	0%	0%	0%	0%
State Patent or TA	27%	22%	30%	16%
State Selected	4%	4%	7%	2%

4. General Fish Effects

CAs and intermediate environmental drivers have specific effects on some fish species and general effects that will impact most fish species similarly. To differentiate clearly between specific and general impacts for the Fine-filter CEs, we developed a base conceptual model (Figure J-6) that details the general interactions between CAs, drivers, and fish and fish habitat. This base conceptual model forms the framework within which CE-specific effects can be understood.

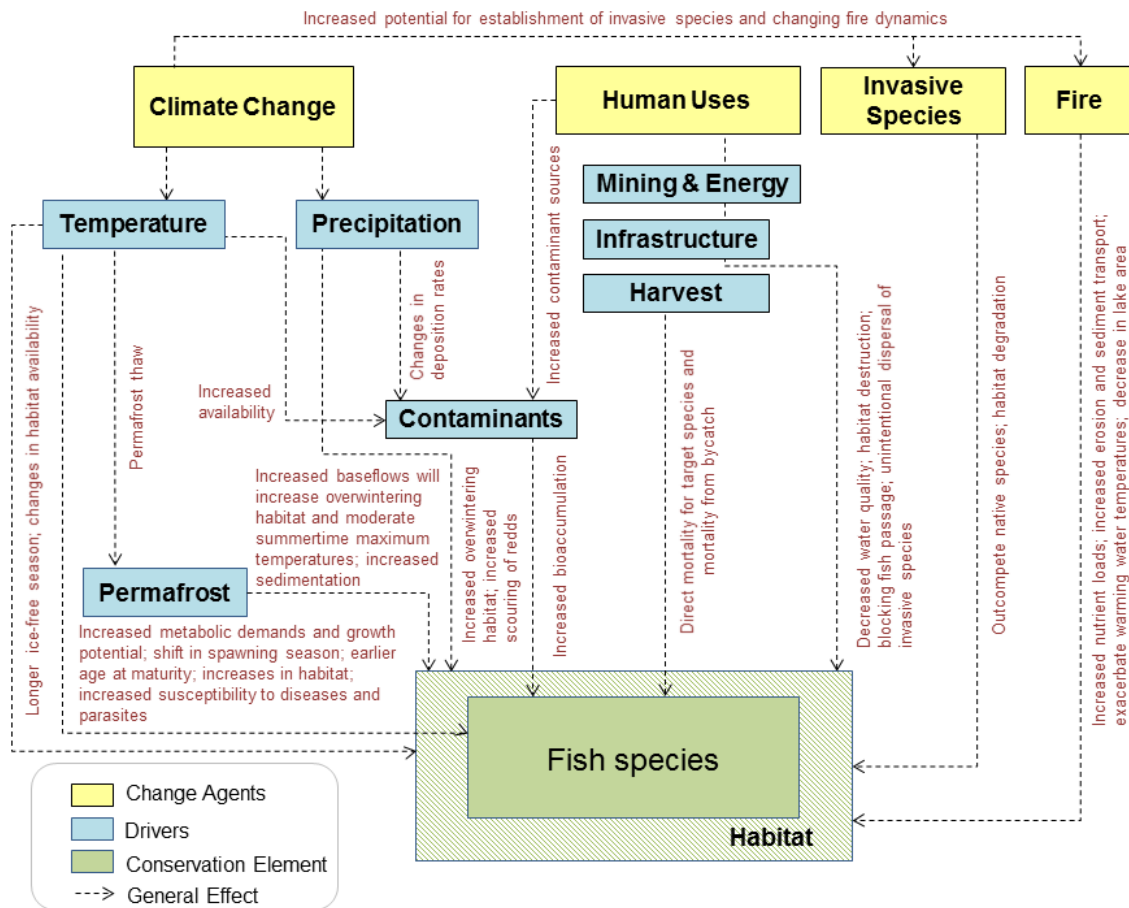


Figure J-6. Conceptual model for general effects on fish and fish habitat.

4.1 Climate Change

Two climate change responses were intersected with the distribution of Aquatic Fine-filter CEs as part of the core analysis: permafrost thaw and thermokarst potential in areas projected to thaw to at least 1-m depth by the 2060s. Lack of data or models relating changes in air temperature and precipitation to water temperature and streamflow precluded spatial analyses relating these key CAs to aquatic species. This section is devoted to a summary of expected climate change impacts in waters of the CYR study area based on results in Section C. Abiotic Change Agents. A literature review describing how these changes will affect aquatic species in the CYR study area is provided.

Climate impacts to fishes are complex, context-specific, and difficult to predict. In regard to climate-related impacts to fish populations in the CYR study area, the interrelated effects of increasing water temperatures, longer ice-free seasons, and changing hydrologic regimes are the primary drivers, in addition to the effects associated with permafrost thaw and thermokarst potential in areas projected to thaw to at least 1-m depth by the 2060s, which were covered in the core analysis.

Longer ice-free seasons coupled with warmer summer water translate to longer growing seasons and, potentially, enhanced prey production and fish growth (Schindler et al. 2005, Carey and Zimmerman 2014). However, in cases where prey availability does not increase to offset the higher metabolic demands associated with warming water, decreased fish growth can be expected (McDonald et al. 1996, Carey and Zimmerman 2014). Warmer water also influences the physiology of incubating embryos and alevins, potentially leading to accelerated development (i.e., earlier hatching and emergence) and changes in survival rates and size at emergence (Beacham and Murray 1990). Advancing emergence and enhanced growth rates may result in younger age at maturity for resident fishes and earlier smolting for anadromous fishes. Spawning will likely shift later in the year for autumn spawners and earlier in the year for spring spawners to correspond with shifts in preferred spawning temperatures. Warmer summer temperatures could modify the distribution of aquatic organisms by limiting movements through stream networks because of thermal barriers, including delaying salmon spawning migrations, and by increasing available habitat in streams where cold temperatures previously limited habitat suitability (e.g., upstream areas). Additionally, warming water temperatures may increase the susceptibility of fish to diseases and parasites (Zuray et al. 2012), increase the availability and effects of contaminants (Schiedek et al. 2007), and decrease biologically available dissolved oxygen (Ficke et al. 2007).

Data from the CYR study area generally show increasing average and maximum streamflow during winter and during spring snowmelt, followed by increased summer base flows and lower summer maximum flows (Brabets and Walvoord 2009, Bennett et al. 2015). Over the last half century, strong, significant increases in 11-day flow events during the late fall/winter have been recorded at rivers in Interior Alaska (Bennett et al. 2015), which could lead to increased incidence of bed-moving spates and, for fall-spawning fishes, scouring of incubating embryos and alevins. Increasing winter base flows could improve habitat conditions for wintering fishes by increasing the volume and stability of wintering habitats. Increased summer base flows may help to moderate increases in stream temperature. For shrinking lakes, diminished connectivity could limit access to spawning areas, affect the amount of available overwintering habitat, and potentially disrupt the timing of annual migrations.

4.2 Fire

Wildfires can lead to increased nutrient loads (Bayley et al. 1992), increased erosion and sediment transport (Benda et al. 2003, Ice et al. 2004), and can exacerbate warming stream temperatures (Dunham et al. 2007, Isaak et al. 2010). These impacts will persist over varying time scales and will likely be strongest in small streams. Increased nutrient loads may increase primary production and, potentially, higher trophic levels, although this effect may be offset by light limitation associated with increased turbidity. In addition, wildfire activity is associated with declines in lake area through removal of the insulating organic layer and subsequent permafrost degradation (Roach et al. 2013).

4.3 Invasive Species

Plants of the *Elodea* genus, the only aquatic invasive plants documented in the CYR study area, can invade and outcompete other aquatic plant species in slow moving streams or shallow lakes and ponds. Studies on *Elodea* impacts are lacking, but we hypothesize several means by which this invasive plant can impact fish populations. *Elodea* can degrade spawning habitats by impeding water flow and increasing sedimentation. It can also create hiding places for northern pike, increasing habitat suitability of this ambush predator and potentially leading to increased predation on fish populations. Finally, decomposing *Elodea* will increase biological oxygen demand, potentially leading to hypoxic or anoxic conditions under ice cover when reaeration is limited.

4.4 Human Uses

Four anthropogenic datasets were intersected with the distribution of four spatially explicit Aquatic Fine-filter CEs as part of the core analysis: impaired waters, contaminated sites, placer mines, and roads. The effects of these anthropogenic impacts were reviewed and discussed in the core analysis section of this report.

Harvest

Many fish species are harvested for subsistence, commercial and sport use within the CYR study area. While commercial fishing in the area is currently relatively small, it has the potential to increase in the future.

Contaminants

As water temperature increases, certain contaminants become more bioavailable (e.g., mercury) and exposure rates of contaminants in fish will likely increase. Mercury is a highly toxic metal that has negative impacts on the health of fish populations as well as wildlife and humans that consume fish. Microbial activity can convert inorganic mercury into its most toxic form, methylmercury (MeHg; Benoit et al. 2003), which is rapidly incorporated into the food web and biomagnifies from one trophic level to the next (Ochoa-Acuña et al. 2002). Warming temperatures within the CYR study area may further exacerbate mercury exposure in fish both by releasing snowpack- and permafrost-entrained mercury and by enhancing conditions that facilitate production of methylmercury (AMAP 2002).

Oil is another contaminant of concern for fish species within the CYR study area. Oil can have the largest impact on eggs, larvae, and juvenile fish because of the reduced capacity for individuals of those life stages to leave the contaminated area. Major construction, especially of roads, will increase erosion and runoff leading to increased stream turbidity and sedimentation, and could introduce contaminants into fish habitats (e.g., vehicular leaks and spills).

5. Chinook Salmon (*Oncorhynchus tshawytscha*)

Chinook salmon typically spend 1 full year in fresh water before migrating to the ocean, where they spend an additional 1–5 years feeding before returning to their natal stream to spawn. Within the CYR study area, Chinook salmon spawn in a broad range of habitats from small headwater streams to large rivers (Figure J-7).

Adult Chinook salmon typically begin their upstream migration in the Yukon River in late May through early July, reaching their spawning grounds in the tributaries or headwaters of the Yukon River by September. Spawning occurs immediately after reaching the spawning grounds and death soon follows (Yukon River Panel 2011). Females deposit eggs in gravel streambeds, the embryos incubate over the winter, and fry emerge from the gravel during the spring. Juveniles are found in small pools and feed on insects and other invertebrates. Overwintering potential of small streams is related to groundwater availability and tied to areas with heavy glacial-fluvial deposits (Yukon River Panel 2011). Chinook salmon is one of the most important subsistence, sport, and commercial fish within the CYR study area, and the most abundant salmon in the Upper Yukon and Tanana River basins (Delaney 2008).

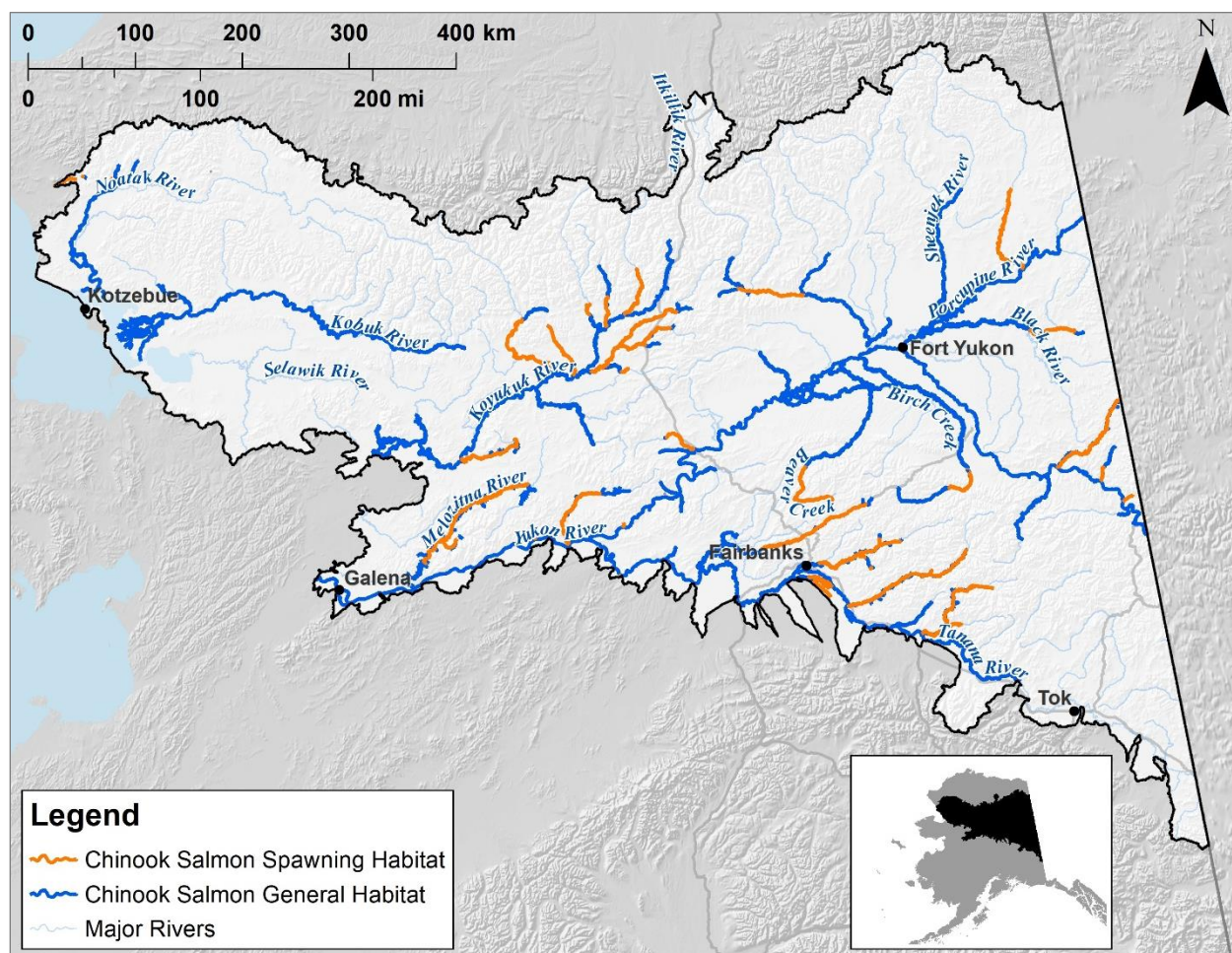


Figure J-7. Chinook salmon distribution and spawning habitats in the CYR study area.

5.1 Conceptual Model

The conceptual model (Figure J-8) is based on a literature review and describes the relationship between the various CAs and natural drivers for Chinook salmon. It is modified from the conceptual model for general effects on fish to include species-specific relationships with CAs, which are shown as bold lines.

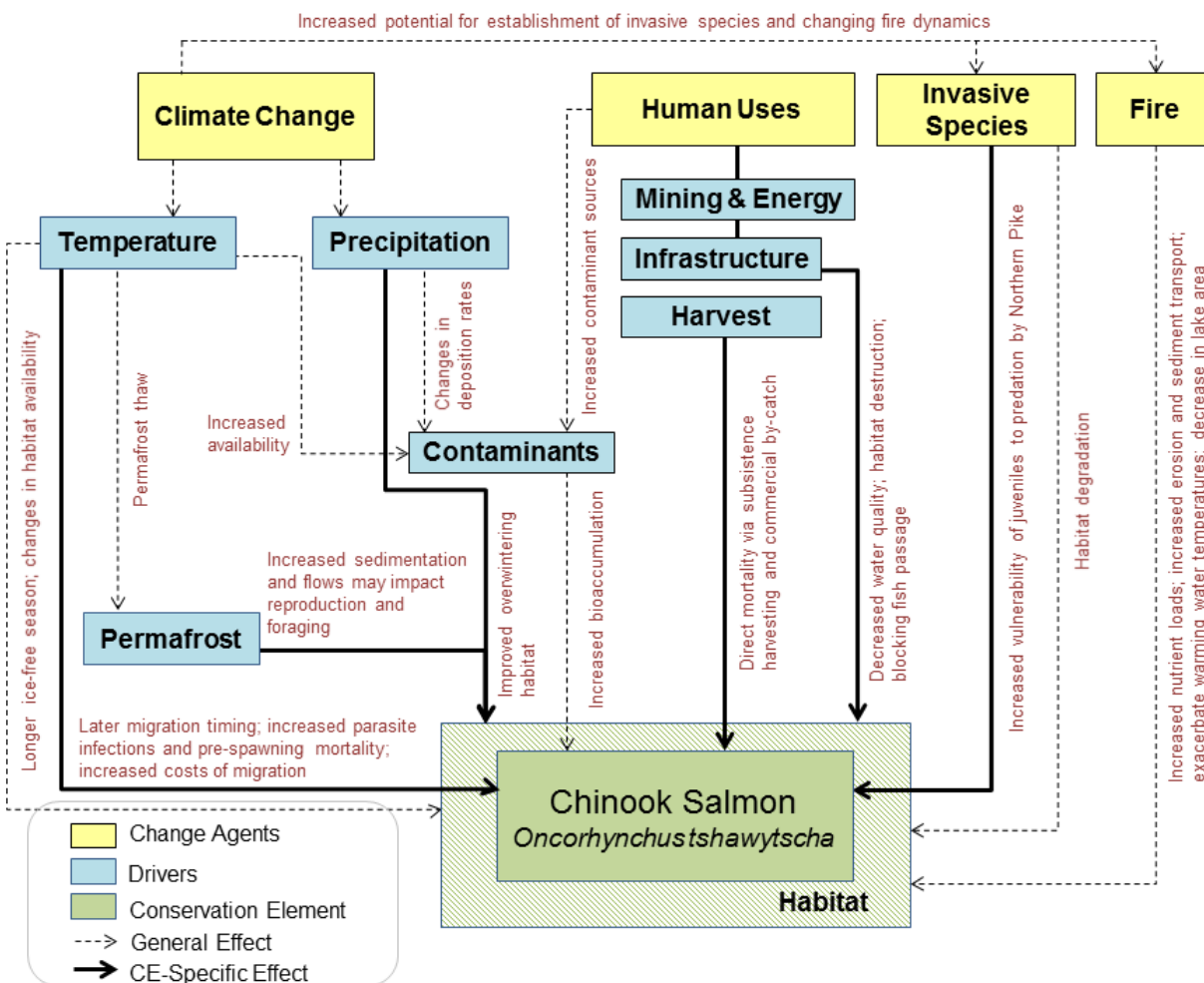


Figure J-8. Conceptual model for Chinook salmon.

5.2 Climate Change

Because juvenile Chinook salmon typically rear for 1 year in streams, they could potentially be more susceptible to changing thermal and hydrologic regimes than chum salmon populations, which migrate to sea soon after emerging from the spawning gravel. An increase in temperature may provide increased growth opportunities due to increased food resources and physiological growth potential. However, if food resources do not increase sufficiently to match increased metabolic demand associated with warmer waters, growth will decrease and may affect survival.

Maturing Chinook salmon begin their spawning runs up the Yukon River earlier during warm years (Mundy and Evenson 2011). Yukon River Chinook salmon travel long distances to

spawning grounds, and increased temperatures will increase energy costs related to migratory movements (Hinch and Rand 1998).

Increasing water temperature may be contributing to infections of Yukon River Chinook salmon by the parasite *Ichthyophonus* observed in recent decades and, potentially, to pre-spawning mortality of adult salmon (Kocan et al. 2003, Zuray et al. 2012). If water temperatures continue to increase in the Yukon River and other waterbodies within the CYR study area, rates of infection and associated pre-spawning mortality could increase.

In the short term, permafrost thaw and increased winter precipitation will likely increase groundwater flows, improving Chinook salmon overwintering habitat in small- to medium-sized 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. For example, high summer flows have been associated with low Chinook salmon productivity in the Chena and Salcha rivers, two CYR spawning tributaries (Neuswanger et al. 2015). Suspended sediment also degrades habitat for aquatic macroinvertebrates, an important food resource for juvenile Chinook salmon (Kemp et al. 2011).

5.3 Invasive Species

Plants of the *Elodea* genus have become established in the Chena River system near Fairbanks (Chena River, Chena Slough, and Chena Lake) and will likely disperse gradually to suitable habitats downstream within the Tanana River and beyond. Where established, *Elodea* may negatively impact Chinook salmon spawning habitat and make juvenile Chinook salmon more vulnerable to predation by northern pike.

5.4 Human Uses

Harvest

Chinook salmon is the primary fish species sought by commercial fishers and a crucial subsistence food source for rural residents. The Chinook salmon run in the Yukon River is composed of two major stocks that originate from the Tanana River and Canada, contributing 21% and 50% of the total run, respectively (Eiler et al. 2006). 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 2014, the number of Chinook salmon returning to the Yukon River drainage was less than expected. Between 1998 and 2004, the number of Chinook salmon harvested in the commercial fishery exceeded the combined number of chum salmon (summer and fall), primarily due to reduced opportunities for chum salmon roe sales and poor chum salmon runs between 1998–2002. From 2008–2012, commercial fisheries directed at Chinook salmon have been eliminated by measures to conserve them, and most of the commercial catch has been incidental to the fishery directed at summer chum salmon.

6. Dolly Varden (*Salvelinus malma*)

The AWC includes anadromous populations of Dolly Varden in the Kobuk and Noatak rivers and resident Dolly Varden habitats were modeled for the entire study area (Figure J-9). Dolly Varden generally mature at five to nine years of age and can spawn multiple times throughout their lifetimes. Tagging studies have shown that anadromous Dolly Varden maintain a strong fidelity to overwintering and spawning areas and that spawning typically occurs in overwintering areas (Viavant et al. 2005, ADF&G 2011). However, some Dolly Varden may overwinter in areas not connected to their natal streams (Crane et al. 2005).

Dolly Varden use habitats associated with discharging groundwater for spawning, rearing, and overwintering. Peak spawning occurs in September and October, usually in headwater streams in the CYR study area (ADF&G 2008). Females lay eggs in small nests dug into gravel streambeds. Hatching of eggs generally occurs in March, and juvenile fish emerge from the gravel in late spring. Juvenile Dolly Varden rear in streams, rivers, and/or lakes for a few years, after which time individuals from anadromous populations may migrate to nearshore coastal. Dolly Varden consume aquatic macroinvertebrates, salmon eggs and fry, and other small fishes. Juveniles feed primarily on macroinvertebrates.

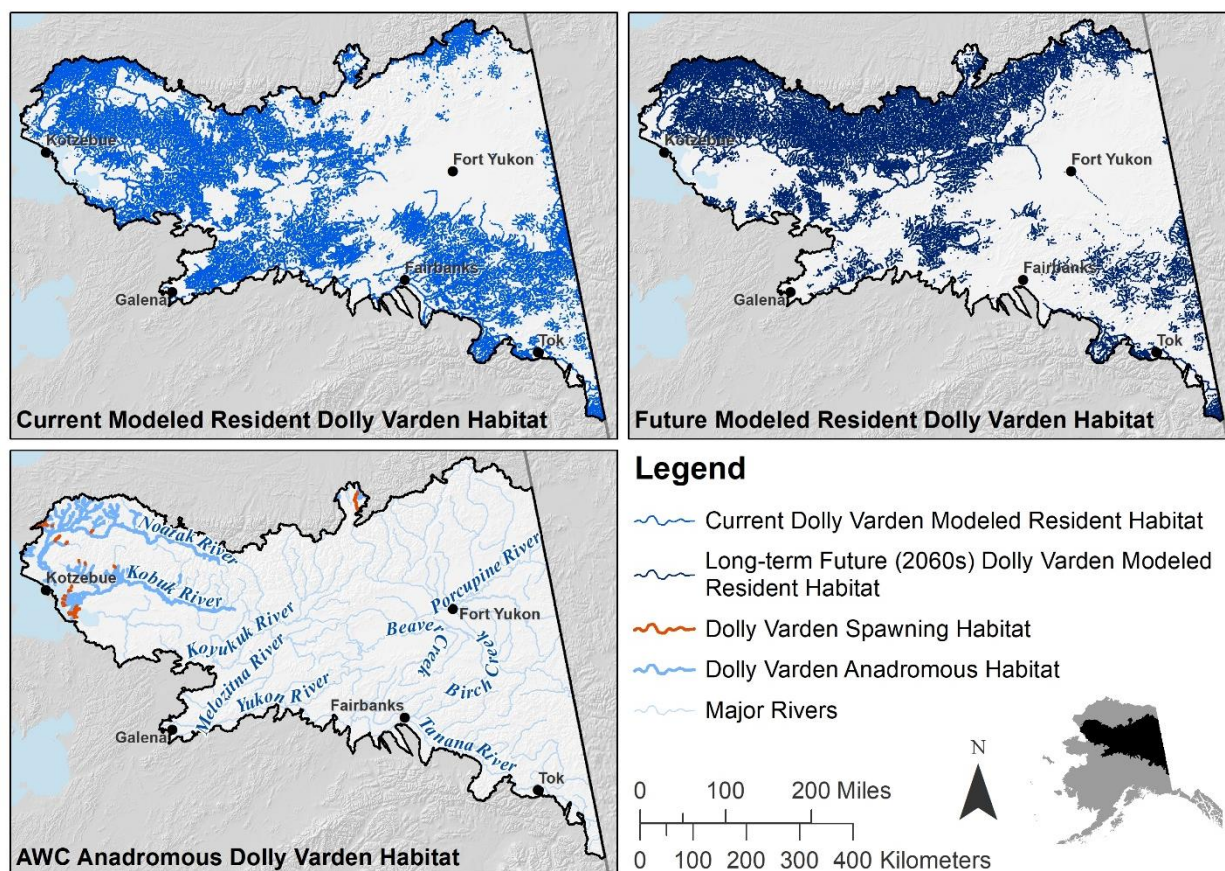


Figure J-9. Modeled current and long-term future resident Dolly Varden habitat and anadromous Dolly Varden habitat (general and spawning) in the CYR study area.

6.1 Conceptual Model

The conceptual model (Figure J-10) is based on a literature review and describes the relationship between the various CAs and natural drivers for Dolly Varden. It is modified from the conceptual model for general effects on fish to include species-specific relationships with CAs, which are shown as **bold** lines.

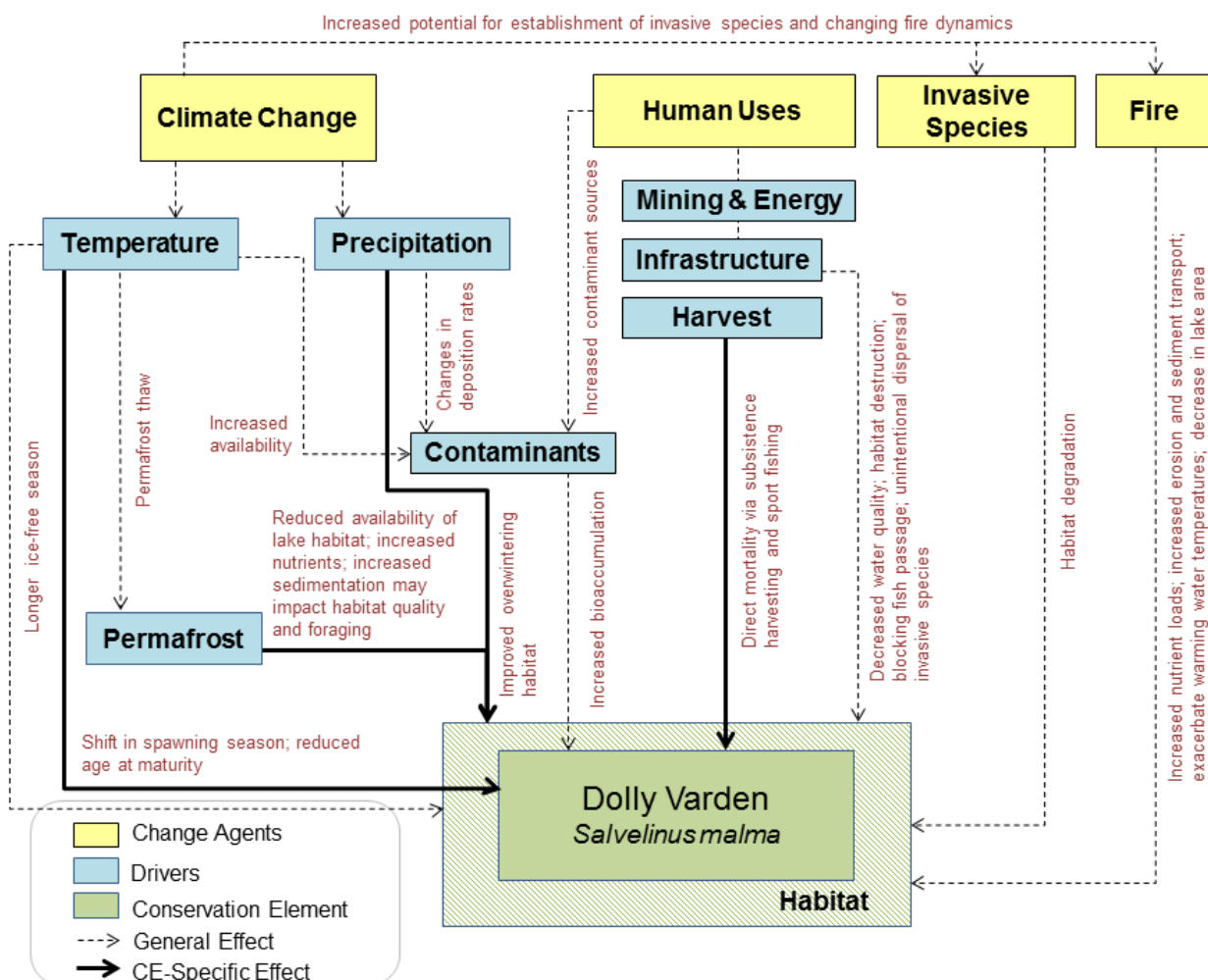


Figure J-10. Conceptual model for Dolly Varden.

6.2 Climate Change

Increasing mean annual temperatures will cause a general trend of permafrost thaw at the landscape level, increasing the soil active layer thickness and the mean annual ground temperature. As permafrost thaws, erosion and runoff into lakes and streams will increase (see Section I. Aquatic Coarse-filter Conservation Elements). Similarly, lake drainage is likely to increase as active layer thickness increases, possibly reducing available habitat for resident lake-dwelling populations of Dolly Varden. Permafrost thaw could increase groundwater flows in winter, improving overwintering habitat and increasing overwintering survival for Dolly Varden. Nutrient input into aquatic habitats will increase as permafrost thaws, potentially increasing primary production and invertebrate food sources (Reist et al. 2006, Bowden et al. 2008).

Increased sedimentation due to permafrost thaw could reduce the quality of spawning habitat and reduce foraging efficiency due to increased turbidity.

Increases in the duration of the ice-free season will extend the growing season for Dolly Varden (Reist et al. 2006). Consequently, the age at maturity will likely decrease because individuals will be able to feed more during any single year. Spawning will likely shift to later in the fall to correspond with the changes in the timing of thermal spawning cues.

6.3 Human Uses

Harvest

Dolly Varden are an important subsistence resource to residents within the CYR study area. Overwintering and spawning populations also provide for sport fisheries.

7. Humpback Whitefish (*Coregonus pidschian*)

Due to a lack of spatial data, humpback whitefish have been identified as a **data gap** and we will not be producing any spatial products for this species. Brown et al. (2012) summarized historic studies on whitefish in the Yukon River, and readers should refer to that source for additional information. However, we cite the original studies summarized by Brown et al. (2012) throughout this section.

The humpback whitefish is found primarily in riverine systems within the CYR study area, although populations within isolated lake systems have been documented as well (Anras et al. 1999). Humpback whitefish mature at four to five years of age and start their upstream migration during the summer and fall. Fidelity to natal spawning areas appears to be high (Hallberg 1989). Spawning takes place in late fall (usually October) and occurs over a gravel substrate in habitats with flowing waters, such as in the upper reaches of rivers (Anras et al. 1999). As with other whitefish, the humpback whitefish broadcasts its eggs, which lodge in the gravel (Morrow 1980). The eggs develop through the winter and larvae hatch in the spring, emerging into the water column during high flows. Larvae are carried downstream by the rapidly flowing water to a wide array of chance destinations that include backwaters along the river, off-channel lakes, and estuary regions at river mouths.

Known humpback whitefish riverine spawning areas in the Yukon River drainage include three in the upper Koyukuk River drainage (Brown 2009), one in the upper reaches of the Yukon Flats (Brown 2000), and at least six in the Tanana River drainage (Kepler 1973, Brown 2006). Many more spawning areas are suspected to occur in the CYR study area. Sampling studies indicate that a spawning migration takes place up the Porcupine River into Yukon, Canada, and that humpback whitefish are also widely distributed in rivers and lakes in the upper Yukon River drainage within Yukon, Canada (Bryan 1973, Walker 1976). However, to our knowledge, riverine spawning areas have not been identified in Yukon, Canada. The upper drainage populations appear to be non-anadromous, remaining in freshwater habitats for life (Brown 2007). Humpback whitefish primarily consume benthic invertebrates (Brown 2007) and colonize off-channel lakes and low-flow stream and river systems during the spring and early summer each year to feed (Alt 1979, Brown 2006, Harper et al. 2007).

7.1 Conceptual Model

The conceptual model (Figure J-11) is based on a literature review and describes the relationship between the various CAs and natural drivers for humpback whitefish. It is modified from the conceptual model for general effects on fish to include species-specific relationships with CAs, which are shown as **bold** lines.

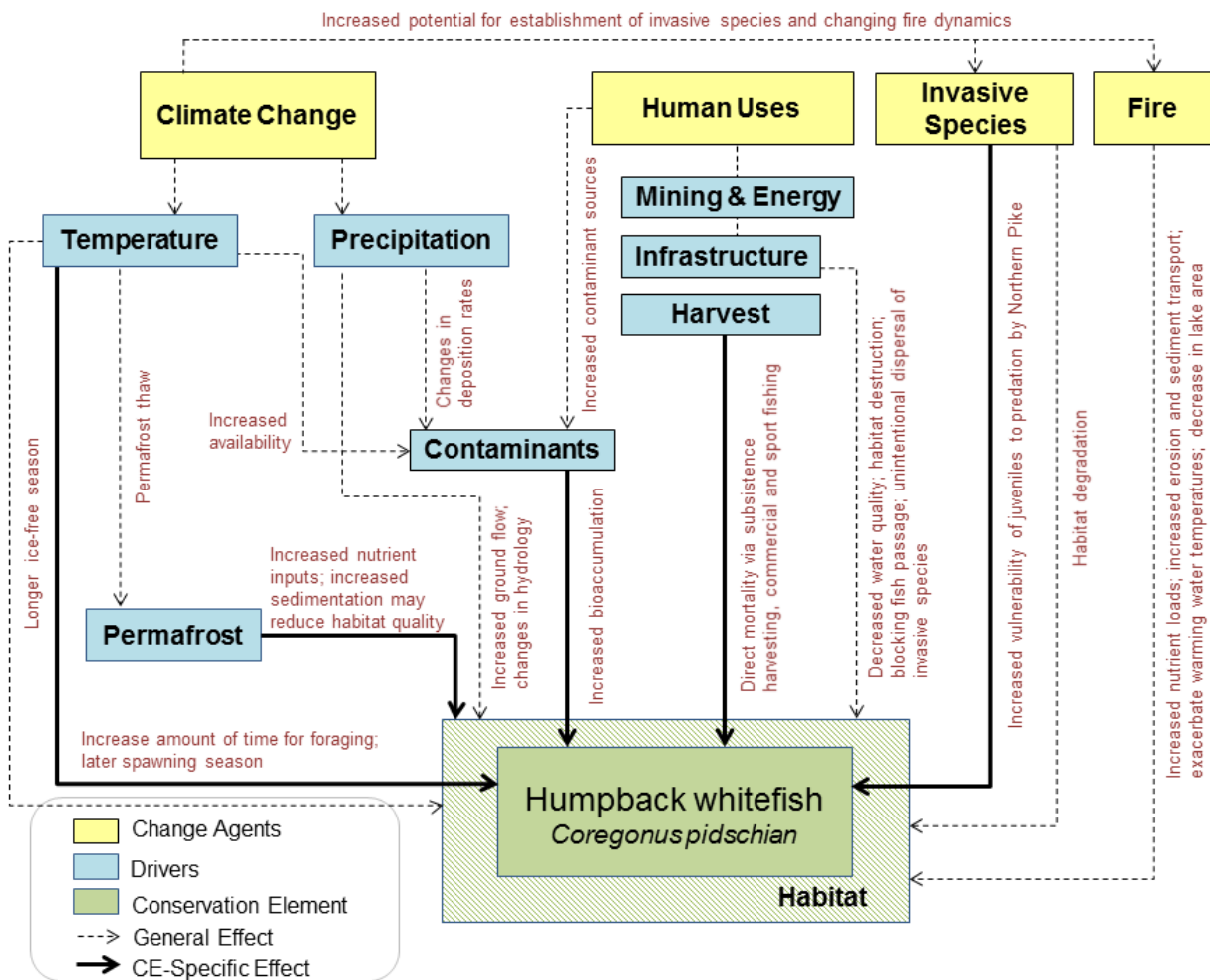


Figure J-11. Conceptual model for humpback whitefish.

7.2 Climate Change

Shallow lakes represent important summer feeding habitats for humpback whitefish. Climate change will increase erosion and runoff into lakes and streams due to a general trend of permafrost thaw at the landscape level (see Section I. Aquatic Coarse-filter Conservation Elements). Similarly, lake drainage is likely to increase as active layer thickness increases. Nutrient input into aquatic habitats will increase as permafrost thaws, thereby increasing primary production and invertebrate populations (Bowden et al. 2008). Increased nutrient input may lead to increased abundance of prey species (Reist et al. 2006). However, increased sedimentation due to permafrost thaw could reduce the quality of spawning habitat and impact foraging abilities.

The ice-free season is the primary feeding time for whitefish species (Reist and Bond 1988). Increases in the duration of the ice-free season will likely increase the amount of time available for foraging (Reist et al. 2006) and may shift spawning to later in the fall.

7.3 Invasive Species

Plants of the *Elodea* genus have become established in the Chena River system near Fairbanks (Chena River, Chena Slough, and Chena Lake) and will likely disperse gradually to suitable habitats downstream within the Tanana River and beyond. Where established, *Elodea* could impact humpback whitefish habitat in ponds, lake margins, and slow-moving streams, and make humpback whitefish more vulnerable to predation by northern pike.

7.4 Human Uses

Harvest

Humpback whitefish are important in the subsistence, commercial, and sport fisheries within the CYR study area (Alt 1994, Brase 2010). Currently, a limited number of permits are issued annually for a spear harvest fishery near the Elliott Highway Bridge. The spear fishery was popular during the 1980s, with peak harvest of approximately 25,000 fish in 1987 (Brase 2010). However, beginning in the early 1990s, a decline in whitefish abundance was observed and the spear fishery was closed until 2007, but remained open to a limited number of permits annually. The cause of the observed decline in humpback whitefish is unknown. Annual harvest data for humpback whitefish within the Yukon and Kuskokwim River drainages are very poor, in part because they are not always distinguished from broad whitefish (Brase and Hamner 2003, Hayes et al. 2008, Whitmore et al. 2008). A small number of recent subsistence research reports have gathered species-specific harvest data for various regions within the study area (Brown et al. 2005, Andersen 2007). All of these harvest data, however, have been generated from winter memories of summer harvests, which have limited utility for management or population assessment purposes. Relative abundance data from a humpback whitefish spawning migration have been collected for the last 10 years in the main-stem Yukon River (S. Zuray, Rapids Research Center, unpublished data).

Contaminants

Exposure to toxic pollutants could reduce the value of humpback whitefish as a subsistence resource. Because humpback whitefish consume mostly lower trophic level species such as invertebrates, they are less likely to contain high levels of contaminants compared to piscivorous species. However, humpback whitefish are long-lived and have the potential to bioaccumulate contaminants over time. Thus, the effects of contaminants on individual fish over time and human exposure of contaminants through consumption of fish is a potential concern.

8. Chum Salmon (*Oncorhynchus keta*)

Chum salmon are anadromous fish that typically begin their seaward migration soon after emerging from the spawning gravel. Chum salmon typically spend two to four winters at sea, however, little is known about the marine migratory patterns of chum salmon originating from the CYR study area. As adults, chum salmon return to their natal streams to spawn in late summer or early fall (Irvine et al. 2009). 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.

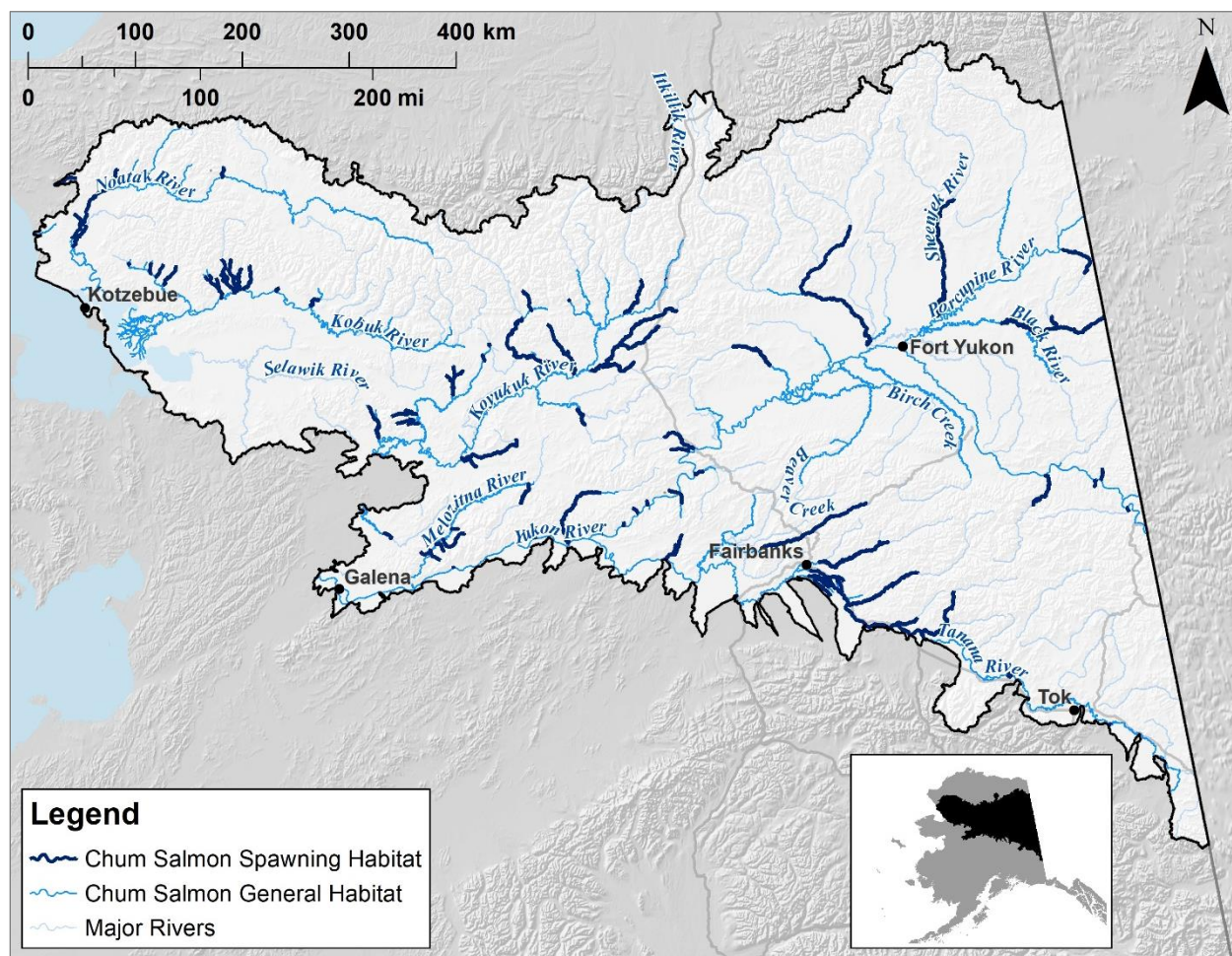


Figure J-12. Chum salmon distribution and spawning habitats in the CYR study area.

Spawning populations of chum salmon have been documented throughout the Yukon River drainage (Burril et al. 2010), in addition to the Kobuk and Noatak rivers (Bendock 1979, Craig and Haldorson 1986; Figure J-18). The lower thermal temperature limit for chum salmon is 2.7 °C (Azumaya et al. 2007), so warming conditions may produce more suitable habitat for chum salmon in both Arctic and Interior Alaska.

Chum salmon spawn in gravel of streams, side channels, and intertidal portions of streams (Buklis 2010). Upwelling groundwater is a requirement of all spawning areas. The upwelling water helps keep silt suspended in spawning areas prone to high silt loads such as side-channel sloughs. Upwelling water also assists in preventing spawning areas from freezing during winter months.

Chum salmon sustain the highest commercial harvests of all Pacific salmon species in Arctic and Interior Alaska. In Interior Alaska, chum salmon are an important source of fresh and dried fish for subsistence and personal use (Buklis 2011).

8.1 Conceptual Model

The conceptual model (Figure J-13) is based on a literature review and describes the relationship between the various CAs and natural drivers for chum salmon. It is modified from the conceptual model for general effects on fish to include species-specific relationships with CAs, which are shown as **bold** lines.

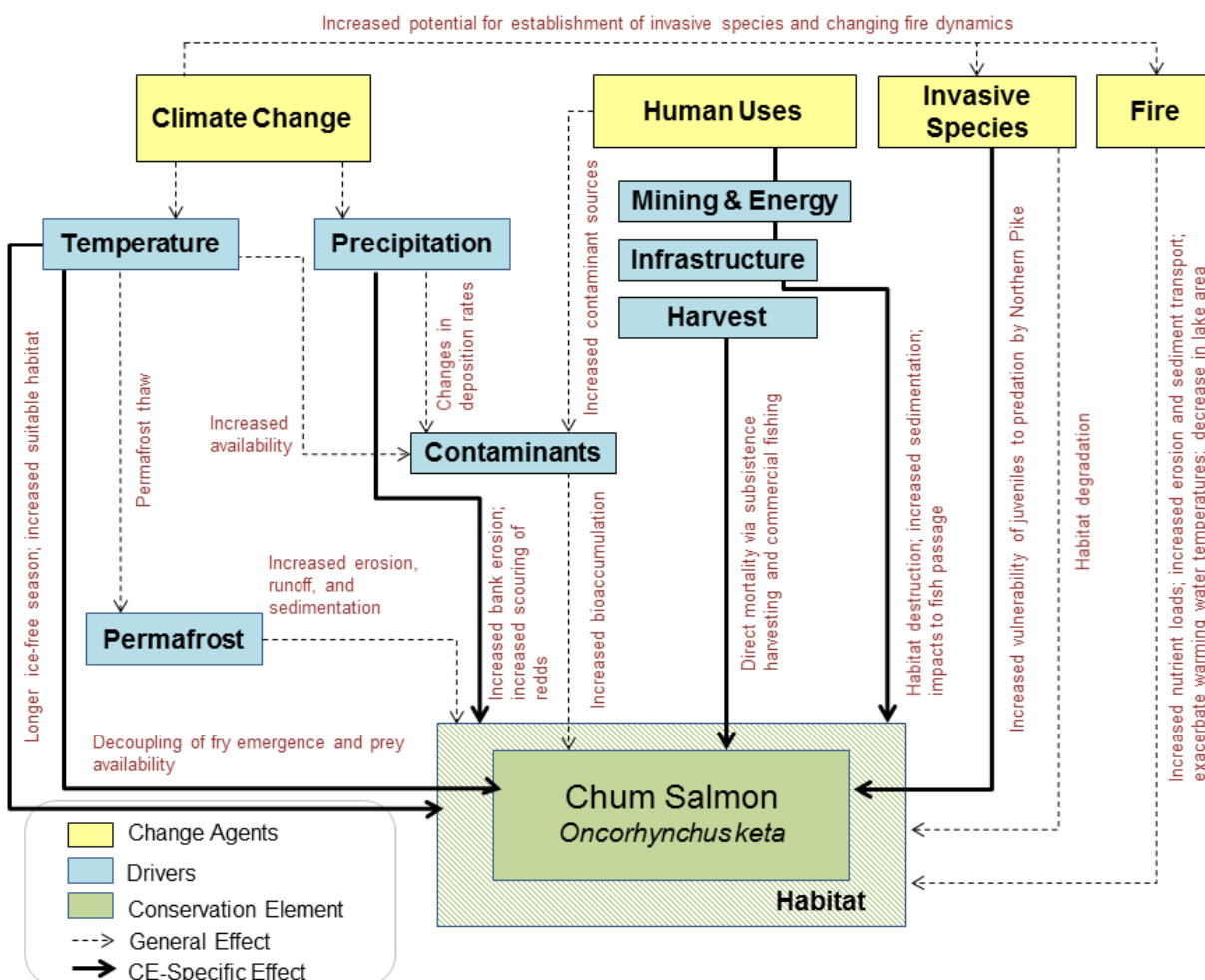


Figure J-13. Conceptual model for chum salmon.

8.2 Climate Change

Water flow through the substrate, water temperature, and dissolved oxygen concentration are important factors that influence redd site selection by chum salmon (Maclean 2003). Chum salmon may benefit from increases in water temperatures and base flows because they tend to select warmer and more stable water temperatures for spawning habitat (Maclean 2003). Increased precipitation (especially in winter) could have negative impacts on chum salmon spawning habitat by increasing the potential scouring of redds and erosion of streambanks. Timing of fry emergence is related to temperature during incubation (Salo 1991), and warmer water temperatures may advance the timing of fry emergence in relation to the availability of prey (Cushing 1990, Gotceitas et al. 1996).

8.3 Invasive Species

Plants of the *Elodea* genus have become established in the Chena River system near Fairbanks (Chena River, Chena Slough, and Chena Lake) and will likely disperse gradually to suitable habitats downstream within the Tanana River and beyond. Where established, *Elodea* may negatively impact chum salmon spawning habitat and make juvenile chum salmon more vulnerable to predation by northern pike.

8.4 Human Uses

The largest potential impacts from development and human activities would be to spawning habitats, since juveniles migrate to sea soon after emerging. Infrastructure and development, 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 (Beschta 1978). Similarly, stream culverts at road crossings may hinder migration routes.

Harvest

Chum salmon are an important subsistence and commercial species in the Yukon River drainage and are the most commonly harvested species (Estensen et al. 2012).

9. Inconnu (*Stenodus leucichthys*)

Inconnu overwinter predominantly in near-shore coastal waters, estuaries, and low gradient rivers. In the CYR study area, inconnu feed at the mouths of major tributaries along the Yukon River during summer months. Inconnu annually make long migrations between overwintering habitat and feeding habitat (L. Stuby, pers. comm.). Therefore, inconnu likely migrate into and out of the CYR study area seasonally, as the study area does not include coastal waters or estuaries. Juvenile inconnu feed on aquatic invertebrates and other small prey while adults feed predominantly on other fish (Brown et al. 2012).

Inconnu mature at 6 to 9 years old for males and 7 to 12 years old for females. Once mature, inconnu spawn multiple times throughout their lifetimes with high spawning site fidelity (Brown and Burr 2012). Because of the energy required for spawning, inconnu often do not spawn every year once mature, although annual spawning does occur (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, inconnu spawn from mid- to late October and in other spawning areas from late September to mid-October (Brown et al. 2012). The age at maturity and the timing of favorable temperature conditions for spawning determine when individuals will migrate from feeding habitats to spawning habitats.

Spawning habitat is located in clear-water streams of moderate size with gravel substrates. The AWC distribution of inconnu included the Kobuk, Selawik, Koyukuk, and Yukon River drainages and some associated tributaries, with spawning reaches identified in the Yukon Flats and the Alatna and Koyukuk watersheds (Figure J-14). Additional inconnu habitats were added to the spatial distribution datasets using published reports (see Section 2.1 Distribution Modeling).

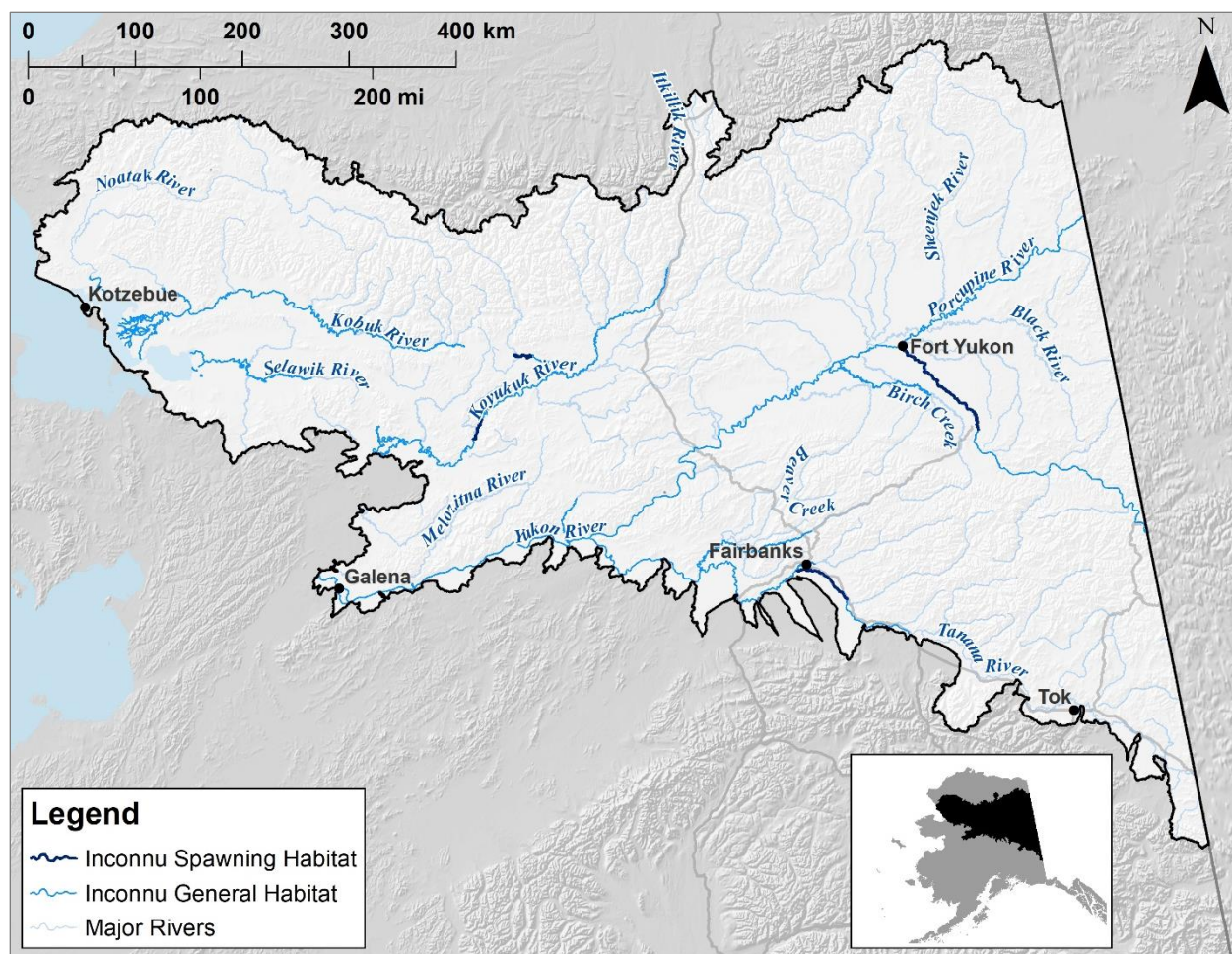


Figure J-14. Inconnu distribution and spawning habitats in the CYR study area.

Spawning individuals sometimes arrive a month or two before spawning to feed in waters near spawning sites. During spawning, eggs are broadcast and settle into the gravel substrate of streams. After the one to two week spawning period, inconnu swim downstream to overwintering habitat (L. Stuby, pers. comm.).

9.1 Conceptual Model

The conceptual model (Figure J-15) is based on a literature review and describes the relationship between the various CAs and natural drivers for inconnu. It is modified from the conceptual model for general effects on fish to include species-specific relationships with CAs, which are shown as bold lines.

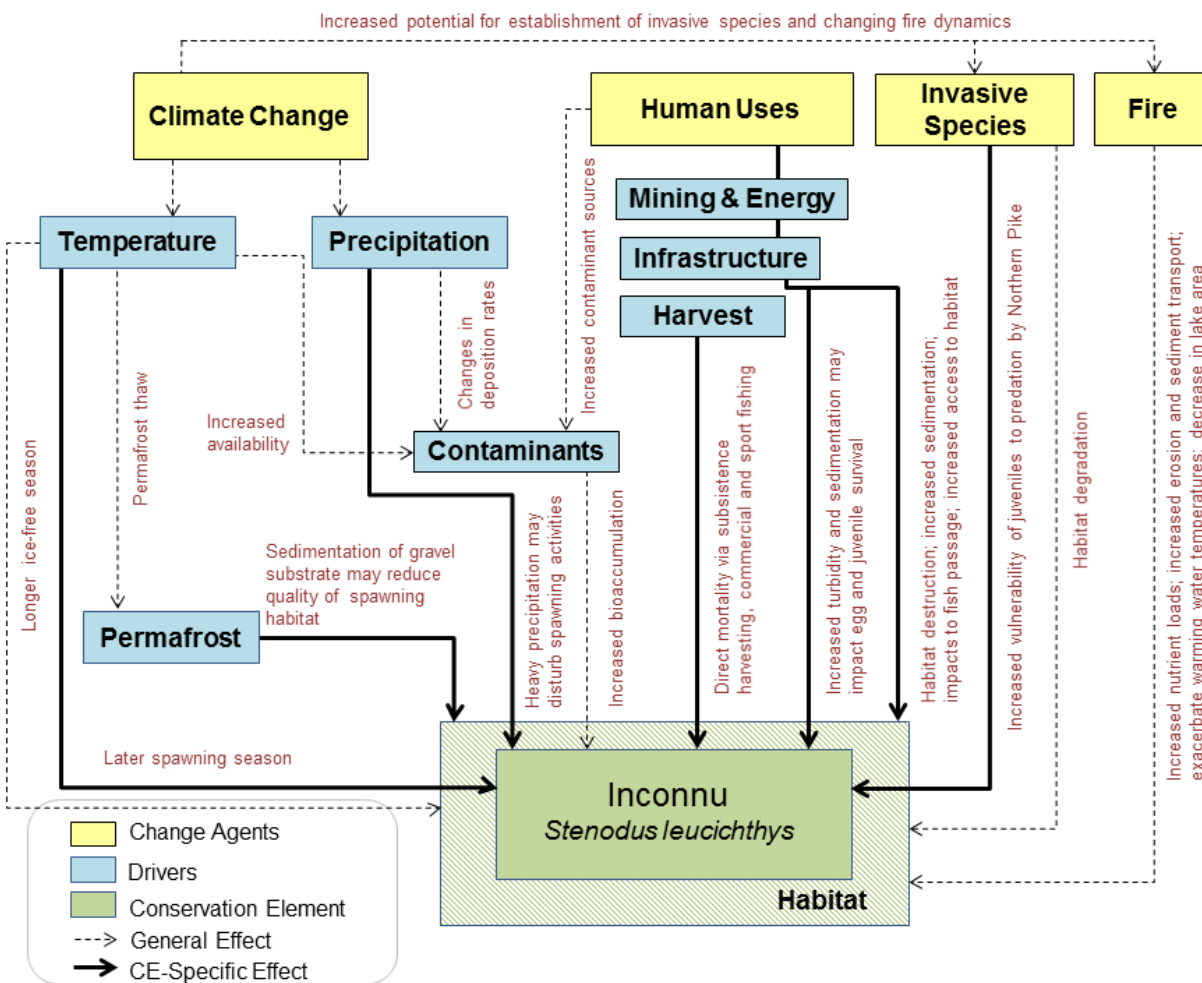


Figure J-15. Conceptual model for inconnu.

9.2 Climate Change

Spawning will shift later in the year to correspond with the time that water temperature approaches 0 °C. Sedimentation of gravel substrates may reduce the quality of spawning habitat (Brown et al. 2012). Heavy precipitation during spawning season may increasingly disturb spawning activities (L. Stuby, pers. comm.).

9.3 Invasive Species

Plants of the *Elodea* genus have become established in the Chena River system near Fairbanks (Chena River, Chena Slough, and Chena Lake) and will likely disperse gradually to suitable habitats downstream within the Tanana River and beyond. Where established, *Elodea* may negatively impact inconnu spawning habitat and make juvenile inconnu more vulnerable to predation by northern pike.

9.4 Human Uses

Major construction, especially of roads will increase erosion and runoff leading to increased stream turbidity and sedimentation. Increased turbidity and sedimentation could have negative impacts on egg and juvenile survival (Brown et al. 2012). Bridges and culverts could affect

inconnu habitat directly by increasing sedimentation or altering migration routes. In addition to direct environmental changes resulting from road construction, roads increase human access to previously remote areas, which facilitates increased recreational use of resources.

Harvest

Inconnu are an important subsistence species, with substantial harvest during the winter on the lower Yukon River (Crawford 1979) and throughout the Yukon River drainage during the ice-free season (Estensen et al. 2012, Jallen et al. 2012). Annual harvest ranges from 12,000 to 20,000 (Brase and Hamner 2003), and many of these are harvested incidentally during fisheries targeting salmon (Brown et al. 2012) and Bering cisco (Estensen et al. 2012). Brown et al. (2012) pointed out that incidental harvest in Canadian commercial fisheries has led to the extinction of inconnu spawning populations there and that Yukon River populations may be similarly vulnerable because they migrate concurrent with salmon and are susceptible to salmon fishing gear (i.e., gill nets and fish wheels). The strength of Yukon River inconnu populations are not monitored, further adding to their vulnerability. Distribution of sport fishing effort, as indicated by catch and harvest, is likewise widespread.

10. Northern Pike (*Esox lucius*)

Due to a lack of spatial data, we did not produce any spatial products for northern pike and have identified this species as a **data gap**.

Northern pike overwinter predominantly in deep, slow moving rivers of medium to large size, deep sloughs, and deep connected lakes. Pike migrate out of their overwintering habitat to spawn in the spring once the ice has melted off the water. Females lay eggs in vegetated margins of lakes, sloughs, and slow moving streams. 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 overwintering habitat (Scanlon 2009). Eggs hatch within approximately 30 days (Alt 1994). After spawning, adults migrate to feed in various locations throughout the ice-free season, preferring warm and shallow habitats (Alt 1994).

Juvenile pike feed on small invertebrates but quickly transition to consuming fish. Adult pike are a top-level predator that primarily consume other fish, although they have also been documented to eat small mammals (e.g., shrews and mice). 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. Where northern pike naturally occur in Alaska, they are valued as a subsistence and sport fish (Alt 1994).

10.1 Conceptual Model

The conceptual model (Figure J-16) is based on a literature review and describes the relationship between the various CAs and natural drivers for northern pike. It is modified from the conceptual model for general effects on fish to include species-specific relationships with CAs, which are shown as bold lines.

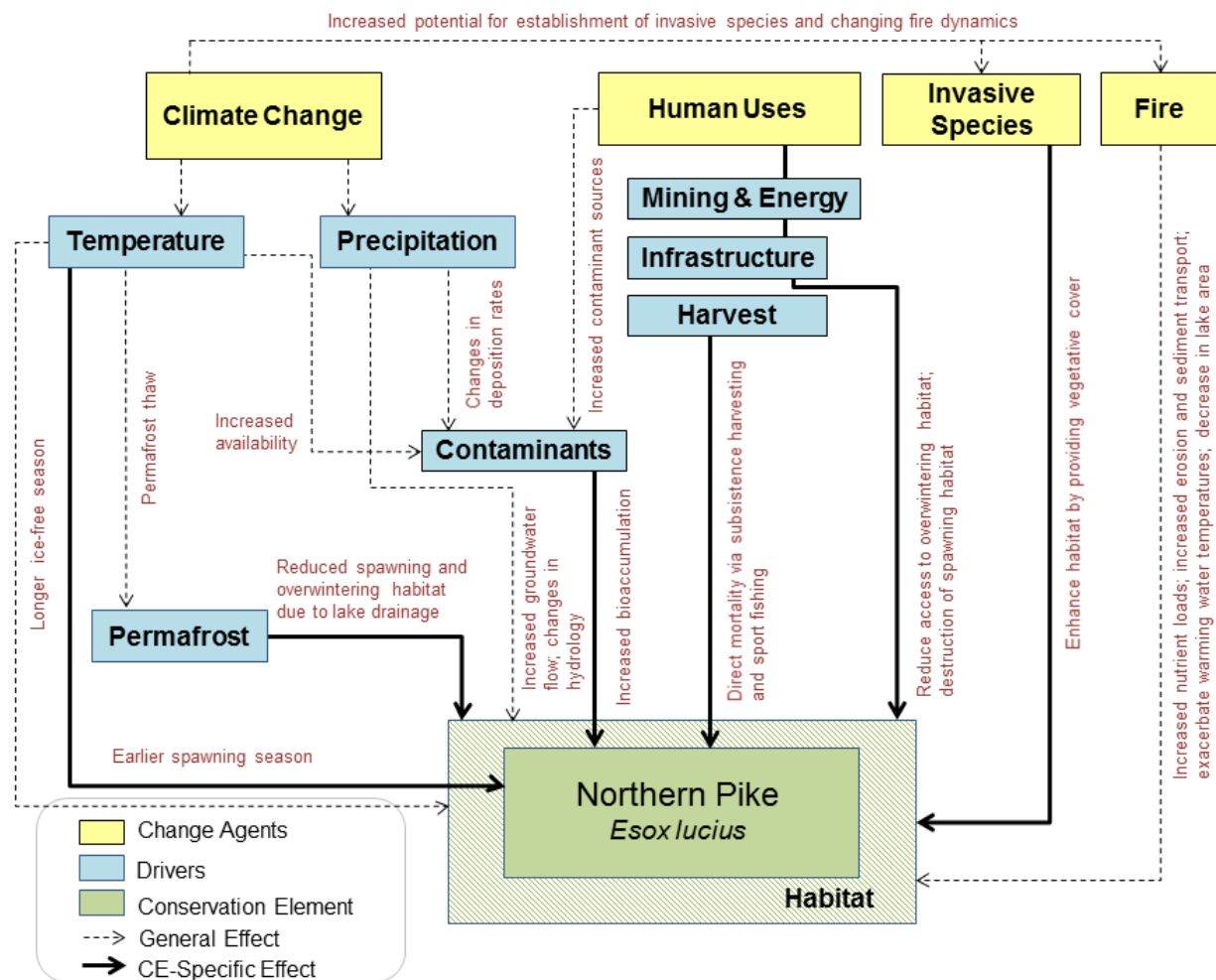


Figure J-16. Conceptual model for northern pike.

10.2 Climate Change

Spawning will shift earlier in the year to correspond with the time that aquatic habitats become ice-free. A trend of lake drainage is likely to increase as the depth of the active layer increases (Rouse et al. 1997). Spawning areas in lake margins may be reduced by lake drainage or may become disconnected from river systems, resulting in an overall reduction of spawning habitat. However, spawning habitat in sloughs and slow, large streams is less likely to be affected. The drainage of lakes will partially reduce available overwintering habitat, although sloughs and deep rivers suitable for overwintering will remain present.

10.3 Invasive Species

Plants of the *Elodea* genus have become established in the Chena River system near Fairbanks (Chena River, Chena Slough, and Chena Lake) and will likely disperse gradually to suitable habitats downstream within the Tanana River and beyond. Where established, *Elodea* may enhance northern pike habitat by providing cover for this ambush predator.

10.4 Human Uses

Construction of roads may reduce the accessible area of sloughs for overwintering. Construction or development, especially large scale mining operations, along vegetated river margins, sloughs, or lake shores could destroy northern pike spawning habitat.

Contaminants

Adult northern pike accumulate high concentrations of methylmercury, 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 pike from western Alaska, adults should consume no more than one pike meal per month (Jewett and Duffy 2007). Future increases in mercury concentrations in aquatic habitat could reduce the value of pike as a subsistence resource or render it unfit for human consumption.

Harvest

Northern pike are an important subsistence and sport fish within the CYR study area.

11. Impacts of Human Activity on Stream Ecology

Management Question W2 specifically asks about *future* road construction and mining. Although both future roads and future mineral potential are included in the long-term LCM, we conducted separate spatial analyses intersecting these future layers with our fish distributions to identify the projects or watersheds with the potential to impact fish species of conservation concern.

MQ V1: How does human activity (e.g., mineral extraction, gravel extraction) alter stream ecology and watershed health (i.e., water quantity, water quality, outflow/stream connectivity, fish habitat, and riparian habitat)?

MQ W2: How might future road construction and mineral extraction infrastructure (e.g., both temporary and permanent roads, pads, pipeline) affect fish habitat, fish distribution, and fish movements (especially chinook, chum, inconnu)?

11.1 Methods

Four datasets were used to represent future road construction in the study area: preferred routes to Nome, Umiat, and Ambler; and proposed forestry roads. These roads were intersected with the distributions of the four spatially explicit Aquatic Coarse-filter CEs (Table J-11, Figure J-17, Figure J-18, Figure J-19, and Figure J-20). The anadromous Dolly Varden habitat distribution and modeled resident Dolly Varden habitat distribution for the 2060s were combined into a single distribution for this analysis.

There are no layers representing future mineral extraction infrastructure for the study area so we used a U.S. Geological Survey (USGS) spatial dataset of 6th-level hydrologic units attributed by their mineral resource potential and certainty for six different deposit types (Jones et al. 2015). For each of the deposit types, 6th-level hydrologic units with any combination of medium to high potential or certainty were intersected with Aquatic Fine-filter CE distribution datasets.

11.2 Results

Road intersections were highest for Dolly Varden because Dolly Varden had the largest distribution in the study area (almost four times that of Chinook salmon). There are numerous documented spawning reaches for Chinook and chum salmon that would be impacted by future road crossings (28 and 40, respectively). Both road construction and road use would pose risks to productivity for these populations.

Roads have many effects on both aquatic habitat and fish movements. Water quality impairments from road crossings include increased sedimentation and delivery of toxic compounds from the road surface (Forman and Alexander 1998). Types of toxic compounds contributed by roads to streams include heavy metals and organic pollutants (e.g., PCBs or hydrocarbons) from vehicles, ozone from vehicle exhaust, and deicing salts (Trombulak and Frissell 2000). Physical habitat impairments from incorrectly sized culverts are numerous and include stream channelization; scouring or erosion downstream of perched culverts; ponding and sedimentation upstream; decreased transport of water, sediments, and wood downstream; and partial to complete blockage, which may lead to failure during flood events (Wheeler et al.

2005). Culverts blocking fish passage leads to differences between upstream and downstream fish communities and densities (Evans et al. 2015, Maitland et al. 2015). Culverts in Southcentral Alaska have been shown to block both upstream and downstream migrations of juvenile salmon (Davis and Davis 2011). Finally, roads are also an important pathway transporting invasive species to aquatic habitats (Trombulak and Frissell 2000).

Table J-11. Future road intersections with general and spawning habitats of Aquatic Fine-filter CEs.

Fine-filter CE	Number of Road Intersections with General Habitat	Number of Road Intersections with Spawning Habitat
Chinook salmon	45	28
Chum salmon	60	40
Inconnu	14	0
Dolly Varden ¹	219	NA

¹Dolly Varden includes current habitat identified in the AWC in addition to long-term future (2060s) modeled resident habitat.

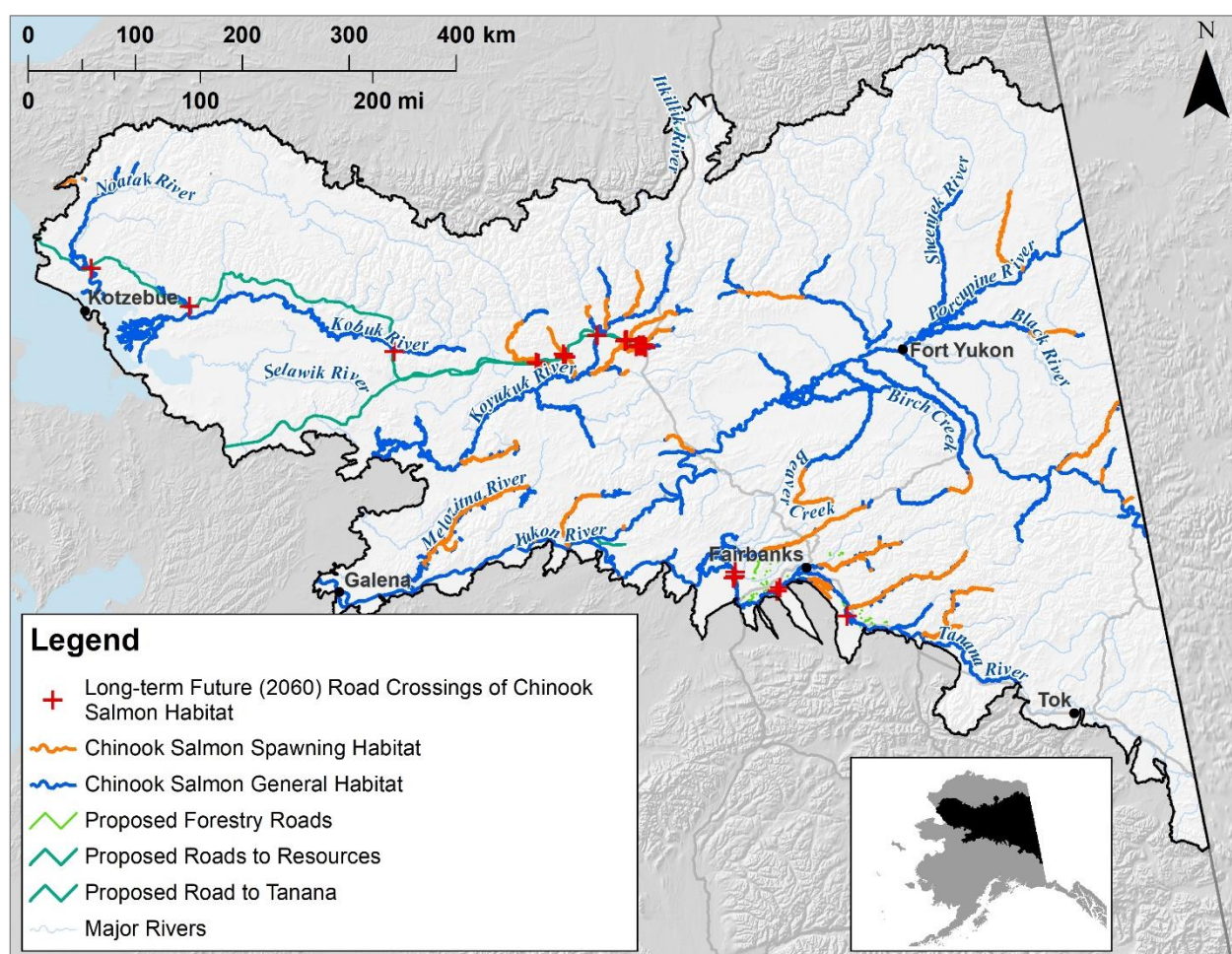


Figure J-17. Chinook salmon habitat and future roads in the CYR study area.

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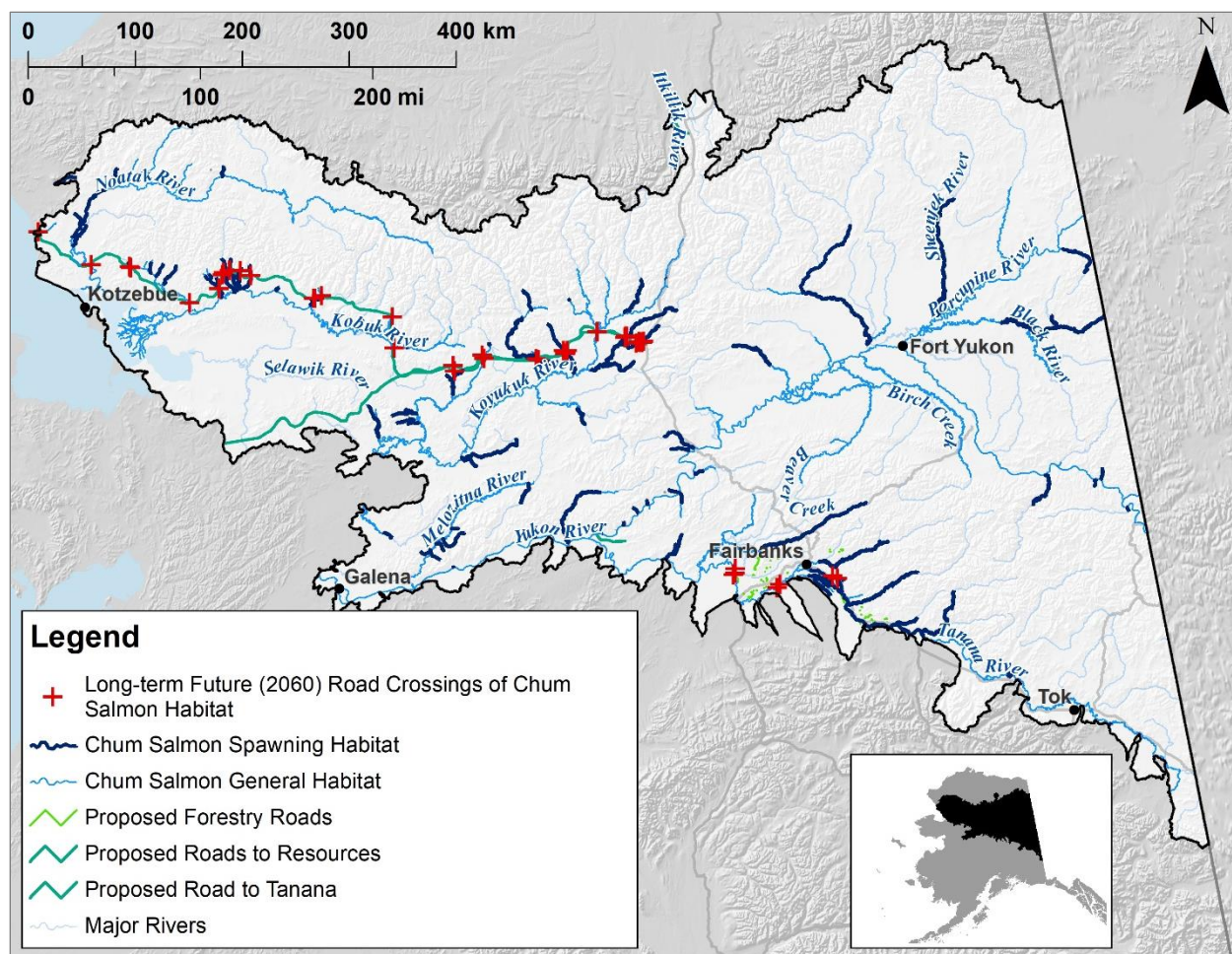


Figure J-18. Chum salmon habitat and future roads in the CYR study area.

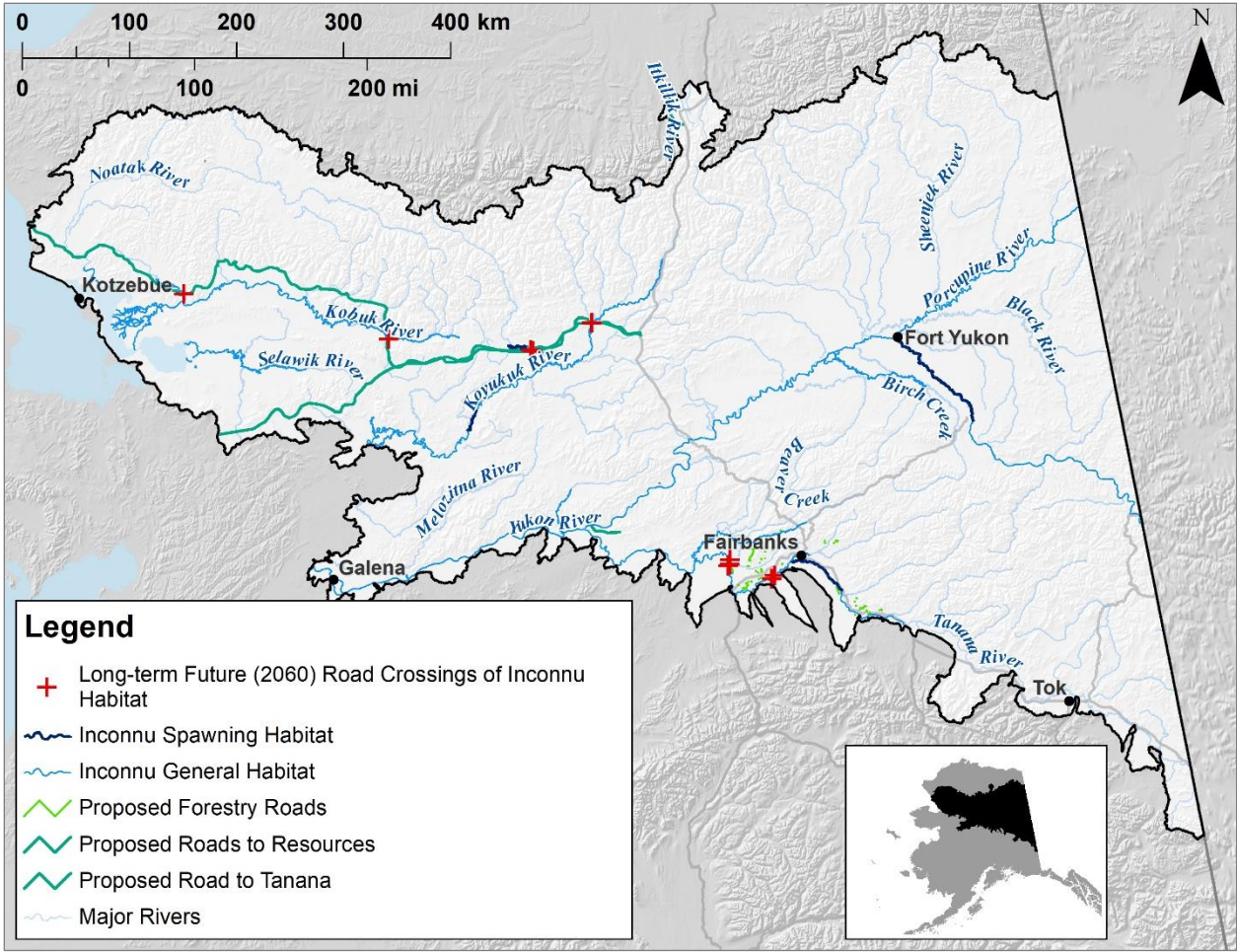


Figure J-19. Inconnu habitat and future roads in the CYR study area.

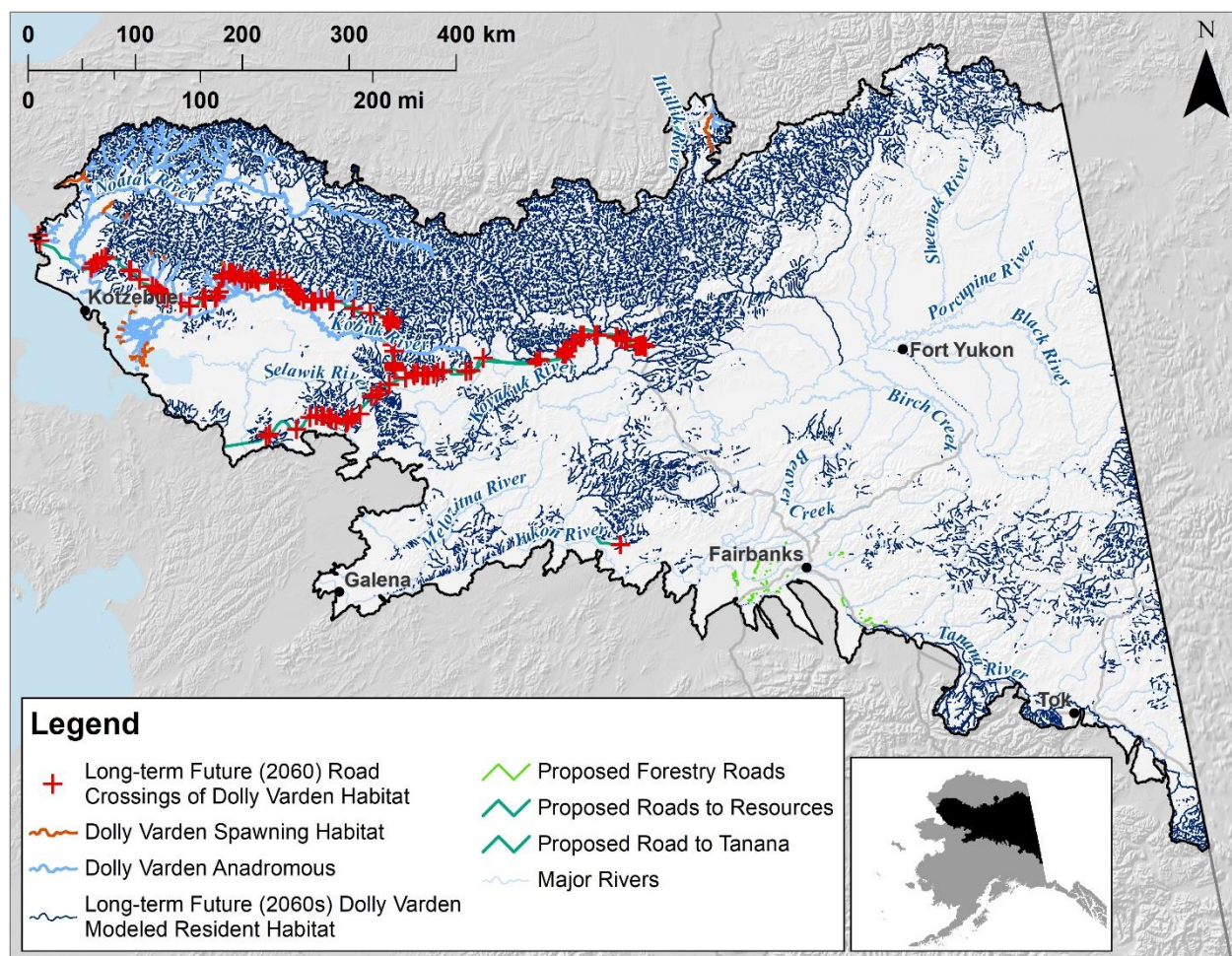


Figure J-20. Dolly Varden habitat and future roads in the CYR study area.

All four spatially explicit Aquatic Fine-filter CEs have the potential to be impacted by future mining in the study area (Table J-12, Figure J-21, Figure J-22, Figure J-23, and Figure J-24). Chinook salmon and Dolly Varden are slightly more susceptible than chum salmon or inconnu, likely because they utilize habitats in smaller, high gradient streams where mineral deposits occur. In the figures, we highlighted watersheds with placer and paleoplacer gold deposits because high gold prices have driven a steady increase in placer mining activity over the past decade (McDowell Group 2014).

Placer mining in streams affects water quality and physical habitat. Water quality impacts include increased turbidity and heavy metal concentrations (LaPerriere and Reynolds 1997, Brabets and Ourso 2013). Physical habitat impacts include removal of riparian vegetation (Van Haveren and Cooper 1992), channelization of the streambed resulting in loss of instream habitat diversity, such as deep pools or riffles (Gilvear et al. 1995), and sedimentation of substrates (Wagener and LaPerriere 1985, Van Nieuwenhuysen and LaPerriere 1986).

Habitat changes due to mining can directly impact fish communities both at the mining operation and downstream. Direct effects may include mortality during mining or sedimentation of spawning gravels suffocating eggs (Harvey and Lisle 1998), while indirect effects include changes to stream food webs. Primary productivity and algal biomass were completely

undetected in heavily mined streams (10–12 active mines) and 50% less in moderately mined streams (3–4 active mines) than in unmined streams (Van Nieuwenhuyse and LaPerriere 1986). Decreases in macroinvertebrate abundance and biomass have also been documented in streams affected by placer mining (Wagener and LaPerriere 1985), with significant changes persisting many years after mining (12–50 years, Milner and Piorkowski 2004).

Studies have documented increased heavy metal exposure (e.g., mercury, arsenic, and antimony) in macroinvertebrate tissues from mining practices in other parts of Alaska (Matz 2012). Juvenile fishes eat macroinvertebrates, so heavy metal accumulation in their prey could have negative health impacts on Aquatic Fine-filter CEs. Adult fish could accumulate high levels of mercury and other contaminants in their tissues.

Table J-12. Mineral potential and effects on Aquatic Fine-filter CEs.

Mineral Deposit Types	Percent of Aquatic Fine-filter CE Habitat Impacted			
	Chinook Salmon	Chum Salmon	Inconnu	Dolly Varden ¹
Rare earth elements	9%	7%	6%	9%
Placer and paleoplacer gold	14%	10%	8%	11%
Platinum group	7%	4%	2%	6%
Carbonate-hosted copper	7%	5%	6%	6%
Sandstone uranium	13%	10%	9%	12%
Tin-tungsten-molybdenum-fluorspar	10%	9%	6%	10%

¹Dolly Varden includes current habitat identified in the AWC in addition to long-term future (2060s) modeled resident habitat.

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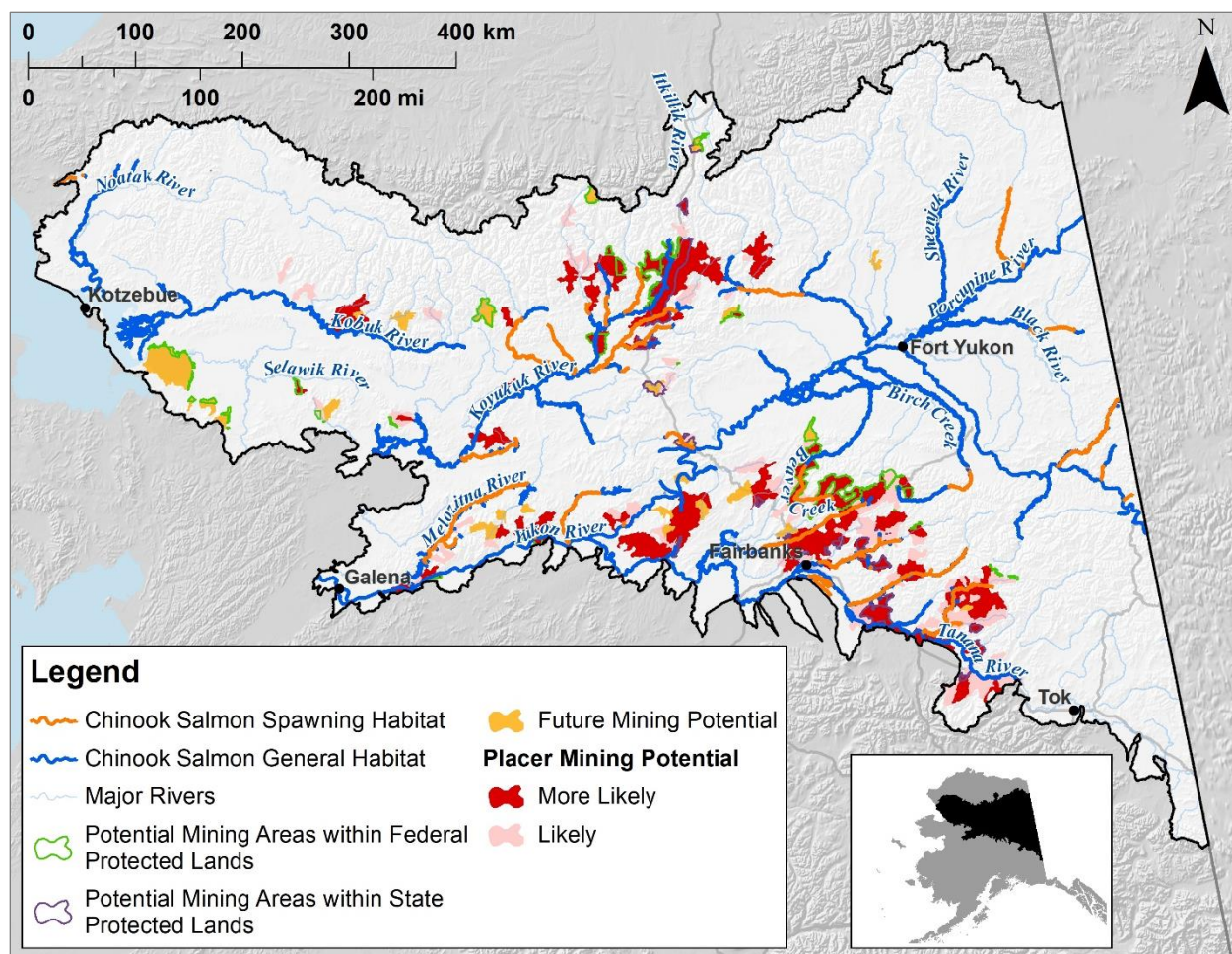


Figure J-21. Chinook salmon habitat and mineral potential in the CYR study area.

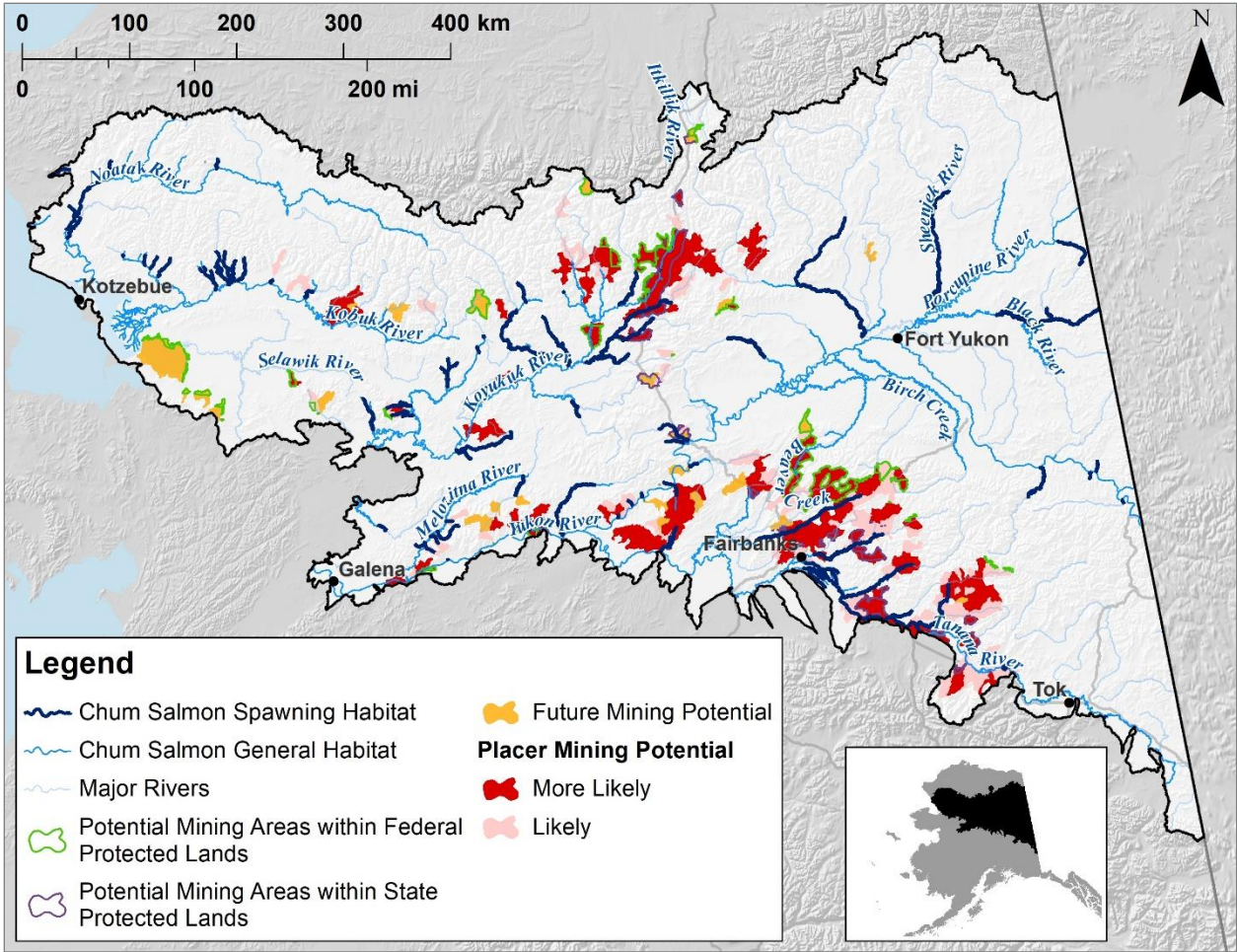


Figure J-22. Chum salmon habitat and mineral potential in the CYR study area.

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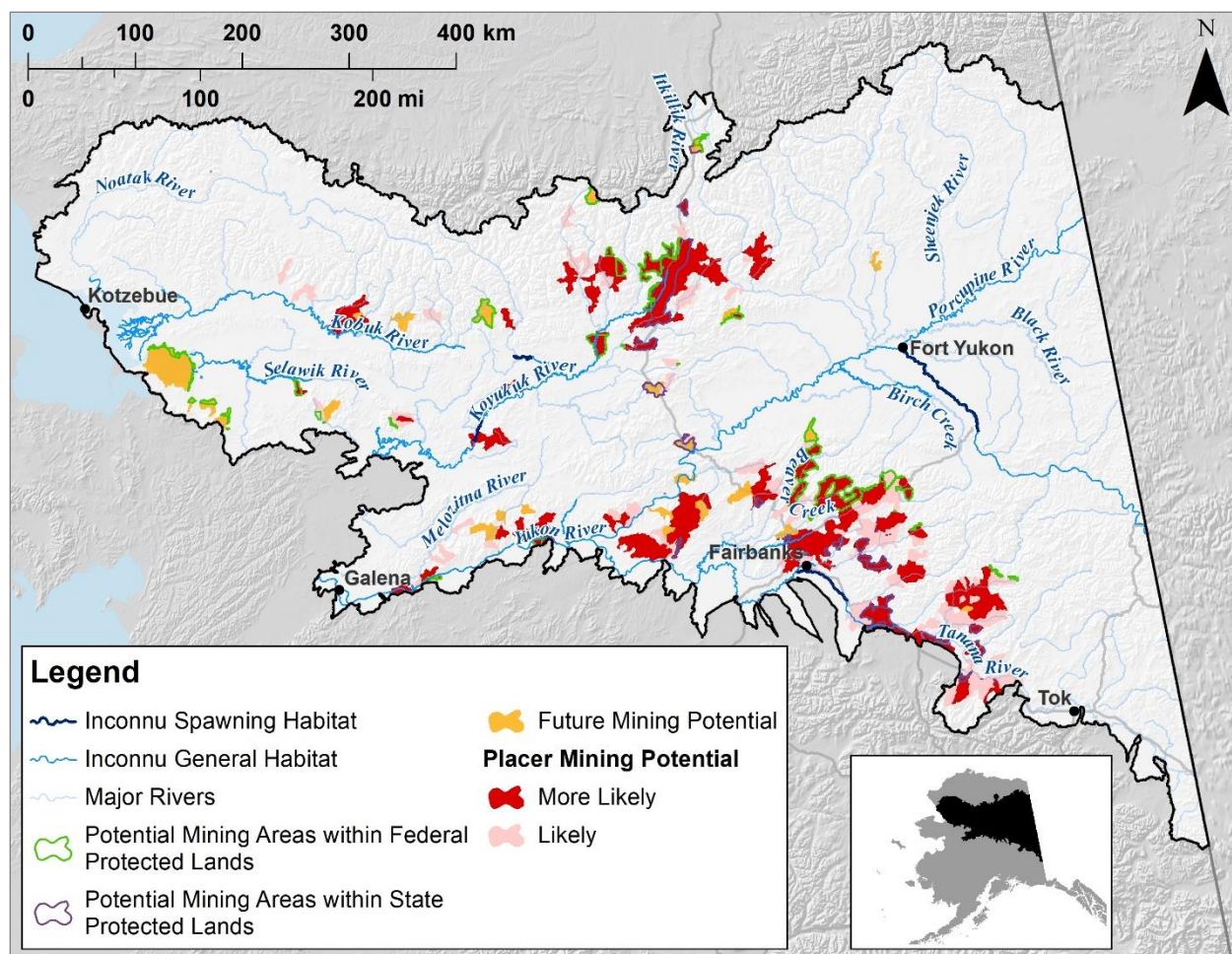


Figure J-23. Inconnu habitat and mineral potential in the CYR study area.

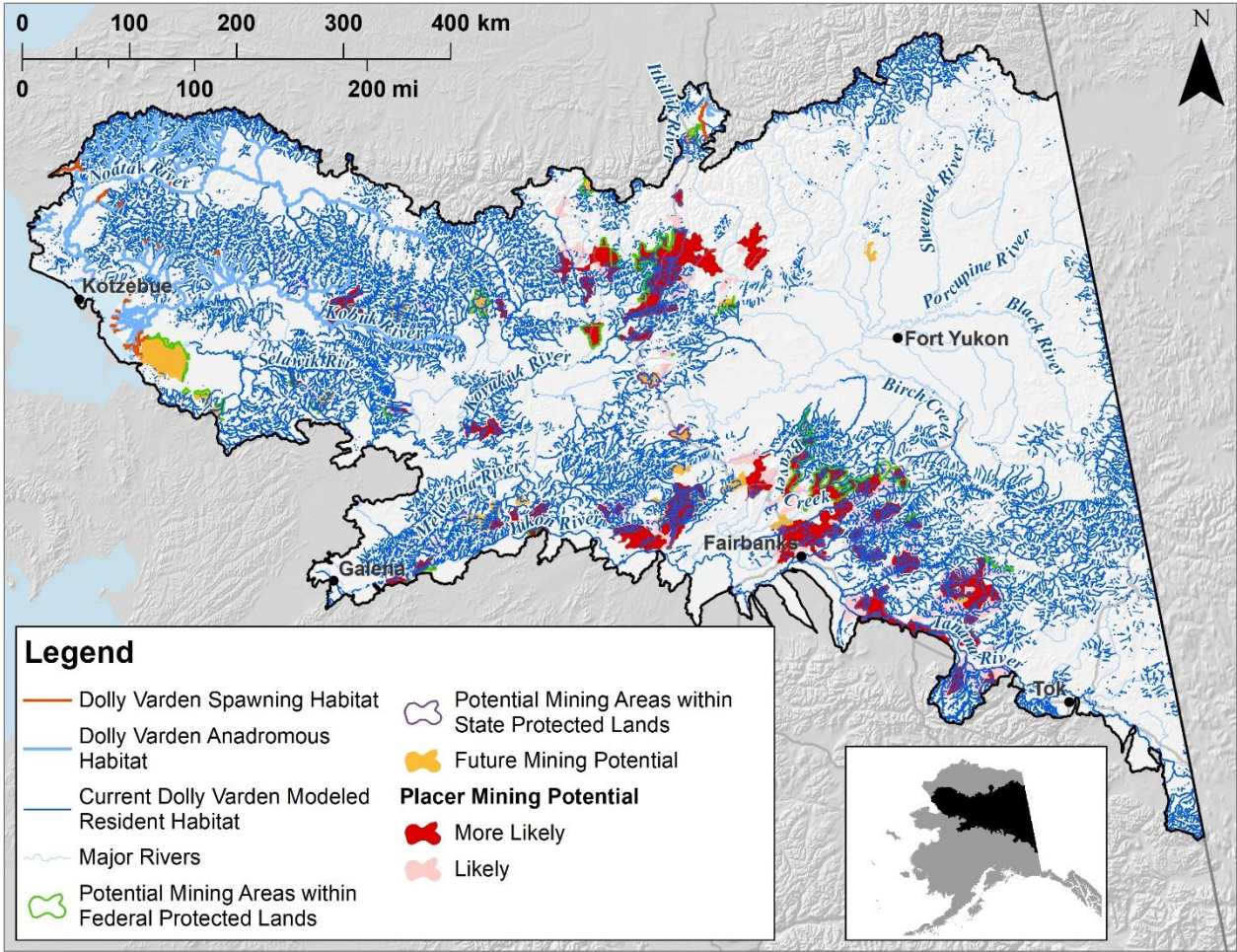


Figure J-24. Dolly Varden habitat and mineral potential in the CYR study area.

12. Data Gaps and Limitations

The only spatial dataset representing fish distribution in the CYR study area was the Anadromous Waters Catalog (AWC). The AWC included habitat for anadromous species, and ADF&G estimates that it represents less than half of the streams, rivers, and lakes actually used by anadromous species. The AWC was used as the sole data source to represent distributions for Chinook salmon and chum salmon. Because Chinook rear in freshwater and new rearing habitats have been discovered far from spawning grounds (Daum and Flannery 2011), Chinook salmon distribution was likely underrepresented in the study area. For both Chinook and chum salmon, additional spawning habitats likely exist that have not been identified. The chum salmon distribution in the AWC included several drainages without spawning habitat. However, because chum salmon juveniles migrate downstream after emergence, the upper reaches of these drainages were likely spawning destinations. Examples include Beaver and Birch creeks, where distributions extend all the way to the White Mountains without any spawning habitats identified.

Both inconnu and Dolly Varden exhibit anadromous and resident life histories. For inconnu, we added to the habitat identified in the AWC based on published reports and input from BLM fish biologists. No spawning areas were identified on the Porcupine or upper Yukon rivers in the inconnu distribution dataset because those spawning areas have not yet been located (Brown et al. 2012). In addition, it was not known whether the additional habitats added to the AWC support anadromous populations.

Dolly Varden distribution was represented by both the anadromous habitats identified in the AWC and a resident habitat distribution model. The AWC may have underrepresented anadromous populations of Dolly Varden because we were unable to find research on their life histories in the Yukon drainage. Potential habitat for resident Dolly Varden populations was modeled using the best available data on presence and absence collected during stream surveys, but these data had the following limitations:

- There were very few data points informing the model given the size of the study area. The data points that did exist were spatially clustered along the road network in the central part of the study area with a few additional data points along the potential road to the Ambler mining district.
- Absence data were obtained from ADF&G projects in the Alaska Freshwater Fish Inventory that targeted the entire fish community. If a target species was not observed during field surveys, it was considered an absence point. These data points may not represent true absences because Dolly Varden could occupy the site during other times of the year than when the sampling occurred.
- Measurement error and sampling method could also lead to not observing a fish when it was actually present.
- Many of the data points were from ADF&G projects that strategically located their sites in order to extend the Anadromous Waters Catalog, which resulted in a bias towards low order streams.
- Most of the data points were from August because that was when ADF&G conducted surveys to extend the AWC. Since Dolly Varden spawn in the fall, the predicted distribution likely represented summer feeding and rearing habitats. Additional sampling at other times of the year could capture spawning and overwintering habitats.

There were no distribution datasets for northern pike or humpback whitefish and very few presence data in the AFFI that could be used for modeling distribution. Distributions for these two Fine-filter CEs were considered data gaps.

In addition to very limited data on species distributions for the CYR study area, the Change Agents datasets were generally poorly applicable to aquatic habitats and species. Decadal average monthly, seasonal, or total annual air temperature and precipitation data at a 771-m grid cell resolution were the best available current (2010s) and long-term future (2060s) climate data. However, neither air temperature nor precipitation have been translated to stream temperatures or discharge, both of which are expected to change under future climate scenarios. Models used to predict habitat suitability for fishes based solely on air temperature tend to perform poorly because air temperature is a poor surrogate for stream temperature (Al-Chokhachy et al. 2013).

13. Literature Cited

- Alaska Department of Fish and Game (ADF&G). 2008. Dolly Varden. Available: http://www.adfg.alaska.gov/static/education/wns/dolly_varden.pdf
- Alaska Department of Fish and Game (ADF&G). 2011. Catalog of waters important for spawning, rearing, or migration of anadromous fishes. Alaska Department of Fish and Game, Juneau, Alaska.
- Al-Chokhachy, R., S. J. Wenger, D. J. Isaak, and J. L. Kershner. 2013. Characterizing the thermal suitability of instream habitat for salmonids: a cautionary example from the Rocky Mountains. *Transactions of the American Fisheries Society* 142:793-801.
- Allan, J. D. 2004. Landscapes and riverscapes: the influence of land use on stream ecosystems. *Annual Review of Ecology, Evolution, and Systematics* 35:257-284.
- Alt, K. T. 1979. Contributions to the life history of the humpback whitefish in Alaska. *Transactions of the American Fisheries Society* 108:156-160.
- Alt, K. T. 1987. Review of sheefish (*Stenodus leucichthys*) studies in Alaska. Alaska Department of Fish and Game, Division of Sport Fish, Juneau, Alaska. 69 pp. Available: <http://www.sf.adfg.state.ak.us/fedaidpdfs/FMS-003.PDF>
- Alt, K. 1994. Northern pike. Alaska Department of Fish and Game Wildlife Notebook Series. Available: http://www.adfg.alaska.gov/static/education/wns/northern_pike.pdf
- Andersen, D. B. 2007. Local and traditional knowledge of whitefish in the upper Koyukuk River drainage, Alaska. Research North, Final Report for FIS Project 04-269, Funded by the U.S. Fish and Wildlife Service, Fisheries Resource Monitoring Program, Anchorage, Alaska.
- Anras, M. L. B., P. M. Cooley, R. A. Bodaly, L. Anras, and R. J. P. Fudge. 1999. Movement and habitat use by lake whitefish in a boreal lake: integrating acoustic telemetry and geographic information systems. *Transactions of the American Fisheries Society* 128:939-952.
- Arctic Monitoring and Assessment Programme (AMAP). 2002. Arctic Pollution 2002: persistent organic pollutants, heavy metals, radioactivity, human health, changing pathways. Oslo, Norway. xii+112 pp.
- Azumaya, T., T. Nagasawa, O. S. Temnykh, and G. V. Khen. 2007. Regional and seasonal differences in temperature and salinity limitations of Pacific salmon (*Oncorhynchus* spp.). *North Pacific Anadromous Fish Commission Bulletin* 4:179-187.
- Baker, M. E., and R. S. King. 2010. A new method for detecting and interpreting biodiversity and ecological community thresholds. *Methods in Ecology and Evolution* 1:25-37.
- Bayley, S. E., D. W. Schindler, K. G. Beaty, B. R. Parker, and M. P. Stainton. 1992. Effects of fires on nutrient yields from streams draining boreal forest and fen watersheds: nitrogen and phosphorus. *Canadian Journal of Fisheries and Aquatic Sciences* 49:584-596.
- Beacham, T. D., and C. B. Murray. 1990. Temperature, egg size, and development of embryos and alevins of five species of Pacific salmon: a comparative analysis. *Transactions of the American Fisheries Society* 119:927-945.
- Benda, L., D. Miller, P. Bigelow, and K. Andras. 2003. Effects of post-fire erosion on channel environments, Boise River, Idaho. *Forest Ecology and Management* 178:105-119.
- Bendock, T. 1979. Inventory and cataloging of Arctic area waters. Alaska Department of Fish and Game Annual Report 20:1-64. Juneau, Alaska.
- Bennett, K. E., A. J. Cannon, and L. Hinzman. 2015. Historical trends and extremes in boreal Alaska river basins. *Journal of Hydrology* 527:590-607.
- Benoit, J. M., C. C. Gilmour, A. Heyes, R. P. Mason, and C. L. Miller. 2003. Geochemical and biological controls over methylmercury production and degradation in aquatic ecosystems. *American Chemical Society Symposium Series* 835:262-297.
- Beschta, R. 1978. Long-term patterns of sediment production following road construction and logging in the Oregon Coast Range. *Water Resources Research* 14:1011-1016.

- Bowden, W., M. Gooseff, A. Balser, A. Green, B. Peterson, and J. Bradford. 2008. Sediment and nutrient delivery from thermokarst features in the foothills of the North Slope. *Journal of Geophysical Research: Biogeosciences* 113:G02026. DOI:10.1029/2007JG000470.
- Brabets, T., and R. Ourso. 2013. Water quality of streams draining from abandoned and reclaimed mined lands in the Kantishna Hills area, Denali National Park and Preserve, Alaska, 2008-2011. U.S. Geological Survey Scientific Investigations Report 2013. 5048. 72 p.
- Brabets, T. P., and M. A. Walvoord. 2009. Trends in streamflow in the Yukon River basin from 1944 to 2005 and the influence of the Pacific Decadal Oscillation. *Journal of Hydrology* 371:108-119.
- Brase, A. L. J. 2010. Fishery management report for recreational fisheries in the Lower Tanana River management area, 2008. Alaska Department of Fish and Game, Fishery Management Report Number 09-46, Juneau, Alaska.
- Brase, A. L. J., and H. H. Hamner. 2003. Subsistence and personal use salmon harvests in the Alaska portion of the Yukon River drainage, 2002. Alaska Department of Fish and Game, Regional Information Report 3A03-13, Juneau, Alaska.
- Breiman, L. 2001. Random forests. *Machine Learning* 45:5-32.
- Brown, R. J. 2000. Migratory patterns of Yukon River inconnu as determined with otolith microchemistry and radio telemetry. M.S. Thesis, University of Alaska Fairbanks.
- Brown, R. J. 2006. Humpback whitefish *Coregonus pidschian* of the upper Tanana River drainage. U.S. Fish and Wildlife Service, Alaska Fisheries Technical Report Number 90, Fairbanks, Alaska.
- Brown, R. J. 2007. Freshwater mollusks survive fish gut passage. *Arctic* 60:124-128.
- Brown, R. J. 2009. Distribution and demographics of whitefish species in the upper Koyukuk River drainage, Alaska, with emphasis on seasonal migration and important habitats of broad whitefish and humpback whitefish. U.S. Fish and Wildlife Service, Alaska Fisheries Technical Report Number 104, Fairbanks, 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. J., N. Bickford, and K. Severin. 2007. Otolith trace element chemistry as an indicator of anadromy in Yukon River drainage Coregonine fishes. *Transactions of the American Fisheries Society* 136:678-690.
- Brown, R. C., N. Brown, W. Braem, N. 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.
- Brown, C., J. Burr, K. Elkin, and R. J. Walker. 2005. Contemporary subsistence uses and population distribution of non-salmon fish in Grayling, Anvik, Shageluk, and Holy Cross. Alaska Department of Fish and Game, Division of Subsistence, Technical Paper No. 289.
- Bryan, J. E. 1973. The influence of pipeline development on freshwater fishery resources of northern Yukon Territory, aspects of research conducted in 1971 and 1972. Pacific Region Department of the Environment, Northern Operations Branch Fisheries Service, Task Force on Northern Oil Development Report No. 73-6, Information Canada Cat. No. R72-9773. Ottawa, Canada.
- Buklis, L. S. 2010. Chum salmon: wildlife notebook series. Alaska Department of Fish and Game. Available: https://www.adfg.alaska.gov/static/education/wns/chum_salmon.pdf
- Burril, S. E., C. E. Zimmerman, and J. E. Finn. 2010. Characteristics of fall chum salmon spawning habitat on a mainstem river in Interior Alaska. U.S. Geological Survey Open-File Report 2010-1164, 20 pp.
- Carey, M. P., and C. E. Zimmerman. 2014. Physiological and ecological effects of increasing temperature on fish production in lakes of Arctic Alaska. *Ecology and Evolution* 4:1981-1993.
- Craig, P. C., and L. Haldorson 1986. Pacific salmon in the North American Arctic. *Arctic* 39:2-7.

Section J. Aquatic Fine-filter Conservation Elements

- Crane, P. A., T. Viavant, and J. K. Wenburg. 2005. Overwintering patterns of Dolly Varden, *Salvelinus Malma*, in the Sagavanirktok River in the Alaskan Central Yukon inferred using mixed-stock analysis. U.S. Fish and Wildlife Service, Conservation Genetics Laboratory.
- Crawford, D. 1979. Lower Yukon River sheefish study, October 1977–June 1978. Alaska Department of Fish and Game, Division of Commercial Fisheries, Sheefish Investigation Number 9, Anchorage, Alaska.
- Cuffney, T. F., R. A. Brightbill, J. T. May, and I. R. White. 2010. Responses of benthic macroinvertebrates to environmental changes associated with urbanization in nine metropolitan areas. *Ecological Applications* 20:1384-1401.
- Cunjak, R. 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. *Canadian Journal of Fisheries and Aquatic Sciences* 53:267-282.
- Cushing, D. 1990. Plankton production and year-class strength in fish populations: an update of the match/mismatch hypothesis. *Advancements in Marine Biology* 26:249-293.
- Cutler, D., T. J. Edwards, K. Beard, A. Cutler, K. Hess, J. Gibson, and J. Lawler. 2007. Random forests for classification in ecology. *Ecology* 88:2783-2792.
- Daum, D. W., and B. G. Flannery. 2011. Canadian-origin Chinook salmon rearing in nonnatal U.S. tributary streams of the Yukon River, Alaska. *Transactions of the American Fisheries Society* 140:207-220.
- Davis, J. C., and G. A. Davis. 2011. The influence of stream-crossing structures on the distribution of rearing juvenile Pacific salmon. *Journal of the North American Benthological Society* 30:1117-1128.
- Delaney, K. 2008. Chinook salmon. Alaska Department of Fish and Game Wildlife Notebook Series. Available: http://www.adfg.alaska.gov/static/education/wns/chinook_salmon.pdf
- Dunham, J. B., A. E. Rosenberger, C. H. Luce, and B. E. Reiman. 2007. Influences of wildfire and channel reorganization on spatial and temporal variation in stream temperature and the distribution of fish and amphibians. *Ecosystems* 10:335-346.
- Durand, J. R., R. A. Lusardi, D. M. Nover, R. J. Suddeth, G. Carmona-Catot, C. R. Connell-Buck, S. E. Gatzke, J. V. Katz, J. F. Mount, P. B. Moyle, and J. H. Viers. 2011. Environmental heterogeneity and community structure of the Kobuk River, Alaska, in response to climate change. *Ecosphere* 2:1-19.
- Eiler, J., T. R. Spencer, J. J. Pella, and M. M. Masuda. 2006. Stock composition, run timing, and movement patterns of Chinook salmon returning to the Yukon River basin in 2004. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-AFSC-165, 107 pp. Available: <http://www.afsc.noaa.gov/Publications/AFSC-TM/NOAA-TM-AFSC-165.pdf>
- Estensen, J. L., S. Hayes, S. Buckelew, D. Green, and D. J. Bergstrom. 2012. Annual management report for the Yukon and northern areas, 2010. Alaska Department of Fish and Game, Fishery Management Report No. 12-23, Anchorage, Alaska.
- Evans, J. Personal communication. Senior Landscape Ecologist. Conservation Lands, Global Science Team. The Nature Conservancy. Laramie, Wyoming.
- Evans, J., M. Murphy, Z. Holden, and S. Cushman. 2011. Modeling Species Distribution and Change Using Random Forest. In: Drew, C., Y. Wiersma, F. Huettmann (eds.). 2011. Predictive Species and Habitat Modeling in Landscape Ecology. Springer. New York. 139-159.
- Evans, N. T., C. W. Riley, and G. A. Lamberti. 2015. Culvert replacement enhances connectivity of stream fish communities in a Michigan drainage network. *Transactions of the American Fisheries Society* 144:967-976.
- 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.
- Forman, R., and L. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics*. 29: 207-231.
- Gergel, S. E., M. G. Turner, J. R. Miller, J. M. Melack, and E. H. Stanley. 2002. Landscape indicators of human impacts on riverine systems. *Aquatic Sciences* 64:118-128.

- Gilvear, D., T. Waters, and A. Milner. 1995. Image analysis of aerial photography to quantify changes in channel morphology and instream habitat following placer mining in interior Alaska. *Freshwater Biology*. 34: 389-398.
- Gotceitas V., V. Puvanendran, L. Leader, and J. Brown. 1996. An experimental investigation of the 'match/mismatch' hypothesis using larval Atlantic cod. *Marine Ecology Progress Series* 130:29-37.
- Hallberg, J. E. 1989. Abundance and size composition of Chatanika River least cisco and humpback whitefish with estimates of exploitation by recreational fishermen. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series Number 108, Juneau, Alaska.
- 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.
- Harper, K. C., F. Harris, R. J. Brown, T. Wyatt, and D. Cannon. 2007. Stock assessment of broad whitefish, humpback whitefish and least cisco in Whitefish Lake, Yukon Delta National Wildlife Refuge, Alaska, 2001–2003. U.S. Fish and Wildlife Service, Alaska Fisheries Technical Report Number 88, Kenai, Alaska.
- Harvey, B. C., and T. E. Lisle. 1998. Effects of suction dredging on streams: a review and an evaluation strategy. *Fisheries* 23:8-17.
- Harvey, C. J., B. J. Peterson, W. B. Bowden, A. E. Hershey, M. C. Miller, L. A. Deegan, and J. C. Finlay. 1998. Biological responses to fertilization of Oksrukuyik Creek, a tundra stream. *Journal of the North American Benthological Society* 17:190-209.
- Hayes, S. J., F. J. Bue, B. M. Borba, K. R. Boeck, H. C. Carroll, L. Boeck, E. J. Newland, K. J. Clark, and W. H. Busher. 2008. Annual management report Yukon and northern areas 2002-2004. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Fishery Management Report No. 08-36. Available: <http://www.sf.adfg.state.ak.us/FedAidPDFs/fmr08-36.pdf>
- 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.
- Huusko, A., L. Greenberg, M. Stickler, T. Linnansaari, M. Nykänen, T. Vehanen, S. Koljonen, P. Louhi, and K. Alfredsen. 2007. Life in the ice lane: the winter ecology of stream salmonids. *River Research and Applications* 23:469-491.
- Ice, G. G., D. G. Neary, and P. W. Adams. 2004. Effects of wildfire on soils and watershed processes. *Journal of Forestry* 102:16-20.
- Irvine, J. R., R. W. Macdonald, R. J. Brown, L. Godbout, J. D. Reist, and E. C. Carmack. 2009. Salmon in the Arctic and how they avoid lethal low temperatures. *North Pacific Anadromous Fish Commission Bulletin* 5:39-50.
- Isaak, D. J., C. H. Luce, B. E. Rieman, D. E. Nagel, E. E. Peterson, D. L. Horan, S. Parkes, and G. L. Chandler. 2010. Effects of climate change and wildfire on stream temperatures and salmonid thermal habitat in a mountain river network. *Ecological Applications* 20:1350-1371.
- Jallen, D. M., W. H. Busher, and T. Hamazaki. 2012. Subsistence and personal use salmon harvests in the Alaska portion of the Yukon River drainage, 2009. Alaska Department of Fish and Game, Division of Sport Fish, Research and Technical Services.
- Jewett, S., and L. Duffy. 2007. Mercury in fishes of Alaska, with emphasis on subsistence species. *Science of the Total Environment* 387:3-27.
- Jiménez-Valverde, A., and J. Lobo. 2007. Threshold criteria for conversion of probability of species presence to either-or presence-absence. *Acta Oecologica*. 31. 361-369.
- Johnson, L. B., and G. E. Host. 2010. Recent developments in landscape approaches for the study of aquatic ecosystems. *Journal of the North American Benthological Society* 29:41-66.

Section J. Aquatic Fine-filter Conservation Elements

- Jones, J. V., III, S. M. Karl, K. A. Labay, N. B. Shew, M. Granitto, T. S. Hayes, J. L. Mauk, J. M. Schmidt, E. Todd, B. Wang, M. B. Weldon, and D. B. Yager. 2015. GIS-based identification of areas with mineral resource potential for six selected deposit groups. Bureau of Land Management Central Yukon Planning Area, Alaska, U.S. Geological Survey Open-File Report 2015–1021. 78 pp.+ 5 appendixes, 12 pls. Available: <http://pubs.usgs.gov/of/2015/1021/>
- 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* 25:1800-1821. DOI:10.1002/hyp.7940.
- Kepler, P. 1973. Sport fish investigations of Alaska: population studies of northern pike and whitefish in the Minto Flats complex with emphasis on the Chatanika River. Alaska Department of Fish and Game, Division of Sport Fish, Annual Performance Report, 1972–1973, Federal Aid in Fish Restoration, Project F-9-5, 14:59–81, G-II-J, Juneau, Alaska.
- King, R. S., M. E. Baker, D. F. Whigham, D. E. Weller, T. E. Jordan, P. F. Kazyak, and M. K. Hurd. 2005. Spatial considerations for linking watershed land cover to ecological indicators in streams. *Ecological Applications* 15:137-153.
- King, R. S., C. M. Walker, A. D. Yeager, C. J. Robbins, S. Cook, J. Maurer, R. D. Doyle, and D. F. Whigham. 2014. From microbes to salmonids: dramatic ecosystem response to low-level dissolved organic carbon additions in an Alaskan headwater stream. Joint Aquatic Sciences Meeting, Portland, Oregon.
- 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.
- LaPerriere, J., and J. Reynolds. 1997. Gold placer mining and stream ecosystems of Interior Alaska. *Freshwaters of Alaska. Ecological Studies* 119: 265-280.
- Liaw, A., and M. Wiener. 2002. Classification and Regression by Random Forest. *R News*. 2. 18-22.
- Liu, C., P. Berry, T. Dawson, and R. Pearson. 2005. Selecting Thresholds of Occurrence in the Prediction of Species Distributions. *Ecography*. 28(3). 385-393.
- Macleane, 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.
- Maitland, B. M., M. Poesch, A. E. Anderson, and S. N. Pandit. 2015. Industrial road crossings drive changes in community structure and instream habitat for freshwater fishes in the boreal forest. *Freshwater Biology* 61:1-18.
- Manel, S., H. Williams, and S. Ormerod. 2001. Evaluating presence–absence models in ecology: the need to account for prevalence. *Journal of Applied Ecology* 38:921-931.
- 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.
- McDonald, M. E., A. E. Hershey, and M. C. Miller. 1996. Global warming impacts on lake trout in Arctic lakes. *Limnology and Oceanography* 41:1102-1108.
- McDowell Group. 2014. The economic impacts of placer mining in Alaska. Prepared for: Alaska Miners Association, Anchorage, Alaska. 25 pp. Available: <http://www.mcdowellgroup.net/wp-content/uploads/2016/01/3.pdf>
- Milner, A. M., and R. J. Piorkowski. 2004. Macroinvertebrate assemblages in streams of Interior Alaska following alluvial gold mining. *River Research and Applications* 20:719-731.
- Morrow, J. 1980. The freshwater fishes of Alaska. Alaska Northwest Publishing, Anchorage, Alaska.
- Mundy, P. R., and D. F. Evenson. 2011. Environmental controls of phenology of high-latitude Chinook salmon populations of the Yukon River, North America, with application to fishery management. *ICES Journal of Marine Science* 68:1155-1164.

- Murphy, M., J. Evans, and A. Storfer. 2010. Quantifying *Bufo boreas* connectivity in Yellowstone National Park with landscape genetics. *Ecology* 91(1): 252-261.
- Neuswanger, J. R., M. S. Wipfli, M. J. Evenson, N. F. Hughes, and A. E. Rosenberger. 2015. Low productivity of Chinook salmon strongly correlates with high summer stream discharge in two Alaskan rivers in the Yukon drainage. *Canadian Journal of Fisheries and Aquatic Sciences* 72:1125-1137.
- Ochoa-Acuña, H., M. S. Sepulveda, and T. S. Gross. 2002. Mercury in feathers from Chilean birds: influence of location, feeding strategy, and taxonomic affiliation. *Marine Pollution Bulletin* 44:340-349.
- Ourso, R. T., and S. A. Frenzel. 2003. Identification of linear and threshold responses in streams along a gradient of urbanization in Anchorage, Alaska. *Hydrobiologia* 501:117-131.
- Pess, G. R., D. R. Montgomery, E. A. Steel, R. E. Bilby, B. E. Feist, and H. M. Greenberg. 2002. Landscape characteristics, land use, and coho salmon (*Oncorhynchus kisutch*) abundance, Snohomish River, Wash., U.S.A. *Canadian Journal of Fisheries and Aquatic Sciences* 59:613-623.
- Reist, J. D., and W. A. Bond. 1988. Life history characteristics of migratory coregonids of the lower Mackenzie River, Northwest Territories, Canada. *Finnish Fisheries Research* 9:133-144.
- Reist, J. D., F. J. Wrona, T. D. Prowse, M. Power, J. B. Dempson, J. R. King, and R. J. Beamish. 2006. An overview of effects of climate change on selected Arctic freshwater and anadromous fishes. *AMBIO: A Journal of the Human Environment* 35:381-387.
- Roach, J. K., B. Griffith, and D. Verbyla. 2013. Landscape influences on climate-related lake shrinkage at high latitudes. *Global Change Biology* 19:2276-2284.
- Rouse, W. R., M. S. V. Douglas, R. E. Hecky, A. E. Hershey, G. W. Kling, L. Lesack, P. Marsh, M. McDonald, B. J. Nicholson, N. T. Roulet, and J. P. Smol. 1997. Effects of climate change on the freshwaters of Arctic and sub-Arctic North America. *Hydrological Processes* 11:873-902.
- Salo, E. O. 1991. Life history of chum salmon (*Oncorhynchus keta*). Pages 233-309 in C. Groot, and L. Margolis, eds. *Pacific salmon life histories*. Univ. B.C. Press, Vancouver, B.C., Canada.
- 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.
- Schiedek, D., B. Sundelin, J. W. Readman, and R. W. Macdonald. 2007. Interactions between climate change and contaminants. *Marine Pollution Bulletin* 54:1845-1856.
- Schindler, D. E., D. E. Rogers, M. D. Scheuerell, and C. A. Abrey. 2005. Effects of changing climate on zooplankton and juvenile sockeye salmon growth in Southwestern Alaska. *Ecology* 86:198-209.
- Slavik, K., B. J. Peterson, L. A. Deegan, W. B. Bowden, A. E. Hershey, and J. E. Hobbie. 2004. Long-term responses of the Kuparuk river ecosystem to phosphorus fertilization. *Ecology* 85:939-954.
- Trombulak, S., and C. Frissell. 2000. Review of Ecological Effects of Roads on Terrestrial and Aquatic Communities. *Conservation Biology* 14: 18-30.
- Van Haveren, B., and D. Cooper. 1992. Rehabilitation potential of riparian systems disturbed by placer mining in Interior Alaska. In: *Achieving Land Use Potential Through Reclamation*. Proceedings of the American Society for Surface Reclamation, Duluth Minnesota, June 15-17, 657-663.
- Van Nieuwenhuysse, E. E., and J. D. LaPerriere. 1986. Effects of placer gold mining on primary production in subarctic streams of Alaska. *Water Resources Bulletin* 22:91-99.
- Viavant, T., P. Crane, and J. Wenburg. 2005. Eastern Central Yukon Dolly Varden genetic stock identification and stock assessment. U.S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program, Final Report (Study No. 01-113). Alaska Department of Fish and Game, Division of Sport Fish, Fairbanks, Alaska.
- Wagener, S. M., and J. D. LaPerriere. 1985. Effects of placer mining on the invertebrate communities of Interior Alaska streams. *Freshwater Invertebrate Biology* 4:208-214.
- Walker, C. E. 1976. Studies on the freshwater and anadromous fishes of the Yukon River within Canada. Department of the Environment, Fisheries and Marine Service, PAC T/76-7, Vancouver, Canada.

Section J. Aquatic Fine-filter Conservation Elements

- Wang, L. Z., J. Lyons, P. Kanehl, and R. Bannerman. 2001. Impacts on stream habitat and fish across multiple spatial scales. *Environmental Management* 28:255-266.
- Wheeler, A., P. Angermeier, and A. Rosenberger. 2005. Impacts of New Highways and Subsequent Landscape Urbanization on Stream Habitat and Biota. *Reviews in Fisheries Science*. 13: 141-164.
- Whitmore, C., M. Martz, J. C. Linderman, Jr., R. L. Fisher, and D. G. Bue. 2008. Annual management report for the subsistence and commercial fisheries of the Kuskokwim area, 2004. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Fishery Management Report Number 08-25, Anchorage, Alaska.
- Yukon River Panel. 2011. Chinook. Available: <http://yukonriverpanel.com/salmon/about/yukon-river-salmon/chinook/>
- Zuray, S., R. Kocan, and P. Hershberger. 2012. Synchronous cycling of *Ichthyophonus* with Chinook salmon density revealed during the annual Yukon River spawning migration. *Transactions of the American Fisheries Society* 141:615-623. DOI 10.1080/00028487.2012.683476.

K. Data Gaps and Omissions

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Summary

Section K. *Data Gaps and Omissions* details the compiled data gaps from all topics included in the REA and describes important omitted management questions.

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1. Data Gaps

During our analyses of the CYR REA, we encountered scenarios where data needed to complete an analysis were not available or limited the scope of the analysis. Highlighting the data needed to better understand the resources of a particular region is an integral part of the REA process. The UA Team highlighted data gaps that were encountered in each section along with limitations to the analyses. In this section, we summarize data gaps as a quick reference for land managers. ***For full context of data gaps and limitations, please refer to appropriate text sections.***

Data gaps are organized by CA and then CE. The end of this section summarizes the process of how Management Questions were selected, the final MQ list, a list of medium-level and omitted MQs, and the original unformatted list of MQs that the UA Team received.

1.1 Climate Change Modeling

Uncertainty relating to climate modeling, climate data, and the cliomes model are described in detail in Section C-1.5. This uncertainty led to some limitations in the temporal and spatial scale at which results could be analyzed and the conclusions that could be drawn from the data. In addition to the constraints imposed by these inherent uncertainties and limitations, there were also constraints to this analysis imposed by gaps for which no climate data were available. These gaps are summarized below.

Temperature

- Available temperature data refer to air temperature only. Although spot data for water temperature from specific sites and locations are available, no systematic, consistent, complete, or gridded data are available. This limits the applicability of SNAP-provided climate data to aquatic assessments.
- Available temperature data at the scale, coverage, and resolution necessary for this analysis were monthly rather than daily resolution. This imposed limitations, especially when trying to relate temperature change to communities, species and habitats. Lack of daily data makes it difficult to project events such as extreme heat, extreme cold, flash floods, and rain-on-snow events.
- Long-term climate stations are extremely sparse in general in Alaska, and very few of these stations are located above 500-m elevation.
- There is a lack of data on microclimates, driven (in part) by the lack of a high resolution DEM.
- There is a need for more studies that explicitly address the climate variables that can be modeled and the response of species (especially CEs) to those variables.

Precipitation

- Precipitation data do not differentiate between rain and snow; nor is any direct metric available for snowpack depth, rain on snow events, or other parameters that directly or indirectly impact certain CEs. However, we were able to add snow day fraction to the climate-related datasets in order to partially meet this need.
- Accurate/reliable PET measurements are a current data gap for the CYR study area and further research is warranted.

1.2 Fire

- There are limited data on fire severity and fire history, therefore, we could not analyze the effects of this important factor.

1.3 Soil Thermodynamics

- The GIPL model cannot predict the formation of specific thermokarst features or the drainage of specific lakes from permafrost thaw. However, the predicted changes in permafrost at the landscape level indicate where such phenomena will be most likely.
- The feedbacks between permafrost thaw and vegetation change are not always clearly understood. Moreover, these threshold dynamics are complicated by feedbacks between fire, vegetation, and climate.
- Permafrost can thaw very rapidly following fire, especially if the organic layer is consumed, but stochastic models cannot predict the exact timing, location, or intensity of fires.
- The joint SNAP/GIPL model represents, at best, data for climate, soils, insulating vegetation and other key variables at 1-km resolution. Discontinuous permafrost can vary at scales much finer than this, due to variable slope and aspect, drainage patterns, and numerous other factors.

1.4 Invasive Species

- Survey data on non-native species are lacking for many regions of the state, including a large portion of the CYR study area. Current surveys are concentrated in areas associated with population centers and along road systems.
- For creating a model for *Elodea* sp., we developed a coarse rubric to define accessibility of lakes by floatplanes, which was not able to include additional factors such as lake depth or shape, presence of obstructions, lack of appropriate approach to shore, etc., that would result in inaccessibility of lakes longer than 1 km. These additional factors are data gaps.
- The probability or frequency of landings was not incorporated; lakes closer to urban centers or those with greater recreational uses are likely to receive more floatplane traffic. This was a data gap at the time of our analysis, but such data were newly available during the publication of this report.

1.5 Insects and Disease

- Range polygons or distribution models for insect agents are not available in Alaska.
- Comprehensive insect damage surveys:
 - Aerial forest damage surveys do not delineate the ranges of insect agents, only those present in high enough concentration to cause defoliation or mortality severe enough to be seen from an airplane.
 - Aerial forest damage surveys have concentrated along major riparian corridors.
 - No more than 25% of the forested area of Alaska is surveyed during a single year.
 - Quantitative damage from invasive insect species is unknown.
 - Long-term insect damage trends are unknown.
- Because of the stochasticity of insect outbreaks, it was not possible to predict or model future insect outbreaks by area, location, or intensity. There is poor understanding of many environmental factors influencing outbreaks.

1.6 Anthropogenic Change Agents

- Most social and economic data are not amenable to aggregate to a regional scale.
- Data available for the boroughs are not always available for non-borough lands.
- There are limited subsistence resource surveys and none is systemically sampled annually. Only existing and available datasets were used.
- Only secondary employment, expenditures, and spending data are available in census data.
- One of the largest data gaps is the lack of a regularly maintained infrastructure dataset (i.e., land and air) that includes dates for expansion or contraction.
- Historic and current resource extraction information has low resolution.
- Forest harvest data are incomplete across region (e.g., Tok).
- Mineral potential is incomplete across region. The USGS mineral report does not cover the entire CYR study area so only the ARDF was used to examine areas outside of the report region.
- The distressed community list has incomplete data. This list, compiled by the Denali Commission, is useful at identifying communities that are distressed, however, the underlying mechanisms are not captured because there is no documentation about which of the two criteria were not met by each community.
- There are limited data regarding recreation use on federally and state-managed land.
- No refined harvest data below GMU are available.
- There is a lack of caribou data from hunters living north of the Yukon River.
- There is a finer resolution of sport harvest data (currently maintained by GMU subunit).
- Limited subsistence data are available:
 - Subsistence surveys are not conducted in every community and there may only be a single year of data.

- Household surveys are also not conducted that often in larger communities (> 1,000 people).
- We have limited access to ADF&G and Tribal harvest data.

1.7 Landscape and Ecology

- Not all landscapes respond the same way to specific land uses (i.e., roads likely have a larger impact on wetlands than uplands), and thus, the LCM serves as a relative measure of impact.
- Along these lines, little empirical data exist for the impacts of specific land uses on ecosystem components that exist in Alaska.
- Accurately mapped local and community road data are identified as a data gap.

1.8 Terrestrial Coarse-Filter Conservation Elements

- No standard vegetation map exists. The AKVM is a mosaic of various source maps, some of which are based on old LandSat imagery, and many maps are out-of-date due to the frequent fire return interval of the region.
- There is a limited accuracy assessment for vegetation maps used in the assessment.
- A comprehensive soil survey is not available.
- Floodplain models are based on IfSAR elevation data, and only part of the CYR study area is available.
- Spatial data for some rare ecosystems are limited or create a data gap.
- Survey data for rare plants are incredibly limited and create a data gap.
- Undescribed rare ecosystems occur in the region. See Table K-1.

1.9 Terrestrial Fine-Filter Conservation Elements

- The ALFRESCO outputs do not include fire severity or precise spatial/temporal predictions of future fires (see Section C., Abiotic Change Agents), therefore, identifying areas where wildfire cycling may increase habitat and forage productivity for the CE species was not possible with these data.
- The spatial representations of caribou seasonal distribution are based on the best available and obtainable information. This included kernel density polygons for the Western Arctic and Central Arctic herds, however, such fine-scale data were not available for the other herds.
- Regarding herd ranges, telemetry data are not available for all caribou herds.
- Caribou diet for herds south of Brooks Range is unknown.
- Grey-cheeked thrush was originally proposed as a Terrestrial Fine-filter CE, however, very little information or data were available to develop an accurate species distribution model, or perform a useful impact analysis. Therefore, Swainson's thrush was substituted into the study.
- More Alaska-specific studies on the effect of climate and prey availability are needed to understand the impacts of different variables on Swainson's thrush survival and reproductive success.

- Waterfowl species population estimates and relative waterfowl density are unknown.

1.10 Aquatic Conservation Elements

- An aquatic habitat classification does not exist.
- The National Hydrography Dataset (NHD) and Digital Elevation Model (DEM) are outdated.
 - The NHD underrepresents small streams.
 - The NHD is very outdated and stream locations and lake areas have likely changed due to natural hydrologic disturbances and climate change.
 - No information on stream order or stream gradient exists.
- Understanding of hydrologic conditions is lacking and there are no hydrologic models.
- There are limited gauging stations and discharge data.
- Limited water temperature data exist.
- We are not able to predict climate change effects. As far as we know, there are no climate change predictions specific to aquatic habitats, such as changes to water temperature or hydrologic regime, available for the study area.
- Fish occurrence data are lacking. The only spatial dataset representing fish distribution in the CYR study area was the Anadromous Waters Catalog (AWC).
- There is a lack of data on long-term trends and temporal change for fish.
- Limited data are available on fish population, movements, as well as overwintering habitats, which could be limiting distributions.
- Lack of information exists on harvest or population sizes (for all except salmon).
- We are lacking genetic baseline for understanding how mixed-stock harvests affect populations.

2. Data Gaps Related to Management Questions

All original MQs from the BLM had overarching questions of “How reliable are these predictions? Are there other data/models that provide information different from the output presented?” We answered these questions when appropriate as some MQs were not model- or predictive-based. The following section summarizes data gaps and limitations and summarizes both questions regarding Management Questions.

2.1 Management Questions Related to Abiotic Change Agents

MQ. A1: How is climate change likely to alter the fire regime in the dominant vegetation classes and riparian zones?

- No other currently available landcover or vegetation model offers a dynamic perspective on fire and vegetative succession.

MQ. B1: How is climate change likely to alter permafrost distribution, active layer depth, precipitation regime, and evapotranspiration in this region?

- The reliability of SNAP climate predictions is discussed in the climate section of this report.
- Existing models of potential evapotranspiration are likely too simplistic to account for fine-scale variations in incoming shortwave radiation, wind speed and humidity. Thus, examining the impacts on vegetation from changes in PET may more effectively be conducted using outputs from the stochastic ALFRESCO fire model.

MQ C1: How will changes in precipitation, evapotranspiration, and active layer depth alter surface water availability and, therefore, ecosystem function (dominant vegetation classes)?

- The reliability of SNAP climate predictions is discussed in the climate section of this report.
- Existing models of potential evapotranspiration are likely too simplistic to account for fine-scale variations in incoming shortwave radiation, wind speed and humidity. Thus, examining the impacts on vegetation from changes in PET may more effectively be conducted using outputs from the stochastic ALFRESCO fire model.

MQ E1: How is climate change affecting the timing of snow melt and snow onset, spring breakup and green-up, and growing season length?

- The reliability of SNAP climate predictions is discussed in the climate section of this report.

2.2 Management Questions Related to Terrestrial Coarse-Filters

MQ B2: What are the expected associated changes to dominant vegetation communities and CE habitat in relation to altered permafrost distribution, active layer depth, precipitation regime, and evapotranspiration?

- Data gaps and limitations of the layers used to develop the CE distributions are described in the Methods portion of Section G. Terrestrial Coarse-filter Conservation Elements.
- See Section C. Abiotic Change Agents for data gaps and limitations pertaining to the SNAP climate models, the GIPL ground temperature model, and the ALFRESCO model.

MQ F3: How are major vegetation successional pathways likely to change in response to climate change, with special emphasis on increased shrub cover and treeline changes?

- See Section C. Abiotic Change Agents for information about the reliability of the SNAP climate models and the ALFRESCO model.
- Information about the various landcover maps available for the region that are suitable for developing CE distributions is presented in the Methods portion of Section G. Terrestrial Coarse-filter Conservation Elements.
- The climate models, ground temperature models, and ALFRESCO model used in this analysis are the only models available for predicting change in temperature, precipitation, permafrost, and vegetation for the study area

MQ G1: Where are refugia for unique vegetation communities (e.g., hot springs, bluffs, sand dunes) and what are the wildlife species associated with them?

- See text for MQ AH1.

MQ AH1: What rare but important habitat types that are too fine to map at the REA scale and are associated with Coarse- (or Fine-) Filter CEs that could help identify areas where more detailed mapping or surveys are warranted before making land use allocations (such as steppe bluff association with dry aspen forest)?

- Rare ecosystems data are limited by the completeness and precision of their respective map sources, which vary among ecosystems. Please see page G-149 for more detailed information regarding the source of each ecosystem.
- A number of Ecosystems of Conservation Concern (G1-G3) that occur in Interior Alaska have not been described or mapped in sufficient detail to be included in our analyses (Table K-1). These undescribed ecosystems of Conservation Concern require further study or literature review for an accurate assessment of their rarity or intrinsic vulnerability, trends, and threats. Although these undescribed rare ecosystems were beyond the scope of this rapid assessment, they are listed in the table below for reference.

Table K-1. Potentially rare ecosystems that may warrant further investigation.

Undescribed Ecosystems of Potential Conservation Concern
Calcareous Fen BpS
Hill Prairie
Sky Islands in Boreal Alaska
Trona (hydrous sodium carbonate and bicarbonate in partially evaporated lake basins)
Vegetation Communities on Basalt Substrates

Wildlife Data Limitations

- The AKGAP distribution models have been developed for a majority of Alaska rare animal species, but distribution models do not exist for every rare species that occurs within the CYR study area, such as the gray-crowned rosy-finch (*Leucosticte tephrocotis*, G5S3).
- Our distribution sets for bird species are limited in that they model only breeding distribution.
- Because we used H.A. Database and AKGAP analysis to infer potential relationships between rare ecosystems and rare animal species, our analysis is also subject to the limitations of those models and should be viewed as hypotheses.
- Spatial correlation between a given ecosystem and a given wildlife species does not necessarily indicate that the species relies upon services provided by that ecosystem that cannot be provided by other more common ecosystems.
- Including birds in a rare ecosystem may provide a biased view of the rare ecosystem with respect to birds as they are more likely to be using surrounding associated habitat instead of the rare ecosystem habitat itself.
- AKGAP models vary in accuracy but during development, each model was subjected to an accuracy assessment to quantify “classification success”—the percent of training points (known occurrence records) correctly predicted as present by the model. Please see text on page G-151 for more detailed information on specific classification success scores.

MQ G2: Which unique vegetation communities (and specifically, which rare plant species) are most vulnerable to significant alteration due to climate change?

- A moisture index such as Actual Evapotranspiration (AET), Potential Evapotranspiration (PET), or an AET:PET Index may have created a more accurate future scenario for the Steppe Bluff BpS, but such indices are a data gap.
- Fine-scale surficial geology maps and soil maps are a data gap.
- The limitations with MaxEnt modeling coincide with the limitations of the quality of data inputs. To evaluate overall model performance, we used the area-under-the-curve (AUC) calculated from a receiver operating characteristic plot that was automatically generated as part of the MaxEnt output from the training and test data. The receiver operating characteristic curve measures a model’s ability to correctly predict presence and absence, and the resulting AUC statistic can be interpreted as the probability that a presence site is correctly predicted relative to a random background site. Area under the curve (AUC) scores can range from 0 to 1.0, with a random prediction scoring 0.5. Hence, scores above 0.5 are more accurate than a random prediction. Both of our models were in the high range

of accuracy and, overall, reflected literature and professional judgement of the rare ecosystems

- No other data exist for rare plant or rare ecosystems for Alaska. See climate sections for other climate data/models. CART (classification and regression tree) and random forest modeling for habitat suitability are alternative methods. However, MaxEnt is more widely used, easier to simulate, and easier to compare results with other scientific studies. An alternative method for identifying species vulnerable to climate change is to use the NatureServe Climate Change Vulnerability Index. However, this index requires specific moisture data that are not available for Alaska.

2.3 Management Questions Related to Terrestrial Fine-Filters

MQ N3: How might Dall sheep distribution shift in relation to climate change?

- Snow depth is an important climatic variable that has an impact on sheep survival and having accurate measures of snow depth will allow for more accurate predictions of future climatic impacts.
- The habitat distribution model was built using the Vegetation Map of Northern, Western, and Interior Alaska and may have inaccuracies associated with erroneous classifications in the base map.

MQ AE1: Where is primary waterfowl habitat located?

- The accuracy of breeding distribution models was not examined within the CYR study area as part of this assessment. However, model accuracy for the entire state of Alaska was assessed using area-under-curve (AUC) as part of the Alaska Gap Analysis Project. Values larger than 0.5 indicated a performance better than random. Model performance for each species is provided on page H-146.
- The Alaska Gap Analysis Project was a generalized effort to produce the first statewide distribution models for all terrestrial vertebrate species in Alaska. Therefore, input data layers were not selected specifically for relevance to waterfowl.

MQ T1: What areas would be most likely to biologically support a reindeer herd?

Seasonal Forage Quality

- The Vegetation Map of Northern, Western, and Interior Alaska was produced by mosaicking the best available (prioritized by detail and accuracy) regional landcover maps into a single spatial coverage. Although regional landcover maps were assessed for accuracy within their coverages, no accuracy assessment has been conducted for the mosaicked dataset. Regional differences in seasonal forage may, therefore, partially be artifacts of inconsistent classification.
- Diet varies between calves, adult females, and adult males, but we combined forage preferences for calves, adult females, and adult males to produce generalized forage quality datasets. However, this generalized approach prevented any insights into sexual segregation within herds.
- Diet also varies by region and herd, and diet studies are not available for all herds so information was generalized to all herds of Central Alaska.

Biological Potential for Reindeer Herding

- Herd ranges constantly change and it was not possible to predict future herd ranges.
- Ranges are estimates for all herds within the study area except for the annual ranges of the Western Arctic, Teshekpuk, Central Arctic, and Porcupine herds.
- Herd ranges selected for this assessment, excluding the four North Slope herds, were digitized from the Alaska Habitat Management Guides.
- Telemetry data are not available for all caribou herds.
- To enable a more detailed and accurate assessment of biological potential for reindeer herding, caribou herd annual and seasonal ranges for the most recent 10 to 15 years should be delineated using standardized kernel density estimation or similar suitable methodology.
- Future biological potential for reindeer herding is dependent on current and future changes in caribou herd ranges. Therefore, the biological potential for reindeer herding will not remain constant into the future.

MQ X1: What have the past cumulative impacts of road construction and mineral extraction been on terrestrial CE habitat and population dynamics?

- Please see MQ X2.

MQ X2: How might future road construction and mineral extraction infrastructure (e.g., both temporary and permanent roads [Umiat, Ambler, Stevens Village], pads, pipeline, both permanent and temporary) affect species habitat, distribution, movements and population dynamics (especially caribou, moose, and sheep)?

- Although an analysis of the association of roads with sport harvests was proposed for MQs X1 and X2, the resolution of sport harvest data prevented any meaningful comparisons.
- Sport harvest data are maintained by GMU subunit and do not make spatial analysis with landscape features possible. In the absence of collecting sport and subsistence harvest data as individual points at the coordinates of the kill, determination of association of roads with harvest levels would require a focused study with collection of new data.
- The impacts of mineral extraction on caribou, moose, and sheep are not well-studied.
- The impacts of infrastructure in general are not well-studied for Dall sheep, likely because major impacts have not been suspected based on little overlap between Dall sheep habitat and distribution of infrastructure.

2.4 Management Questions Related to Aquatic Fine-Filters

MQ V1: How does human activity (e.g., mineral extraction, gravel extraction) alter stream ecology and watershed health (i.e., water quantity, water quality, outflow/stream connectivity, fish habitat, and riparian habitat)?

- Please see MQ W2.

MQ W2: How might future road construction and mineral extraction infrastructure (e.g., both temporary and permanent roads, pads, pipeline) affect fish habitat, fish distribution, and fish movements (especially chinook, chum, and inconnu)?

- Please see the data gaps and limitation section for Aquatic Fine-filter on pages K-7–K-9.

3. Highest Ranked Management Questions

Given the rapid nature of the REA, the BLM National Operations Center (NOC) suggested we limit the number of Management Questions (MQs) to around 20 (with a maximum of 30). In previous REA projects we had success on selecting MQs using the Delphi survey method to prioritize and focus our MQs. The UA team replicated the same approach for the Central Yukon REA.

The Central Yukon Field Office generated an original list of MQs. This first list in its unaltered state is located in section 2.6 of this document. The UA Team responded with the feasibility of answering the questions and parsed out the questions because the recommended MQs had several questions embedded into the topic.

The UA team sent out the parsed out list of MQs to the AMT and asked members to rank the top 20 questions, which 20 additional questions were next priority (mid), and which questions were of lowest priority to them (remove). The following definitions were provided with the MQs.

- **Top**—this is a critical question that needs to be addressed, irrespective of data availability or any other limitations.
- **Mid**—I/we think this is an important question, but need some preliminary data to assess its relevancy to the REA.
- **Remove**—this is an important question, but given REA timeframe/budget/scope, it can be removed from this assessment.

Each AMT member was asked to consider the following guidance from the BLM NOC on how to craft a good Management Question:

- Is the MQ about large-scale, region-wide issues?
- Can the MQ be answered by available geospatial information, remote sensing, or acceptable surrogates at the landscape scale?
- If the MQ cannot be addressed spatially, would a literature review be an appropriate use of the REA?
- If it is an inventory question, can it be addressed within the timeframe of the REA?
- Does the MQ inform a specific practical management decision or resource allocation to be made (i.e., Which areas due to resource vulnerability require protection as ACECs? Which areas should be avoided for authorization of new roads or utility corridors?)
- Does the MQ identify the potential subsequent decision process and or action associated with the answer to the question?
- Has the MQ been answered in another recently completed ecoregional assessment and is there additional information that warrants reexamining this issue?

After receiving 10 responses from our first ranking by the AMT, 18 MQs surfaced as being the top or mid priority MQs by the majority of the voting members of the AMT. The UA team met with the AMT and Technical Team members during our first AMT meeting on September 5, 2014 and discussed the MQ ranking process, survey method, and asked for additional MQs to be considered. Based on this process, one additional MQ was added to the list to be included in a second round of voting. To ensure consistency and confidence in our MQ selection, we sent out

another round of MQ surveys to ensure the first ranking was agreed upon by the majority of the AMT.

The second round of MQ surveys resulted in seven responses. The results were tallied based on ranks for each question then reordered based on those tallies. Questions that were consistently ranked as either Top 20 or Mid 20 by over half of the voting AMT members were selected as our final list of MQs (Table K-2). In addition to the 20 MQs, we also identified 12 alternative MQs with almost half of the AMT agreeing on these questions being either top 20 or mid 20 MQs (Table K-3). These questions were considered as replacement MQs if any of the final MQs could not be adequately addressed by the UA team, pending AMT approval.

Table K-2. Final working list of MQs for the Central Yukon REA. Shown is the Management Question, and the associated CE or CA.

MQ#	Management Question	CE	CA
A1	How is climate change likely to alter the fire regime in the dominant vegetation classes and riparian zones?	Terrestrial (Vegetation)	Fire
AE1	Where is primary waterfowl (black scoter or trumpeter swan) habitat located?	Terrestrial (waterfowl)	Climate/Land Use and Development
AH1	What rare but important habitat types that are too fine to map at the REA scale and are associated with coarse- (or fine-) filter CEs that could help identify areas where more detailed mapping or surveys are warranted before making land use allocations (such as steppe bluff association with dry aspect forest)?	Terrestrial	
B1	How is climate change likely to alter permafrost distribution, active layer depth, precipitation regime, and evapotranspiration in this region?	Terrestrial (Vegetation)	Soil Thermodynamics
B2	What are the expected associated changes to dominant vegetation communities and CE habitat?	Terrestrial (Vegetation)	Soil Thermodynamics
C1	How will changes in precipitation, evapotranspiration, and active layer depth alter surface water availability and, therefore, ecosystem function (dominant vegetation classes)?	Terrestrial (Vegetation)	Climate
E1	How is climate change affecting the timing of snow melt and snow onset, spring breakup and green-up, and growing season length?	Terrestrial (Vegetation)	Climate
F3	How are major vegetation succession pathways likely to change in response to climate change, with special emphasis on increased shrub cover and treeline changes?	Terrestrial (Vegetation)	Climate
G1	Where are refugia for unique vegetation communities (e.g., hot springs, bluffs, sand dunes) and what are the wildlife species associated with them?	Terrestrial (Vegetation)	Climate
G2	Which unique vegetation communities (and specifically, which rare plant species) are most vulnerable to significant alteration due to climate change?	Terrestrial (Vegetation)	Climate

Section K. Data Gaps and Limitations

MQ#	Management Question	CE	CA
L1	What are caribou seasonal distribution and movement patterns?	Terrestrial (Caribou)	Climate/Land Use and Development
N3	How might sheep distribution shift in relation to climate change?	Terrestrial (Sheep)	Climate/Land Use and Development
Q1	Which subsistence species (aquatic and terrestrial) are being harvested by whom and where is harvest taking place?	Terrestrial and Aquatic	Land Use and Development
T1	The introduction of free-ranging reindeer herds to this region has been proposed. What areas would be most likely to biologically support a reindeer herd?	Terrestrial (Reindeer/Caribou /Vegetation)	
U1	Compare the footprint of all types of landscape and landscape disturbances (anthropogenic and natural changed) over the last 20 and 50 years.		Land Use and Development
U3	How and where is the anthropogenic footprint most likely to expand 20 and 50 years into the future?		Land Use and Development
V1	How does human activity (e.g., mineral extraction, gravel extraction) alter stream ecology and watershed health (i.e., water quantity, water quality, outflow/stream connectivity, fish habitat, and riparian habitat)?	Aquatic (Fish)	Land Use and Development
W2	How might future road construction and mineral extraction infrastructure (e.g., both temporary and permanent roads, pads, pipeline) affect fish habitat, fish distribution, and fish movements (especially chinook, chum, sheefish)?	Aquatic (Fish)	Land Use and Development
X1	What have the past cumulative impacts of road construction and mineral extraction been on terrestrial CE habitat and population dynamics?	Terrestrial (Mammals)	Land Use and Development
X2	How might future road construction and mineral extraction infrastructure (e.g., both temporary and permanent roads [Umiat, Ambler, Stevens Village], pads, pipeline, both permanent and temporary) affect species habitat, distribution, movements and population dynamics (especially caribou, moose, sheep)?	Terrestrial (Mammals)	Land Use and Development

4. Medium Ranked Management Questions

Table K-3 is a list of alternative MQs in the event a highest priority MQ could not be answered.

Table K-3. Second-Tier MQs, based on the Delphi survey of MQs. Questions were subsequently weighted to reflect scores of high, moderate, and low priority ranks. The cumulative scores for these questions represent the next highest priority. These questions were retained as alternative MQs.

MQ #	Recommended Management Question	CE	CA
AD1	How will climate-related changes in snow cover, active layer depth, and breakup affect regulation (specifically the allowed timing of) of winter travel on BLM-managed lands?	Climate	
AE2	How might waterfowl (black scoter or trumpeter swan) distribution shift in relation to climate change?	Terrestrial (waterfowl)	Climate/ Land Use and Development
IN5	Where should potential roads to Ambler, Nome, Umiat, and Stevens village (100 foot wide road or utility corridors from the Dalton Highway) be placed in order to protect conservation system units (as far away as possible from the CSUs)?	Land Use and Development	
J1	What are baseline characteristics and trends (historic based on data and TEK as well as future based on anticipated development) in quality and quantity of fish habitat (lakes and streams) as well as fish distribution and movement?	Aquatic (Fish)	Land Use and Development
K1	How will caribou winter and summer habitat be affected by climate change?	Terrestrial (Caribou)	Climate
L3	How might caribou seasonal distribution and movement patterns shift in relation to climate change?	Terrestrial (Caribou)	Climate/ Land Use and Development
O1	What additional baseline data (i.e., drivers) are needed for fish, birds, and other terrestrial species for enhancing food security (health and safety of subsistence food)?	Terrestrial and Aquatic	Land Use and Development
Q2	What are historic and projected trends in subsistence harvest of these species? How reliable are these predictions?	Terrestrial and Aquatic	Land Use and Development
V3	What percentage of headwater streams in the region are currently in an intact/pristine state?	Aquatic (Fish)	Land Use and Development
W1	What have the past cumulative impacts of road construction and mineral extraction been on aquatic CE habitat and population dynamics?	Aquatic (Fish)	Land Use and Development
Y1	What and where are the impacts of mineral and gravel extraction development (i.e., gravel pad and road construction) on vegetation communities and hydrology (known impacts include burial, dust, saline runoff, and altered soil moisture)?	Terrestrial (Vegetation)	Land Use and Development
Z1	Which BLM lands create important linkages between conservation system units (via roads and waterways)?		Land Use and Development

5. Omitted Management Questions

Table K-4 is a list of MQs that were removed by the UA Team as being out of scope or low priority by the AMT.

Table K-4. List of MQs that were omitted or low priority.

Conservation Element	Change Agent	MQ #	Recommended Management Question	Effort Required by UA	In Scope?	Possible Approach
	Land Use and Development	AB1	Where should potential roads to Ambler, Nome, Umiat, and Stevens village (100-foot wide road or utility corridors from the Dalton Highway) be placed in order to protect existing human infrastructure (as far away as possible from existing infrastructure)?	Substantial: Could be addressed using products of core analysis	No	spatial
	Land Use and Development	AC1	Where are the locations of geological substrates suitable for extraction (e.g., precious metals, gravel) and locations suitable/unsuitable for infrastructure development (e.g., roads, maintenance stations)?	Low	Potentially. HOWEVER, suitability for infrastructure development is out of scope (engineering study).	spatial
	Climate	AD2	How will these projected changes affect how BLM regulates permittee access (specifically the timing of access)?	Substantial	No	literature review
Terrestrial (waterfowl)	Climate/Land Use and Development	AE3	How might waterfowl (blackscoter or trumpeter swan) distribution shift in relation to development (especially roads)?	Low	Yes	spatial
	Land Use and Development	AF1	What are the visual resource inventory classifications for the Utility Corridor and the remote western lands?	Substantial	No	spatial

Section K. Data Gaps and Limitations

Conservation Element	Change Agent	MQ #	Recommended Management Question	Effort Required by UA	In Scope?	Possible Approach
	Land Use and Development	AG1	How will the viewshed and visual sensitivity change with the potential development of access roads to mining and energy operations?	Substantial	No	spatial
	Land Use and Development	AG2	What are the visual impacts from gravel pits, pipelines, and other developments?	Substantial	No	spatial
	Land Use and Development	AG3	How far can they be seen from the air and the ground?	Substantial	No	spatial
Terrestrial (Vegetation)	Soil Thermodynamics	D1	How will expected changes in permafrost distribution and active layer depth alter the hydrological cycle in the region?	Substantial	Yes. However, we will be limited to existing information and models.	spatial and literature review
Terrestrial (Vegetation)	Soil Thermodynamics	D2	How will these manifest as changes to terrestrial and aquatic CE habitat quality and quantity (in dominant vegetation classes as well as riparian zones within each)?	Substantial	Yes. However, the resolution of the permafrost model is likely to limit our ability to address this question spatially at a meaningful scale.	spatial and literature review
Terrestrial (Vegetation)	Climate	E2	How does [change in snow melt/onset, spring breakup and green up and season length] vary between dominant vegetation classes and riparian zones?	Low	Yes	spatial
Terrestrial (Vegetation)	Climate	F1	What are the major vegetation successional pathways for upland and lowland forest and tundra vegetation classes?	Low if using existing descriptions. HOWEVER, if more description is required: moderate effort and a substantial effort would be required to create state-and-transition models.	Yes	literature review

Section K. Data Gaps and Limitations

Conservation Element	Change Agent	MQ #	Recommended Management Question	Effort Required by UA	In Scope?	Possible Approach
Terrestrial (Vegetation)	Climate	F2	What are the most common disturbances impacting each and how do these disturbances impact successional trajectories?	Low if using existing descriptions. HOWEVER, if more description is required: moderate effort and a substantial effort would be required to create state-and-transition models.	Yes	literature review
Terrestrial (Soils)		H1	Where are the areas of greatest topographic and soils diversity?	Substantial	Potentially	spatial
Terrestrial	Climate/Social Thermodynamics	I1	What are the current locations and rates of inland erosion and how might these change in the future?	Substantial effort and would be highly speculative. HOWEVER, moderate effort for a simple GIS model of erosion-prone areas.	Yes	spatial
Terrestrial	Climate/Social Thermodynamics	I2	In areas likely to be subject to erosion (including, but not limited to, flooding in riparian zones and fire affected areas) what are the expected changes to habitat and cultural sites?	Low if data are available. HOWEVER, if limited data then literature review: moderate effort.	Yes	spatial and literature review
Terrestrial (Caribou)	Climate	K2	What evidence exists for increased shrub cover?	Moderate effort	Yes	literature review
Terrestrial (Caribou)	Climate	K3	What are the likely impacts of increased shrub cover on caribou habitat?	Moderate effort	Yes	literature review
Terrestrial (Caribou)	Climate	K4	How will projected habitat changes alter caribou utilization patterns?	Moderate	Yes. HOWEVER, we will not be able to project how utilization patterns would change.	spatial

Section K. Data Gaps and Limitations

Conservation Element	Change Agent	MQ #	Recommended Management Question	Effort Required by UA	In Scope?	Possible Approach
Terrestrial (Caribou)	Climate/Land Use and Development	L2	How are caribou seasonal distribution and movement patterns related to season and weather?	Moderate	Yes. HOWEVER, we are limited to only existing information, and interpretation would likely be limited to overall climatic patterns.	spatial
Terrestrial (Caribou)	Climate/Land Use and Development	L4	How might caribou seasonal distribution and movement patterns shift in relation to development (especially roads)?	Distribution: substantial effort. Movement patterns: substantial effort (if data available).	Yes	spatial
Terrestrial (Caribou)	Climate/Land Use and Development	L5	Where is future development likely to most impact hunter access to caribou populations?	Low	Yes	spatial
Terrestrial (Moose)	Land Use and Development	M1	For moose populations in this region what is historic and current distribution and density?	Substantial effort (if data available)	No	literature review
Terrestrial (Moose)	Land Use and Development	M2	What major drivers behind the shifts in moose distribution have been identified?	Substantial effort (if data available)	Yes	literature review
Terrestrial (Moose)	Land Use and Development	M3	What is the history of moose harvest by subsistence users per given area within the region?	Moderate	Yes	literature review
Terrestrial (Sheep)	Climate/Land Use and Development	N1	Where is primary sheep habitat located?	Low	Yes	spatial
Terrestrial (Sheep)	Climate/Land Use and Development	N2	How does sheep distribution shift in response to season and weather?	Moderate	Yes. HOWEVER, we are limited to only existing information, and interpretation would likely be limited to overall climatic patterns.	spatial
Terrestrial (Sheep)	Climate/Land Use and Development	N4	How might sheep distribution shift in relation to development (especially roads)?	Low	Yes	spatial

Section K. Data Gaps and Limitations

Conservation Element	Change Agent	MQ #	Recommended Management Question	Effort Required by UA	In Scope?	Possible Approach
Terrestrial (Sheep)	Climate/Land Use and Development	N5	Where is future development likely to most impact hunter access to sheep populations?	Low	Yes	spatial
Terrestrial and Aquatic	Land Use and Development	O2	What are known drivers and what drivers require more information?	Substantial effort (we would include key data gaps)	Yes	literature review
Terrestrial and Aquatic	Land Use and Development	P1	What are the major ecosystem services provided by the lands and waters within this REA?	Substantial effort	No	literature review
Terrestrial and Aquatic	Land Use and Development	P2	What factors influence their value and can any of the services be quantified?	Substantial effort	No	literature review
Terrestrial and Aquatic	Land Use and Development	Q3	What is the economic value (market equivalent) of these species?	Substantial effort	No	economic analysis
Terrestrial and Aquatic	Land Use and Development	R1	What real and perceived limitations to access and/or collection of subsistence resources (aquatic and terrestrial) by local residents are caused by non-subsistence hunting and fishing activity?	Substantial effort (significant data gaps and limitations)	Yes. HOWEVER, perceived limitations would be limited to existing information and could be considered out of scope.	literature review
Terrestrial and Aquatic	Land Use and Development	R2	In which areas are the real and perceived limitations to access and/or collection of subsistence resources (as a result of non-subsistence hunting and fishing activity) occurring?	Low	Yes	literature review
Terrestrial and Aquatic	Land Use and Development	R3	What solutions to conflicts are promoted by local resident subsistence users?	Substantial effort (significant data gaps)	No	literature review

Section K. Data Gaps and Limitations

Conservation Element	Change Agent	MQ #	Recommended Management Question	Effort Required by UA	In Scope?	Possible Approach
Terrestrial and Aquatic	Land Use and Development	S1	What real and perceived limitations to access and/or collection of subsistence resources (aquatic and terrestrial) by local residents are associated with human infrastructure (mineral extraction, roads)?	Real limitations: potential data gaps and 'real' is ambiguous. Physical limitations: moderate effort. Other limitations: substantial effort. Perceptual limitations: substantial effort.	Yes	literature review
Terrestrial and Aquatic	Land Use and Development	S2	How might [real and perceived limitations] change in response to planned future development, especially new roads?	Obvious physical limitations: low additional effort	Yes	literature review
Terrestrial and Aquatic	Land Use and Development	S3	What solutions to conflicts are promoted by local resident subsistence users for specific limitations?	Substantial effort (potential significant data gap)	No	literature review
Terrestrial (Reindeer/Caribou/Vegetation)		T2	How would introduction of a reindeer herding program affect caribou and vegetation?	Moderate	Yes.	literature review
Terrestrial (Reindeer/Caribou/Vegetation)		T3	What is the economic service of maintaining intact caribou habitat in comparison to the economic gain of reindeer herding (market value)?	Substantial effort (potential significant data gap)	No	economic analysis
	Land Use and Development	U2	Where are these footprints located now?	Low (data gap potential)	Yes	spatial
	Land Use and Development	U4	What is the viewshed of large anthropogenic features? How far can they be seen from the air and the ground?	Substantial effort	No	spatial
Aquatic (Fish)	Land Use and Development	V2	Specifically, what is the relative importance of headwater streams to stream ecology and watershed health?	Moderate effort (if data available)	Yes	literature review

Section K. Data Gaps and Limitations

Conservation Element	Change Agent	MQ #	Recommended Management Question	Effort Required by UA	In Scope?	Possible Approach
Aquatic (Fish)	Land Use and Development	V4	What is the ecological value of maintaining intact headwater streams?	Moderate effort	Yes	literature review
Terrestrial (Vegetation)	Land Use and Development	Y2	How and where might these impacts spread as the anthropogenic footprint expands?	Moderate	Yes	spatial
	Land Use and Development	Z2	Which BLM lands provide transportation development linkages (roads) for non-conservation system unit lands?	Substantial effort	No	spatial

6. Original Management Questions

The following table is the list of management questions that were created from the BLM Central Yukon Field Office and were provided to the UA Team for feedback (Table K-5). The UA Team worked with these MQs and responded with a “gut” reaction as to the feasibility of answering the questions to the BLM Central Yukon Field Office. Additionally, the UA Team parsed out the questions because the recommended MQs had several questions embedded into the topic.

Table K-5. Original MQs created by the Central Yukon Field Office and provided to the UA Team.

Broad Category	Sub Category	Topic	Recommended Management Question	Recommended Analysis	Notes
Conservation Element	Climate Change	Fire	How is climate change likely to alter the fire regime in the following large-scale vegetation communities; upland tundra, lowland tundra, upland forest, lowland forest, as well as riparian zones within each? How reliable are these predictions? Are there other data/models which provide information that is different than the output presented?	Inherent REA product with special emphasis on specific ecosystems. Perhaps defining these vegetation communities (for this and other questions below) is better done as Coarse Scale CE (but this can serve as an example).	
Conservation Element	Climate Change	Permafrost	How is climate change likely to alter permafrost distribution, active layer depth, precipitation regime, and evapotranspiration in this region? What are the expected associated changes to vegetation communities (specifically upland tundra, lowland tundra, upland forest, lowland forest, as well as riparian zones within each) and CE habitat? How reliable are these predictions? Are there other data/models which provide information that is different than the output presented?	Inherent REA product with special emphasis on specific ecosystems.	
Conservation Element	Climate Change	Hydrology	How will changes in precipitation, evapotranspiration, and active layer depth alter surface water availability and, therefore, ecosystem function (specifically in lowland tundra, lowland forest, and riparian zones within each)? How reliable are these projections? Are there other data/models which provide information that is different than the output presented?	Inherent REA product with special emphasis on specific ecosystems.	

Section K. Data Gaps and Limitations

Broad Category	Sub Category	Topic	Recommended Management Question	Recommended Analysis	Notes
Conservation Element	Climate Change	Hydrology	How will expected changes in permafrost distribution and active layer depth alter the hydrological cycle in the region? How will these manifest as changes to terrestrial and aquatic CE habitat quality and quantity (specifically upland tundra, lowland tundra, upland forest, lowland forest, as well as riparian zones within each)? How reliable are these predictions? Are there other data/models which provide information that is different than the output presented?	Inherent REA product with special emphasis on connection between permafrost and hydrology.	
Conservation Element	Climate Change	Seasonality	How is climate change affecting the timing of snow melt and snow onset, spring breakup and green-up, and growing season length? How does this vary between upland tundra, lowland tundra, upland forest, lowland forest, and riparian zones? How is this likely to change in the future and how reliable are these projections? Are there other data/models which provide information that is different than the output presented?	Inherent REA product with special emphasis on specific ecosystems.	
Conservation Element	Climate Change	Vegetation	What are the major vegetation successional pathways for upland and lowland forest and tundra vegetation classes? What are the most common disturbances impacting each and how do these disturbances impact successional trajectories? How are these pathways likely to change in response to climate change, with special emphasis on increased shrub cover and treeline changes? How reliable are these projections? Are there other data/models which provide information that is different than the output presented?	Literature search and text report. GIS depiction of projected changes in shrub cover and treeline advance.	
Conservation Element	Climate Change	Vegetation	Where are refugia for unique vegetation communities (e.g., hot springs, bluffs, sand dunes) and what are the wildlife species associated with them? Which unique vegetation communities (and specifically, which rare plant species) are most vulnerable to significant alteration due to climate change? How reliable are these projections? Are there other data/models which provide information that is different than the output presented?	Inherent REA product with special refugia analysis and emphasis on unique vegetation and wildlife communities. Rare Plant habitat modelling using Max Ent.	

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Broad Category	Sub Category	Topic	Recommended Management Question	Recommended Analysis	Notes
Conservation Element	Baseline Info	Soils	Where are the areas of greatest topographic and soils diversity?	GIS analysis.	
Conservation Element	Climate Change	Erosion	What are the current locations and rates of inland erosion and how might these change in the future? In areas likely to be subject to erosion (including, but not limited to, flooding in riparian zones and fire affected areas) what are the expected changes to habitat and cultural sites? How reliable are these projections? Are there other data/models which provide information that is different than the output presented?	GIS depiction of areas likely to be affected by erosion (riparian zones and burn scars) overlain with known cultural sites and CE habitat with projections of flood and fire based on climate change.	
Conservation Element	Climate Change	Fish	What are baseline characteristics and trends (historic based on data and TEK as well as future based on anticipated development) in quality and quantity of fish habitat (lakes and streams) as well as fish distribution and movement?	Deduce historic trends in each of the above by analyzing historic data and compiling records of TEK. Inherent REA analysis to project future trends.	
Conservation Element	Climate Change	Caribou	How will caribou winter and summer habitat be affected by climate change? Specifically, what evidence exists for increased shrub cover and what are the likely impacts on caribou habitat? How will projected changes alter caribou utilization patterns? How reliable are these projections? Are there other data/models which provide information that is different than the output presented?	Inherent REA product with special emphasis on specific questions.	
Conservation Element	Climate Change	Caribou	What are caribou seasonal distribution and movement patterns? How are they related to season and weather? How might these shift in relation to climate change and development (especially roads)? Where is future development likely to most impact hunter access to caribou populations? Are there other data/models which provide information that is different than the output presented?	Literature review specific to the region. GIS depiction of distribution, likely habitat and current and future access routes to caribou populations.	
Conservation Element	Climate Change	Moose	For moose populations in this region what is historic, current and historic distribution and density? What major drivers behind the shifts in moose distribution have been identified? What is the history of moose harvest by subsistence users per given area within the region?	Inherent REA product with special attention to when moose populations became established (where not previously detected).	

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Broad Category	Sub Category	Topic	Recommended Management Question	Recommended Analysis	Notes
Conservation Element	Climate Change	Sheep	Where is primary sheep habitat located and how does sheep distribution shift in response to season and weather? How might these shift in relation to climate change and development (especially roads)? Where is future development likely to most impact hunter access to sheep populations?	Literature review specific to the region. GIS depiction of likely habitat and current and future access routes to sheep populations.	
Subsistence	Socioeconomic	Food security	What additional baseline data (i.e., drivers) are needed for fish, birds, and other terrestrial species for enhancing food security (health and safety of subsistence food)? What are known drivers and what drivers require more information?	Analysis output should be aimed specifically to provide driver information necessary for full food security analysis. www.iccalaska.org/servlet/content/Traditional%20Knowledge.html	
	Socioeconomic	Ecology	What are the major ecosystem services provided by the lands and waters within this REA? What factors influence their value and can any of the services be quantified?	Full-scale ecosystem service analysis by ISER.	
Subsistence	Socioeconomic	Food harvest	Which subsistence species (aquatic and terrestrial) are being harvested by whom and where is harvest taking place? What are historic and projected trends in subsistence harvest of these species? How reliable are these predictions? What is the economic value (market equivalent) of these species?	Data compilation: ADFG current and historical hunt records, OSM current and historical hunt records. Ecosystem service analysis to estimate economic value of food obtained through subsistence harvesting.	
Subsistence	Socioeconomic	Food harvest	What real and perceived limitations to access and/or collection of subsistence resources (aquatic and terrestrial) by local residents are caused by non-subsistence hunting and fishing activity? Where are controversial areas located? What solutions to conflicts are promoted by local resident subsistence users?	Literature/text product. GIS portrayal of subsistence use areas and high use hunting and fishing areas. Identification of data gaps.	
Subsistence	Socioeconomic	Food harvest	What real and perceived limitations to access and/or collection of subsistence resources (aquatic and terrestrial) by local residents are associated with human infrastructure (mineral extraction, roads)? How might this change in response to planned future development, especially new roads? What solutions to conflicts are promoted by local resident subsistence users for specific limitations?	Literature/text product. GIS portrayal of subsistence use areas and current/proposed human infrastructure. Identification of data gaps. Ecosystem service analysis comparing future development benefits to loss in subsistence opportunity.	

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Broad Category	Sub Category	Topic	Recommended Management Question	Recommended Analysis	Notes
Subsistence	Socioeconomic	Reindeer	The introduction of free-ranging reindeer herds to this region has been proposed. What areas would be most likely to biologically support a reindeer herd? How would introduction of a reindeer herding program affect caribou and vegetation? What is the economic service of maintaining intact caribou habitat in comparison to the economic gain of reindeer herding (market value)?	Literature search and text report. GIS depiction of potentially high value reindeer herd locations. Ecosystem service analysis to estimate economic value of food obtained through subsistence harvesting. Reindeer as CE?	
Development Impacts or Issues	Baseline Info	Visual Resources	What are the visual resource inventory classifications for the Utility Corridor and the remote western lands?	Conduct GIS viewshed analysis to establish visual resource inventory baseline for landscape scenic quality and contrast levels. Road accessible areas should follow the procedure in the BLM VRM handbook to establish VRI classifications. A GIS analysis can be used to establish VRI classifications in the in areas without road access.	BLM VRM Manual 8400 and VRM Handbooks 8410 and 8431
Development Impacts or Issues	Socioeconomic	Landscape disturbance	Compare the footprint of all types of landscape disturbances (anthropogenic and natural) over the last 20 and 50 years. Where are these footprints located now? How and where is the anthropogenic footprint most likely to expand 20 and 50 years into the future? What is the viewshed of large anthropogenic features? How far can they be seen from the air and the ground?	Bar Chart Comparison (e.g., square miles of gravel extraction, hardrock mining, fire, road footprints, gravel pads, village expansion). GIS depiction of anthropogenic footprint and projected footprint locations. Viewshed analysis of anthropogenic features. Combine efforts above into Visual Resource Management analysis (see manual link).	BLM VRM Manual 8400 and VRM Handbooks 8410 and 8431
Development Impacts or Issues	Socioeconomic	Landscape disturbance	How will the viewshed and visual sensitivity change with the potential development of access roads to mining and energy operations? What are the visual impacts from gravel pits, pipelines, and other developments? How far can they be seen from the air and the ground?	Conduct GIS viewshed analysis to establish visual resource sensitivity levels to changes on the landscape.	BLM VRM Manual 8400 and VRM Handbooks 8410 and 8431

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Broad Category	Sub Category	Topic	Recommended Management Question	Recommended Analysis	Notes
Development Impacts or Issues	Ecology	Fish	How does human activity (e.g., mineral extraction, gravel extraction) alter stream ecology and watershed health (i.e., water quantity, water quality, outflow/stream connectivity, fish habitat, and riparian habitat)? Specifically, what is the relative importance of headwater streams to stream ecology and watershed health? What percentage of headwater streams in the region are currently in an intact/pristine state? What is the ecological value of maintaining intact headwater streams?	Literature review specific to the region. GIS depiction of headwater stream location and disturbance history. Ecosystem service approach to glean economic value of maintaining intact streams (especially headwater streams) vs. development (disturbance) of headwater streams.	
Development Impacts or Issues	Ecology	Fish	What have the past cumulative impacts of road construction and mineral extraction been on aquatic CE habitat and population dynamics? How might future road construction and mineral extraction infrastructure (e.g., both temporary and permanent roads, pads, pipeline) affect fish habitat, fish distribution, and fish movements (especially chinook, chum, and sheefish)?	Literature review specific to the region. GIS depiction highlighting waterway intersection with current and future development. Ecosystem service analysis to compare the economic value of development (roads, pads, pipeline) vs. maintenance of unaltered habitat and intact populations of aquatic CE species.	
Development Impacts or Issues	Ecology	Mammals	What have the past cumulative impacts of road construction and mineral extraction been on terrestrial CE habitat and population dynamics? How might future road construction and mineral extraction infrastructure (e.g., both temporary and permanent roads [Umiat, Ambler, Stevens Village], pads, pipeline, both permanent and temporary) affect species habitat, distribution, movements and population dynamics (especially caribou, moose, and sheep)? How reliable are these predictions?	GIS depiction of human footprint (current and future). Ecosystem service analysis to compare the economic value of development (roads, pads, pipeline) vs. maintenance of unaltered habitat and intact populations of terrestrial CE species.	
Development Impacts or Issues	Ecology	Landscape disturbance	What and where are the impacts of mineral and gravel extraction development (i.e., gravel pad and road construction) on vegetation communities and hydrology (known impacts include burial, dust, saline runoff and altered soil moisture)? How and where might these impacts spread as the anthropogenic footprint expands?	GIS exercise showing likely areas to be impacted by development (including actual development and adjacent areas likely to be impacted).	

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Broad Category	Sub Category	Topic	Recommended Management Question	Recommended Analysis	Notes
Development Impacts or Issues	Ecology	Landscape disturbance	Which BLM lands create important linkages between conservation system units (via roads and waterways)? Which BLM lands provide transportation development linkages (roads) for non-conservation system unit lands?	GIS exercise on habitat connectivity to inform the following two questions.	
Development Impacts or Issues			Where should potential roads to Ambler, Nome, Umiat, and Stevens village (100-foot wide road or utility corridors from the Dalton Highway) be placed in order to protect conservation system units (as far away as possible from the CSUs)?	GIS exercise which may be performed solely in house (BLM GIS).	
Development Impacts or Issues			Where should potential roads to Ambler, Nome, Umiat, and Stevens village (100-foot wide road or utility corridors from the Dalton Highway) be placed in order to protect existing human infrastructure (as far away as possible from existing infrastructure)?	GIS exercise which may be performed solely in house (BLM GIS).	
Development Impacts or Issues	Socioeconomic	Landscape disturbance	Where are the locations of geological substrates suitable for extraction (e.g., precious metals, gravel) and locations suitable/unsuitable for infrastructure development (e.g., roads, maintenance stations)?	GIS depiction of known high value areas and areas with elevational contours amenable to road construction.	
Development Impacts or Issues	Climate Change	Seasonality	How will climate-related changes in snow cover, active layer depth, and breakup affect regulation (specifically the allowed timing of) of winter travel on BLM managed lands? How will these projected changes affect how BLM regulates permittee access (specifically the timing of access)? How reliable are these projections? Are there other models which provide information that is different than the output presented?	Analyze based on current winter restrictions to overland travel (i.e., staging will not be allowed until October 1 of each year. Winter cross country travel will only be allowed when there is a snow cover of 12" and frost depth to 6" for overland moves in the foothills and 12" freeze/6" snow on the coastal plain.) GIS depiction of waterways likely to be used for winter transport and projections of breakup timing.	