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 three habitats considered to be of high ecological importance in the region and potential impacts of CAs on these habitats.

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1. Summary of Aquatic Habitats (Coarse-Filter Conservation Elements)

Aquatic Coarse-Filter CEs are regionally important and characterize habitats that encompass many of the dominant ecological processes and patterns of the North Slope study area. Together the Coarse-Filter CEs address the habitat requirements of most native species. Four habitats (Table I-1) were selected as Coarse-Filter CEs: large streams, small streams, deep connected lakes, and shallow connected lakes. Stream distributions were mapped using data obtained from the National Hydrography Datasets (NHD; see Methods below). Deep and shallow connected lakes were mapped based on the NHD and additional datasets that had lake depth information (see Methods below).

Table I-1. Aquatic Coarse-Filter CEs selected for the North Slope REA.

Aquatic Coarse-Filter CEs	Ecological Importance
Large streams	High stream connectivity in the spring, source of freshwater and silt to river deltas; important spawning, rearing, and overwintering habitat; migration corridor habitat
Small streams	High stream connectivity in the spring; fish rearing and potentially spawning and overwintering
Deep connected lakes	Important breeding habitat for aquatic insects, fish, and waterbirds, and provide important overwintering habitat for fish
Shallow connected lakes	Summer foraging habitat for fish

The Coarse-Filter CEs section is organized by first describing the methods used to develop the distribution models for all the CEs. We then describe the characteristics, spatial distribution, and relationship of Aquatic Coarse-Filter CEs to the current and 2040 medium and high scenario landscape condition, as well as selected climate and CA variables understood to be critical.

2. Methods

For each Aquatic Coarse-Filter CE we developed distribution maps based on data obtained from the NHD and additional datasets (Table I-2). The NHD is a digital representation of the stream network and lakes shown on USGS topographic maps, which was created from historic aerial photos and is the best available spatial data of aquatic resources for the study area. However, the NHD has several limitations:

- The NHD underrepresents small streams because they are often masked by vegetation cover and not visible on aerial photography
- The NHD is outdated (most topographic maps were created in the 50's and 60's) and stream locations and lake areas have likely changed due to natural hydrologic disturbances and climate change
- Both stream order and stream gradient are needed to map aquatic habitats; the NHD is not attributed with stream order and does not align with valley bottoms in the Digital Elevation Model (DEM) so stream gradient cannot be calculated accurately

Additionally, the best available DEM for the study area is the National Elevation Dataset (60 m pixels). Due to the limitations of the NHD, aquatic habitats must be mapped by creating a stream network from the DEM, which has its own set of drawbacks:

- Utilizing a coarse DEM to map streams results in a gross oversimplification of the stream network length and complexity
- The DEM does not match the NHD, which is the best available representation of what exists on the ground
- When creating a stream network from a DEM, a decision must be made regarding the size of the watershed required to initiate a first order stream; there is no available data relating area to perennial flow initiation for the study area and due to the diversity of topographic, geologic, and permafrost characteristics across the North Slope study area, this relationship is expected to vary

In addition to the limitations of the data available for mapping aquatic habitats, it was beyond the scope of this project to create an aquatic habitat classification relating aquatic habitat types to physical, chemical, and biological conditions for the North Slope study area. Thus, for large and small streams, we developed distribution maps that were drawn directly from the NHD without additional processing or attribution. For deep and shallow connected lakes we used additional datasets (Table I-2) to identify shallow lakes (<1.6m) and deep lakes (>1.6m). However, not all lakes within the North Slope study area had lake depth data.

Table I-2. Source datasets for the distribution of Aquatic Coarse-Filter CEs.

Dataset Name	Data source
National Hydrography Dataset Waterbodies	USGS
National Hydrography Dataset Flowlines	USGS
Bathymetry of Alaskan Arctic lakes	BLM
SAR derived lake depths	GINA

Conceptual Models

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

Attributes and Indicators

Attributes and indicators helped to define the relationships between Conservation Elements (CEs) and Change Agents (CAs), and, where possible, the thresholds associated with these relationships. For each Coarse-Filter CE, we identified a number of attributes derived through the conceptual model, and assigned indicators to them based on available spatial data layers. Whenever possible, thresholds derived from the literature were set to categorize the data into standard reporting categories (i.e. indicator ratings).

Although numerous attributes and indicators affecting Aquatic Coarse-Filter CEs were identified during early phases of this REA (see results Table I-5), limited information exists for specific threshold effects of attributes and indicators for Coarse-Filter CEs. For example, currently there are no climate change predictions specific to aquatic habitats, such as changes to water temperature or hydrologic regime. Thus, not all of the attributes and indicators identified from the literature were included in this analysis because appropriate geospatial data were not available. Further information on the data gaps for each CE and their indicators are discussed briefly below and in Section K-1.1 and K-1.11.

Core Analysis

For each Aquatic Coarse-Filter CE, we assessed the current (2010), medium development scenario (2040), and high development scenario (2040) status. See Section F-2 for information on how status was calculated. For each Aquatic Coarse-Filter CE, we extracted and overlaid current CE distributions with the current, near-term (2020s), and long-term (2060s) status of relevant CA variables (Table I-3). The relevant CA variables are those considered to be most critical in structuring the Coarse-Filter CEs and include: temperature, change in length of growing season, areas of thermokarst, and permafrost. Distribution maps, conceptual models, and core analyses are presented for each Aquatic Coarse-Filter CE sections.

Table I-3. Source datasets for Core Analysis.

Dataset Name	Data source
Mean July temperature difference from 2010s-2020s and 2010s-2060s	SNAP, UAF
Change in length of growing season from 2010s-2020s and 2010s-2060s	SNAP, UAF
Areas of thermokarst from 2010s-2020s and 2010s-2060s	IEM Project, Genet, H., UAF
Change in mean annual ground temperature at one meter (MAGT) from 2010s-2020s and 2010s-2060s	GIPL and SNAP, UAF
Change in active layer thickness (ALT) from 2010s-2020s and 2010s-2060s	GIPL and SNAP, UAF

Management Questions (MQs)

There was one management question specific to Aquatic Coarse-Filter CEs that related to potential impacts of water withdrawal for oil and gas activities (MQ AC 1). We do not have the data available to answer this question spatially, thus we provided a literature review of the potential impacts that oil and gas activities could have on aquatic habitats within the North Slope study area. This MQ is addressed at the end of the Aquatic Coarse-Filter CE section.

3. Distribution on Public and Private Lands

We used the relative proportion Aquatic Coarse-Filter CE distribution falling within agency boundaries as a proxy for relative amount of management responsibility. The distribution of lakes in relation to areas managed both publicly and privately within the study area reflect the overall ratio of land ownership in the REA, with the highest percentages of species distributions occurring on BLM land (Table I-4).

Table I-4. Percentage of all lakes, deep lakes, shallow lakes, all streams, large streams, and small streams on public and private lands in the North Slope study area.

Land Owner	Aquatic Coarse-Filter (%)					
	All Lakes	Deep Lakes	Shallow Lakes	All Streams	Large Streams	Small Streams
Bureau of Land Management	75.03	83.28	61.26	46.44	38.00	47.55
Fish and Wildlife Service	1.33	0.79	2.26	16.19	15.41	16.29
Military	0.05	0.03	0.13	0.02	0.04	0.02
National Park Service	2.16	0.01	0.06	9.46	14.19	8.84
Native Patent or IC	7.48	5.74	8.66	9.13	13.34	8.58
Native Selected	0.27	0.17	0.16	0.62	0.77	0.59
Private	0.00	0.00	0.00	0.00	0.00	0.00
State Patent or TA	13.57	9.91	27.43	17.08	16.74	17.13
State Selected	0.11	0.07	0.05	1.06	1.51	1.00

4. Large Streams (Rivers) and Small Streams

Within the study area, small and large stream ecosystems provide important habitat for aquatic insects, fish, and waterbirds. Large streams (Figure I-1), referred to as rivers below, are those with sufficient depth to allow for deep pool areas, which provide overwintering habitat. Small streams are generally slow moving and freeze completely during the winter. However, some small streams (Figure I-2) may provide overwinter habitat in the form of springs and deep pools.

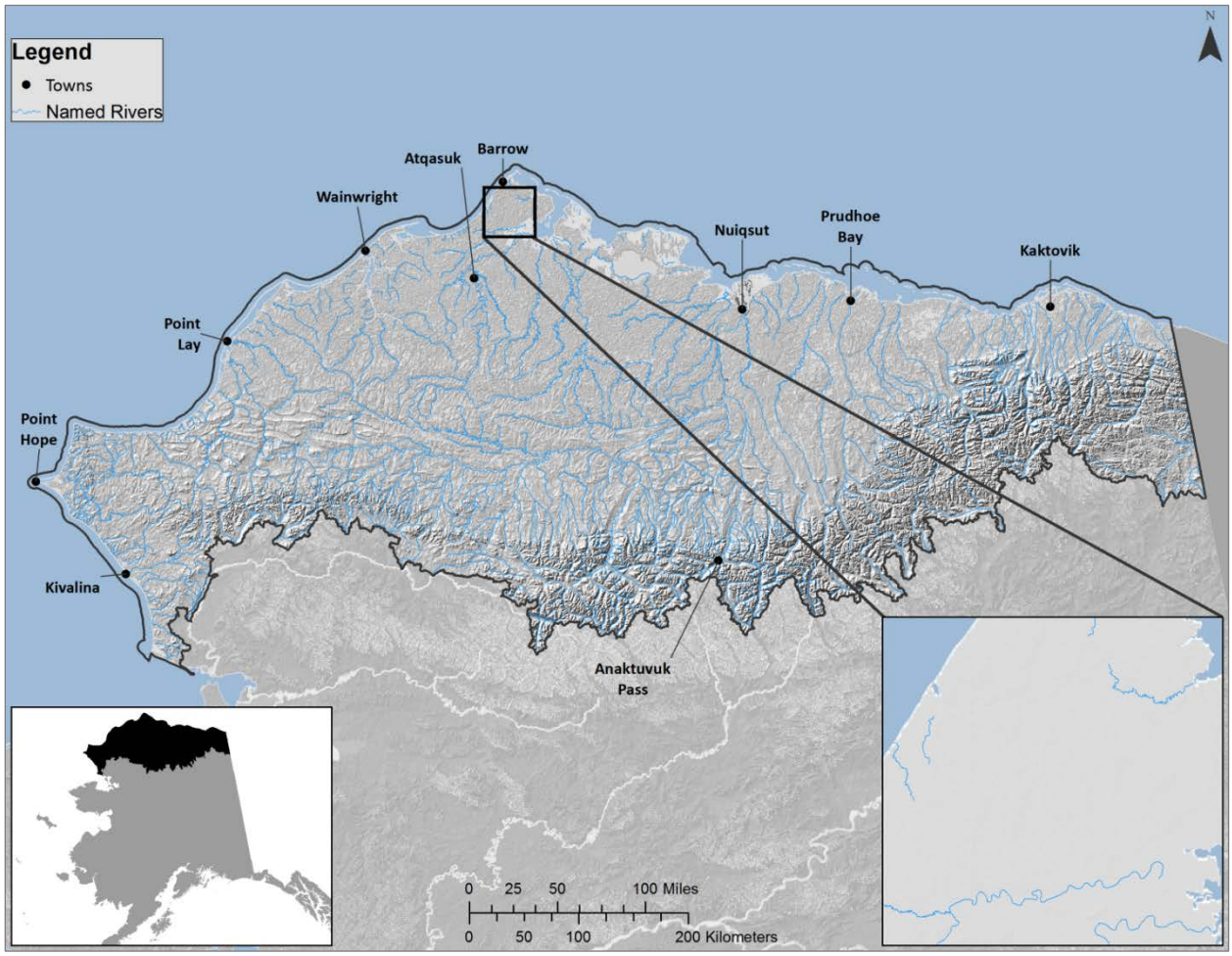

Figure I-1. Distribution of large rivers within the North Slope study area.

Stream and river ecosystems support extensive spawning and rearing habitat for numerous fish species in the study area. Streams and rivers also provide important habitat for aquatic invertebrates. Additionally, rivers and small streams provide important transportation and recreational uses for local residents. Rivers are typically less productive than smaller streams due to warmer temperatures in smaller tributaries (Hobbie 1995). Consequently, smaller streams are often preferred summer feeding habitat for many fish species and aquatic insects.

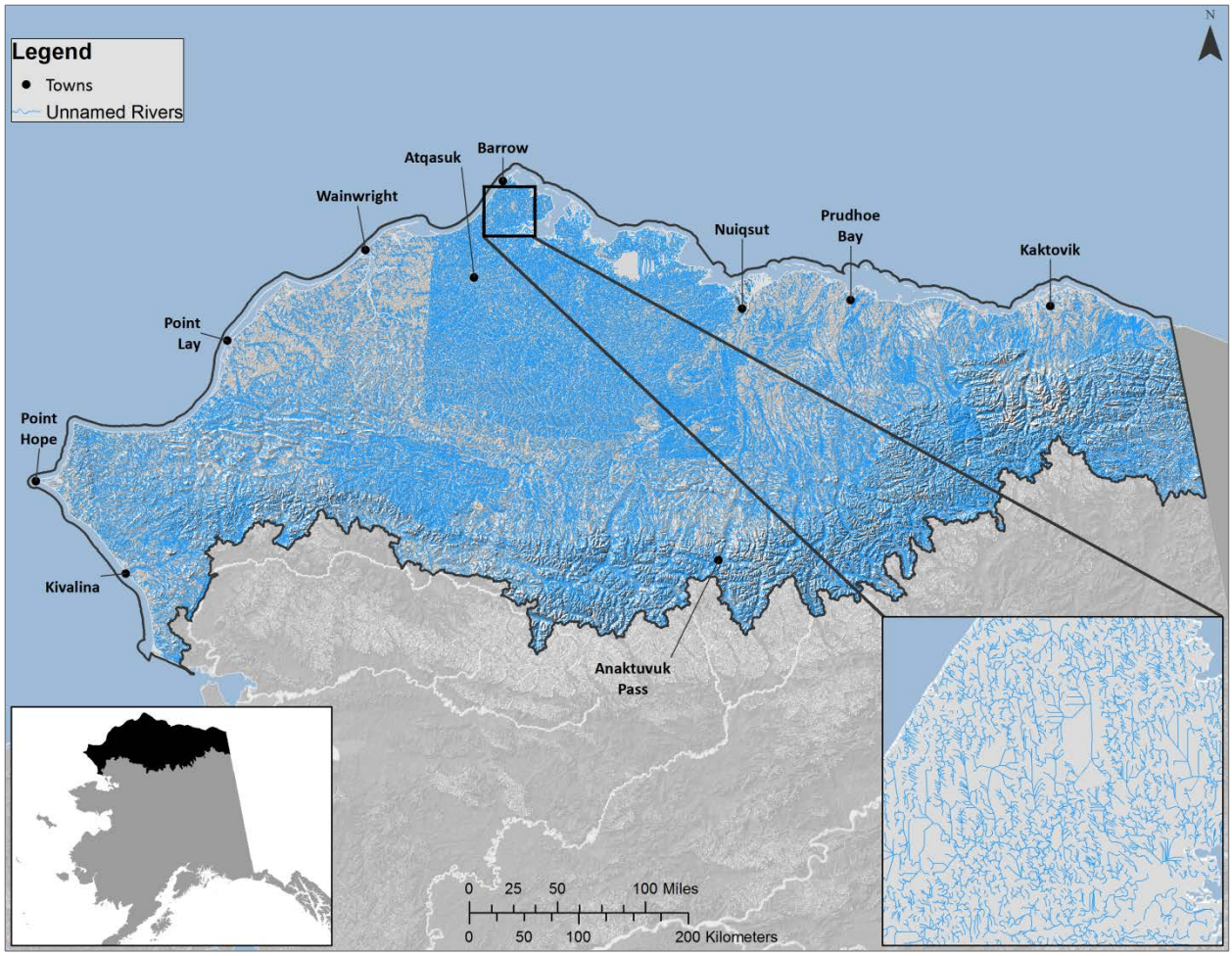

Figure I-2. Distribution of small streams throughout the North Slope study area.

4.1. Conceptual Model

The conceptual models below (Figure I-3 and Figure I-4) are based on a review of the literature and describe the relationship between the various CAs and natural drivers for rivers and small streams. The boxes and arrows represent the state of knowledge about streams and the relationship to each attribute.

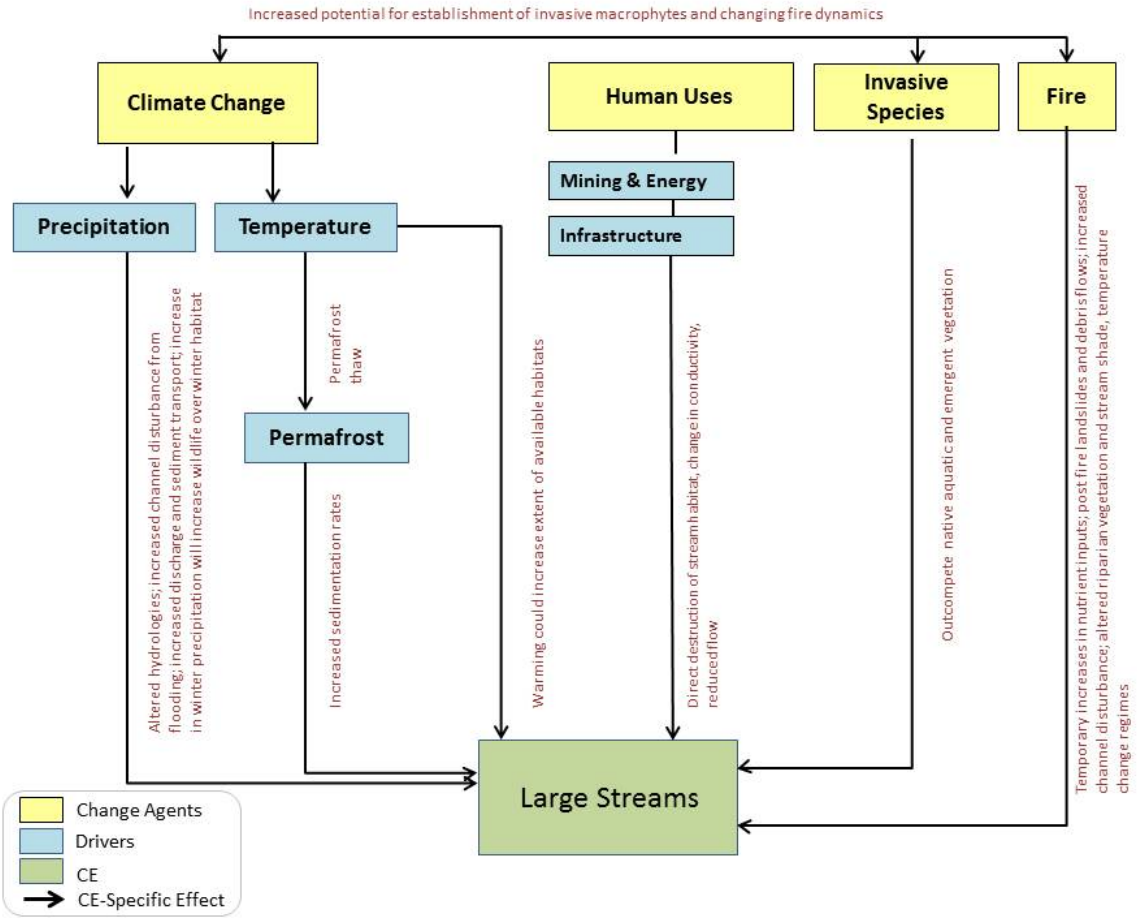

Figure I-3. Principal interactions among population drivers and CAs for large streams, rivers, within the North Slope study area.

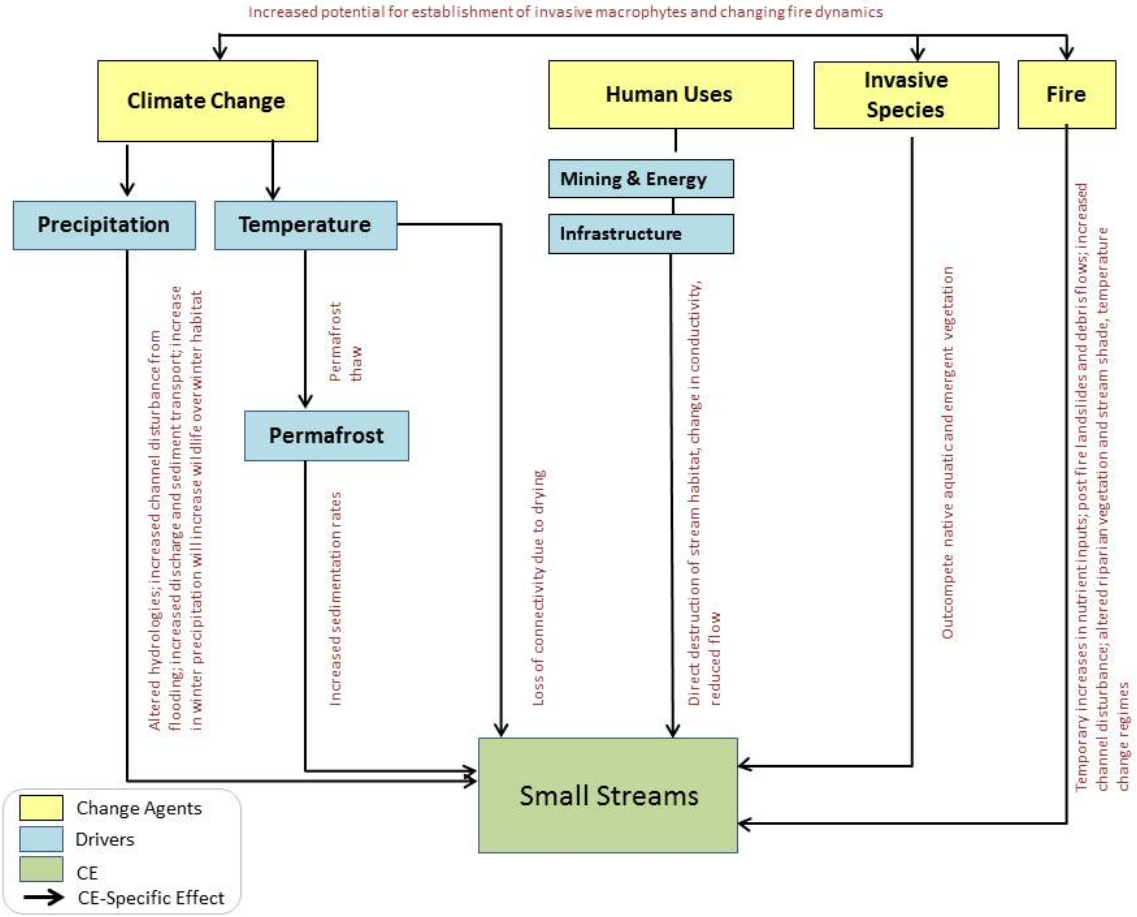

Figure I-4. Principal interactions among population drivers and CAs for small streams within the North Slope study area.

4.2. Attributes and Indicators

Relevant attributes and indicators that can be used to assess the status of the small streams and rivers are: winter precipitation, summer temperature, frost-free days/season length, mean annual ground temperature, fire frequency, contaminated sites, habitat fragmentation, and riparian invasive species (Table I-5).

Table I-5. Attributes and Indicators for small streams and rivers.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[1]	Dec-Feb total precipitation	Habitat	Less precipitation			More precipitation
	Winter precipitation[2]	Dec-Feb total precipitation	Habitat	More precipitation			Less precipitation
	Summer temperature[3]	June-August mean monthly air temperature	Habitat				
	Frost-free days/Season length[4]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Habitat				
Climate	Change in mean annual ground temperature at one meter (MAGT)[5]	Permafrost thaw	Habitat	From below -1m to above +1m			No Change

[1] Specific thresholds are unknown; Increased winter precipitation could increase available overwintering habitat for fish (by increasing the volume of water).
[2] Specific thresholds are unknown; Increased precipitation could result in increased run-off and sedimentation negatively impacting stream habitat.
[3] Specific thresholds are unknown; Low flow periods due to warmer, dryer air temperatures.
[4] Reist et al. 2006; General thresholds; Earlier ice-break up could change timing of processes that affect stream morphology (e.g., channel enlargement and scour of habitat).
[5] GIPL model, Lloyd et al. 2003; Brabets and Walvoord 2009; General thresholds; Changes in groundwater flow and stream discharge.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Fire	Fire frequency[6]	Fire return interval	Habitat	High return interval			Low return interval
	Fire frequency[7]	Fire return interval	Habitat	Low return interval			High return interval
Anthropogenic development	Contaminated sites[8]	Water quality	Habitat				
	Habitat fragmentation[9]	Road development	Habitat	Numerous intersections with streams			No intersection with streams
Invasive species	Riparian invasive species[10]	Out-compete native aquatic species	Habitat				

[6] Davis et al. 2013; Thresholds are general based on this study; Fires strip stabilizing vegetation from the landscape and increase erosion and runoff, resulting in higher sediment inputs to streams.
[7] Davis et al. 2013; Thresholds are general based on this study; Fire increases nutrient inputs.
[8] Thresholds will depend on specific contaminants at a site and proximity to streams; Oil contamination.
[9] Thresholds will depend on specific proximity of fish habitat to a site; Disrupt fish migratory movements; Stranding events.
[10] Specific thresholds are unknown; Small streams with slow moving waters would be most susceptible to invasion of *Elodea* spp.

4.3. Abiotic Change Agent Analysis

Climate

Future precipitation scenarios show a relatively high degree of uncertainty due to the inherent temporal and spatial variability of precipitation (see Section C). However, model results suggest increased summer rainfall and increased winter snowfall. An increase in precipitation during summer could be accompanied by increased flooding, sedimentation, and erosion which could have negative impacts for stream and river ecosystems of this region. Increased precipitation coupled with permafrost thaw may increase groundwater flows, which provide important overwintering habitats for Arctic grayling and Dolly Varden (Reist et al. 2006a).

Increases in summer air temperature will likely lead to increased stream and lake temperatures. Warmer water temperatures may result in range contractions for arctic fishes who are distributed wholly or primarily in northern areas and adapted to relatively colder waters, < 10˚ C (Reist et al. 2006a). Coldwater fishes with wide thermal tolerances (e.g. northern pike) will extend their ranges northward, while the effects of increased temperatures on coldwater species with more narrow thermal tolerances (e.g. lake trout) may be negative (Reist et al. 2006a). Furthermore, the effect of warmer summer temperatures on evaporation and evapotranspiration combined with permafrost thaw will result in lower stream flows (Prowse et al. 2006), which have been shown to negatively affect growth in adult Arctic grayling and positively affect growth in young-of-the-year (Reist et al. 2006b). Fish metabolic demands increase under warmer temperatures and populations that are currently food limited will require increased food resources to maintain current growth rates (Reist et al. 2006b). Increased nutrients from permafrost thaw and a longer ice-free season may result in increased freshwater productivity to match fish growth requirements (Reist et al. 2006b).

Permafrost

Permafrost thaw and thermokarst erosion have been shown to enhance groundwater discharge to streamflow within other parts of Alaska (Brabets and Walvoord 2009). Changes in groundwater flow, especially during spring and winter, could alter the timing and extent of ice cover and alter stream habitats. These changes to stream habitats will likely impact aquatic organisms (e.g., fish migrations) by changing stream velocities, water temperatures, concentrations of suspended sediments, and cause erosion (Prowse 2001). Small streams are especially dependent on perennial stream flow and because of this permafrost thaw and an increase in depth of the active layer could alter stream hydrology, increase channel disturbance from flooding, and increase discharge and sediment transport (Dingman 1973). Fish spawning areas might be especially susceptible to the effects of permafrost thaw as scouring of eggs and destruction of spawning habitat are likely. However, studies within the North Slope have found a link between permafrost thaw and increases in nutrients such as nitrogen and phosphorous which could have positive impacts for aquatic organisms (Reist et al. 2006b, Bowden et al. 2008).

The numbers of ice free days – estimated based on when the mean running water temperature is predicted to cross the 0°C point in the spring and fall -- is expected to change by only 2-3 days in the

near-term (2020s). In the long-term (2060s) however, the number of ice free days is expected to increase by anywhere from 10-16 days, depending on sub-region (See Section C: Table C-9). Ice breakup is a major driver of important events that supply riparian habitats with the essential influx of sediment, nutrients, and water. Ice break up is also critical to morphological changes such as channel enlargement, scouring of substrate habitat, and the successional processes of riparian vegetation. The timing of fish movements from winter habitats to summer spawning and foraging habitats are largely dictated by ice break up in the spring. With a projected increase in the number of ice fee days, the timing of fish migrations may occur earlier in the season (Figure I-5). Likewise, fish movements from summer to overwintering habitats may shift to later in the year to correspond with the time that aquatic habitats become ice-free.

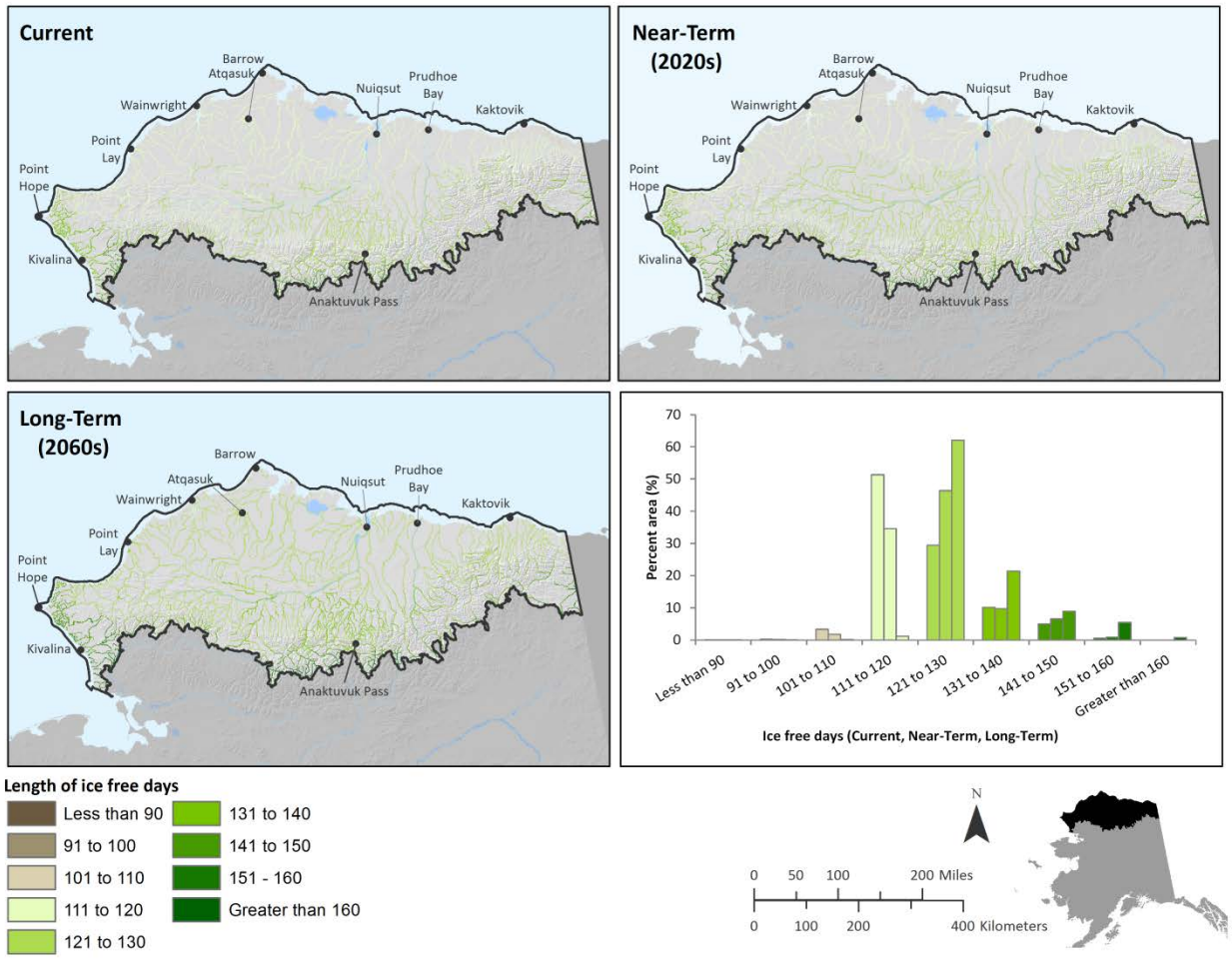

Figure I-5. Length of ice free days at current, near-term future (2020s), and long-term future (2060s) time intervals within the distribution of named rivers in the North Slope study area.

Fire

Changes in wildfire frequency, extent, and severity could have important compounding effects on stream and river ecosystems. Increased wildfire activity could result in warmer stream temperatures,

altered stream hydrology, increased landslides, and altered channel disturbances. Additionally, fires that burn across small streams may cause fish mortalities from excessive temperatures, although these effects are often short-term (Hitt 2003). Fires also alter riparian vegetation and stream shade (Pettitt and Naiman 2007), resulting in more chronic thermal effects within streams.

4.4. Invasive Species

Invasive plant species have the potential to outcompete native aquatic and emergent vegetation. However, few invasive plant species have been documented within the study area and no aquatic species have been documented (see Section D. Biotic Change Agents). *Elodea* spp. is an invasive aquatic plant that has recently been documented in southcentral Alaska and Chena Slough, near Fairbanks. *Elodea* spp invade and outcompete other aquatic plant species in slow moving streams or small, shallow lakes and ponds. Thus, small streams with slow moving waters would be most susceptible to invasion of *Elodea* spp., but many other variables such as proximity to roads and transportation hubs are important indicators to the likelihood of *Elodea* spp. colonizing stream habitats within the study area.

4.5. Current Status and Future Landscape Condition

Construction or development along stream margins will likely alter stream and lake connectivity, remove or impair riparian vegetation and function, and increase sedimentation to important aquatic habitats. Similarly, removal of vegetation along streams banks for construction or infrastructure development may alter stream thermal regimes (Moore et al. 2005). These activities could have cascading negative effects on stream resources and aquatic organisms within the study area.

4.6. Applications

The stream and river distribution maps provide managers and researchers with baseline distribution information within the North Slope study area. Because streams and rivers are ubiquitous and abundant throughout the study area it is hard to discern specific stream systems using the map scale provided in Figure I-1 and Figure I-2. However, the original GIS data layers for all maps are available as a final product and will be served on-line. This will allow specific areas of interest to be seen at a finer scale to better evaluate the distribution of these resources.

4.7. Limitations

The lack of an aquatic habitat classification for the study area represents a huge data gap that could be preventing more effective management of aquatic habitat resources. This is especially important given the spatial inaccuracies and limited attribute information in the NHD necessary to map aquatic habitats. Even an updated NHD (e.g., NHD Plus) and an updated digital elevation model with finer resolution (i.e., <60m) would significantly increase our ability to more accurately and reliably map stream locations, calculate stream gradient, and estimate stream flow and velocity. Additionally, information on stream connectivity would greatly enhance our understanding of potential fish migration corridors and provide further information on the importance of stream connectivity in the functioning of downstream waters.

Limited information exists for specific threshold effects of CA attributes and indicators (Table I-5). For example, there currently are no climate change predictions thresholds for specific to aquatic habitats, such as changes to water temperature or hydrologic regime. Water temperature plays a vital role in fish reproduction and survival. Many fish species are sensitive to even slight increases in temperature, thus baseline water temperature data is essential to better understand current conditions and to help managers develop long-term monitoring strategies to understand the potential impacts of future increases in temperature.

4.8. Literature Cited

Bowden ,W., M. Gooseff, A. Balser, A. Green, B. J. Peterson, and J. Bradford. 2008. Sediment and nutrient delivery from thermokarst features in the foothills of the North Slope, Alaska: Potential impacts on headwater stream ecosystems. J. Geophys. Res. 113, G02026, doi:10.1029/ 2007JG000470.

Brabets, T. and M. Walvoord. 2009. Trends in streamflow in the Yukon River Basin from 1944 to 2005 and the influence of the Pacific Decadal Oscillation. J. Hydro 271:108-119.

Davis, J., C. Baxter, E. Rosi-Marshall, J. Pierce, and B. Crosby. 2013. Anticipating stream ecosystem responses to climate change: Toward predictions that incorporate effects via land-water linkages. Ecosystems 16:909-922.

Dingman, S. 1973. Effects of permafrost on stream flow characteristics in the discontinuous permafrost zone of central Alaska. Pages 447-453 *in* Permafrost: North American Contribution to the Second International Conference. Washington, DC: National Academy of Sciences.

Hitt, N. P. 2003. Immediate effects of wildfire on stream temperature. J. Freshwater Eco 18:171–173.

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

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.

Moore, R. D., D. L. Spittlehouse, and A. Story. 2005. Riparian microclimate and stream temperature response to forest harvesting: a review. Journal of American Water Resources Association 41:813–834.

Pettit N., and R. Naiman. 2007. Fire in the riparian zone: characteristics and ecological consequences. Ecosystems 10: 673–687.

Prowse, T. 2001. River-ice ecology. I: Hydrologic, geomorphic, and water-quality aspects. Journal of Cold Regions Engineering 15:1–16.

Prowse, T. D., F. J. Wrona, J. D. Reist, J. J. Gibson, J. E. Hobbie, L. M. J. Lévesque, and W. F. Vincent. 2006. Climate change effects on hydroecology of arctic freshwater ecosystems. Ambio 35:347–358.

Reist, J. D., F. J. Wrona, T. D. Prowse, M. Power, J. B. Dempson, R. J. Beamish, J. R. King, T. J. Carmichael, and C. D. Sawatzky. 2006a. General effects of climate change on Arctic fishes and fish populations. Ambio 35:370–380.Reist, J., F. Wrona, T. Prowse, M. Power, J. Dempson, J. King, and R. Beamish. 2006b. An overview of effects of climate change on selected arctic freshwater and anadromous fishes. Ambio 35:381-38.

5. Deep and Shallow Lakes

There are thousands of lakes (Figure I-6) within the North Slope study area that range from small shallow (generally <1.6m deep) to large deep lakes such as Teshekpuk Lake. Most lake bottoms are composed of fine substrates throughout the study area though lakes within the Brooks Range are composed more commonly of gravel bottoms. Many lake connections are ephemeral especially during open water season (at break up and through the summer).

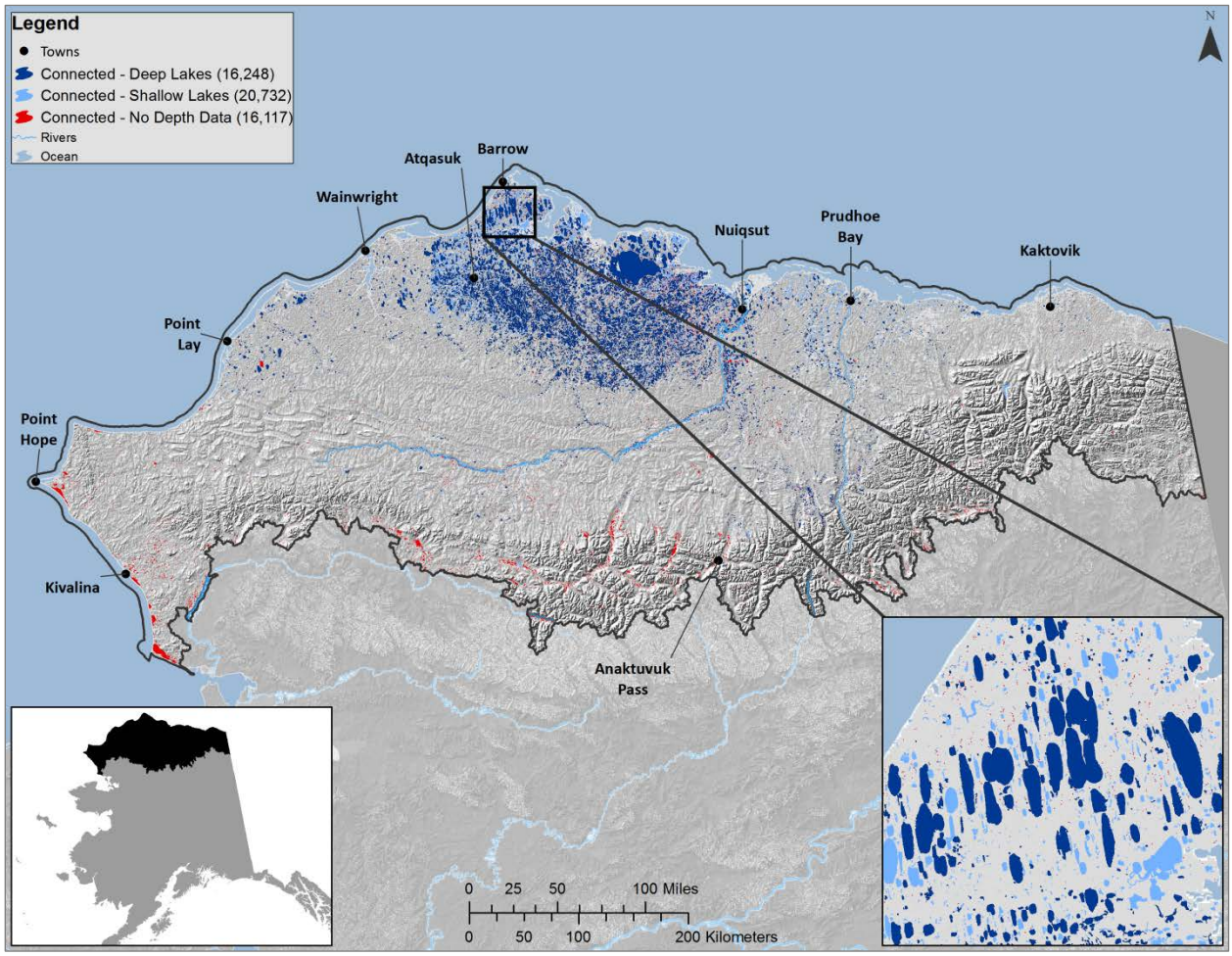

Figure I-6. Distribution of all connected lakes within the North Slope study area.

Deep and shallow connected lakes throughout the study area support a rich biodiversity of aquatic organisms and represent important foraging and breeding habitat for aquatic insects, fish, waterfowl and shorebirds. Additionally, lake ecosystems provide important recreational and personal uses for local residents (e.g., subsistence harvest of fish and wildlife).

5.1. Deep Connected Lakes

Deep connected lakes (Figure I-7) are generally greater than 1.6m depth (Mellor 1982, Jeffries et al. 1996, Grunblatt and Atwood 2013) and characterized by low temperatures, low prey densities, short open water periods, and limited overwintering habitat. Because of their depth and perennial flow, it is less likely that deep connected lakes freeze completely during winter, therefore providing important winter refuge for fish and other aquatic organisms.

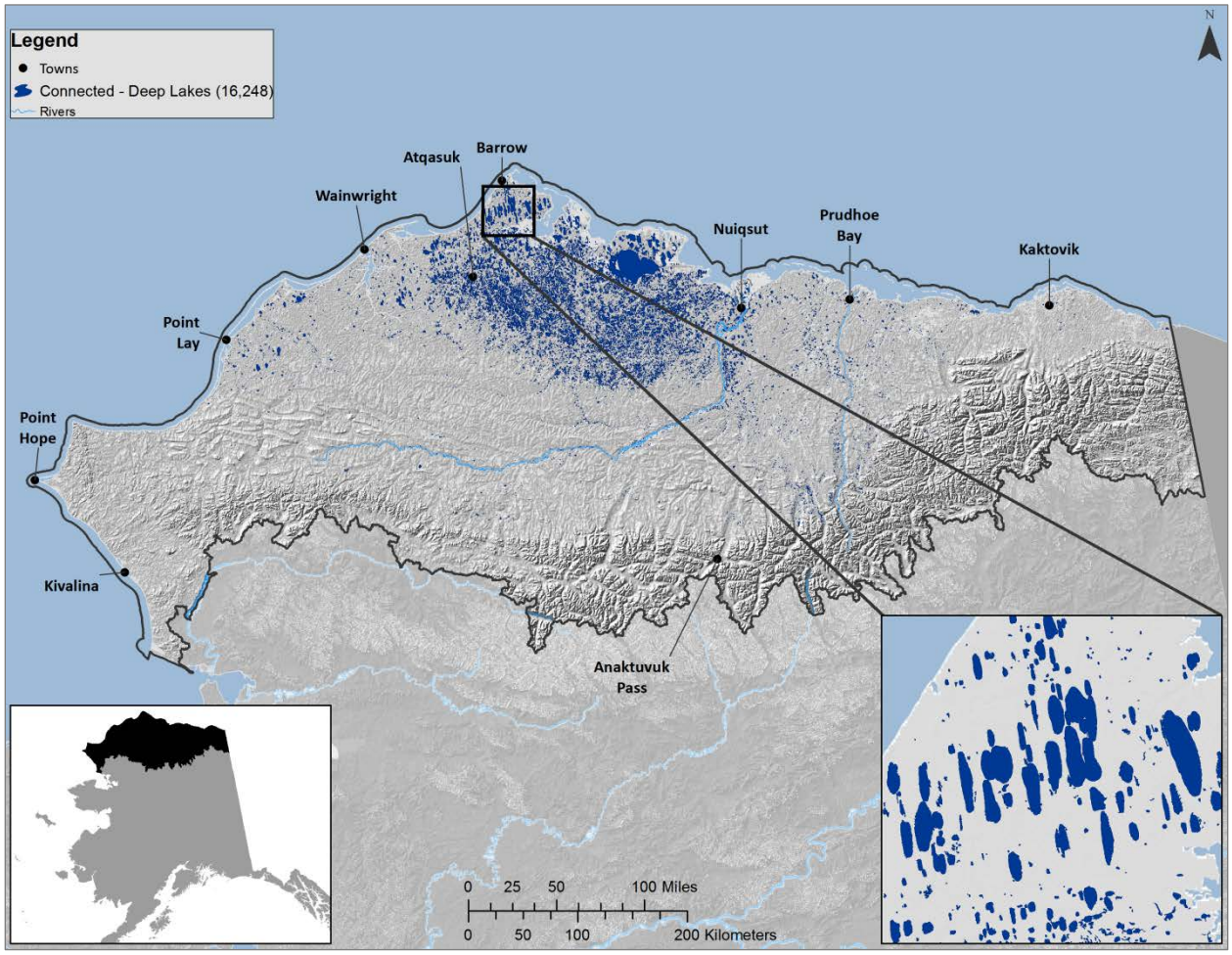

Figure I-7. Distribution of deep (>1.6m depth) lakes within the North Slope study area.

5.2. Shallow Connected Lakes

Shallow lakes (Figure I-8) are ubiquitous in the study area and represent approximately 40% of the landscape (Sellmann et al. 1975, Hinkel et al. 2005). Shallow lakes typically freeze to the bottom and only contain liquid water during the summer months (Kozlenko and Jeffries 2000). Shallow lakes do not provide fish overwintering habitat; however, they are used by fish for foraging habitats during the open water season. Most shallow lakes are dependent on surface runoff for recharge and are subject to substantial evaporative loss during summer (Miller et al. 1980). Lake connections can vary greatly and

change throughout the open-water season, with ephemeral connections commonly occurring during high flows in the spring.

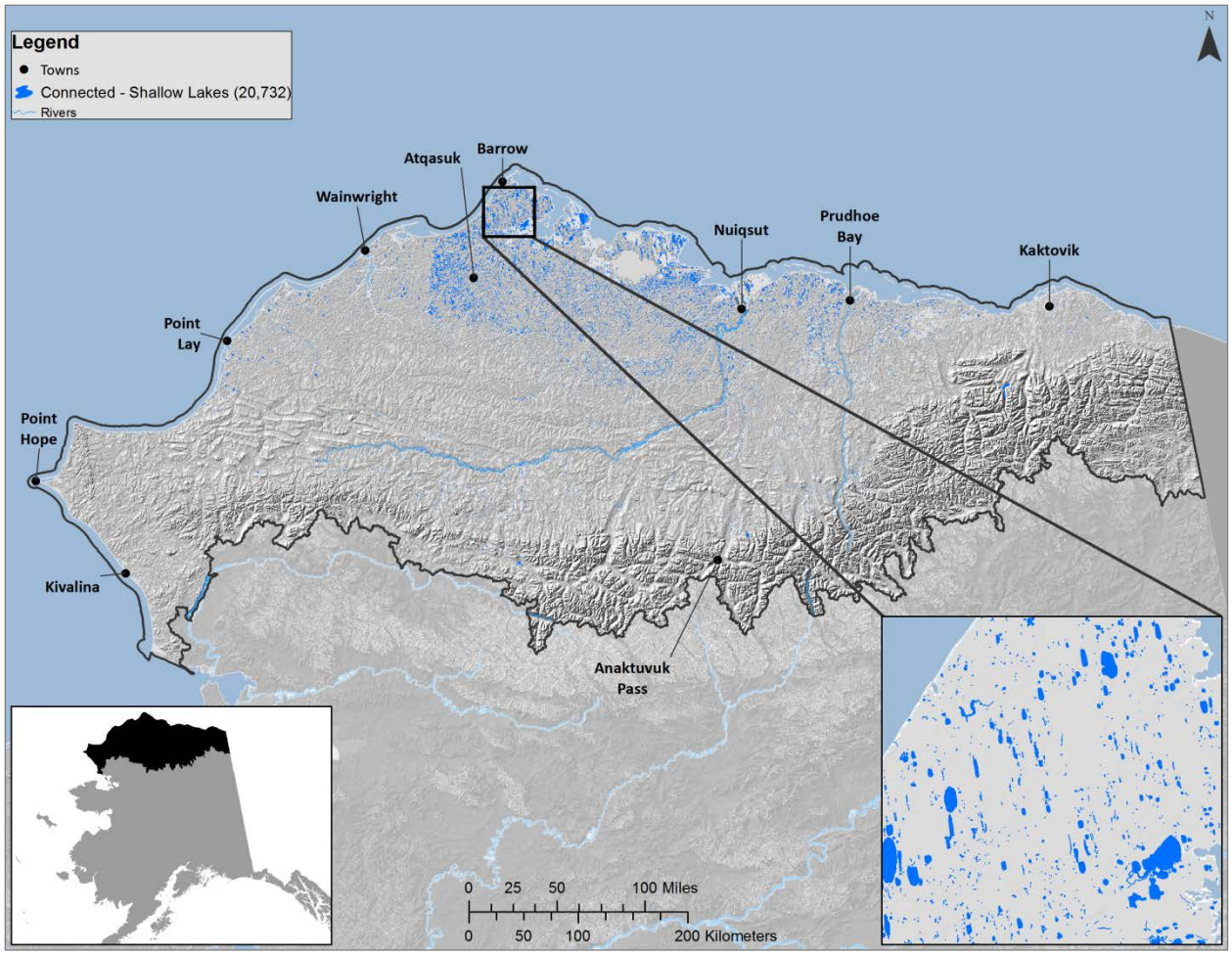

Figure I-8. Distribution of shallow (<1.6m depth) lakes within the North Slope study area.

5.3. Conceptual Model

The conceptual models below (Figure I-9 and Figure I-10) are based on a review of the literature and describe the relationships between the various CAs and natural drivers for deep connected lakes and shallow connected lakes. The boxes and arrows represent the state of knowledge about lakes and the relationship to each attribute.

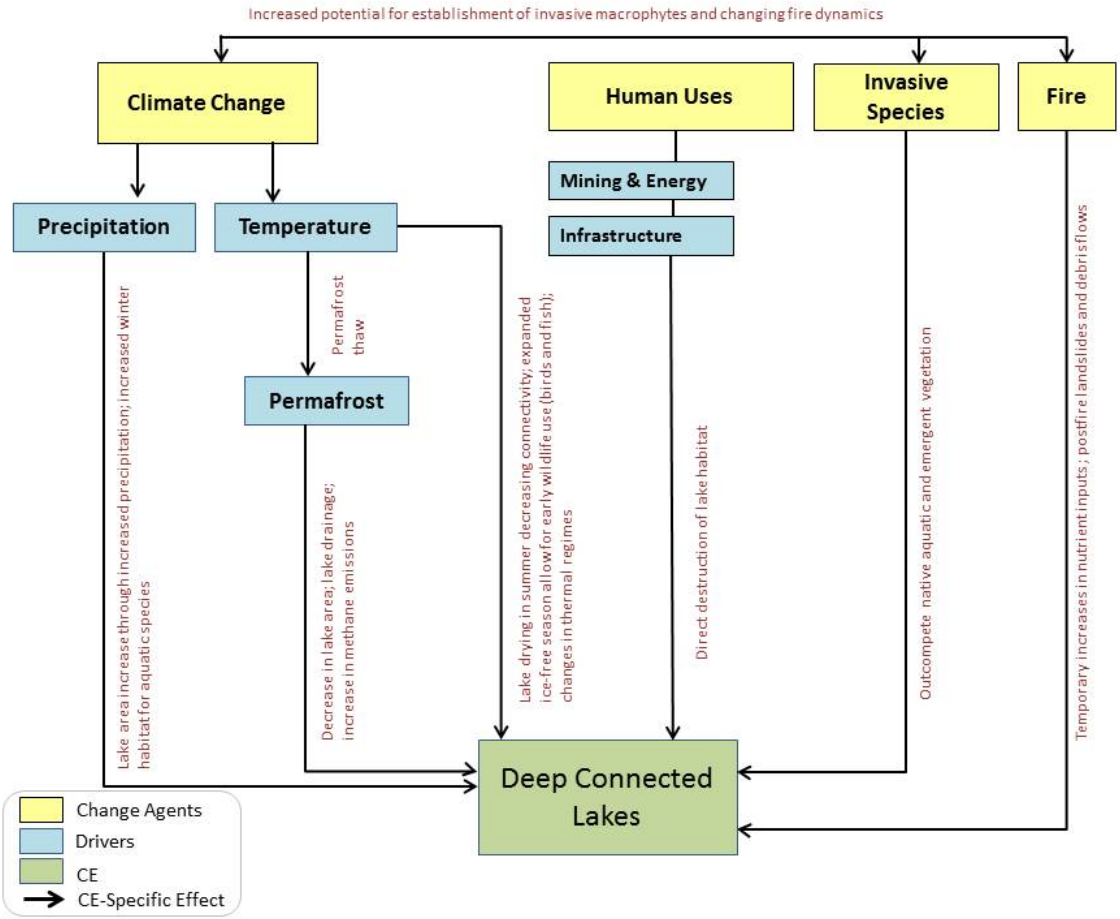

Figure I-9. Principal interactions among population drivers and CAs for deep connected lakes within the North Slope study area.

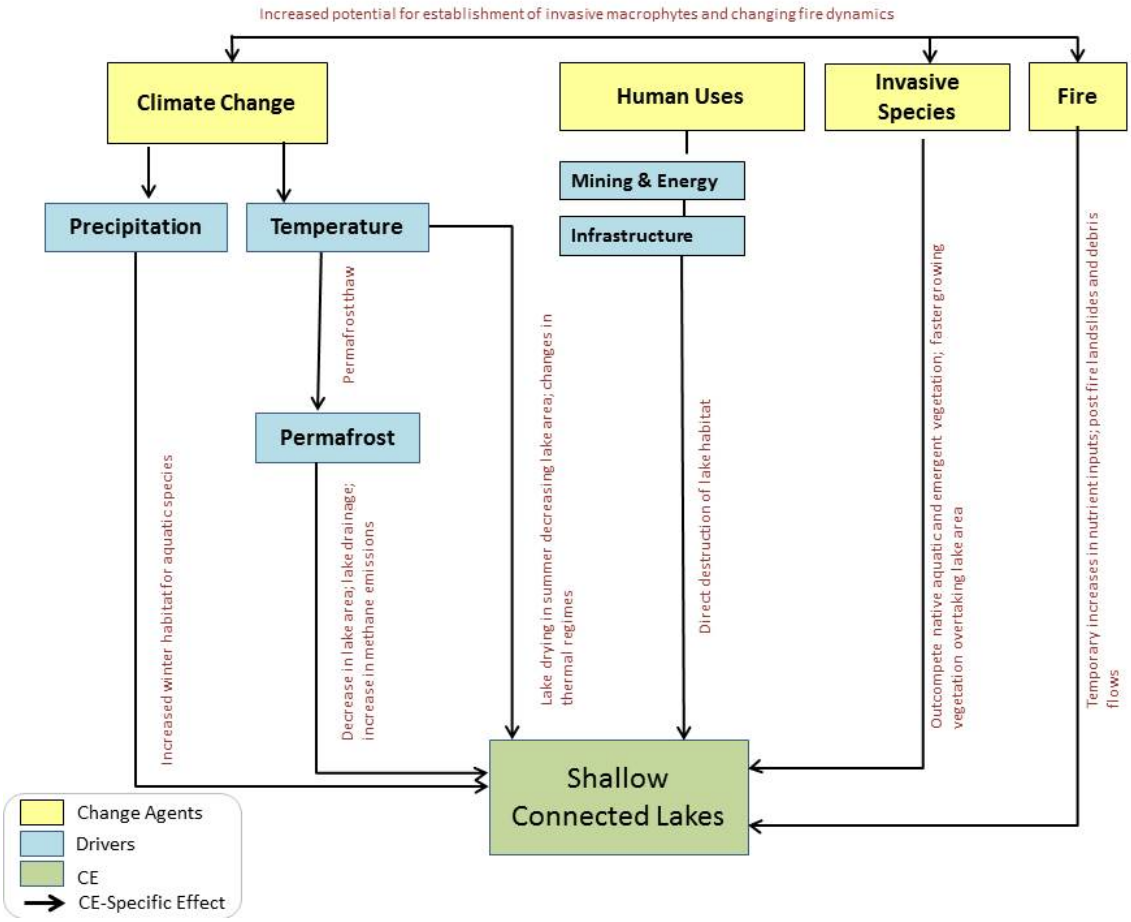

Figure I-10. Principal interactions among population drivers and CAs for shallow connected lakes within the North Slope study area.

5.4. Attributes and Indicators

Spatial data, most of which are available from this assessment, can be used to assess the status of deep and shallow connected lakes and include: winter precipitation, summer temperature, rain on snow events, mean annual ground temperature, fire frequency, contaminated sites, oil and gas activities, and riparian invasive species (Table I-6).

Table I-6. Attributes and Indicators for connected lakes.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[11]	Dec-Feb total precipitation	Habitat	Less precipitation			More precipitation
	Winter precipitation[12]	Dec-Feb total precipitation	Habitat	More precipitation			Less precipitation
	Summer temperature[13]	June-August mean monthly air temperature	Habitat				
	Rain on snow events[14]	Dec-Feb	Habitat	Snow fraction below 80% for more than one winter month	Snow fraction below 80% for one winter month	Snow fraction below 90% for one winter month	Snow fraction over 90% for all winter months
	Change in mean annual ground temperature at one meter (MAGT)[15]	Permafrost thaw	Habitat	From below -1m to above +1m			No Change

[11] Specific thresholds are unknown. Increased winter precipitation could increase available overwintering habitat for fish (by increasing the volume of water).
[12] Specific thresholds are unknown. Increased precipitation could result in increased run-off and sedimentation negatively impacting lake habitat.
[13] Specific thresholds are unknown. Lake drying due to warmer, dryer air temperatures, increased evapotranspiration which could lead to reduced run off.
[14] Based on Hansen et al. 2011;-thresholds are general.
[15] Based on GIPL model, Lloyd et al. 2003; Brabets and Walvoord 2009; thresholds are-general. Changes in groundwater contribution to baseline and seasonal flow.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Fire	Fire frequency[16]	Fire return interval	Habitat	High return interval			Low return interval
	Fire frequency[17]	Fire return interval	Habitat	Low return interval			High return interval
Anthropogenic development	Contaminated sites[18]	Water quality	Habitat				
	Oil and gas activities[19]	Water withdrawal	Habitat	Lakes used by fish			Lakes not used by fish
Invasive species	Riparian invasive species[20]	Out-compete native aquatic species	Habitat				

[16] Based on Davis et al. 2013; thresholds are general. Fires strip stabilizing vegetation from the landscape and increase erosion and runoff, resulting in higher sediment inputs to lakes.
[17] Based on Davis et al. 2013; thresholds are general. Fire increases nutrient inputs.
[18] Thresholds will depend on specific contaminants at a site and proximity to streams. Oil contamination that can alter groundwater interactions and negatively impact habitat for aquatic species.
[19] Based on BLM 2006;-thresholds are general. Effect water quality, reduce spawning habitat for burbot and reduce overwintering and foraging habitat for all other Coarse-Filter CEs.
[20] Specific thresholds are unknown. Shallow connected lakes would be most susceptible to invasion of *Elodea* spp.

5.5. Abiotic Change Agent Analysis

Climate

With warmer air temperatures, lake ice will freeze later and melt sooner, thereby lengthening the ice-free season. Warmer temperatures combined with increased snow cover are expected to have a significant impact on the annual heat budget of arctic lakes (Schindler and Smol 2006). Increased snow cover will insulate lakes and result in thinner ice. Reduced ice cover will create new habitat, especially in lakes that are frozen most of the year. Thinner lake ice will melt faster in spring, which could lead to earlier spring ice breakup and increased water temperature. Earlier ice breakup could result in channel blockage for lakes with connected streams. Changes in the freeze-thaw cycle that affect lake connectivity could alter migration movements of fish species such as broad whitefish that move into deeper connected lakes in the winter and migrate to shallower lakes for feeding and spawning in the summer.

Warmer temperatures coupled with increased evapotranspiration, especially later in the summer and early fall, could cause a drying effect and potentially decrease connectivity between streams and lakes. A lack of connectivity between inlet and outlet streams would limit access to important spawning areas, affect the amount of available overwintering habitat, and potentially disrupt the timing of annual migrations for fish species. However, the impact of temperature and evapotranspiration on loss of lake connectivity is influenced by other factors including overall lake size and lake depth.

Drier and warmer summer temperatures could reduce lake recharge because more water would be absorbed into soil. Snow melt during the spring is the primary source of water and nutrient recharge to both deep and shallow connected lakes in the study area. With increased temperatures, additional snow melt in lakes within areas that have thicker permafrost could result in increased lake area. These changes however, would be temporary if temperatures continue to rise.

Although specific effects of climate change on water temperature are not clear, the warming trend will likely result in both positive and negative impacts on aquatic biota and lake habitats. Increased water temperatures (Figure I-11) could increase primary productivity which could in turn improve the quality of fish feeding habitat by changing the abundance of prey species (Reist et al. 2006b). Water temperature is also critical in determining timing of different life history stages of fish. For instance, increased water temperatures could decrease the amount of time required for egg development and fish rearing and overall fish age at maturity. Increased temperatures within lake habitats could also impact timing of fish migrations, prevalence of disease, and long-term survival of fish, especially more cold-tolerant species such as Arctic grayling and burbot.

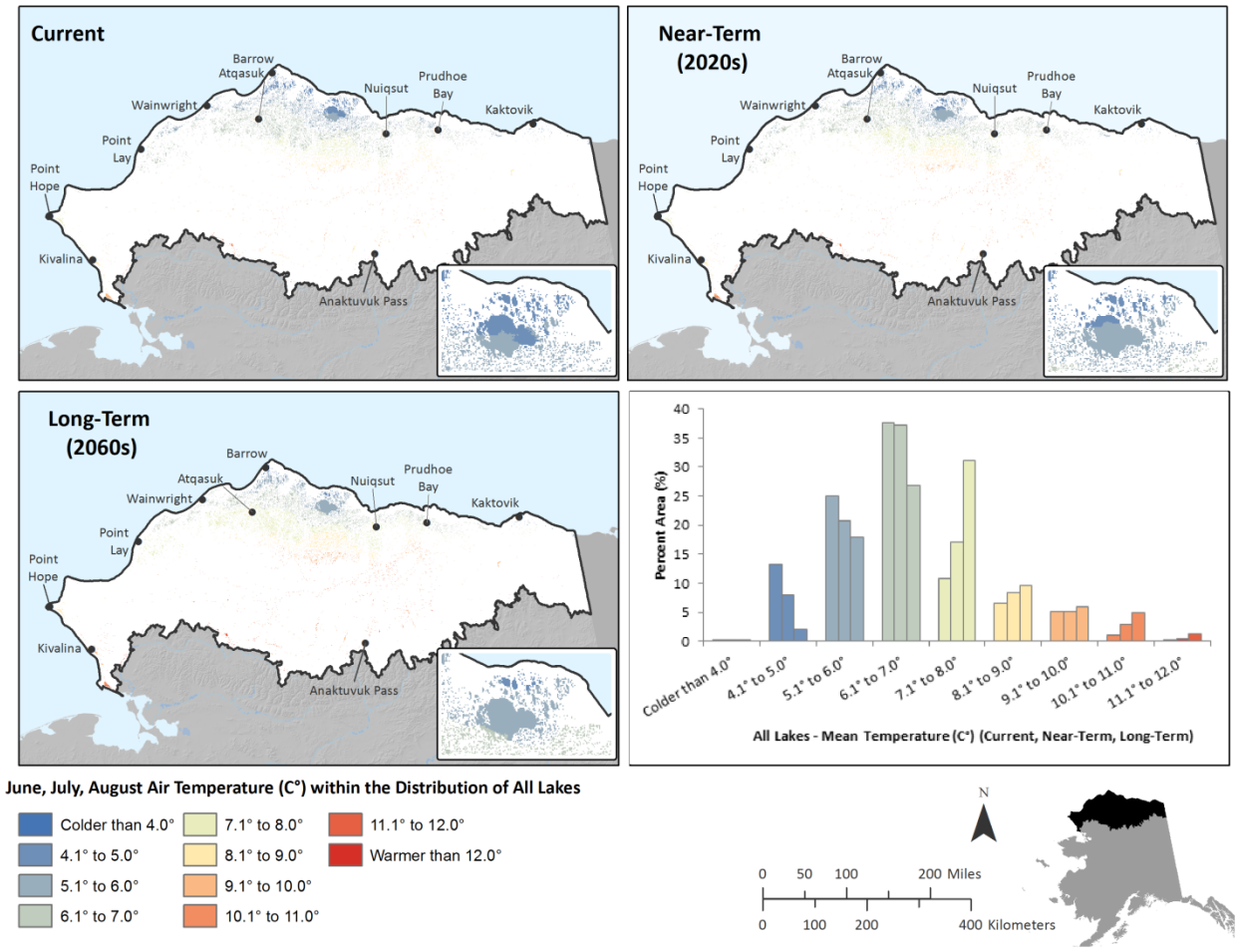

Figure I-11. Distribution of lakes and modeled increase in July temperature change from 2010 - 2060 within the North Slope study area.

Permafrost

Loss of permafrost, particularly when coupled with thermokarst-prone conditions and increased evaporation, increases the potential for lakes to shrink or dry out (especially shallow lakes) in the study area (Roach et al. 2013). Thawing of permafrost has also been linked to increases in substrate permeability and increased drainage for all lakes (Roach et al. 2013). New drainage networks could form if surrounding ice wedges degrade. However, other studies have documented an increase in lake area as a consequence of increased snow melt and more erosion due to permafrost thaw (Jones et al. 2011, Plug and West 2009, and Turner et al. 2014). Thus, lakes may drain entirely with permafrost melting, or lake levels may rise with increased inflow. Lastly, thawing permafrost could temporarily increase nutrient loading to lakes and increase primary productivity (Hobbie et al. 1995). This would benefit numerous fish and wildlife species that forage in these lakes. In addition to direct effects on lake habits, thawing permafrost along lake margins could increase the amount of methane released from lakes to the atmosphere (Walter et al. 2007).

Overlaying lake distribution and thermokarst predisposition (as defined by soil type, ice richness, and topographic variables) yields a complex picture of possible hydrologic change (Figure I-12). Most of the area with the greatest potential for thermokarst has permafrost with a mean annual ground temperature colder than -6.0°C. This suggests total thaw and collapse would be unlikely in either the near or long term. Although the interior of the Coastal Plain has cold and stable permafrost, lakes in this thermokarst-prone area suggests new drainage patterns are likely to emerge with small shifts in Active Layer Thickness (ALT). Thermokarst slumping is most likely to occur at a micro rather than macro scale, with localized drying of better-drained areas, and perhaps wetter conditions in others. Around the edges of lakes, loss of frozen soil may lead to slumping. However, potential thermokarst risk is low in areas near Point Hope and Kivalina where the mean annual group temperature is already increasing (suggesting continued permafrost loss) suggesting little risk of hydrologic change due to thermokarsts in those areas.

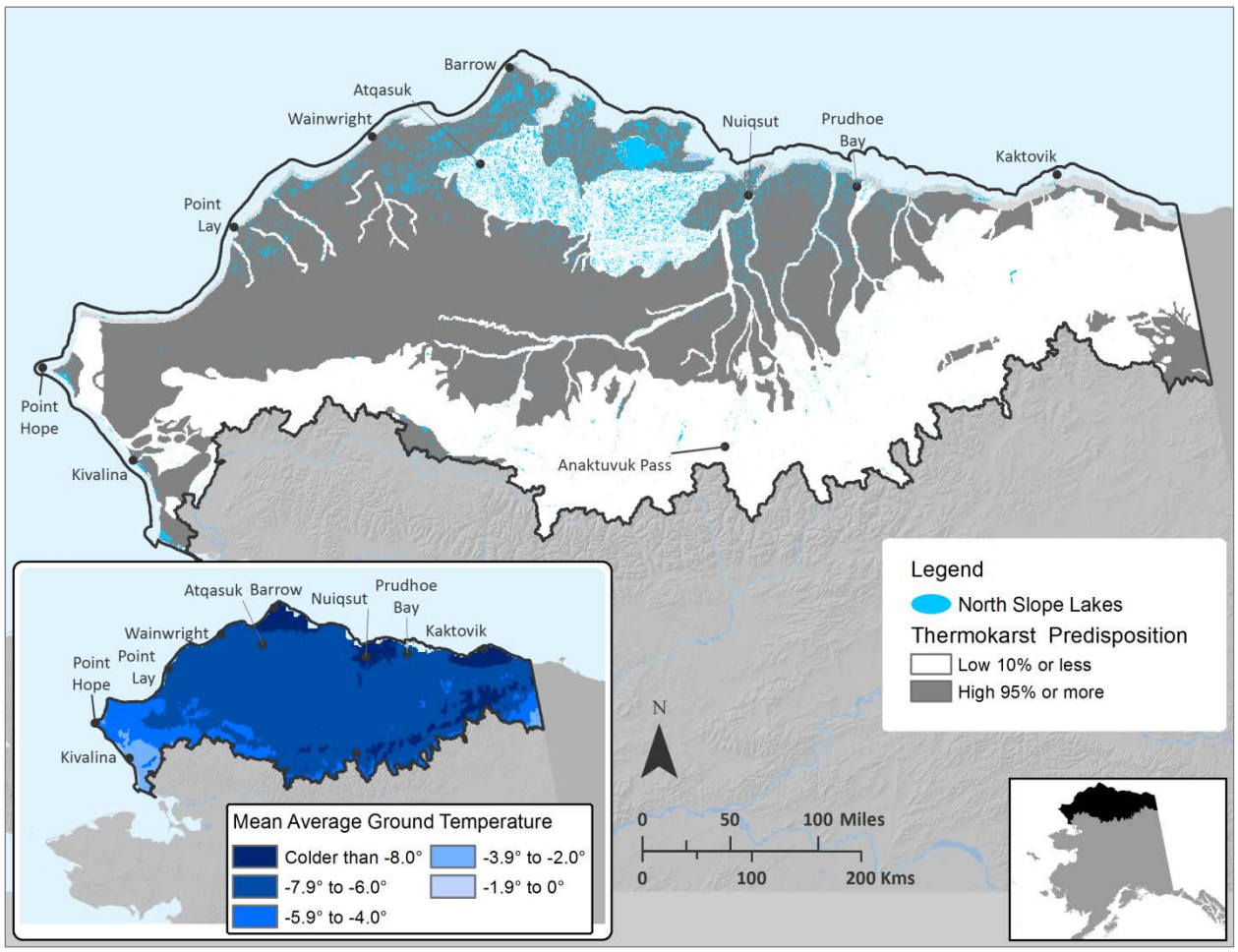

Figure I-12. Relationship between the current distribution of lakes and thermokarst potential.

Fire

Increased wildfire activity could result in increased landslides and debris flows along lake edges and shorelines. Increases in nutrient inputs could temporarily benefit aquatic organisms (e.g., juvenile fish and aquatic insects).

5.6. Invasive Species

Invasive plant species have the potential to outcompete native aquatic and emergent vegetation. However, few invasive plant species have been documented within the study area and no invasive aquatic species have yet been documented in the region (See Section D). *Elodea* spp. is an invasive aquatic plant that has recently been documented in south central Alaska and Chena Slough, near Fairbanks. *Elodea* spp. generally invade and outcompete other aquatic plant species in slow moving streams or small, shallow lakes and ponds. Thus, shallow connected lakes may be more susceptible to potential *Elodea* spp. invasions than deep connected lakes.

5.7. Current Status and Future Landscape Condition

Construction or development, especially oil and gas operations near deep connected lakes could increase sedimentation to lakes. Run-off from unpaved roads can result in sedimentation to lakes increasing turbidity and impacting water quality for aquatic organisms and human use. Oil and gas activities near streams that are connected to lake systems could also have negative impacts on the water quality of connected lakes. Changes in water quantity caused by withdrawals during exploration are typically from deep lakes during winter, while water withdrawals during operations and for domestic uses would also occur during the open-water season. Winter withdrawal from lakes for the creation of roads and other infrastructure has the potential to negatively impact overwintering fish populations by disrupting connectivity to other waterbodies and/or reducing lake area. Increased development, especially the construction of new roads can also facilitate the dispersal of invasive species into lakes. Increased road access for communities may increase fishing pressure and possibly negatively impact water quality of lakes.

Different from other REAs in Alaska, we worked closely with the NSSI Scenarios project to incorporate future human footprint estimates from their scenario exercises (see Section E). Instead of near and long-term futures, we use the “Medium” and “High” oil and gas scenarios generated as part of that effort. Due to the limited scope of the scenarios project, and the anticipated lack of population change in the villages, our future human footprint is largely driven by changes in oil and gas infrastructure. Future oil and gas infrastructure associated with the Medium Scenario develops part of the Greater Moose’s Tooth region of NPR-A, and further expands the development currently at Point Thompson. The Liberty drilling pads are expanded, and there is a new pipeline built connecting offshore activities to the Point Thompson region in the Medium Scenario as well. Additionally, we included the road and relocation of Kivalina in the Medium Scenario. The High Scenario included all the same development of the Medium Scenario, but expanded the Greater Moose’s Tooth development to include a pipeline connecting development on Smith Bay, develops a pipeline and road from the potential Chukchi Sea facilities, and

develops a pipeline connecting Umiat to other oil and gas infrastructure. Although offshore activities are included in the NSSI scenarios, we did not include those developments given our terrestrial focus. Additionally, we assumed all current oil infrastructure would continue to operate into the future. Given the uncertainty in future human footprint models, especially in the High Scenario, the results should be considered representative of potential changes to overall landscape condition. Shallow, deep, and all lakes status under the current, medium and high development show similar results (Table I-7, Figure I-13, Figure I-14,and Figure I-15), that is, the condition is quite high. However, it is important to note that although shallow lakes are considered to have very high condition in general they differ by almost 10% between the shallow and deep lakes for the high development scenario and are potentially more at risk by development than the deep lakes (89.6% and 97.4% respectively).

Table I-7. Landscape condition displayed as percent total area within the distribution of shallow, deep, and all lakes.

Aquatic Coarse-Filter CE		**Landscape Condition (% Area)**				
		Very Low	**Low**	**Medium**	**High**	**Very High**
All Lakes	Current	0.31	0.78	0.98	1.19	96.74
	Medium Scenario	0.31	0.79	1.01	1.23	96.66
	High Scenario	0.31	0.98	1.28	1.54	95.89
Shallow Lakes	Current	0.77	2.30	3.09	3.13	90.71
	Medium Scenario	0.77	2.31	3.16	3.20	90.56
	High Scenario	0.77	2.60	3.45	3.50	89.68
Deep Lakes	Current	0.20	0.40	0.45	0.69	98.26
	Medium Scenario	0.20	0.40	0.47	0.72	98.21
	High Scenario	0.20	0.58	0.75	1.04	97.43

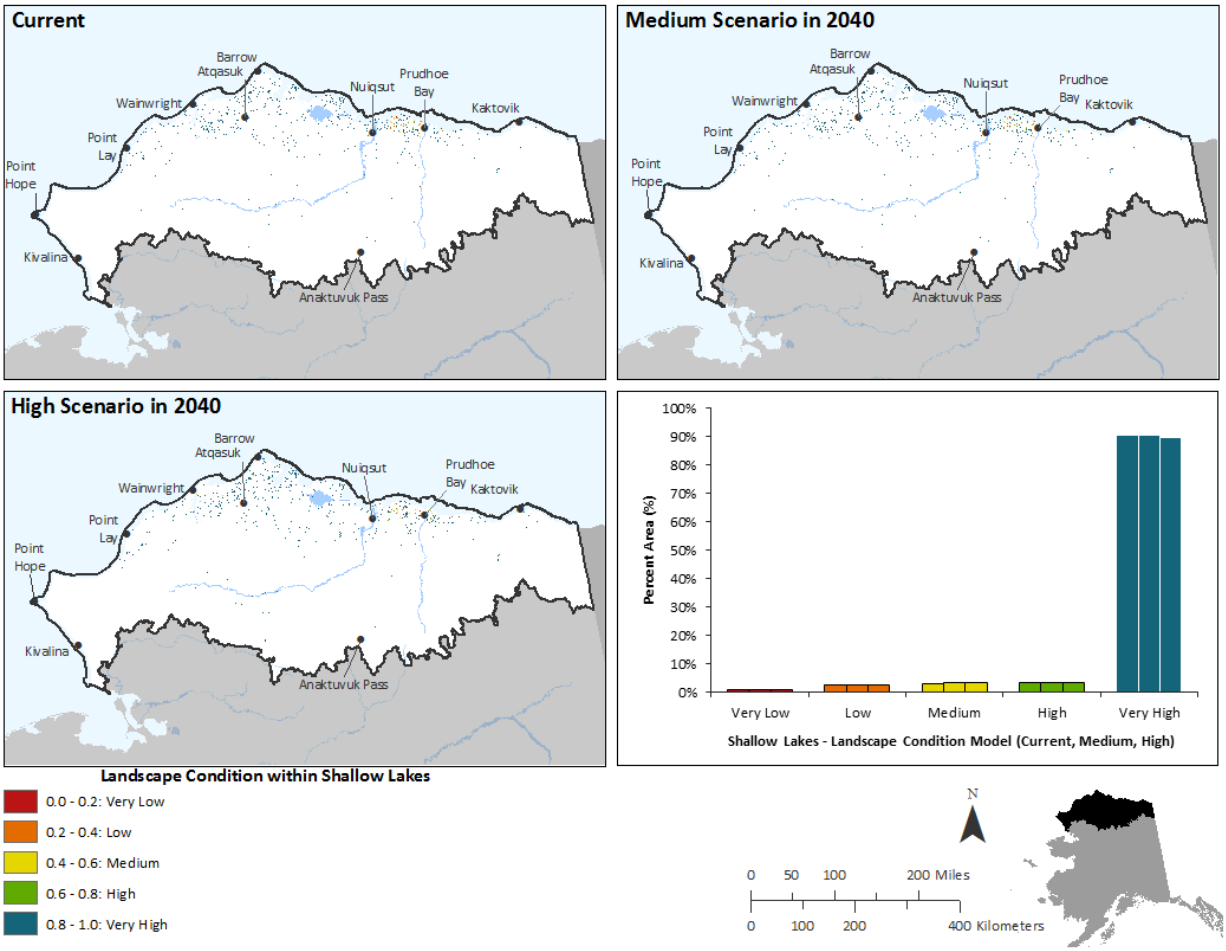

Figure I-13. Current, medium scenario (2040), and high scenario (2040) future landscape condition (summarized at the 5th level HUC) within current shallow lakes habitat in the North Slope study area.

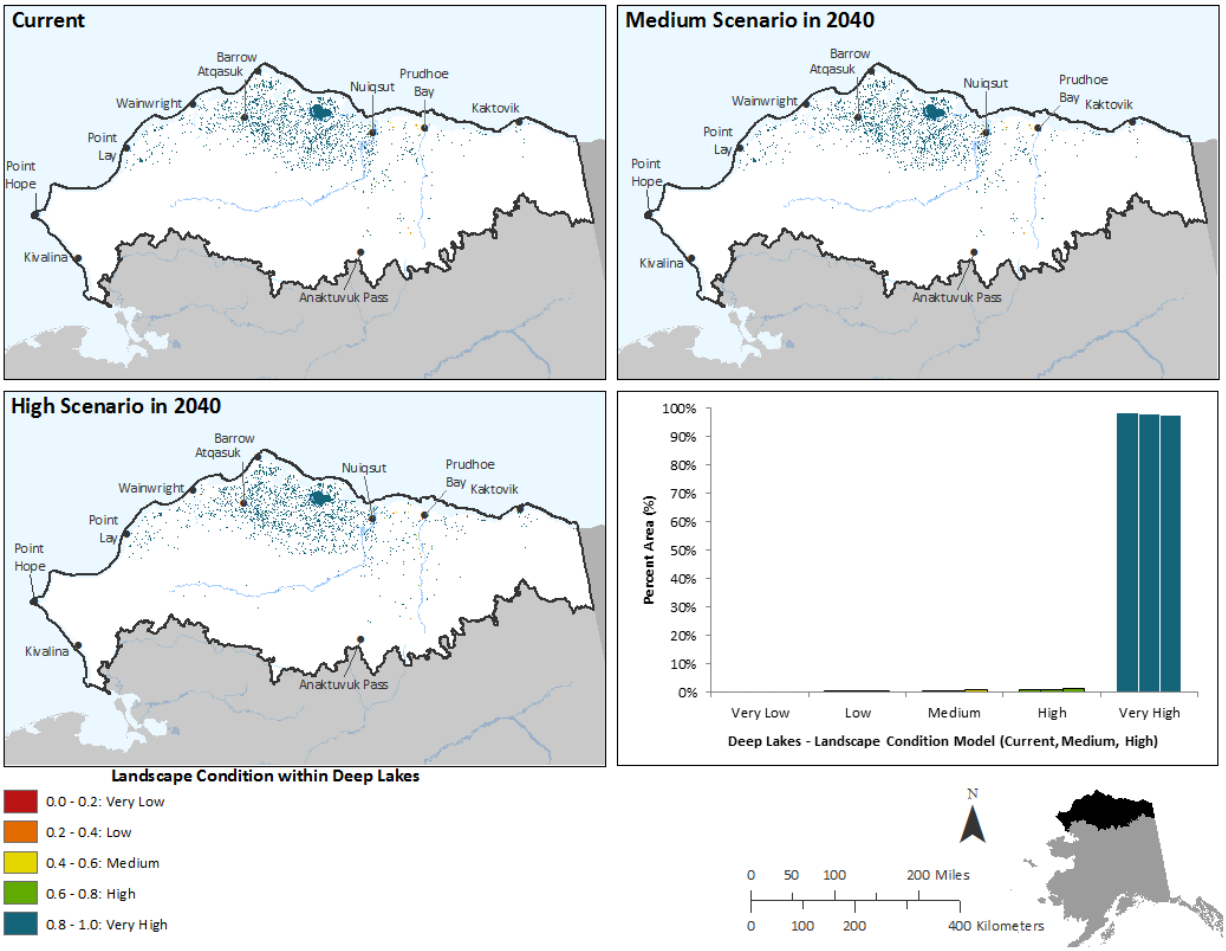

Figure I-14. Current, medium scenario (2040), and high scenario (2040) future landscape condition (summarized at the 5th level HUC) within current deep lakes habitat in the North Slope study area.

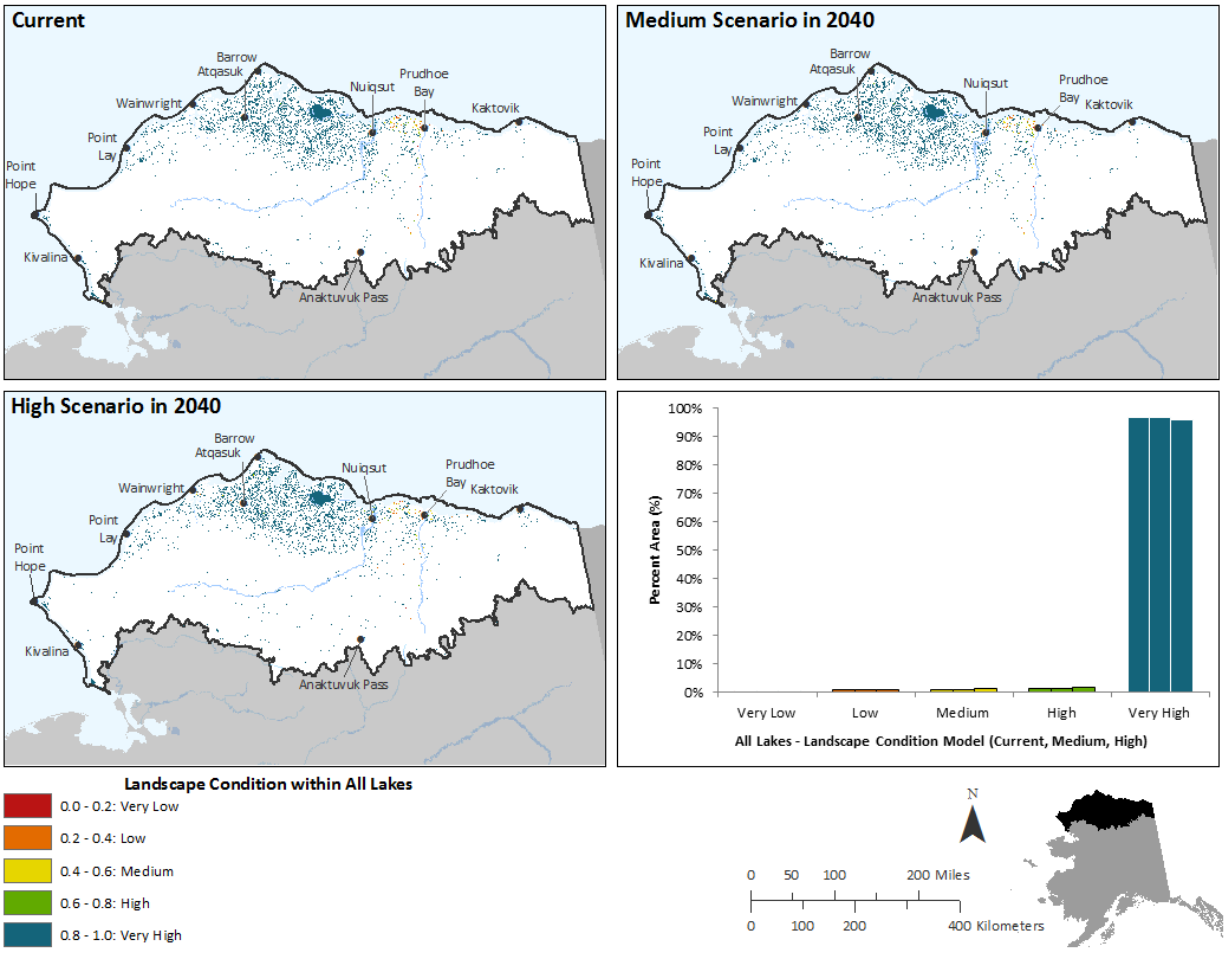

Figure I-15. Current, medium scenario (2040), and high scenario (2040) future landscape condition (summarized at the 5th level HUC) within current distribution of all lakes in the North Slope study area.

5.8. Applications

Lake distribution maps provide baseline information within the North Slope study area. Because lakes are abundant throughout the study area it is hard to discern specific lakes using the map scale provided (Figure I-6). However, the original GIS data layers for all maps are available as a final product and will be served on-line. This will allow specific areas of interest to be seen at a finer scale to better evaluate the distribution of these resources.

5.9. Limitations

The lack of an aquatic habitat classification for the study area represents a huge data gap that could be preventing more effective management of aquatic habitat resources. This is especially important given the spatial inaccuracies and limited attribute information in the NHD necessary to map aquatic habitats. The NHD is outdated (most topographic maps were created in the 50's and 60's) and lake areas have likely changed due to natural hydrologic disturbances and climate change. Limited information also

exists for specific threshold effects of CA attributes and indicators Table I-5). For example, there currently are no climate change predictions thresholds for specific to aquatic habitats, such as changes to water temperature or hydrologic regime.

5.10. Literature Cited

BLM. 2006. National Petroleum Reserve-Alaska (NPR-A) Northwest Planning Area winter exploration drilling program: FEX, L.P. Prepared by USDOI BLM, Alaska Arctic Field Office, Fairbanks District Office, Anchorage Field Office, Alaska. Available: http://www.blm.gov/pgdata/etc/medialib/blm/ak/aktest/energy/egy_maps.Par.94059.File.dat/fex_npra_ea_final.pdf.

Brabets, T. and M. Walvoord. 2009. Trends in streamflow in the Yukon River Basin from 1944 to 2005 and the influence of the Pacific Decadal Oscillation. J. Hydro 271:108-119.

Davis, J., C. Baxter, E. Rosi-Marshall, J. Pierce, and B. Crosby. 2013. Anticipating stream ecosystem responses to climate change: Toward predictions that incorporate effects via land-water linkages. Ecosystems 16:909-922.

Grunblatt, J. and D. Atwood. 2013. Mapping lakes for winter liquid water availability using SAR on the North Slope of Alaska. Int. J. Appl. Earth Observ. Geoinf., http://dx.doi.org/10.1016/j.jag.2013.05.006

Hansen, 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.

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

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

Jeffries M. O., K. Morris, and G. E. Liston. 1996. A method to determine lake depth and water availability on the North Slope of Alaska with spaceborne imaging radar and numerical ice growth modelling. Arctic 49:367–374.

Jones, B. M., G. Grosse, C. D. Arp, M. C. Jones, K. M. W. Anthony, and V. E. Romanovsky. 2011. Modern thermokarst lake dynamics in the continuous permafrost zone, northern Seward Peninsula, Alaska. Journal of Geophysical Research-Biogeosciences 116, G00M03, doi:10.1029/2011JG001666.

Kozlenko, N. and M. O. Jeffries. 2000. Bathymetric mapping of shallow water in thaw lakes on the North Slope of Alaska with spaceborne imaging radar. Arctic 53:306–316.

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.

Mellor, J. 1982. Bathymetry of Alaskan Arctic lakes: A key to resource inventory with remote sensing methods, Ph. D. Thesis, Institute of Marine Science, University of Alaska.

Miller, M. C., R. T. Prenki, and R. J. Barsdate. 1980. Physics. Pages 51-75 *in* J. E. Hobbie, ed. Limnology of tundra ponds, Barrow, Alaska. Academic Press.

Plug, L. J., and J. J. West 2009. Thaw lake expansion in a two-dimensional coupled model of heat transfer, thaw subsidence, and mass movement. Journal of Geophysical Research-Earth Surface 114, F01002, doi:10.1029/2006JF000740.

Reist, J., F. Wrona, T. Prowse, M. Power, J. Dempson, J. King, and R. Beamish. 2006. An overview of effects of climate change on selected arctic freshwater and anadromous fishes. Ambio 35:381-38.

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

Sellmann, P. V., L. Brown, R. I. Lewellen, H. L. McKim, and C. J. Merry. 1975.The classification and geomorphic implications of thaw lakes on the Arctic Coastal Plain, Alaska, Res. Report 344., U. S. Army Cold Regions Research and Engineering Lab., Hanover, NH. 20 pp.

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.

Turner, K. W., B. B. Wolfe, T. W. D. Edwards, T. C. Lantz, R. I. Hall, and G. Larocque . 2014. Controls on water balance of shallow thermokarst lakes and their relations with catchment characteristics: a multi-year, landscape-scale assessment based on water isotope tracers and remote sensing in Old Crow Flats, Yukon (Canada). Global Change Biology 20:1585-1603.

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

6. Water Withdrawal from Lakes

MQ AC 1	How does water withdrawal from lakes for oil and gas activities (year-round industrial and domestic use and winter operations) affect lake water quantity and water quality, outflow/stream connectivity, and down-basin habitat?

6.1. Introduction

Lakes within the North Slope study area are an important resource that support year-round oil and gas activities. Water withdrawal activities related to winter operations (e.g., building ice roads) usually takes place beginning in December or January, or when the tundra is sufficiently frozen (Hinzman et al. 2006). Year-round water withdrawals supply drilling operations, support camps, and facilities by providing potable water and dust control. Possible effects of water withdrawal include impacts to water quantity, quality, and direct impacts to aquatic biota.

We were not able to answer this question with spatial datasets due to the lack of available geospatial lake data. Data on lakes used for water withdrawal are available, as Meridian, Township and Range (MTRS) location references, but these data have not been provided with individual latitude and longitude locations. Moreover, this coarse location data is recorded for each permit in their respective permit, not in a central database available for this project. It was beyond the scope of this project to get these data entered into a digitally available format. Thus, we have identified this MQ as a **data gap**. Below we provide an overview of the potential affects that water withdrawal may have on aquatic habitats within the North Slope study area.

6.2. Water quantity

Lakes that do not freeze to the bottom in winter are an important source of water for ice road construction. Shallow lakes can also be used during the non-winter months for water withdrawal purposes. Ice roads are the main form of transportation in the winter and essential to oil and gas industrial activities. Lakes that do not freeze to the bottom provide critical habitat for overwintering fish and water withdrawals from these lakes could negatively impact fish populations. The BLM has developed requirements regarding the amount of water removed depending on lake characteristics, including depth and fish species present (NPRA Final Integrated Activity Plan/Environmental Impact Statement 2012). For example, lakes deeper than seven feet that contain sensitive fish species can only have 15% of the volume of water under the ice removed. Lakes between five and seven feet deep that have sensitive species will be considered on a case-by-case basis. Lakes that are greater than five feet deep with non-sensitive fish (ninespine stickleback and/or Alaska blackfish) can have up to 30% of the calculated volume of water removed. If there are no fish present in a lake, withdrawal cannot exceed 35% of the total volume of any lake.

Water withdrawals may have short- and long-term impacts on water quantity. For example, in the short-term winter water withdrawals can impact overwinter survival of fish populations by reducing the overall volume of water. In the long-term (2060), reduced water levels could affect invertebrates,

aquatic vegetation, and waterfowl that rely on these lakes for nesting and feeding habitats. Additionally, longer-term effects of lake drawdown may impede the ability of fish to return to the same lake in subsequent years.

One of the biggest concerns with water withdrawal from lakes is that the lake might not receive sufficient water recharge during spring snow melt. However, studies focused on recharge of water withdrawal lakes found that spring snowmelt provided sufficient water to recharge lakes (Baker 2002, Miller 2005, Hinzman et al. 2006). Thus, current guidelines for water withdrawal may be protective enough such that water quantity of lakes, at least for winter water withdrawals are sufficient. However, further study at a broader scale is warranted to determine if this pattern is consistent across both deep and shallow lakes within the study area.

6.3. Water quality

Changes to water quality as a result of water withdrawal could include changes in temperature, dissolved oxygen, and other water quality variables (e.g., pH, turbidity, alkalinity, etc.). In particular, fish are sensitive to low oxygen concentrations and reduced water volume in lakes may lead to increased depletion of oxygen, especially during the winter. Numerous studies have measured the effects of water withdrawal on water quality and the majority of these studies found no difference between lakes used for water withdrawal and reference lakes (Miller 2005, Hinzman 2006, Baker 2002, Cott et al. 2008). Instead, lake variation (e.g., lake size, lake depth, physiochemical properties) and not water-withdrawal activities were the most important predictors of water quality changes (Cott et al. 2008, Baker 2002, Chambers et al. 2008).

Similarly, Miller (2005) and Hinzman (2006) found no difference between temperature changes and other water quality variables in lakes that were used for water withdrawal and control lakes. For example, dissolved oxygen levels in lakes were good throughout winter months regardless of water withdrawal (Miller 2005). Pumping from shallow lakes during the open-water season has not been studied as extensively as deep lakes in winter, but it's likely to have a greater effect on water quality than pumping a comparable volume from deeper lakes.

Water withdrawals also have the potential to cause erosion and siltation which could increase turbidity and suspended solid concentrations in both lakes and streams. In addition, activities related to water withdrawal have the potential to affect surface water quality through accidental spills of fuel or lubricants.

6.4. Outflow/stream connectivity and down basin habitat

Understanding risks associated with water withdrawal on stream connectivity and down basin habitat is not well known. Withdrawal from lakes during the open-water season may alter stream connectivity to lakes. If water volume is reduced enough to affect outflow stream connectivity this could have impacts on fish migration corridors. As a result, fish may become stranded in disconnected habitats and unable to access preferred habitats for feeding or spawning, or return to preferred overwintering habitats. Water withdrawal could also affect the timing of stream flow, altering the velocity of streams and

impacting both insect and fish populations (Spence et al. 1996). Because glacial systems are characterized by low flow in winter, stream connectivity may be especially vulnerable to impacts of water withdrawals in winter. However, most water withdrawal activities occur north of the Brooks Range where glacial habitats are more common.

6.5. Literature Cited

Baker, M. 2002. National Petroleum Reserve-Alaska, NPR-A, 2002 lake monitoring and recharge study. 25288-MBJ-DOC-001. 158 pp.

Chambers, M. K., D. M. White, M. R. Lilly, L. D. Hinzman, K. M. Hilton, and R. C. Busey, 2008. Exploratory analysis of the winter chemistry of five lakes on the North Slope of Alaska. Journal of the American Water Resources Association 44:316-327.

Cott, P. A., P. K. Sibley, A. M. Gordon, R. A. Bodaly, K. H. Mills, W. M. Somers, and G. A. Fillatre. 2008. Effects of water withdrawal from ice-covered lakes on oxygen, temperature, and fish. JAWRA Journal of the American Water Resources Association, 44:328-342.

Hinzman, L. D., M. R. Lilly, D. L. Kane, D. D. Miller, B. K. Galloway, K. M. Hilton, and D. M. White. 2006. Physical and chemical implications of mid-winter pumping of tundra lakes – North Slope, Alaska. December 2006, University of Alaska Fairbanks, Water and Environmental Research Center, Report INE/WERC 06.15, Fairbanks, Alaska. 152 pp. plus appendices.

Miller, D. L. 2005. The physical and chemical effects of mid-winter pumping of tundra lakes on the North Slope, Alaska. Master's Thesis, University of Alaska Fairganks, 158 pp.

Spence, B. C, G. A. Lornnicky, R. M. Hughes, and R. P. Novitzki. 1996. An ecosystem approach to salmonid conservation. TR-4501-96-6057. ManTech Environmental Research Services Corp., Corvallis, Oregon.

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 five fish species considered to be of high ecological importance in the region.

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1. Summary of Aquatic Species (Fine-Filter Conservation Elements)

Five regionally important fish species were selected as Aquatic Fine-Filter Conservation Elements (CEs) to represent the variety of fish species of conservation concern and/or subsistence importance within the North Slope study area (Table J-1). For the purposes of the REA, chum salmon were selected as representatives of salmonids, and broad whitefish are treated as representative of whitefish species. Burbot represent a top-level predator with the potential for significant bioaccumulation of toxins. Dolly Varden are included to encompass higher elevation and steeper gradient stream habitats, as well as both anadromous and freshwater life history.

We identified the Fine-Filter CEs as a **data gap** during the data discovery phase of this project. Similar to previous REAs in Alaska (Seward Peninsula and Yukon-Kuskokwim REAs), aquatics data related to both Coarse-Filters CEs and Fine-Filters CEs have been very limited and have largely been identified as data gaps. The Fine-Filter CEs for the North Slope study area are especially data limited to the point that we were not able to accurately produce distribution models or maps for any of our Fine-Filter CEs.

Occurrence data do exist for these Fine-Filter CEs within the North Slope study area, however most of these data are presently available only in non-digitized format (e.g., hardcopies, inventory reports, unpublished data, etc.). Due to the lack of spatial data available, we collaborated with BLM Fisheries Biologists to assist with their efforts to enter these fish distribution datasets into the geodatabase RipFish that was developed and is maintained by BLM. Our contribution to this database serves as a final product for the Aquatic Fine-Filter CEs and will allow managers to readily have access to fish distribution data and conduct future spatial analyses. This database will further facilitate effective management decisions related to fish distributions and the potential effects that development and climate change may have on CEs in the North Slope study area.

Table J-1. Aquatic Fine-Filter Conservation Elements selected for the North Slope REA.

Aquatic Fine-Filter CEs	Ecological Importance
Arctic grayling (*Thymallus arcticus*)	Arctic grayling are resident fish distributed throughout the stream network and in lake habitats across the North Slope study area.
chum salmon (Oncorhynchus keta)	Chum salmon are representative of anadromous fish, and provide nutrient inputs to both aquatic and terrestrial ecosystems, providing a food resource for large predators and humans.
burbot (*lota lota*)	Burbot are long-lived resident fish that are mostly found in deep lakes. They eat other fish, making them susceptible to bioaccumulation of contaminants and potential indicators of change in the arctic. Burbot are used in localized subsistence fisheries.
broad whitefish (*Coregonus nasus)*	Broad whitefish are an important subsistence species for communities within the North Slope study area. In addition, they exhibit both anadromous and resident forms and utilize a diversity of lake and river habitats on the coastal plain for overwintering, rearing, and spawning.
Dolly Varden (Salvelinus malma)	Dolly Varden are utilized heavily by residents of Kaktovik and Kivalina and are well distributed throughout the stream network, especially in the eastern coastal plain and in the Brooks Range and Foothills ecoregions. They are both anadromous and freshwater resident within the North Slope study area.

1.1. Management Questions (MQs)

There were two management questions specific to Aquatic Fine-Filter CEs. The first MQ was focused on identifying baseline characteristics and trends in fish habitat, distribution, and movements (MQ AF 1). The second MQ related to the potential impacts that oil and gas infrastructure may have on fish habitat, distribution, and movements (MQ AC 2). We do not have the data available to answer these MQs spatially, thus we provided a literature review of baseline data and the potential impacts that oil and gas infrastructure could have on fish and their behavior and habitats within the North Slope study area. These MQs are addressed at the end of the Aquatic Fine-Filter CEs section.

1.2. Distribution Models and Conceptual Models Methods

As described above, fish species data for the North Slope study area are especially data limited to the point that we were not able to accurately produce distribution models for any of the selected fish species. However, we did collaborate with BLM Fisheries Biologists to enter fish distribution datasets into the BLM geodatabase "RipFish" by manually searching reports and entering in spatial data associated with the Aquatic Fine-Filter CEs. In addition to this, we also developed conceptual models for each fish species through an extensive literature review to describe the relationship between the various Change Agents (CAs) and natural drivers for all fish species and one model for all fish species in general. Conceptual models are box and arrow figures that represent the state of knowledge about fish and its relationships to each attribute. CAs and the environmental parameters that they affect, or drivers, have specific effects on particular fish species and general affects that will impact most fish species similarly. We also identified attributes and indicators (environmental predictors) to assist with evaluation of status for each CE. These define the relationships between CEs and CAs, and, where possible, the thresholds associated with these relationships. For each Fine-Filter CE we identified a number of attributes derived through the conceptual model, and assigned indicators to them based on available spatial data layers. Whenever possible, thresholds derived from the literature were set to categorize the data into standard reporting categories (i.e. indicator ratings).

1.3. Results

Conceptual Model

The conceptual model below (Figure J-1) is for fish species in general. The boxes and arrows represent the state of knowledge about fish and its relationships to each attribute. CAs and the environmental parameters that they affect, or drivers, have specific effects on particular fish species and general affects that will impact most fish species similarly. To differentiate clearly between specific and general impacts, we propose a base conceptual model that details the general interactions between CAs, drivers, and fish habitat as well as fish in general.

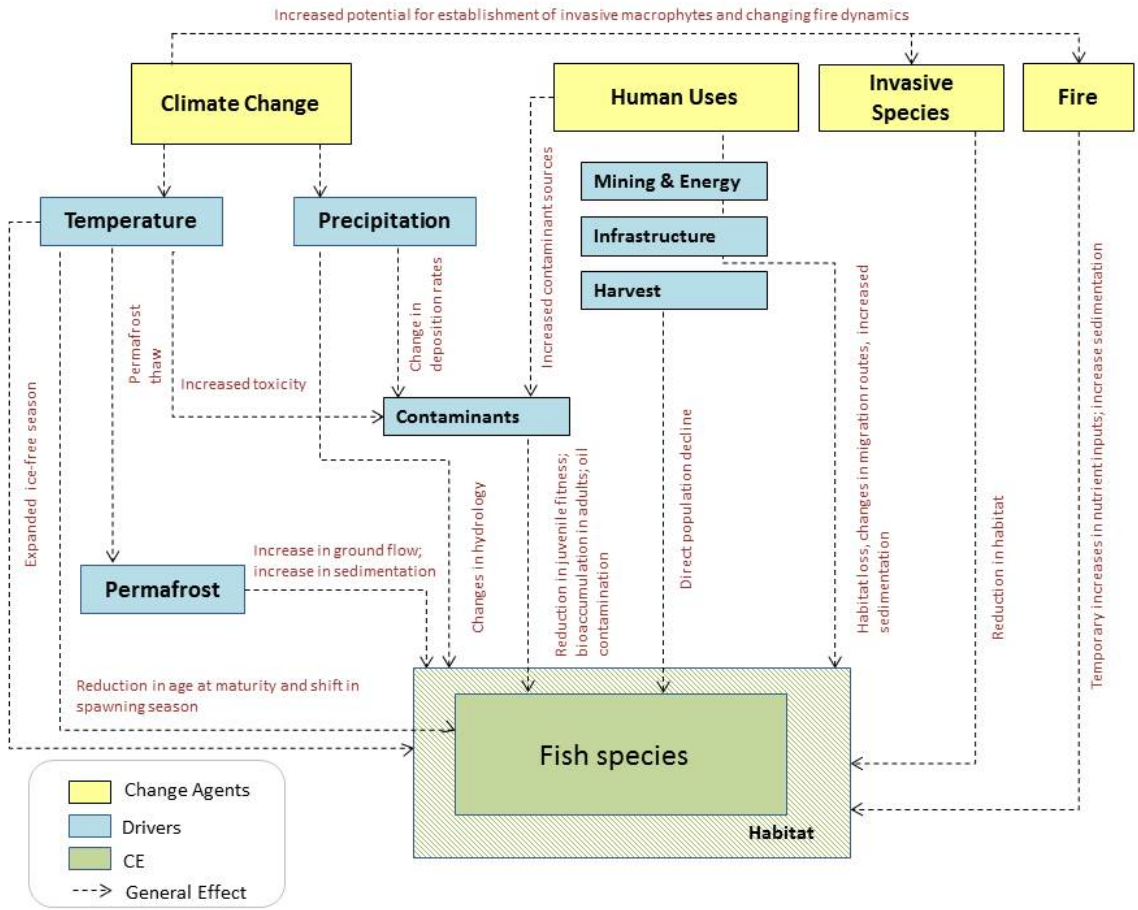

Figure J-1. Principal interactions among population drivers and Change Agents for fish species in the North Slope study area.

Attributes and Indicators

Key CA attribute and indicators for all fish species include: winter precipitation, summer temperature, frost-free days/season length, mean annual ground temperature, road development, habitat fragmentation, contaminated sites, and oil and gas activities (Table J-2).

Table J-2. Attributes and Indicators for all Fine-Filter fish species in the North Slope study area.

CA or Driver	Key Attribute	Indicator	Effect/ Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[1]	Dec-Feb total precipitation	Fish overwintering habitat	Less precipitation			More precipitation
	Winter precipitation[2]	Dec-Feb total precipitation	Fish overwintering habitat	More precipitation			Less precipitation
	Summer temperature[3]	Mean ambient air temperature (June-August)	Increased susceptibility to disease	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C
	Temperature[4]	Year-round temperature	Habitat Physiological stress	Water temperature increase of > 4°C	Water temperature increase of 2°C-4°C		No temperature increase

[1] Specific thresholds are unknown; Increased winter precipitation could increase available overwintering habitat (by increasing the volume of water).
[2] Specific thresholds are unknown; Increased precipitation could result in increased run-off and sedimentation negatively impacting habitat.
[3] Based on Zuray et al. 2012; Thresholds based on salmonid studies and may not apply to all CEs.
[4] Based on Reist et al. 2006, Schiedek et al. 2007; Increased water temperatures could preclude some species from preferred habitat; increase physiological stress.

CA or Driver	Key Attribute	Indicator	Effect/ Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	Temperature[5]	Year-round temperature	Contaminant exposure				
Climate	Frost-free days/Season length[6]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Increased juvenile growth rates			Increased number of frost-free days	
	Frost-free days/Season length[7]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Increase fish feeding time; shifts in time of spawning			Increased number of frost-free days	
	Change in mean annual ground temperature at one meter (MAGT)[8]	Permafrost thaw	Reduce habitat quality	From below -1m to above +1m			No Change

[5] AMAP 2002; Thresholds unknown; Increased water temperatures allow for certain contaminants to become more bioavailable.

[6] Reist et al. 2006; General thresholds; A longer ice-free season could improve the quality of feeding habitats with an increase in primary productivity due to longer periods of solar exposure.

[7] Reist et al. 2006; General thresholds; A longer ice-free season will decrease the amount of time that fish spend overwintering and increase the amount of time that fish can spend feeding; Spawning shifts to correspond with ice-free season.

[8] Lloyd et al 2003 (based on GIPL model); Bowden et al. 2008 (based on general effects); Increased stream turbidity from erosion and runoff may reduce primary production and aquatic invertebrate populations, lowering the quality of fish feeding habitat and reduce spawning habitat.

CA or Driver	Key Attribute	Indicator	Effect/ Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	Change in mean annual ground temperature at one meter (MAGT)[9]	Permafrost thaw	Improve habitat quality	From -1m to above +1m			No Change
Fire	Fire frequency[10]	Fire return interval	Feeding (summer) habitat	High return interval			Low return interval
	Fire frequency[11]	Fire return interval	Feeding (summer) habitat	Low return interval		High return interval	
Anthropogenic development	Contaminated sites[12]	Water quality	Habitat				

[9] Lloyd et al 2003 (based on GIPL model); Bowden et al. 2008 (based on general effects). Permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations.

[10] Davis et al. 2013; Thresholds are general based on this study; Fires strip stabilizing vegetation from the landscape and increase erosion and runoff, resulting in higher sediment inputs to streams and lakes.

[11] Davis et al. 2013; Thresholds are general based on this study; Fire increases nutrient inputs.

[12] Thresholds will depend on specific contaminants at a site and proximity to waterbodies; Oil contamination.

CA or Driver	Key Attribute	Indicator	Effect/ Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	Road development[13]	Water quality	Habitat	Numerous intersections with streams and lakes			No intersection with streams and lakes
	Habitat fragmentation[14]	Road development	Habitat				
	Oil and gas activities[15]	Water withdrawal	Habitat	Lakes used by fish			Lakes not used by fish

[13] Thresholds will depend on specific proximity of fish habitat to a site; Turbidity, metals and hydrocarbon contamination, temperature changes.
[14] Thresholds will depend on specific proximity of fish habitat to a site; Disrupt fish migratory movements; stranding events.
[15] BLM 2006; General thresholds; Affect water quality, reduce spawning habitat for burbot and reduce overwintering and foraging habitat for all other Fine-Filter CEs.

Abiotic Change Agent Analysis

Climate

Although projected increases in air temperature are not always linearly correlated with increases in water temperature, the warming trend will result in two phenomena that have major impacts on fish habitat: increase in the duration of the ice-free season for lakes and rivers and permafrost thaw. Warmer air temperatures will increase the length of the ice-free season to a later freeze-up date and an earlier thaw date. A reduction in the length of the growing season (a proxy that directly relates to ice-free season) will decrease the amount of time that fish spend overwintering and increase the amount of time that fish can spend feeding (Reist et al. 2006). As a consequence, the age at maturity for fish will decrease because individuals will be able to feed more during any single year (Brown et al. 2012). Changes in water temperatures can also alter the timing of life history events, such as sexual maturation and timing of migration and spawning, and limit preferred habitats (Reist et al. 2006). Spawning will likely shift later in the year for autumn spawners and earlier in the year for spring spawners to correspond with the time that aquatic habitats become ice-free. Additionally, warmer water temperatures will have cascading effects on the susceptibility of fish to diseases and parasites (Zuray et al. 2012), increase the availability and effects of contaminants (Schiedek et al. 2007), and decrease biologically available dissolved oxygen (Ficke et al. 2007).

Increasing annual temperatures will cause a general trend of permafrost thaw at the landscape level, increasing the depth of the soil active layer and the mean annual ground temperature (see Section C). Deeper active layer and thermokarst could result in redistribution of water and new drainage networks and could also lead to increased erosion and sedimentation. Sedimentation of gravel-substrate in streams will reduce the quality of spawning habitat for species that rely on gravel substrate to hide their eggs (Brown et al. 2012). Additionally, increased stream turbidity from erosion and runoff may reduce primary production and aquatic invertebrate populations, lowering the quality of fish feeding habitat by reducing the abundance of prey species either directly or indirectly (Owens et al. 2005). On the other hand, permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations (Bowden et al. 2008). Increased nutrient input will improve the quality of fish feeding habitat with the direct or indirect increased abundance of prey species (Reist et al. 2006). Effects of permafrost thaw are likely to be localized, and could result in positive effects on some fish habitats, while incurring negative effects on other fish habitats.

A predicted increase in winter precipitation could potentially increase available overwintering habitat directly by increasing the volume of water and indirectly through the loss of snow insulation which would reduce ice thickness. Increased precipitation could also result in increased run-off and sedimentation to fish habitat.

The combination of climate CAs and their effects on fish CEs are complex and often interconnected. Consequently, the future long-term impacts to fish CEs and aquatic habitats remain unclear.

Fire

Fire removes stabilizing vegetation from the soil surface and can result in an increase in erosion and runoff, resulting in higher sediment inputs to streams and rivers. Increased runoff has the potential to decrease both primary productivity and aquatic invertebrate populations through increased turbidity. The increases in erosion and runoff in burned areas also increase nutrient inputs to aquatic habitats (Davis et al. 2013). These effects are temporary and are typically limited by the re-establishment of vegetation.

Contaminants

As water temperature increases, certain contaminants become more bioavailable (e.g., mercury) and exposure rates of contaminants in fish will likely increase. Mercury is a highly toxic metal that has negative impacts on the health of fish populations as well as wildlife and humans that consume fish. Microbial activity can convert inorganic mercury into its most toxic form, methlymercury (MeHg) (Benoit et al. 2003), where it is rapidly incorporated into the food web and biomagnifies from one trophic level to the next (Ochoa-acuña et al. 2002). Warming temperatures within the North Slope study area may further exacerbate mercury exposure in fish within this region by both releasing snowpack- and permafrost-entrained mercury, and by enhancing conditions that facilitate methylproduction (AMAP 2002).

Oil contamination is another contaminant of concern for fish species within the study area. Oil contamination has the largest impact on embryos because of their reduced capacity to leave the contaminated area (Short et al. 2003, Moles et al. 1979).

Current Status and Future Landscape Condition

Most development on the North Slope is related to oil and gas industries. Fish species on the North Slope can be affected by a number of factors related to development including: changes in water quality, construction of stream crossings, winter water withdrawals, and release of contaminants. Habitat alterations to stream flow or changes to underlying sediments caused by stream crossings can lead to changes in water temperature, turbidity, and dissolved ion concentrations, which in turn could have negative impacts on fish populations. Major construction, especially of roads will increase erosion and runoff leading to increased stream turbidity and sedimentation, and could introduce contaminates (e.g., vehicular leaks and spills) into fish habitats. Additionally, the construction of roads (both permanent and temporary) may channelize river systems and hinder fish migration routes between different habitats.

For example, in a recent study focused on the impacts of stream crossing structures in the North Slope oilfields near Prudhoe Bay indicated that 29% of the crossings evaluated restricted or completely blocked fish passage (Morris and Winters 2008).

Harvest

Many fish species are harvested for subsistence and sport use within the North Slope study area (See Section E. Anthropogenic Change Agents). While commercial fishing in the area is relatively small at present time, it has the potential to increase in the future.

Invasive Species

Invasive plant species have the potential to outcompete native aquatic and emergent vegetation. However, few invasive plant species are documented within the study area, none of which are aquatic species (See Section D. Biotic Change Agents). *Elodea* spp. is an invasive aquatic plant of concern that has recently been documented in south central Alaska and Chena Slough, near Fairbanks. *Elodea* spp. generally invade and outcompete other aquatic plant species in slow moving streams or small, shallow lakes and ponds.

1.4. Applications and Limitations

Understanding the response to climate-associated changes on fish species is difficult with inadequate distribution data. Our efforts to assist BLM with entering fish distribution data into the RipFish database have contributed greatly to our understanding of fish baseline data for the study area. However, information on feeding and overwintering areas, migrations and movements, and population level studies are lacking. Future research efforts should focus on obtaining these data for the study area.

1.5. Literature Cited

Arctic Monitoring and Assessment Programme (AMAP). 2002. Arctic Pollution 2002: Persistent organic pollutants, heavy metals, radioactivity, human health, changing pathways. Oslo, Norway. xii+112p.

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.

Bowden, W. B., M. N. Gooseff, A. Balser, A. Green, B. J. Peterson, and J. Bradford. 2008. Sediment and nutrient delivery from thermokarst features in the foothills of the North Slope, Alaska: potential impacts on headwater stream ecosystems. Journal of Geophysical Research 113:20-26.

Brown, R., C. Brown, N. Braem, W. Carter III, N. Legere, and L. Slayton. 2012. Whitefish biology, distribution, and fisheries in the Yukon and Kuskokwim River drainages in Alaska: a synthesis of available information. Alaska Fisheries Data Series Number 2012-4. Fairbanks Field Office, Fish and Wildlife Service, U.S. Department of the Interior. Fairbanks, Alaska. 316 pp.

Bureau of Land Management, U.S. Department of the Interior (BLM). 2006. National Petroleum Reserve-Alaska (NPR-A) Northwest Planning Area winter exploration drilling program: FEX, L.P. Prepared by USDOI BLM, Alaska Arctic Field Office, Fairbanks District Office, Anchorage Field Office, Alaska. Available: http://www.blm.gov/pgdata/etc/medialib/blm/ak/aktest/energy/egy_maps.Par.94059.File.dat/fex_npra_ea_final.pdf

Davis, J., C. Baxter, E. Rosi-Marshall, J. Pierce, and B. Crosby. 2013. Anticipating stream ecosystem responses to climate change: Toward predictions that incorporate effects via land-water linkages. Ecosystems 16:909-922.

Ficke, A., C. Myrick, and L. Hansen. 2007. Potential impacts of global climate change on freshwater fisheries. Reviews in Fish Biology and Fisheries 17:581-613.

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.

Moles, A., S.D. Rice, and S. Korn. 1979. Sensitivity of Alaskan freshwater and anadromous fishes to Prudhoe Bay crude oil and benzene. Trans. Am. Fish. Soc. 108(4):408-414.

Morris, W. A., and J. F. Winters. 2008. A survey of stream crossing structures in the North Slope oilfields. Technical Report No. 08-01. Office of Habitat Management and Permitting, Alaska Department of Fish and Game, Fairbanks, Alaska. 392 pp.

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.

Owens, P.N., Batalla, R.J., Collins, A.J., Gomez, B., Hicks, D.M., Horowitz, A.J., Kondolf, G.M., Marden, M., Page, M.J., Peacock, D.H., Petticrew, E.L., Salomons, W. and Trustrum, N.A. 2005. Fine-Grained Sediment in River Systems: Environmental Significance and Management Issues. River Res. Appl., 21, *693–717*.

Reist, J., F. Wrona, T. Prowse, M. Power, J. Dempson, J. King, and R. Beamish. 2006. An overview of effects of climate change on selected Arctic freshwater and anadromous fishes. Ambio. 35:381-387.

Schiedek, D., B. Sundelin, J. W. Readman, and R.W. Macdonald. 2007. Interactions between climate change and contaminants. Marine Pollution Bulletin 54:1845-1856.

Short, J. W., S. D. Rice, R. A. Heintz, M. G. Carls, and A. Moles. 2003. Long-Term Effects of Crude Oil on Developing Fish: Lessons from the Exxon Valdez Oil Spill , Energy Sources, 25:6, 509-517.

Zuray, S., R. Kocan, and P. Hershberger. 2012. Synchronous cycling of Ichthyophoniasis with Chinook salmon density revealed during the annual Yukon River spawning migration. 28 Transactions of the American Fisheries Society 141: 615-623. DOI 10.1080/00028487.2012.683476.

2. Dolly Varden (*Salvelinus malma*)

Dolly Varden occur in the study area as lake-resident, stream-resident, and anadromous populations; although, they are considered to be predominantly anadromous within the study area. Anadromous Dolly Varden are commonly harvested subsistence fisheries in the study area. Dolly Varden generally mature at five to nine years of age and can spawn multiple times throughout their lifetimes. Dolly Varden tagging studies have shown that overwintering and spawning habitats may change over time due to changes in channel morphology affecting groundwater inputs (Viavant 2004). Documented spawning habitats east of the Dalton Highway were in the upper reaches of watersheds and timing of spawning ranged from mid-August to late September (Viavant 2004). However, some Dolly Varden may overwinter in areas not connected to their natal streams (Crane et al. 2005). Major river drainages used by Dolly Varden for spawning, rearing, and overwintering habitat include the Colville, Kuparak, Canning, and Sagavanirktok (Scanlon 2012).

Dolly Varden habitats and life histories are based on descriptions in Morrow (1980). Dolly Varden use habitats associated with groundwater discharge for spawning, rearing, and overwintering. However, these habitats in the study area comprise a relatively small proportion of overall stream habitats and thus, are limiting to populations. Overwintering habitat is especially critical and limited to small streams with spring-fed areas. Spawning occurs from August through late September. Females lay eggs in small, dugout nests in stream gravel beds. Hatching of eggs generally occurs in March, and juvenile fish emerge from the gravel in late spring and after break-up, which generally begins in late May. Dolly Varden migrate to streams and river channels that were previously frozen, and to the nearshore coastal waters for feeding and rearing. Larger juvenile and adult fish consume salmon fry, salmon eggs, invertebrates, and small fish. Juveniles feed primarily on macroinvertebrates.

2.1. Conceptual Model

The conceptual model below (Figure J-2) is based on a review of the literature and describes the relationship between the various CAs and natural drivers for Dolly Varden. The boxes and arrows represent the state of knowledge about Dolly Varden and the relationship to each attribute.

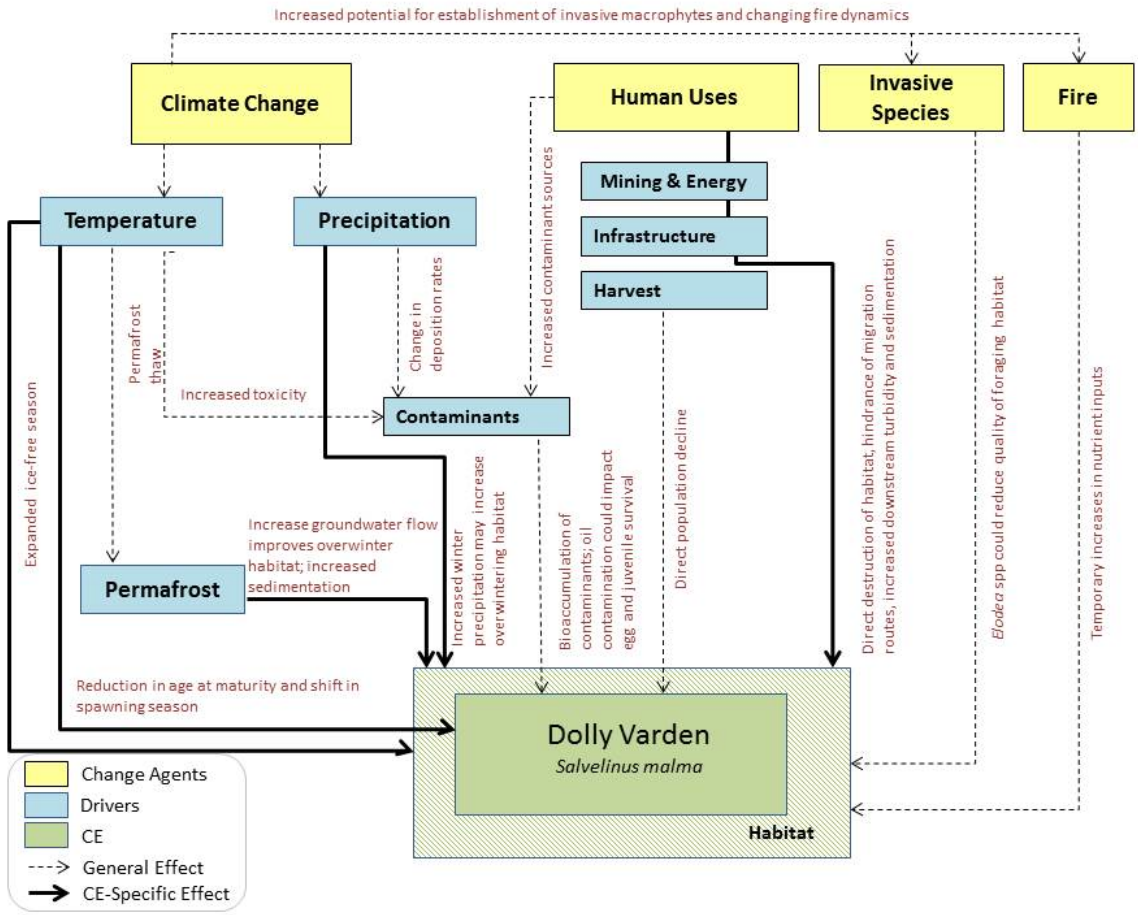

Figure J-2. Principal interactions among population drivers and CAs for Dolly Varden within the North Slope study area.

2.2. Attributes and Indicators

CA attribute and indicator data for Dolly Varden include: winter precipitation, summer temperature, frost-free days/season length, mean annual ground temperature, road development, habitat fragmentation, contaminated sites, and oil and gas activities (Table J-3).

Table J-3. Attributes and Indicators for Dolly Varden.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[16]	Dec-Feb total precipitation	Overwintering habitat	Less precipitation			More precipitation
	Winter precipitation[17]	Dec-Feb total precipitation	Overwintering habitat	More precipitation			Less precipitation
	Summer temperature[18]	June-August mean monthly air temperature	Summer habitat	Warmer air temperature			No change in air temperature
	Summer temperature[19]	June-August mean monthly air temperature	Parasite infections	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C
	Frost-free days/Season length[20]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Shift in spawning time			Increased number of frost-free days	

[16] Specific thresholds are unknown; Increased winter precipitation could increase available overwintering habitat (by increasing the volume of water).
[17] Specific thresholds are unknown; Increased precipitation could result in increased run-off and sedimentation negatively impacting habitat.
[18] Nolan et al. 2011; General thresholds; Decrease in glacial melt run-off as a result of warming climate glacier retreat.
[19] Zuray et al. 2012; Thresholds based on salmonid studies; Warmer waters may increase the prevalence of diseases and parasites.
[20] Specific thresholds are unknown; Spawning will shift later in the fall to correspond with the time that aquatic habitats become ice-free.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	Frost-free days/Season length[21]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Juvenile growth			Increased number of frost-free days	
	Change in mean annual ground temperature at one meter (MAGT)[22]	Permafrost thaw	Loss of habitat for lake resident populations				
	Change in mean annual ground temperature at one meter (MAGT)[23]	Permafrost thaw	Increased overwintering habitat				
	Change in mean annual ground temperature at one meter (MAGT)[24]	Permafrost thaw	Foraging habitat	From below -1m to above +1m			No Change

[21] Reist et al. 2006; general thresholds; The age at maturity for Dolly Varden will likely decrease because individuals will be able to feed more during any single year.
[22] Lloyd et al. 2003 (based on GIPL model); Lake drainage will result in loss of habitat or decline in lake area.
[23] Increased ground flows in winter as a consequence of permafrost thaw could improve overwintering habitat for Dolly Varden.
[24] GIPL model, Lloyd et al. 2003 (based on GPL model); Bowden et al. 2008 (based on general effects); Increased nutrient input with permafrost thaw will improve feeding habitat by increasing primary productivity.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Anthropogenic development	Road development[25]	Water quality	Habitat	Numerous intersections with streams and lakes			No intersection with habitats
	Habitat fragmentation[26]	Road development	Habitat	Numerous intersections with streams and lakes			No intersection with habitats
	Contaminated sites[27]	Water quality	Habitat				
	Oil and gas activities[28]	Water withdrawal	Habitat	Lakes used by Dolly Varden			Lakes not used by Dolly Varden

[25] Thresholds will depend on specific proximity of fish habitat to a site; Turbidity, metals and hydrocarbon contamination, temperature changes.
[26] Thresholds will depend on specific proximity of fish habitat to a site; Disrupt fish Dolly Varden movements; stranding events.
[27] Thresholds will depend on specific contaminants at a site and proximity to waterbodies; Oil contamination.
[28] BLM 2006; General thresholds; Effect water quality, reduce foraging and overwintering habitat.

2.3. Abiotic Change Agent Analysis

Climate

Increasing annual temperatures are predicted to increase permafrost thaw in the study area, increasing the depth of the soil active layer and the mean annual ground temperature (see Section C). As a consequence, there will likely be increased erosion and runoff into lakes and streams. Similarly, lake drainage, as a consequence of permafrost thaw, is likely to increase as the depth of the active layer increases. Increased lake drainage, will likely reduce available habitat for resident lake populations of Dolly Varden. On the other hand, permafrost thaw could increase groundwater flow in winter improving overwintering habitat and increasing overwintering survival for Dolly Varden. Permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations (Bowden et al. 2008). Increased nutrient input will improve the quality of fish feeding habitat with the direct or indirect increased abundance of prey species (Reist et al. 2006). Increased sedimentation in streams will reduce the quality of spawning habitat for Dolly Varden because they rely on gravel substrate to hide their eggs.

With projected increased temperatures, the duration of the ice-free season will likely increase which will improve the quality of feeding habitats as those habitats will remain ice-free for a longer period of time (Reist et al. 2006). Consequently, the age at maturity for Dolly Varden will likely decrease because individuals will be able to feed more during any single year. Spawning will shift later in the fall to correspond with the changes in the duration of the ice-free season. Warmer waters may also increase the prevalence of diseases and parasites (Reist et al. 2006).

Increased temperatures within the study area will have a significant impact on glacial stream systems. Glacial melt and runoff is an important source of late summer discharge to streams and rivers that provide sufficient flow allowing Dolly Varden to reach spawning and overwintering habitats (Nolan et al. 2011). With the loss of sufficient late summer discharge, overwintering habitat could become even more limited for Dolly Varden in streams directly influenced by glacier run-off (e.g., streams within the Brooks Range area). Furthermore, a decrease in discharge could negatively impact Dolly Varden that use glacial systems to complete their migrations from summer feeding areas to spawning and overwintering habitats.

A predicted increase in winter precipitation could potentially increase available overwintering habitat directly (by increasing the volume of water) and indirectly through the loss of snow insulation which would reduce ice thickness. Increased precipitation could also result in increased run-off and sedimentation to Dolly Varden habitat.

Contaminants

Melting glaciers can release contaminants that have accumulated from years of atmospheric deposition, including persistent organic pollutants and mercury, into streams and lakes where fish can readily absorb these pollutants (Blais et al. 2001). Dolly Varden commonly use glacial streams, especially in the Brooks Range area and therefore may be vulnerable to high exposure rates of contaminants as glaciers

continue to melt. Furthermore, because Dolly Varden can be piscivorous during the juvenile and adult freshwater stages, they have the propensity to bioaccumulate and biomagnify organochlorine and heavy metal contaminants.

2.4. Current Status and Future Landscape Condition

Major construction, especially of roads will increase erosion and runoff leading to increased stream turbidity and sedimentation. Increased turbidity and sedimentation could have negative impacts on egg and juvenile survival. Road development at stream crossings could disrupt migratory pathways and alter access between key summering and wintering habitats. Much road development occurs during the winter which could have negative impacts on Dolly Varden overwintering habitat. Water removal and gravel extraction can have population-level effects on Dolly Varden due to the limited overwintering habitat on the North Slope.

Harvest

Dolly Varden are an important subsistence resource to North Slope residents (Craig 1989). Overwintering and spawning populations also provide for sport fisheries. Dolly Varden represents approximately 40% of the total subsistence harvest fisheries in Kaktovik (Pedersen 2005). Recent Dolly Varden subsistence harvests for the North Slope area range from approximately 4,000-10,000 (Scanlon 2012). Recent estimated annual sport harvests are around 1,000 for the entire North Slope, catches are around 5,000, and total effort is around 5,000 angler days (Scanlon 2012). Annual average sport harvest of Dolly Varden for 2001-2012 was 5,053 fish and annual sport catch averaged 18,000-20,000 (Scanlon 2012). Sport harvest of Dolly Varden on the North Slope is currently estimated to be within sustainable limits (Scanlon 2012).

2.5. Literature Cited

Blais, J. M., D. W. Schindler, M. Sharp, E. Braekevelt, M. Lafrenière, K. McDonald, D. G. Muir, and W. M. Strachan. 2001. Fluxes of semivolatile organochlorine compounds in Bow Lake, a high-altitude, glacier-fed, subalpine lake in the Canadian Rocky Mountains. Limnology and oceanography 46:2019-2031.

Bureau of Land Management, U.S. Department of the Interior (BLM). 2006. National Petroleum Reserve-Alaska (NPR-A) Northwest Planning Area winter exploration drilling program: FEX, L.P. Prepared by USDOI BLM, Alaska Arctic Field Office, Fairbanks District Office, Anchorage Field Office, Alaska. Available: http://www.blm.gov/pgdata/etc/medialib/blm/ak/aktest/energy/egy_maps.Par.94059.File.dat/fex_npra_ea_final.pdf

Bowden, W. B., M. N. Gooseff, A. Balser, A. Green, B. J. Peterson, and J. Bradford. 2008. Sediment and nutrient delivery from thermokarst features in the foothills of the North Slope, Alaska: potential impacts on headwater stream ecosystems. Journal of Geophysical Research 113:20-26.

Crane, P. A., Viavant, T., and J. K. Wenburg. 2005. Overwintering patterns of Dolly Varden, Salvelinus Malma, in the Sagavanirktok River in the Alaskan North Slope inferred using mixed-stock analysis. US Fish and Wildlife Service, Conservation Genetics Laboratory.

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.

Nolan, M., R. Churchwell, J. Adams, J. McClelland, K. D. Tape, S. Kendall, A. Powell, K. Dunton, D. Payer, and P. Martin. 2011. Predicting the impact of glacier loss on fish, birds, floodplains, and estuaries in the Arctic National Wildlife Refuge. Pages 49-54 *in* C. N. Medley, G. Patterson, and M. J. Parker. Proceedings of the Fourth Interagency Conference on Research in the Watersheds: Observing, Studying and Managing for Change. US Geological Survey Scientific Investigations Report No. 2011-5169.

Pedersen, S., and L. Alfred Jr. 2005. Kaktovik 2000-2002 subsistence fishery harvest assessment. Alaska Department of Fish and Game and Kaktovik Inupiat Corporation, Fairbanks, Alaska. 58 pp.

Reist, J., F. Wrona, T. Prowse, M. Power, J. Dempson, J. King, and R. Beamish. 2006. An overview of effects of climate change on selected Arctic freshwater and anadromous fishes. Ambio. 35:381-387.

Scanlon, B. 2012. Fishery management report for sport fisheries in the Northwest/North Slope Management area, 2012. Alaska Department of Fish and Game, Fishery Management Report No. 12-45, Anchorage.

Viavant, T. 2004. Eastern North Slope Dolly Varden Genetic Stock Identification and Stock Assessment. US Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program.

Zuray, S., R. Kocan, and P. Hershberger. 2012. Synchronous cycling of Ichthyophoniasis with Chinook salmon density revealed during the annual Yukon River spawning migration. 28 Transactions of the American Fisheries Society 141: 615-623. DOI 10.1080/00028487.2012.683476.

3. Broad whitefish (*Coregonus nasus*)

Broad whitefish are typically anadromous, although freshwater resident populations have been documented in lakes and streams within the study area. Broad whitefish mature between five to eight years of age, depending upon the population (Brown et al. 2012). Similarly, the longest lived broad whitefish range from 16 years in the mainstem Yukon River to one 35-year-old fish from the McKenzie River Delta (Brown et al. 2012). Spawning occurs in late fall to early winter in gravel stream beds (ADF&G 1986). After spawning, broad whitefish migrate downstream to overwinter under the ice in deep freshwater pools in rivers and lakes (Morris 2006). Migration to their summer feeding areas in salt water begins during spring break up. The diet of broad whitefish is composed of marine and freshwater invertebrates.

Studies have documented the importance of small drainages with lake connectivity for broad whitefish summer habitat on the North Slope (Morris 2006). Suitable overwintering habitat is one of the most severe constraints on broad whitefish populations and the use of ephemeral streams to move into lake habitats for overwintering is especially important (Morris 2006). Broad whitefish were documented using a diversity of habitats for overwintering in the Teshekpuk Lake area, such as the coalesced lakes at the headwaters of the Mayoriak River, in deep pools (> 15 feet) of the Mayoriak River, and the lower reaches of the Chipp River and its connected lakes (Morris 2006).

3.1. Conceptual Model

The conceptual model below (Figure J-3) is based on a review of the literature and describes the relationship between the various CAs and natural drivers for Dolly Varden. The boxes and arrows represent the state of knowledge about Dolly Varden and the relationship to each attribute.

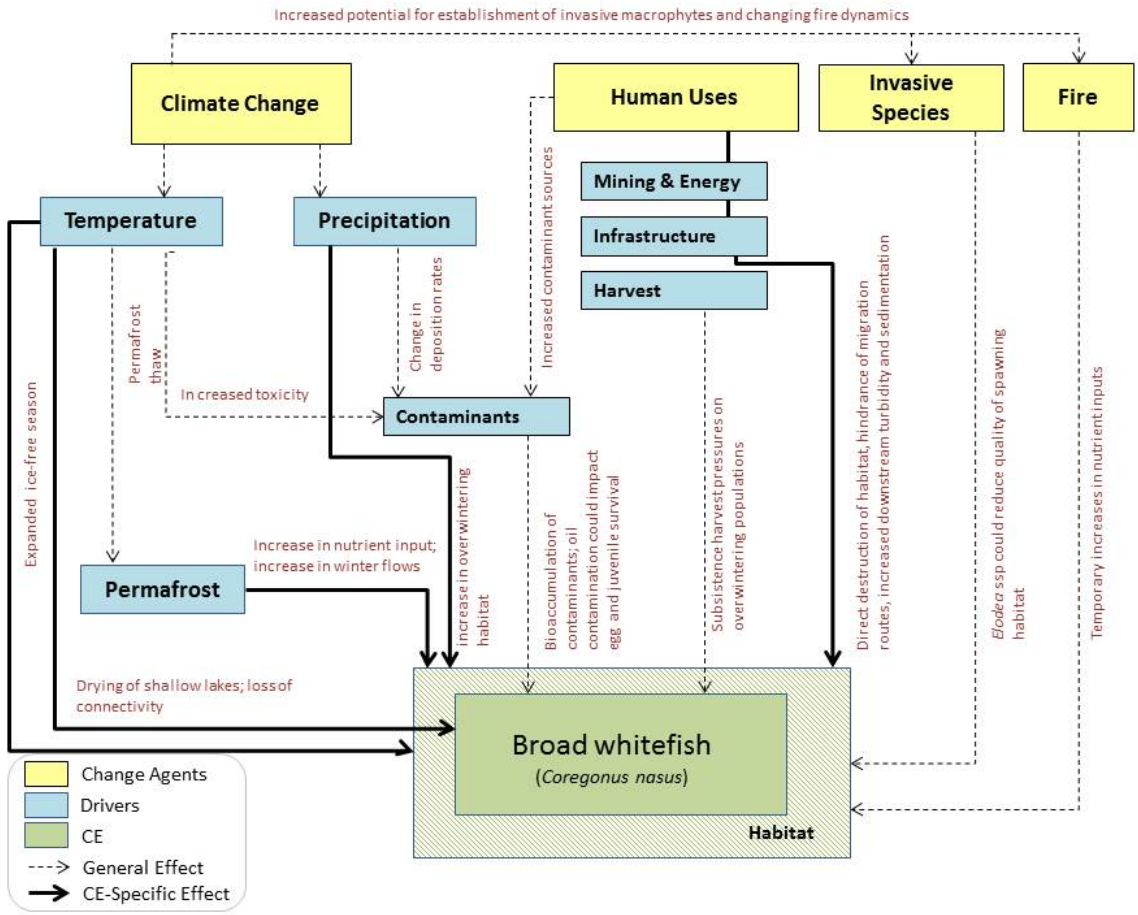

Figure J-3. Principal interactions among population drivers and CAs for Broad whitefish within the North Slope study area.

3.2. Attributes and Indicators

Key CA attribute and indicator data for broad whitefish include: winter precipitation, summer temperature, frost-free days/season length, mean annual ground temperature, road development, habitat fragmentation, oil and gas activities, and contaminated sites (Table J-4).

Table J-4. Attributes and indicators for Broad whitefish.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[29]	Dec-Feb total precipitation	Overwintering habitat	Less precipitation			More precipitation
	Winter precipitation[30]	Dec-Feb total precipitation	Overwintering habitat	More precipitation			Less precipitation
	Summer temperature[31]	June-August mean monthly air temperature	Summer habitat	Warmer temperature			No change in temperature
	Summer temperature[32]	June-August mean monthly air temperature	Parasite infections	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C
	Frost-free days/Season length[33]	Cumulative days with temps above 0 °C (Days between DOT	Egg development and shifts in spawning time			Increased number of frost-free	

[29] Specific thresholds are unknown; Increased winter precipitation could increase available overwintering (by increasing the volume of water).
[30] Specific thresholds are unknown; Increased precipitation could result in increased run-off and sedimentation negatively impacting habitat.
[31] Specific thresholds are unknown; Loss of lake connectivity; lake drying.
[32] Zuray et al. 2012; Thresholds based on salmonid studies; Warmer waters may also increase the prevalence of diseases and parasites.
[33] Specific thresholds are unknown; With an earlier breakup period, egg development time would likely be reduced and it's possible that spawning will shift to later in the fall.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
		and DOF)				days	
	Frost-free days/Season length[34]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Juvenile growth			Increased number of frost-free days	
	Change in mean annual ground temperature at one meter (MAGT)[35]	Permafrost thaw	Overwintering habitat			Increased rates of thaw	
	Change in mean annual ground temperature at one meter (MAGT)[36]	Permafrost thaw	Foraging habitat	From below -1m to above +1m			No Change

[34] Reist and Bond 1988; Reist 2006; General thresholds; The age at maturity for broad whitefish will likely decrease because individuals will be able to feed more during any single year.
[35] Specific thresholds are unknown; Increased ground flows in winter as a consequence of permafrost thaw could improve overwintering habitat.
[36] Lloyd et al. 2003 (based on GIPL model); Bowden et al. 2008 (based on general effects); Increased nutrient input with permafrost thaw will improve feeding habitat by increasing primary productivity.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Anthropogenic development	Road development[37]	Water quality	Habitat	Numerous intersections with habitats			No intersection with habitats
	Habitat fragmentation[38]	Road development	Habitat	Numerous intersections with habitats			No intersection with habitats
	Oil and gas activities[39]	Water withdrawal	Habitat disturbance or loss	Lakes used by broad whitefish			Lakes not used by broad whitefish
	Contaminated sites[40]	Water quality	Habitat				

[37] Thresholds will depend on specific proximity of fish habitat to a site; Turbidity, metals and hydrocarbon contamination, temperature changes.
[38] Morris and Winters 2008; Thresholds are general; Disrupt fish migratory movements; direct destruction of habitat, erosion, sedimentation.
[39] BLM 2006; Thresholds are general; Effect water quality, reduce spawning habitat and reduce overwintering habitat.
[40] Thresholds will depend on specific contaminants at a site and proximity to waterbodies; Oil contamination could reduce egg survival and spawning habitat.

3.3. Abiotic Change Agent Analysis

Climate

Broad whitefish rely on productive shallow lakes for summer foraging and ephemeral stream systems to move into lake habitats for overwintering (Morris 2006). With projected increases in temperature and permafrost thaw, the potential for drying of shallow lakes is a concern for populations of broad whitefish in the study area. A loss of connectivity to lakes could have negative consequences for broad whitefish populations. A loss of connectivity, or decline in lake area could affect migrations into summer feeding habitat (Morris 2006). Furthermore, shallow lakes that are commonly used as summer feeding habitats by broad whitefish are especially susceptible to increases in temperature and lake drying. Thus, broad whitefish that use these lakes could be exposed to lethal or near lethal temperatures during the summer and/or experience stranding events due to loss of connectivity from summer feeding habitats into overwintering habitats. If migratory corridors between highly productive foraging lakes and cooler river systems were reduced across the landscape due to warmer temperatures, lake-feeding broad whitefish could experience increased summer mortality.

With projected increased temperatures, the duration of the ice-free season will likely increase. A longer ice-free season could improve the quality of feeding habitats as those habitats will likely experience an increase in primary productivity due to longer periods of solar exposure (Reist et al. 2006). The open water period is the primary feeding time for broad whitefish (Reist and Bond 1988) thus, the age at maturity will likely decrease because individuals will be able to feed more during any single year. With an earlier breakup period, egg development time would likely be reduced and it's possible that spawning will shift to later in the fall to correspond with the time that water temperature approaches 0°C or the time that aquatic habitats become ice-free, respectively. However, warmer waters may also increase the prevalence of diseases and parasites (Reist et al. 2006).

Permafrost thaw will likely increase groundwater flows in winter improving overwintering habitat for broad whitefish which will likely increase overwintering survival, at least temporarily. Permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations (Bowden et al. 2008). Thus, increased nutrient input will improve the quality of fish feeding habitat with the direct or indirect increased abundance of prey species (Reist et al. 2006).

A predicted increase in winter precipitation could potentially increase available overwintering habitat directly by increasing the volume of water and indirectly through the loss of snow insulation which would reduce ice thickness. Increased precipitation could also result in increased run-off and sedimentation.

Contaminants

As water temperature increases, certain contaminants become more bioavailable (e.g., mercury) and thus, exposure rates of contaminants in fish will likely increase with a warming climate (AMAP 2002). Broad whitefish is an important subsistence fish to residents on the North Slope, and exposure to toxic pollutants could reduce the value of broad whitefish as a subsistence resource. Because broad whitefish

consume mostly lower trophic level species such as invertebrates, they are less likely to contain high levels of contaminants, compared to piscivorous species such as Dolly Varden and chum salmon. However, broad whitefish are a long-lived species and have the potential to bioaccumulate contaminants over time. Thus, the effects of contaminants on individual fish over time and human exposure of contaminants through consumption of fish is a potential concern.

Oil field operations have the potential to introduce contaminants to aquatic habitats, including broad whitefish habitats within the North Slope study area. Whereas, some contaminants such as organochlorines (e.g., PCBs, DDT, and POPs) and mercury have both local and distant anthropogenic sources, petroleum products are directly related to local activities. Spilled petroleum products may arise from activities such as drilling and transportation of personnel and materials. Contaminants on roads from vehicle leakage may run off into drainages affecting water quality. Petroleum products may persist in aquatic environments for years after a spill or leak. Petroleum products can directly affect the health of fish by impacting their ability to adequately take up oxygen or through ingestion, which may compromise other physiological functions (Peterson et al. 2003). Oil contaminations can also severely impact egg, larvae, and juvenile survival because of their reduced capacity to leave the contaminated area (Brown et al. 2012).

3.4. Current Status and Future Landscape Condition

Road development for oil and gas exploration and water withdrawal are considered to be the most important development concerns within the North Slope study area. Major construction, especially of roads will increase erosion and runoff leading to increased stream turbidity and sedimentation. Increased turbidity and sedimentation could have negative impacts on egg and juvenile survival (Brown et al. 2012). Road development at stream crossings could disrupt migratory pathways and alter access between key summering and wintering habitats. Due to the use of small drainages, including ephemeral streams, any development that would impede fish passage within these small drainages, could have negative impacts on broad whitefish populations within the North Slope study area (Morris 2006). Broad whitefish are considered potentially sensitive to water withdrawal activities, especially during the winter when habitat is most limiting (BLM 2006). Bridges and culverts used for development of oil production could affect broad whitefish habitat directly by increasing sedimentation or altering migration routes.

In addition to direct environmental changes resulting from road construction, roads increase human access to previously remote areas, which facilitates increased recreational use of resources.

Harvest

Broad whitefish is one of the most heavily harvested subsistence fish species on the North Slope. Currently, no agency manages broad whitefish on the North Slope. The community of Nuiqsut operates subsistence fisheries year-round, although most fishing efforts occur in summer and fall. On the Colville Delta, reported summer harvests have ranged from 3,000-4,000 broad whitefish.

3.5. Literature Cited

ADF&G. 1986. Alaska Habitat Management Guide, Arctic Region, Vol. II: Distribution, abundance, and human use of fish and wildlife. Division of Habitat, Juneau.

AMAP. 2002. Arctic Pollution 2002: Persistent organic pollutants, heavy metals, radioactivity, human health, changing pathways. Oslo, Norway. xii+112p.

Bowden, W. B., M. N. Gooseff, A. Balser, A. Green, B. J. Peterson, and J. Bradford. 2008. Sediment and nutrient delivery from thermokarst features in the foothills of the North Slope, Alaska: potential impacts on headwater stream ecosystems. Journal of Geophysical Research 113:20-26.

Brown, R., C. Brown, N. Braem, W. Carter III, N. Legere, and L. Slayton. 2012. Whitefish biology, distribution, and fisheries in the Yukon and Kuskokwim River drainages in Alaska: a synthesis of available information. Alaska Fisheries Data Series Number 2012-4. Fairbanks Field Office, Fish and Wildlife Service, U.S. Department of the Interior. Fairbanks, Alaska. 316 pp.

Bureau of Land Management, U.S. Department of the Interior (BLM). 2006. National Petroleum Reserve-Alaska (NPR-A) Northwest Planning Area winter exploration drilling program: FEX, L.P. Prepared by USDOI BLM, Alaska Arctic Field Office, Fairbanks District Office, Anchorage Field Office, Alaska. Available: http://www.blm.gov/pgdata/etc/medialib/blm/ak/aktest/energy/egy_maps.Par.94059.File.dat/fex_npra_ea_final.pdf

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.

Morris, W. A. 2006. Seasonal movements and habitat use of broad whitefish (Coregonus nasus) in the Teshekpuk Lake Region of the National Petroleum Reserve-Alaska, 2003-2005. ADNR Office of Habitat Management and Permitting, Technical Report # 06-04, pp. 18-19, 77, and 86.

Morris, W. A., and J. F. Winters. 2008. A survey of stream crossing structures in the North Slope oilfields. Technical Report No. 08-01. Office of Habitat Management and Permitting, Alaska Department of Fish and Game, Fairbanks, Alaska. 392 pp.

Peterson, C. H., S. D. Rice, J. W. Short, D. Esler, J. L. Bodkin, B. E. Ballachey, and D. B. Irons. 2003. Long-term ecosystem response to the Exxon Valdez oil spill. Science 302:2082–2086.

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., F. Wrona, T. Prowse, M. Power, J. Dempson, J. King, and R. Beamish. 2006. An overview of effects of climate change on selected Arctic freshwater and anadromous fishes. Ambio. 35:381-387.

Zuray, S., R. Kocan, and P. Hershberger. 2012. Synchronous cycling of Ichthyophoniasis with Chinook salmon density revealed during the annual Yukon River spawning migration. 28 Transactions of the American Fisheries Society 141: 615-623. DOI 10.1080/00028487.2012.683476.

5. Chum Salmon (*Oncorhynchus keta*)

Chum salmon are anadromous fish that spawn in summer and fall; juveniles migrate directly to the ocean where they spend two to four winters at sea. It is assumed that chum salmon that spawn in the Arctic spend most of their marine phase in the North Pacific, but may spend their first winter in the Beaufort Sea, offshore deep under pack ice (Irvine et al. 2009).

As adults, chum salmon almost always return to spawn in their natal stream to spawn in late summer or early fall (Morrow 1980). Embryos hatch after 3–4 months, depending on water temperature and remain in the gravel while continuing to absorb nutrients from the egg yolk for an additional 60–90 days before emerging (Morrow 1980). Fry emerge from the gravel during spring (April-May) and migrate to the ocean within days or a few weeks after hatching (Salo 1991). Juvenile chum salmon that hatch far upriver begin feeding on insect larvae while still moving toward the sea (Morrow 1980).

Spawning populations of chum salmon have been documented in the Colville River and elsewhere in the study area (Bendock 1979, Craig and Haldorson 1986), but it is unknown whether these spawning events sustain consistent runs of chum. There are several chum salmon spawning locations in the study area documented in the ADF&G Anadromous Waters Catalog: Noatak River, Kiyak Creek, Wulik River, Kivalina River, Pitmegea River, Kuchiak Creek, Kaolak River, an unnamed tributary to the Ketik River, Mikigealiak River, Kungok River, an unnamed tributary to the Kungok River, Kugrua River, Meade River, Colville River, and the Itkillik River (Johnson and Coleman 2014). Winter temperatures of Arctic marine waters are generally lethal for salmon (Irvine et al. 2009). Groundwater-fed streams are usually many degrees warmer than other streams in the study area, thus the eggs may be able to survive. The lower thermal temperature limit for chum salmon is 2.7 °C. (Azumaya et al. 2007). Typical Arctic stream temperatures average between 0 - 0.5°C in winter months, but pockets of groundwater provide shelter with temperatures between 2 - 5°C throughout winter months (Craig and Haldorson 1986). Warming conditions may be producing more suitable habitat for salmon in the Arctic.

5.1. Conceptual Model

The conceptual model below (Figure J-4) is based on a review of the literature and describes the relationship between the various CAs and natural drivers for chum salmon. The boxes and arrows represent the state of knowledge about chum salmon and the relationship to each attribute.

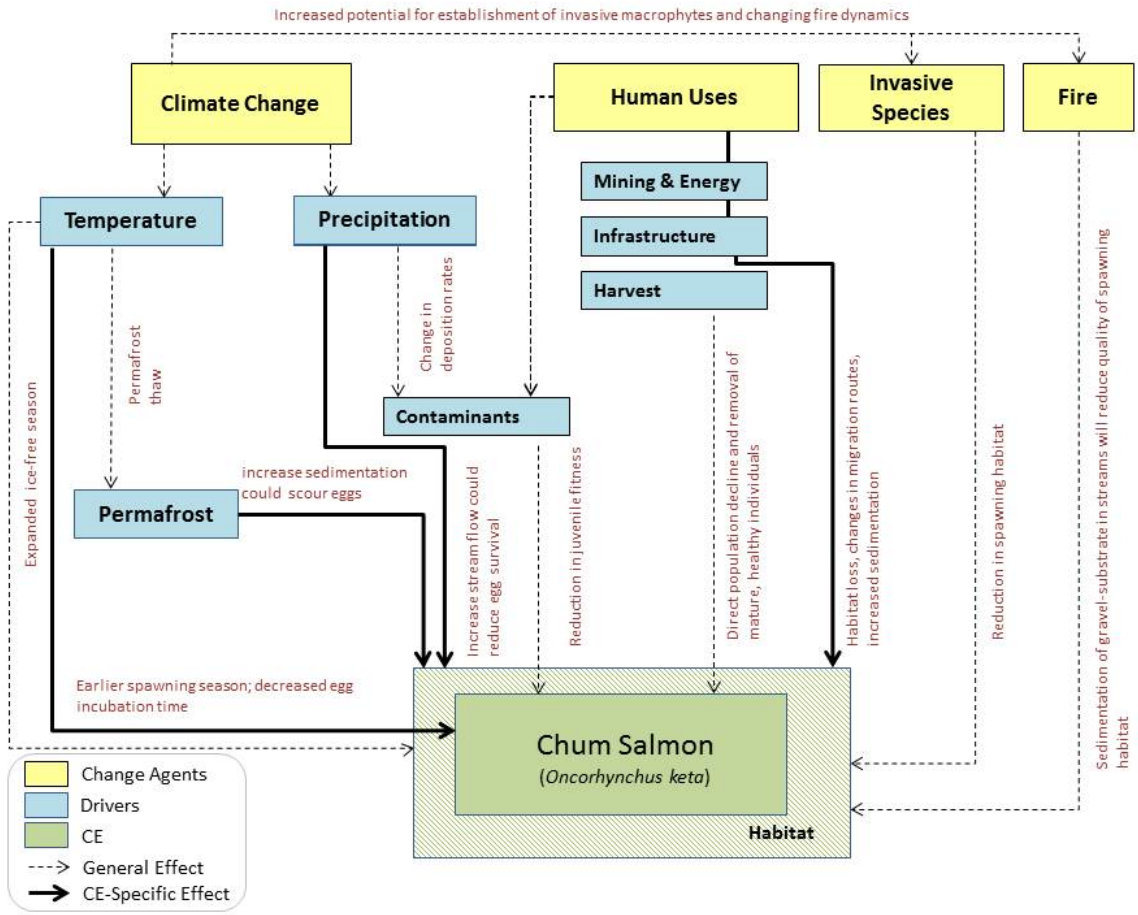

Figure J-4. Principal interactions among population drivers and CAs for Chum Salmon within the North Slope study area.

5.2. Attributes and Indicators

Key CA attribute and indicator data for chum salmon include: winter precipitation, fall temperature, mean annual ground temperature, summer temperature, road development, habitat fragmentation, and contaminated sites (Table J-4).

Table J-5. Attributes and Indicators for Chum Salmon.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[41]	Nov-Dec total precipitation	Spawning habitat	More precipitation			Less precipitation
	Fall temperature[42]	Mean ambient Fall air temperature (Sept-Dec)	Chum salmon embryonic development	Water temperature below 0°C	Water temperature between 0°C - 4.0°C	Water temperature around 4.0 °C	Water temperature between 4.0 °C - 10 4.0 °C
	Fall temperature[43]	Mean Sept air temperature	Pre-spawning mortality	Water temperature above 20°C	Water temperature above 15°C		
	Change in mean annual ground temperature at one meter (MAGT)[44]	Permafrost thaw	Spawning habitat	From below -1m to above +1m			No Change

[41] Lisle 1989; Thresholds general; Increased precipitation could result in increased run-off and scour redds.
[42] Morrow 1980; Raymond 1981; Beacham et al. 1988; Chum salmon need initial incubation temperatures of about 4.0 °C for successful early embryonic development; warmer water temperatures may reduce hatch time.
[43] Murphy 1985; Pre-spawning mortality related to increased temperatures.
[44] GIPL model, Lloyd et al. 2003 (based on GPL model); Lisle 1989 (based on general effects); Increased permafrost thaw could cause scour of salmon redd's.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	Summer temperature[45]	June-August mean monthly air temperature	Parasite infections	Water temperature above 20°C	Water temperature above 15°C	Water temperature around 15°C	Water temperature below 15°C
Anthropogenic development	Road development[46]	Water quality	Spawning habitat	Numerous intersections with streams			No intersection with streams
	Habitat fragmentation[47]	Road development	Spawning habitat	Numerous intersections with streams			No intersection with streams
	Contaminated sites[48]	Water quality	Habitat				

[45] Zuray et al. 2012; Warmer waters may increase the prevalence of diseases and parasites.

[46] Thresholds will depend on specific proximity of fish habitat to a site; Turbidity, metals and hydrocarbon contamination, temperature changes from impoundment; overall effects on spawning habitat.

[47] Morris and Winters 2008; thresholds are general; Disrupt fish migratory movements; direct destruction of habitat, erosion, sedimentation.

[48] Thresholds will depend on specific contaminants at a site and proximity to waterbodies; Oil contamination could reduce egg survival and spawning habitat.

5.3. Abiotic Change Agent Analysis

Climate

Water flow through substrate, water temperature, and dissolved oxygen concentration (Maclean 2003) are important factors that influence redd site selection by chum salmon. Increased permafrost thaw and snow melt may increase the rate of stream discharge and the potential for scour and sedimentation of chum salmon redds (Lisle 1989). Increased precipitation (especially in winter) could have similar negative impacts on chum salmon spawning habitat by increasing the potential scouring of redds and erosion of streambanks. Time of fry emergence is related to water temperature during incubation (Salo 1991) and thus, changes during the early part of incubation can affect time of emergence. As water temperatures increase, egg incubation rates will increase and time to emergence and migration will decrease. Chum salmon may benefit from warmer water temperatures by creating a more stable water temperature for spawning (Maclean 2003). Chum salmon need initial incubation temperatures of about 4.0 °C for successful early embryonic development (Raymond 1981, Beacham et al. 1988). Warmer water temperatures in fall chum spawning sites may also be important in controlling the timing of their emergence in relation to the availability of their prey (Cushing 1990, Gotceitas et al. 1996). However, an increase in water temperatures coupled with low water flow could cause higher fish densities and depleted oxygen concentrations, resulting in high pre-spawning mortality (Murphy 1985).

5.4. Current Status and Future Landscape Condition

The majority of the chum salmon's life occurs in the marine environment, thus the largest impact of road development and oil and gas operations would affect spawning habitat since juveniles do not rear in streams. However, if adult chum salmon overwinter in freshwater habitats in the study area, then overwintering populations could be affected by winter development activities. Road construction has the potential to cause high sediment loads in streams (Beschta 1978). Similarly, stream culverts at road crossings may hinder migration routes (Morris and Winters 2008).

Harvest

Subsistence and sport harvest studies for chum salmon in the study area are limited. However, estimates of sport chum salmon harvest in Brooks Range drainages from 1994-2004 was less than 15 individuals for all years, except for 2000 when 763 individuals were reportedly harvested (Jennings et al. 2007). A recent study in Elsoon Lagoon documented the harvest of 483 chum salmon from the lagoon during 20 July – 31 August, 2008 (North Slope Borough et al. 2009).

5.5. Literature Cited

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.

Beacham, T. D., C. B. Murray, and R. E. Withler. 1988, Age, morphology, developmental biology, and biochemical genetic variation of Yukon River fall chum salmon, Oncorhynchus keta, and comparisons with British Columbia populations. Fishery Bulletin 86:663-674.

Bendock, T. 1979. Inventory and cataloging of Arctic area waters. Juneau: Alaska Department of Fish and Game Annual Report 20:1-64.

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.

Craig, P. C., and L. Haldorson. 1986. Pacific salmon in the North American Arctic. Arctic 39:2-7.

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.

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.

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.

Jennings, G. B., K. Sundet, and A. E.Bingham. 2007. Participation, catch, and harvest in Alaska sport fisheries during 2004. Alaska Department of Fish and Game, Fishery Data Series No. 07-40, Anchorage.

Johnson, J., and J. Coleman. 2014. Catalog of Waters Important for Spawning, Rearing, or Migration of Anadromous Fishes – Arctic Region, Effective June 1, 2014. Alaska Department of Fish and Game, Special Publication No. 14-01, Anchorage.

Lisle, T. 1989. Sediment transport and resulting deposition in spawning gravels, north coastal California. Water Resources Research 25:1303-1319.

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.

Maclean, S. 2003. Influences of hydrological processes on the spatial and temporal variation in spawning habitat quality for two chum salmon stocks in interior Alaska. Masters thesis, University of Alaska Fairbanks. 93 pp.

Morris, W. A., and J. F. Winters. 2008. A survey of stream crossing structures in the North Slope oilfields. Technical Report No. 08-01. Office of Habitat Management and Permitting, Alaska Department of Fish and Game, Fairbanks, Alaska. 392 pp.

Morrow, J. 1980. The freshwater fishes of Alaska. Alaska Northwest Publishing, Anchorage, AK.

Murphy, M. 1985. Die-offs of pre-spawn adult pink salmon and chum salmon in southeastern Alaska. North American Journal of Fish Management 5:302–308.

North Slope Borough Department of Wildlife Management , MJM, ADF&G, BLM , ABR, Inc.--Environmental Research & Services. 2009. 2008 Harvest Surveys in Elson Lagoon Summary Preliminary Findings. Accessed on 07 January 2014: http://www.industrycortex.com/datasheets/profile/1006382668/2008-harvest-surveys-in-elson-lagoon-summary-preliminary-finding

Raymond, J. 1981. Incubation of fall chum salmon Oncorhynchus keta (Walbaum) at Clear Air Force Station, Alaska: Alaska Department of Fish and Game, Information Leaflet No. 189.

Salo, E. 1991. Life history of chum salmon (Oncorhynchus keta). Pages 233-309 *in* C. Groot and L. Margolis, eds. Pacific Salmon Life Histories. UBC Press, Vancouver, British Columbia, Canada.

Zuray, S., R. Kocan, and P. Hershberger. 2012. Synchronous cycling of Ichthyophoniasis with Chinook salmon density revealed during the annual Yukon River spawning migration. 28 Transactions of the American Fisheries Society 141: 615-623. DOI 10.1080/00028487.2012.683476.

6. Arctic Grayling (*Thymallus arcticus*)

Arctic grayling are one of the most widespread fish species within the North Slope study area and are found exclusively in fresh water throughout the year. Arctic grayling are well adapted to the rigors of the arctic climate as they spend their entire life cycle within aquatic habitats on the North Slope. They can be migratory or relatively sedentary and remain in the same section of a stream year round (Morris 2003). Similar to most other arctic fishes, available overwintering habitat is critical to their survival and is considered to be the major limiting factor for populations of Arctic grayling. Their tolerance of low dissolved oxygen levels allows grayling to survive the long winters in areas where many other species would perish ("Arctic Grayling", para. 4). After spring break-up, Arctic grayling begin movements into streams and rivers that were previously frozen (Morris 2003). Glacial rivers in the Brooks Range area are important migration corridors to tundra streams where grayling spawn and rear (Tack 1980). Arctic grayling typically spawn in May and June in riffle areas of streams. After spawning, they move from smaller streams to the main streams and rivers where they spend the summer (Morrow 1980). Some Arctic grayling demonstrate strong site fidelity, returning every year to the same spawning and feeding areas (Morrow 1980). Juveniles emerge from the gravel in late June and early July and remain in the foothill streams throughout the summer. In late fall (before freeze-up), Arctic grayling move into overwintering areas in clear river channels associated with year round springs and deep pools (West et al. 1992). Arctic grayling are considered generalists, but primarily consume macroinvertebrates (Hobbie et al. 1995). They will also eat salmon eggs and out-migrating salmon smolts. Grayling mature between the age of six and nine years and can live for up to 30 years (ADF&G 2015).

Arctic grayling require colder water temperatures than most other fish with thermal maximum temperatures for adults around 20°-25°C (Stewart et al. 2007). For adults, temperatures above 15°C are considered to induce stress, and temperatures greater than 20°C cannot be tolerated for long without mortality. However, juveniles can tolerate warmer waters (between 10°- 20°C). Thus water temperature of summer rearing and feeding habitats is an important determinant of the summer distribution of Arctic grayling, such that larger grayling tend to be found in the cooler upper reaches of rivers, whereas smaller grayling tend to be located in warmer downstream reaches.

6.1. Conceptual Model

The conceptual model below (Figure J-5) is based on a review of the literature and describes the relationship between the various CAs and natural drivers for Arctic grayling. The boxes and arrows represent the state of knowledge about Arctic grayling and the relationship to each attribute.

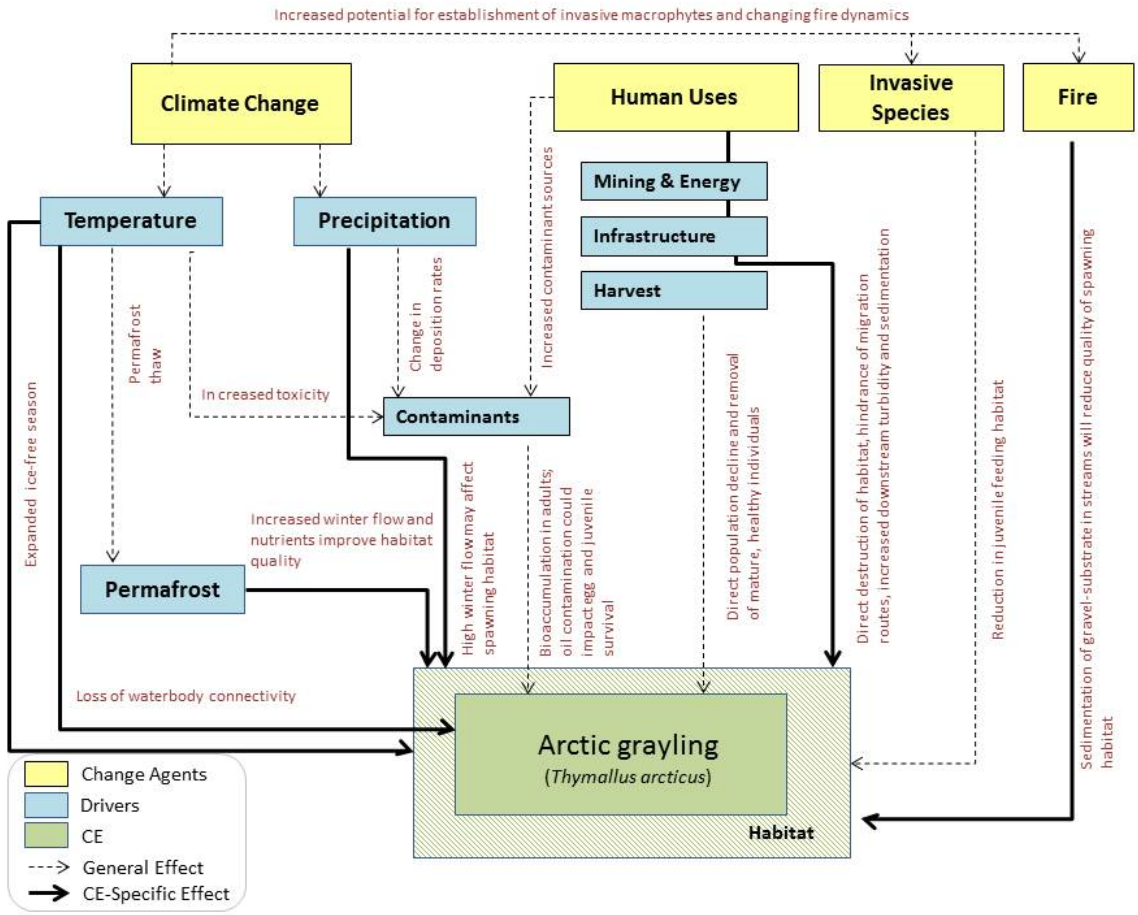

Figure J-5. Principal interactions among population drivers and CAs for Arctic grayling within the North Slope study area.

6.2. Attributes and Indicators

Key CA attribute and indicator data for Arctic grayling include: winter precipitation, summer temperature, frost-free days/season length, mean annual ground temperature, road development, habitat fragmentation, oil and gas activities, and contaminated sites (Table J-6).

Table J-6. Attributes and Indicators for Arctic grayling.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[49]	Dec-Feb total precipitation	Overwintering habitat	Less precipitation			More precipitation
	Winter precipitation[50]	Dec-Feb total precipitation	Overwintering habitat	More precipitation			Less precipitation
	Summer temperature[51]	June-August mean monthly air temperature	Adult survivorship	Water temperature between 20°C-25°C	Water temperature above 20°C		Water temperature below 15°C
	Summer temperature[52]	June-August mean monthly air temperature	Parasite infections	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C
	Frost-free days/Season length[53]	Cumulative days with temps above 0 °C (Days between DOT	Egg development and shifts in spawning time			Increased number of frost-free	

[49] Specific thresholds are unknown; Increased winter precipitation could increase available overwintering (by increasing the volume of water).
[50] Specific thresholds are unknown; Increased precipitation could result in increased run-off and sedimentation negatively impacting habitat.
[51] Stewart et al. 2007; Thermal stress.
[52] Zuray et al. 2012; Thresholds based on salmonid studies; Warmer waters may increase the prevalence of diseases and parasites.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
		and DOF)				days	
	Frost-free days/Season length[54]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Juvenile growth			Increased number of frost-free days	
	Change in mean annual ground temperature at one meter (MAGT)[55]	Permafrost thaw	Overwintering habitat			Increased rates of thaw	
	Change in mean annual ground temperature at one meter (MAGT)[56]	Permafrost thaw	Foraging habitat	From below -1m to above +1m			No Change
Anthropogenic development	Road development[57]	Water quality	Habitat	Numerous intersections with habitats			No intersection with habitats
	Habitat	Road development	Habitat	Numerous intersections			No intersection

[53] Specific thresholds are unknown; With an earlier breakup period, egg development time would likely be reduced and it's possible that spawning will shift to later in the fall.

[54] Reist and Bond 1988; Reist et al. 2006; General thresholds; The age at maturity for Arctic grayling will likely decrease because individuals will be able to feed more during any single year

[55] Specific thresholds are unknown; Increased ground flows in winter as a consequence of permafrost thaw could improve overwintering habitat.

[56] GIPL model, Lloyd et al. 2003 (based on GPL model); Bowden et al. 2008 (based on general effects); Increased nutrient input with permafrost thaw will improve feeding habitat by increasing primary productivity.

[57] Thresholds will depend on specific proximity of fish habitat to a site; Turbidity, metals and hydrocarbon contamination, temperature changes.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	fragmentation[58]			with habitats			with habitats
	Oil and gas activities[59]	Water withdrawal	Habitat disturbance or loss	Lakes used by Arctic grayling			Lakes not used by arctic grayling
	Contaminated sites[60]	Water quality	Habitat				

[58] Morris and Winters 2008; thresholds are general; Disrupt fish migratory movements; direct destruction of habitat, erosion, sedimentation.
[59] BLM 2006; Thresholds are general; Effect water quality, reduce spawning habitat and reduce overwintering habitat.
[60] Thresholds will depend on specific contaminants at a site and proximity to waterbodies; Oil contamination could reduce egg survival and spawning habitat.

6.3. Abiotic Change Agent Analysis

Climate

With projected increased temperatures, the duration of the ice-free season will likely increase (see Section C). A longer ice-free season could improve the quality of feeding habitats as those habitats will likely experience an increase in primary productivity due to longer periods of solar exposure (Reist et al. 2006). Permafrost thaw will likely increase groundwater flows in winter improving overwintering habitat for Arctic grayling which will likely increase overwintering survival, at least temporarily. Permafrost thaw may increase nutrient input into aquatic habitats thereby increasing primary production and invertebrate populations (Bowden et al. 2008). Thus, increased nutrient input will improve the quality of fish feeding habitat with the direct or indirect increased abundance of prey species (Reist et al. 2006). A predicted increase in winter precipitation could potentially increase available overwintering habitat directly (by increasing the volume of water) and indirectly through the loss of snow insulation which would reduce ice thickness. Increased precipitation could also result in increased run-off and sedimentation.

Increased temperatures (coupled with increased evapotranspiration) may affect connectivity between stream and lake habitats and limit access to spawning and overwintering habitats (Reist et al. 2006). Warmer waters may also increase the prevalence of diseases and parasites (Reist et al. 2006).

Contaminants

As water temperature increases, certain contaminants become more bioavailable (e.g., mercury) and thus, exposure rates of contaminants in fish will likely increase with a warming climate (AMAP 2002). Similar to broad whitefish, Arctic grayling consume mostly lower trophic level species such as invertebrates, and are less likely to contain high levels of contaminants (e.g. heavy metals and organochlorines), compared to piscivorous species such as Dolly Varden and chum salmon. However, because Arctic grayling are a long-lived species they have the potential to bioaccumulate contaminants over time and may concentrate levels of contaminants. High contaminant levels are a concern for individual fish as well as wildlife and humans that consume them.

Oil field operations have the potential to introduce contaminants to aquatic habitats within the study area. Whereas, some contaminants such as organochlorines (e.g., PCBs, DDT, and POPs) and mercury have both local and distant anthropogenic sources, petroleum products are directly related to local activities. Spilled petroleum products may arise from activities such as drilling and transportation of personnel and materials. Contaminants on roads from vehicle leakage may runoff into drainages affecting water quality. Petroleum products may persist in aquatic environments for years after a spill or leak and can directly affect the health of fish by impacting their ability to adequately take up oxygen through ingestion, which may compromise other physiological functions (Peterson et al. 2003). Oil contamination has the largest impact on embryos because of their reduced capacity to leave the contaminated area (Short et al. 2003, Moles et al. 1979).

Bridges and culverts used for development of oil production could affect Arctic grayling habitat directly by increasing sedimentation or altering migration routes. Additionally, road development will provide access for humans to utilize streams or reaches previously inaccessible and this could potentially increase fishing pressure in local streams.

6.4. Current Status and Future Landscape Condition

Road development for oil and gas exploration and water withdrawal are considered to be some of the most important development concerns within the study area (see Section E). Oil exploration typically occurs during winter months which could have negative impacts on Arctic grayling overwintering populations. Arctic grayling are considered potentially sensitive to water withdrawal activities, especially during the winter when habitat is most limiting (BLM 2006). Road development at stream crossings could disrupt migratory pathways and alter access between key summering and wintering habitats. Due to the use of small drainages, including ephemeral streams, any development that would impede fish passage within these small drainages, could have negative impacts on Arctic grayling populations within the study area (Morris 2006). Furthermore, because Arctic grayling growth rates are low and recruitment is variable they may not respond to disturbance well (Buzby and Deegan 2000). In addition to direct environmental changes resulting from road construction, roads increase human access to previously remote areas, which facilitates increased recreational use of resources.

Harvest

Arctic grayling is an important subsistence species within the study area. Sport fishing effort is generally light, but variable, with most effort focused on streams and lakes along the Dalton Highway (Scanlon 2012). Estimated harvest of Arctic grayling within the North Slope was 2,204 in 2011 and the 10-year average was 3,028 (Scanlon 2012). Arctic grayling catch in 2011 was estimated around 12,000 fish (Scanlon 2012).

6.5. Literature Cited

ADF&G. 2015. Arctic Grayling (*Thymallus arcticus*) Species Profile. Available: http://www.adfg.alaska.gov/index.cfm?adfg=arcticgrayling.main

AMAP. 2002. Arctic Pollution 2002: Persistent organic pollutants, heavy metals, radioactivity, human health, changing pathways. Oslo, Norway. xii+112p.

BLM. 2006. National Petroleum Reserve-Alaska (NPR-A) Northwest Planning Area winter exploration drilling program: FEX, L.P. Prepared by USDOI BLM, Alaska Arctic Field Office, Fairbanks District Office, Anchorage Field Office, Alaska. Available: http://www.blm.gov/pgdata/etc/medialib/blm/ak/aktest/energy/egy_maps.Par.94059.File.dat/fex_npra_ea_final.pdf

Bowden, W. B., M. N. Gooseff, A. Balser, A. Green, B. J. Peterson, and J. Bradford. 2008. Sediment and nutrient delivery from thermokarst features in the foothills of the North Slope, Alaska: potential impacts on headwater stream ecosystems. Journal of Geophysical Research 113:20-26.

Buzby, K. M., and L. A. Deegan. 2000. Inter-annual fidelity to summer feeding sites in Arctic grayling. Environmental Biology of Fishes 59:319–327.

Deegan, L. A., and B. J. Peterson. 1992. Whole river fertilization stimulates fish production in an arctic tundra river. Canadian Journal of Fisheries and Aquatic Sciences 49:1890-1901.

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

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.

Moles, A., S.D. Rice, and S. Korn. 1979. Sensitivity of Alaskan freshwater and anadromous fishes to Prudhoe Bay crude oil and benzene. Trans. Am. Fish. Soc. 108(4):408-414.

Morris, W. 2003. Seasonal movements and habitat use of Arctic grayling (thymallus arcticus), burbot (lota lota), and broad whitefish (coregonus nasus) within the fish creek drainage of the National Petroleum Reserve-Alaska, 2001-2002. Alaska Department of Natural Resources Technical Report No. 03-02. Anchorage, AK.

Morris, W. A. 2006. Seasonal movements and habitat use of broad whitefish (Coregonus nasus) in the Teshekpuk Lake Region of the National Petroleum Reserve-Alaska, 2003-2005. ADNR Office of Habitat Management and Permitting, Technical Report # 06-04, pp. 18-19, 77, and 86.

Morris, W. A., and J. F. Winters. 2008. A survey of stream crossing structures in the North Slope oilfields. Technical Report No. 08-01. Office of Habitat Management and Permitting, Alaska Department of Fish and Game, Fairbanks, Alaska. 392 pp.

Morrow, J. 1980. The freshwater fishes of Alaska. Alaska Northwest Publishing, Anchorage, AK.

Peterson, C. H., S. D. Rice, J. W. Short, D. Esler, J. L. Bodkin, B. E. Ballachey, and D. B. Irons. 2003. Long-term ecosystem response to the Exxon Valdez oil spill. Science 302:2082–2086.

Reist, J., F. Wrona, T. Prowse, M. Power, J. Dempson, J. King, and R. Beamish. 2006. An overview of effects of climate change on selected Arctic freshwater and anadromous fishes. Ambio. 35:381-387.

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.

Scanlon, B. 2012. Fishery management report for sport fisheries in the Northwest/North Slope Management area, 2012. Alaska Department of Fish and Game, Fishery Management Report No. 12-45, Anchorage.

Short, J. W., S. D. Rice, R. A. Heintz, M. G. Carls, and A. Moles. 2003. Long-Term Effects of Crude Oil on Developing Fish: Lessons from the Exxon Valdez Oil Spill , Energy Sources, 25:6, 509-517.

Stewart, D. B., N. J. Mochnacz, J. D. Reist, T. J. Carmichael, and C. D. Sawatzky. 2007. Fish life history and habitat use in the Northwest Territories: Arctic grayling (Thymallus arcticus). Can. Manuscr. Rep. Fish. Aquat. Sci. 2797. 55 pp.

Tack, S. 1980. Distribution, abundance and natural history of the Arctic grayling in the Tanana River drainage. Alaska Dept. of Fish and Game. Fed. Aid in Fish Restoration, Annual Report of Progress, 1979-1980. 21 (F-90-12). 32 pp.

West, R. L., M. W. Smith, W. E. Barber, J. B. Reynolds, and H. Hop. 1992. Autumn migration and overwintering of Arctic grayling in coastal streams of the Arctic National Wildlife Refuge, Alaska. Transactions of the American Fisheries Society 121:709-715.

Zuray, S., R. Kocan, and P. Hershberger. 2012. Synchronous cycling of Ichthyophoniasis with Chinook salmon density revealed during the annual Yukon River spawning migration. 28 Transactions of the American Fisheries Society 141: 615-623. DOI 10.1080/00028487.2012.683476.

7. Burbot (*Lota lota*)

Burbot are commonly found in well oxygenated streams and deep lakes (Morris 2003). Burbot are widespread in distribution throughout the study area, but their abundance is considered relatively low. The low abundance of burbot may be attributed to inefficient sampling gear and thus their distribution and abundance is likely underestimated for this area. Migratory patterns are not well known, but in general, burbot are rather sedentary fish except for movements between feeding and spawning areas (Morrow 1980). Burbot are unique in that they spawn under the ice, usually between January and February and fry hatch in March or April. During spawning, adults will gather in large groups and form a writhing mass with a few females at the center, surrounded by many males (Cahn 1936). Burbot mature in six to seven years and are a relatively long-lived species that can live up to 20 years (Morrow 1080). Optimal water temperature for burbot is reported at 15.6-18.3 °C (Scott and Crossman 1973). Juveniles feed on insects for the first few years, and then shift to a mostly piscivorous diet as adults (Morrow 1980). Although considered relatively sluggish in nature, burbot are voracious predators that feed at night. Similar to most other fish species on the North Slope, overwintering habitat is a major factor constraining burbot populations.

7.1. Conceptual Model

The conceptual model below (Figure J-6) is based on a review of the literature and describes the relationship between the various CAs and natural drivers for Burbot. The boxes and arrows represent the state of knowledge about Burbot and the relationship to each attribute.

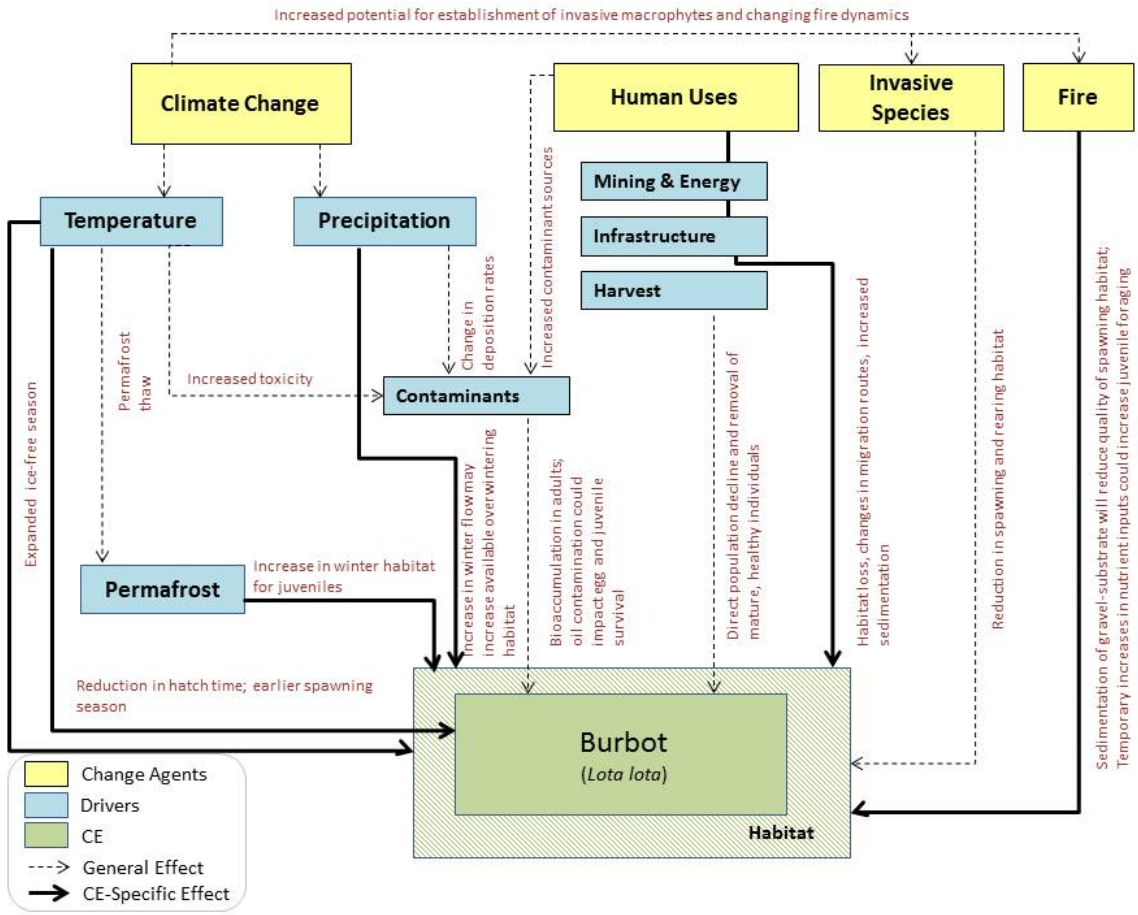

Figure J-6. Principal interactions among population drivers and CAs for Burbot within the North Slope study area.

7.2. Attributes and Indicators

Key CA attribute and indicator data for burbot include: winter precipitation, summer temperature, frost-free days/season length, mean annual ground temperature, road development, habitat fragmentation, oil and gas activities, and contaminated sites (Table J-4).

Table J-7. Attributes and Indicators for Burbot.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
Climate	Winter precipitation[61]	Dec-Feb total precipitation	Spawning habitat	Less precipitation			More precipitation
	Summer temperature[62]	June-August mean monthly air temperature	Summer habitat	Warming water temperatures			No change in water temperature
	Summer temperature[63]	June-August mean monthly air temperature	Parasite infections	Water temperature above 20 °C	Water temperature above 15°C		Water temperature below 15°C
	Frost-free days/Season length[64]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Egg development and juvenile growth	Water temperature below 0°C	Water temperature below 3.6°C	Water temperature around 3.6°C	Water temperature above 3.6°C

[61] Specific thresholds are unknown; Increased winter precipitation could increase available overwintering (by increasing the volume of water).
[62] Specific thresholds are unknown; Loss of lake connectivity; lake drying.
[63] Zuray et al. 2012; Thresholds based on salmonid studies; Warmer waters may also increase the prevalence of diseases and parasites.
[64] McCrimmon 1959; Increased temperature may reduce hatching time and increase the amount of time that fish can spend feeding.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	Frost-free days/Season length[65]	Cumulative days with temps above 0 °C (Days between DOT and DOF)	Juvenile growth			Increased number of frost-free days	
	Change in mean annual ground temperature at one meter (MAGT)[66]	Permafrost thaw	Overwintering habitat			Increased rates of thaw	
	Change in mean annual ground temperature at one meter (MAGT)[67]	Permafrost thaw	Foraging habitat	From below -1m to above +1m			No Change
Anthropogenic development	Road development[68]	Water quality	Habitat	Numerous intersections with habitats			No intersection with habitats
	Habitat fragmentation[69]	Road development	Habitat	Numerous intersections with habitats			No intersection with habitats

[65] Reist and Bond 1988; Reist et al. 2006; General thresholds; The age at maturity for burbot will likely decrease because individuals will be able to feed more during any single year.
[66] Specific thresholds are unknown; Increased ground flows in winter as a consequence of permafrost thaw could improve overwintering habitat.
[67] GIPL model, Lloyd et al. 2003 (based on GPL model); Bowden et al. 2008 (based on general effects); Increased nutrient input with permafrost thaw will improve feeding habitat by increasing primary productivity.
[68] Thresholds will depend on specific proximity of fish habitat to a site; Turbidity, metals and hydrocarbon contamination, temperature changes.
[69] Morris and Winters 2008; Thresholds are general; Disrupt fish migratory movements; direct destruction of habitat, erosion, sedimentation.

CA or Driver	Key Attribute	Indicator	Effect/Impact	Indicator Rating			
				Poor	Fair	Good	Very Good
	Oil and gas activities[70]	Water withdrawal	Habitat disturbance or loss	Lakes used by burbot			Lakes not used by burbot
	Contaminated sites[71]	Water quality	Habitat				

[70] BLM 2006; Thresholds are general; Effect water quality, reduce spawning habitat and reduce overwintering habitat.
[71] Thresholds will depend on specific contaminants at a site and proximity to waterbodies; Oil contamination could reduce egg survival and spawning habitat.

7.3. Abiotic Change Agent Analysis

Climate

Burbot are especially well adapted to cold water temperatures. An increase in water temperature as a result of climate change could negatively impact burbot populations (Jackson et al. 2008). Warmer air temperatures will increase the length of the ice-free season to a later freeze-up date and an earlier thaw date (see Section C). A lengthening of the duration of the ice free season could have an impact on the timing of spawning and egg hatching for burbot in the study area. Burbot eggs need approximately 71 days with temperatures between 0 °C-3.6 °C to hatch (McCrimmon 1959). Thus, an increase in temperature may reduce hatching time and increase the amount of time that fish can spend feeding. As a consequence, the age at maturity for burbot may decrease because individuals will be able to feed more during any single year. Changes in water temperatures can also alter the timing of life history events, such as sexual maturation and timing of migration and spawning (Reist et al. 2006). An increase in winter precipitation could potentially increase available overwintering habitat directly by increasing the volume of water and indirectly through the loss of snow insulation which would reduce ice thickness. Warmer waters may also increase the prevalence of diseases and parasites (Reist et al. 2006).

Contaminants

As water temperature increases, certain contaminants become more bioavailable (e.g., mercury) and exposure rates of contaminants in fish will likely increase. Studies in arctic Canada have documented high concentrations of mercury and polychlorinated biphenyl (PCB) in burbot (Carrie et al. 2010). Because these contaminants bioaccumulate and biomagnify they have the potential to accumulate levels that pose a direct health risk to humans and wildlife that consume them. Warming temperatures within the study area may further exacerbate contaminants exposure in burbot within this region by both releasing snowpack and permafrost-entrained mercury, and by enhancing conditions that facilitate methylmercury production (AMAP 2002). Future increases in mercury concentrations in aquatic habitat could pose a health risk to individual fish and potentially reduce the value of burbot as a subsistence resource.

Oil field operations have the potential to introduce contaminants to aquatic habitats within the study area. Whereas, some contaminants such as organochlorines (e.g., PCBs, dichlorodiphenyltrichloroethane metabolites (DDT), and persistent organic pollulants (POPs)) and mercury have both local and distant anthropogenic sources, petroleum products are directly related to local activities. Spilled petroleum products may arise from activities such as drilling and transportation of personnel and materials. Contaminants on roads from vehicle leakage may runoff into drainages affecting water quality. Petroleum products may persist in aquatic environments for years after a spill or leak and can directly affect the health of fish by impacting their ability to adequately take up oxygen through ingestion, which may compromise other physiological functions (Peterson et al. 2003). Oil contamination has the largest impact on embryos because of their reduced capacity to leave the contaminated area (Short et al. 2003, Moles et al. 1979).

7.4. Current Status and Future Landscape Condition

Most development in the study area is related to oil and gas industries (see Section E). Habitat alterations to stream flow or changes to underlying sediments caused by stream crossings can lead to changes in water temperature, turbidity, and dissolved ion concentrations, which in turn could have negative impacts on burbot populations. Major construction, especially of roads will increase erosion and runoff leading to increased stream turbidity and sedimentation, and could introduce contaminates into these habitats (e.g., vehicular leaks and spills). Because burbot spawn during the winter, water withdrawals from lakes could have negative impacts on spawning populations.

Harvest

Ice-fishing for burbot during winter is a popular fishing practice in the study area. Sport fisheries of burbot occur throughout the study area, but are relatively modest compared to other fish species. The largest fisheries occur in the Copper River area. Burbot sport fisheries increased from 1977-1983 by 30% annually (across the state) as a result of increased access to fishing sites and increased human population related to the construction of the Trans-Alaska Pipeline (Stapanian et al. 2010). Statewide harvest from 2002-2011 average 5,600 fish with no apparent trend during that time period. Little is known of the burbot subsistence fisheries on in the study area.

7.5. Literature Cited

AMAP. 2002. Arctic Pollution 2002: Persistent organic pollutants, heavy metals, radioactivity, human health, changing pathways. Oslo, Norway. xii+112p.

BLM. 2006. National Petroleum Reserve-Alaska (NPR-A) Northwest Planning Area winter exploration drilling program: FEX, L.P. Prepared by USDOI BLM, Alaska Arctic Field Office, Fairbanks District Office, Anchorage Field Office, Alaska. Available: http://www.blm.gov/pgdata/etc/medialib/blm/ak/aktest/energy/egy_maps.Par.94059.File.dat/fex_npra_ea_final.pdf

Bowden, W. B., M. N. Gooseff, A. Balser, A. Green, B. J. Peterson, and J. Bradford. 2008. Sediment and nutrient delivery from thermokarst features in the foothills of the North Slope, Alaska: potential impacts on headwater stream ecosystems. Journal of Geophysical Research 113:20-26.

Cahn, A. R. 1936. Observations on the breeding of the lawyer, Lota maculosa. Copeia 1936:163–165.

Carrie, J., F. Wang, H. Sanei, R. W. Macdonald, P. M. Outridge, and G. A. Stern. 2009. Increasing contaminant burdens in an Arctic fish, burbot (Lota lota), in a warming climate. Environmental Science and Technology 44:316-322.

Jackson, J. R., A. J. VanDeValk, J. L. Forney, B. F. Lantry, T. E. Brooking, and L. G. Rudstam. 2008. Long-term trends in Burbot abundance in Oneida Lake, New York: life at the southern edge of the range in an era of climate change. Pages 131-152 *in* V. L. Paragamian and D. H. Bennett, eds. Burbot: ecology, management, and culture. American Fisheries Society, Symposium 59, Bethesda, MD.

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.

McCrimmon, H. R. 1959. Observations on spawning of burbot in Lake Simcoe, Ontario. The Journal of Wildlife Management 23:447-449.

Moles, A., S.D. Rice, and S. Korn. 1979. Sensitivity of Alaskan freshwater and anadromous fishes to Prudhoe Bay crude oil and benzene. Trans. Am. Fish. Soc. 108(4):408-414.

Morris, W. 2003. Seasonal movements and habitat use of Arctic grayling (thymallus arcticus), burbot (lota lota), and broad whitefish (coregonus nasus) within the fish creek drainage of the National Petroleum Reserve-Alaska, 2001-2002. Alaska Department of Natural Resources Technical Report No. 03-02. Anchorage, AK.

Morris, W. A., and J. F. Winters. 2008. A survey of stream crossing structures in the North Slope oilfields. Technical Report No. 08-01. Office of Habitat Management and Permitting, Alaska Department of Fish and Game, Fairbanks, Alaska. 392 pp.

Morrow, J. 1980. The freshwater fishes of Alaska. Alaska Northwest Publishing, Anchorage, AK.

Peterson, C. H., S. D. Rice, J. W. Short, D. Esler, J. L. Bodkin, B. E. Ballachey, and D. B. Irons. 2003. Long-term ecosystem response to the Exxon Valdez oil spill. Science 302:2082–2086.

Reist, J., F. Wrona, T. Prowse, M. Power, J. Dempson, J. King, and R. Beamish. 2006. An overview of effects of climate change on selected Arctic freshwater and anadromous fishes. Ambio. 35:381-387.

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.

Scott, W. B. and E. J. Crossman. 1973. Freshwater fishes of Canada. Bulletin of the Fisheries Research Board of Canada 184, Ottawa, Ontario, Canada.

Short, J. W., S. D. Rice, R. A. Heintz, M. G. Carls, and A. Moles. 2003. Long-Term Effects of Crude Oil on Developing Fish: Lessons from the Exxon Valdez Oil Spill , Energy Sources, 25:6, 509-517.

Stapanian, M. A., V. L. Paragamian, C. P. Madenjian, J. R. Jackson, J. Lappalainen, M. J. Evanson, and M. D. Neufeld. 2010. World-wide status of burbot and conservation measures. Fish and Fisheries 11:34-56.

Zuray, S., R. Kocan, and P. Hershberger. 2012. Synchronous cycling of Ichthyophoniasis with Chinook salmon density revealed during the annual Yukon River spawning migration. 28 Transactions of the American Fisheries Society 141: 615-623. DOI 10.1080/00028487.2012.683476.

8. Baseline Fish Information

MQ AF 1	What are the baseline characteristics and trends in fish habitat (lakes and streams), fish distribution, and fish movements?

8.1. Methods

We identified the Fine-Filter CEs (fish) as a **data gap** due to sparse fish occurrence data within the North Slope study area. Fish occurrence data have been collected within the study area, however most of these data are presently available only in non-digitized format (e.g., hardcopies, inventory reports, unpublished data, etc.). Due to the lack of spatial data available, we began collaboration with BLM fisheries biologists to assist with their efforts to enter these fish distribution datasets into the geodatabase RipFish that was developed and is maintained by BLM. Our contribution to this database serves as a final product for the Aquatic Fine-Filter CEs and will allow managers to readily have access to fish distribution data and conduct future spatial analyses. For this MQ we provide a literature review on fish movements and life history information for the Fine-Filter CEs.

8.2. Broad whitefish

Trends in Movements

Broad whitefish are typically anadromous, although freshwater resident populations have been documented in lakes and streams within the North Slope study area. Spawning occurs in late fall to early winter in gravel stream beds (ADF&G 1986). After spawning, broad whitefish migrate downstream to overwinter under the ice in lakes that are deep enough and do not freeze to the bottom, as well as rivers and streams with deep pools (Morris 2006).

Studies have documented the importance of small drainages with lake connectivity for broad whitefish summer habitat on the North Slope (Morris 2006). Suitable overwintering habitat is one of the most severe constraints on broad whitefish populations and the use of ephemeral streams to move into lake habitats for overwintering is especially important (Morris 2006). Broad whitefish have been documented using a diversity of habitats for overwintering in the Teshekpuk Lake area, such as the coalesced lakes at the headwaters of the Mayoriak River, in deep pools (> 15 feet) of the Mayoriak River, and the lower reaches of the Chipp River and its connected lakes (Morris 2006).

Broad whitefish telemetry studies within the Fish Creek drainage and Teshekpuk Lake area have provided insight into summer and winter habitat use as well as general movements within the study area (Morris 2006). Overall, habitat use and movement is highly variable and site fidelity appears to be low (Morris 2006). After ice break up in the spring (though some movements occur under the ice) broad whitefish move between lakes and river drainages and to coastal feeding areas (Craig 1984, Morris 2006). Due to the broad range of habitats used for spawning, foraging, and overwintering, Morris (2006) suggested this species is likely more resilient to localized disturbances.

See database RipFish with recently entered occurrence points (Figure J-7).

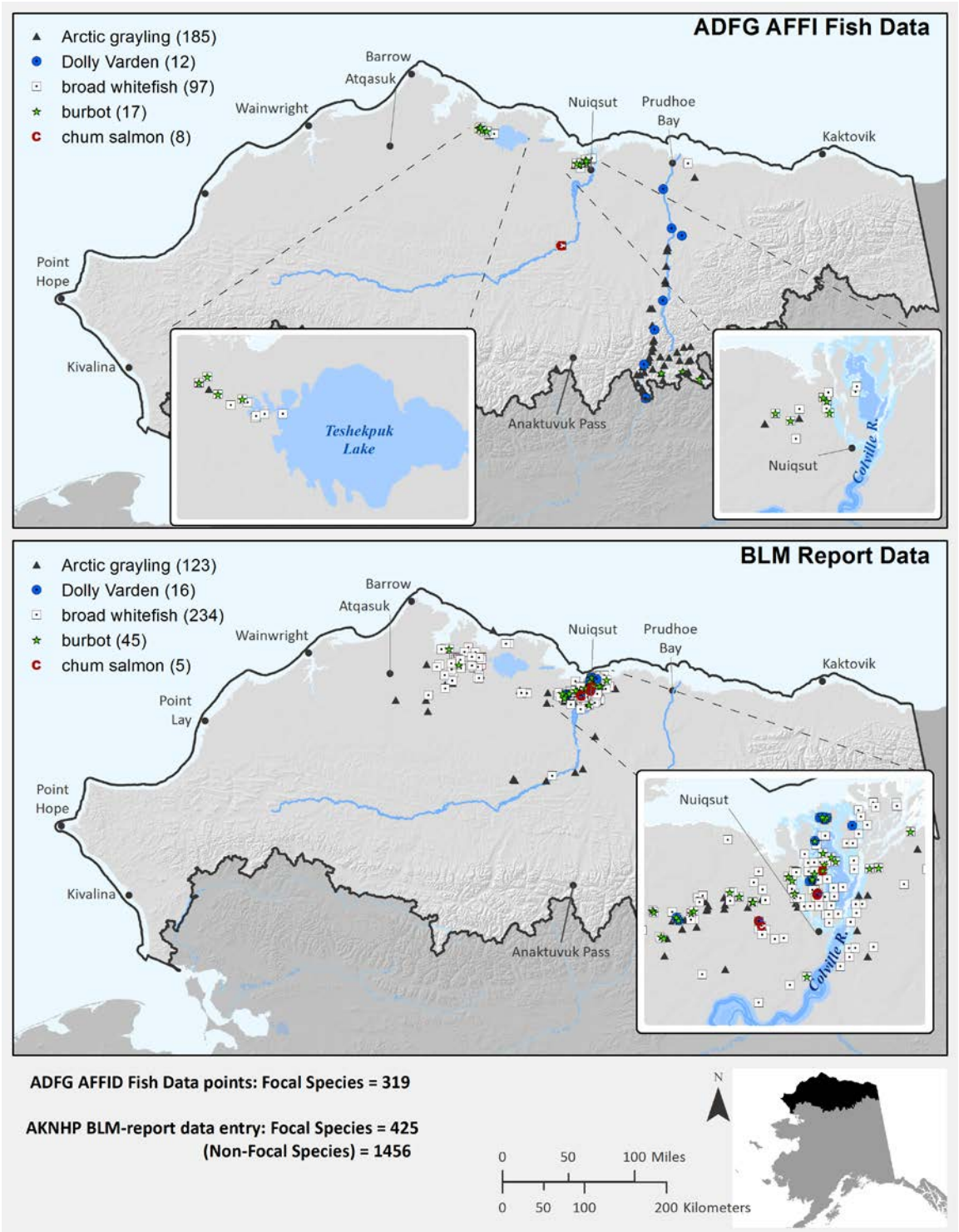

Figure J-7. Existing occurrence point data from AK Department of Fish and Game (ADF&G) Alaska Freshwater Fish Inventory (AFFI) and Bureau of Land Management (BLM) for all five fish species.

8.3. Dolly Varden

Trends in Movements

Dolly Varden occur in the study area as lake-resident, stream-resident, and anadromous populations although they are considered to be predominantly anadromous within the study area. Small streams (including headwater streams) and habitats associated with discharging groundwater are used by Dolly Varden for spawning, rearing, and overwintering. However, these habitats on the North Slope comprise a relatively small proportion of overall stream habitats and thus, are limiting to populations. Overwintering habitat is especially critical and limited to small streams with spring-fed areas.

Movements from winter to summer habitat are poorly studied, but it is assumed that Dolly Varden move away from overwintering areas after spring break-up. Dolly Varden tagging studies have shown that overwintering and spawning habitats may change over time due to changes in channel morphology affecting groundwater inputs (Viavant 2004). Dolly Varden may overwinter in areas not connected to their natal streams (Crane et al. 2005). Major river drainages used by Dolly Varden for spawning, rearing, and overwintering habitat include the Colville, Kuparak, Canning, and Sagavanirktok (Scanlon 2012). Radio telemetry studies within the Kagvik Creek found individual movements were minimal during the winter (Scanlon 2004). It is assumed that Dolly Varden make short distance movements during the winter when looking for better oxygenated waters (Scanlon 2004).

Younger individuals and resident forms will spend the summer foraging within freshwater habitats, whereas, anadromous adults will move to nearshore coastal waters for feeding (Viavant 2004, Scanlon 2004). Dolly Varden generally mature at five to nine years of age and can spawn multiple times throughout their lifetimes (ADF&G 1986). Anadromous adults migrate to the sea at maturity. See database RipFish with recently entered occurrence points (Figure J-7).

8.4. Arctic grayling

Trends in Movements

Arctic grayling are resident species found in freshwater habitats throughout the year within the study area. They can be migratory or relatively sedentary and remain in the same section of a stream year round. Similar to most other arctic fishes, available overwintering habitat is critical to their survival and is considered to be the major limiting factor for populations within the study area.

Their tolerance of low dissolved oxygen levels allows grayling to survive the long winters in areas where many other species would perish. Additionally, Arctic grayling require colder water temperatures than most other fish with thermal maximum temperatures for adults around 20–25 °C (Stewart et al. 2007). For adults, temperatures above 15 °C are considered to induce stress, and temperatures greater than 20 °C cannot be tolerated for long without mortality. However, juveniles can tolerate warmer waters (between 10–20 °C). Thus water temperature of summer rearing and feeding habitats is an important determinant of the summer distribution of Arctic grayling, such that larger grayling tend to be found in

the cooler upper reaches of rivers, whereas smaller grayling tend to be located in warmer downstream reaches.

Some individuals have been documented traveling up to 100 miles from their summer feeding areas to overwintering habitat, while some individuals remain in the same stream year round (ADF&G 2015). Glacial rivers in the Brooks Range area are important migration corridors to tundra streams where grayling spawn and rear (Tack 1980). Arctic grayling migrate to their spawning areas in early spring. Some individuals demonstrate strong site fidelity, returning every year to the same spawning and feeding areas (Morrow 1980, Morris 2003). Spawning usually occurs in outlet streams of shallow lakes and inlet streams of deep lakes (Tack 1980). Arctic grayling usually begin their migration from spawning habitat to feeding habitats after spring break-up (Tack 1980). Migration to overwintering habitat begins in early fall before ice formation (ADF&G 2015, Tack 1980).

8.5. Chum salmon

Trends in Movements

Chum salmon are anadromous fish that spawn in summer or fall; juveniles migrate directly to the ocean where they spend two to four winters at sea. Very little is known about chum salmon distribution and movements within the study area. Spawning populations of chum salmon have been documented in the Colville River and elsewhere on the North Slope (Bendock 1979, Craig and Haldorson 1986), but it is unknown whether these spawning events sustain consistent runs of chum salmon.

In general, chum salmon almost always return to spawn in their natal stream in late summer or early fall (Morrow 1980). Embryos hatch after 3–4 months, depending on water temperature and remain in the gravel while continuing to absorb nutrients from the egg yolk for an additional 60–90 days before emerging (Morrow 1980). Fry emerge from the gravel during spring (April–May) and migrate to the ocean within days or a few weeks after hatching (Salo 1991).

Overwintering habits of chum salmon are also poorly studied within the North Slope study area, but it's assumed that chum salmon spend their first winter in the Beaufort Sea, offshore deep under pack ice, and then migrate to the North Pacific for the remainder of their marine phase (Irvine et al. 2009). Winter temperatures of arctic marine waters are generally lethal for salmon. The lower thermal temperature limit for chum salmon is 2.7 °C (Azumaya et al. 2007). Typical arctic stream temperatures average between 0 and 0.5 °C in winter months, but pockets of groundwater provide shelter with temperatures between 2-5 °C throughout winter months (Craig and Haldorson 1986). Warming conditions may be producing more suitable habitat for salmon in the Arctic. See database RipFish with recently entered occurrence points (Figure J-7).

8.6. Burbot

Trends in Movements

Burbot are commonly found in well oxygenated streams and deep lakes (Morris 2003). Burbot are considered to be widespread in distribution throughout the study area, but at relatively low abundance. Migratory patterns are not well known, but in general, burbot are rather sedentary fish except for movements between feeding and spawning areas (Morrow 1980). Burbot are unique in that they spawn under the ice, usually between January and February and fry hatch in March or April. During spawning, adults will gather in large groups and form a writhing mass with a few females at the center, surrounded by many males (Cahn 1936). Burbot mature in six to seven years and are a relatively long-lived species that can live up to 20 years. Optimal water temperature for burbot is reported at 15.6–18.3°C (Scott and Crossman 1973). Juveniles feed on insects for the first few years, and then shift to a mostly piscivorous diet as adults (Morrow 1980). Although considered relatively sluggish in nature, burbot are voracious predators that feed at night.

Similar to most other fish species on the North Slope, overwintering habitat is a major factor constraining burbot populations. Overwintering areas have been documented in the Colville, the Sagavanirktok, and Kuparuk Rivers (Bendock 1980). Very little is known about burbot movements within the study area. However, Morris (2003) documented movements of up to 30km within the main channel habitats of Inigok Creek, Fish Creek, and Judy Creek. See database RipFish with recently entered occurrence points (Figure J-7).

8.7. Literature Cited

ADF&G. 1986. Alaska Habitat Management Guide, Arctic Region, Vol. II: Distribution, abundance, and human use of fish and wildlife. Division of Habitat, Juneau. ADF&G 2007. http://www.adfg.alaska.gov/static/education/wns/arctic_grayling.pdf, accessed 25 February 2015.

ADF&G. 2015. Arctic Grayling (*Thymallus arcticus*) Species Profile. Available: http://www.adfg.alaska.gov/index.cfm?adfg=arcticgrayling.main

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.

Bendock, T. 1979. Inventory and cataloging of Arctic area waters. Juneau: Alaska Department of Fish and Game Annual Report 20:1-64.

Cahn, A. R. 1936. Observations on the breeding of the lawyer, Lota maculosa. Copeia 1936:163–165.

Craig, P. C. 1984. Fish use of coastal waters of the Alaskan Beaufort Sea: a review. Transactions of the American Fisheries Society 113:265-282.

Craig, P. C., and L. Haldorson. 1986. Pacific salmon in the North American Arctic. Arctic 39:2-7.

Crane, P. A., Viavant, T., and J. K. Wenburg. 2005. Overwintering patterns of Dolly Varden, Salvelinus Malma, in the Sagavanirktok River in the Alaskan North Slope inferred using mixed-stock analysis. US Fish and Wildlife Service, Conservation Genetics Laboratory.

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.

Morris, W. A. 2003. Seasonal movements and habitat use of Arctic grayling (*Thymallus arcticus*), burbot (*Lota lota*), and broad whitefish (*Coregonus nasus*) within the Fish Creek drainage of the National Petroleum Reserve-Alaska, 2001-2002 Technical Report No. 03-02, 119 pp.

Morris, W. A., L. Moulton, J. Bacon, J. Rose, and M. Whitman. 2006. Seasonal Movements and Habitat Use of Broad Whitefish (Coregonus nasus) in the Teshekpuk Lake Region of the National Petroleum Reserve-Alaska, 2003-2005. ADNR Office of Habitat Management and Permitting, Technical Report # 06-04, pp. 18-19, 77, and 86.

Morrow, J. 1980. The freshwater fishes of Alaska. Alaska Northwest Publishing, Anchorage, AK.

Salo, E. 1991. Life history of chum salmon (Oncorhynchus keta). Pages 233-309 *in* C. Groot and L. Margolis, eds. Pacific Salmon Life Histories. UBC Press, Vancouver, British Columbia, CA.

Scanlon, B. 2004. Assessment of the Dolly Varden spawning population in Kagvik Creek, Alaska. Alaska Department of Fish and Game, Fishery Data Series No. 04-06, Anchorage.

Scanlon, B. 2012. Fishery management report for sport fisheries in the Northwest/North Slope Management area, 2012. Alaska Department of Fish and Game, Fishery Management Report No. 12-45, Anchorage.

Scott, W. B. and E. J. Crossman. 1973. Freshwater fishes of Canada. Bulletin of the Fisheries Research Board of Canada 184, Ottawa, Ontario, Canada.

Stewart, D. B., N. J. Mochnacz, J. D. Reist, T. J. Carmichael, and C. D. Sawatzky. 2007. Fish life history and habitat use in the Northwest Territories: Arctic grayling (Thymallus arcticus). Can. Manuscr. Rep. Fish. Aquat. Sci. 2797. 55 pp.

Tack, S. L. 1980. Migrations and distributions of Arctic grayling, Thymallus arcticus (Pallas), in Interior and Arctic Alaska. Alaska Department of Fish and Game, 34 pp.

Viavant, T. 2004. Eastern North Slope Dolly Varden Genetic Stock Identification and Stock Assessment. US Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program.

9. Effects of Oil and Gas on Fish

MQ AC 2	How does oil and gas infrastructure (e.g. roads, pads, pipeline), both permanent and temporary, affect fish habitat, fish distribution, and fish movements?

Oil and gas infrastructure includes the construction of roads, pads, and pipelines that have the potential to cause adverse effects to important fish habitat, to fish distributions, and to fish movements within the study area. Aquatic habitats within the study area provide important spawning, foraging, rearing, and overwintering habitat for both anadromous and freshwater fishes. Development within or near aquatic habitats may result in direct impacts to fish species and habitats at the development location, but also within surrounding areas and downstream from these activities.

9.1. Methods

We identified the Fine-Filter CEs (fish) as a **data gap** due to sparse fish occurrence data within the study area. Fish occurrence data have been collected, but most of these data are not electronically available. Consequently, we were not able to produce distribution maps for any of the fish species which precluded us from conducting spatial analysis related to this question. Instead, we provide a literature review of the potential impacts of oil and gas infrastructure on fish habitats, distribution, and movements. See Section E. for a thorough review of oil and gas development and associated infrastructure within the study area.

9.2. Results

Infrastructure and development for oil and gas activities, such as road construction (gravel and ice roads), pads, pipelines, and culverts, can have detrimental effects on fish spawning, rearing, and overwintering habitat. A number of factors related to development can have impacts on fish and their habitats including: direct habitat alterations, changes in water quality and quantity (e.g., from winter water withdrawals), and release of contaminants.

Road construction has the potential to cause direct destruction of habitat as well as high sediment loads in streams that can adversely affect fish embryo survival (Everest et al. 1987) and fry emergence and increased predation (Weaver and Fraley 1993). Similarly, stream culverts at road crossings may channelize river systems, impede fish passage, and alter migration routes to overwintering and feeding areas. For example, a recent study focused on the impacts of stream crossing structures near Prudhoe Bay found that 29% of the crossings evaluated restricted or completely blocked fish passage (Morris and Winters 2008). Additionally, habitat alterations to stream flow or changes to underlying sediments caused by stream crossings can lead to changes in water temperature, turbidity, and dissolved ion concentrations, which in turn could have negative impacts on fish populations (Hanley et al. 1983). Efforts to mitigate these impacts have been developed and include building bridges instead of culverts, or constructing culverts on smaller streams. Additionally, streams and rivers designated as Essential Fish Habitat (EFH) are provided regulatory protection under the Anadromous Fish Act. Similarly, pipelines

cannot be built within 500 feet of fish-bearing waterbodies thus limiting more direct impacts from this type of infrastructure (BLM 2012).

Temporary infrastructure, including the building of ice roads has the potential to alter water quantities in streams and lakes and affect overall water quality. A review of the impacts of water withdrawal on fish habitat is discussed in Section I.

Removal of stream vegetation during construction or infrastructure development can have short-term affects by altering stream temperatures and affecting thermal regimes by increasing the amount of sunlight exposure (Beschta et al.1988, Moore et al. 2005). Similarly, contamination of fish habitats can have both short-term and long-term impacts, depending on the time of year and the type and extent of contamination. Road construction can result in the increase of erosion and runoff leading to increased stream turbidity and sedimentation. Furthermore, vehicular leaks and spills could introduce contaminates directly into fish habitats. Oil contamination has the largest impact on embryos because of their reduced capacity to leave the contaminated area (Short et al. 2003, Moles et al. 1979). Thus, spills that occur within spawning habitats could have the most detrimental effects on fish populations.

Populations of resident species such as burbot and grayling may experience the greatest impacts from oil and gas infrastructure given that they are dependent, year-round, on freshwater habitats within the study area. On the other hand, chum salmon and other anadromous species spend the majority of their life in the marine environment thus potential impacts are likely to be localized to spawning and the relatively short juvenile rearing period. Fish species that predominately use low-gradient streams, may be more susceptible to increased sedimentation (due to lower stream flow) related to road development activities than other species.

Gravel mined for road and pad development has evolved since the opening of the Prudhoe Bay Oilfield in 1968. Early practices included mining from river floodplains, but agencies discouraged this method by the mid-1970s when mining practices were modified to target uplands sites for multiple users (Mclean 1993). Many of these mine sites were converted to reservoirs and subsequent studies by U.S. Fish and Wildlife Service and Alaska Department of Fish & Game led to the finding that they were providing high quality habitat for fish and wildlife (Ott et al. 2014). New policies beginning in the late-80s allowed for gravel mining in floodplain habitats when the potential enhancement of fish and wildlife habitats could be shown (Mclean 1993).

Rehabilitation practices for gravel pits include connecting them to streams and rivers so that they can be recolonized and excavating along the shoreline to provide shallow littoral habitat for juveniles fish (Mclean 1993, Jorgenson and Joyce 1994). Monitoring of reclaimed gravel pits has shown that multiple species may use them in both summer and winter, depending upon the diversity of habitats present and the size of the stream to which it is connected (Jorgenson and Joyce 1994).

9.3. Literature Cited

Beschta, R. L., and R.L. Taylor. 1988. Stream temperature increases and land use in a forested Oregon watershed. JAWRA Journal of the American Water Resources Association 24:19-25.

BLM. 2012. National Petroleum Reserve-Alaska, DRAFT Integrated Activity Plan/ Environmental Impact Statement. Volume 2, Chapter 4 (sections 4.1 to 4.6).

Everest, F. H. R. L. Beschta, J. D. Scrivener, K. V. Koski, J. R. Sedell, and C. J. Cederholm. 1987. Fine sediment and salmonid production— a paradox. Pages 98-142 *in* E. Salo and T. Cundy, eds. Streamside management and forestry and fishery interactions. University of Washington, College of Forestry Resources, Cont. 57, Seattle, WA.

Hanley, P. T., J. E. Hemming, J. W., Morsell, T. A. Morehourse, L. E. Leask, and G. S. Harrison. 1983. A handbook for management of oil and gas activities on lands in Alaska. FWS/OBS 80/23. Dames and Moore and Institutes of Social and Economic Research. Report prepared for Div. of Biological Services, U.S. Fish and Wildlife Service. Washington, D.C. 46 pp.

Jorgenson, M. T., and M. R. Joyce. 1994. Six strategies for rehabilitating land disturbed by oil development in Arctic Alaska. Arctic 47:374–390.

Mclean, R. F. 1993. North Slope Gravel Pit Performance Guidelines. Fairbanks, AK.

Moore, R., D. L. Spittlehouse, and A. Story. 2005. Riparian microclimate and stream temperature response to forest harvesting: A review. JAWRA Journal of the American Water Resources Association 41:813-834.

Morris, W. A., and J. F. Winters. 2008. A survey of stream crossing structures in the North Slope oilfields. Technical Report No. 08-01. Office of Habitat Management and Permitting, Alaska Department of Fish and Game, Fairbanks, Alaska. 392 pp.

Ott, A. G., J. F. Winters, W. A. Morris, and P. T. Bradley. 2014. North Slope Flooded Gravel Mine Sites, Case Histories. Fairbanks, AK.

Weaver, T. M. and J. J. Fraley. 1993. A method to measure emergence success of westslope cutthroat trout fry from varying substrate compositions in a natural stream. North American Journal of Fisheries Management 13:817-822.