Summary of Issues Facing Canadian-origin Yukon River Chinook Salmon: A Review of Limiting Ecosystem and Habitat Factors

Al von Finster, Alyssa Murdoch, Jessica Gill, Tim Hawkins, Jean Hodgson, and Karlie Knight

Fisheries and Oceans Canada
Yukon Transboundary Main Office
100-419 Range Road
Whitehorse, YT Y1A 3V1

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By

Al von Finster[1], Alyssa Murdoch[2,3], Jessica Gill[4], Tim Hawkins[5], Jean Hodgson[5], and Karlie Knight[6]

[1]Independent,
Box 31742
Whitehorse YT Y1A 6L3

[2]Ministry of Natural Resources
Trent University, DNA Building, 2140 East Bank Drive
Peterborough ON K9J 7B8

[3]Trent University
Trent University, DNA Building, 2140 East Bank Drive
Peterborough ON K9J 7B8

[4]Fisheries and Oceans Canada
401 Burrard Street
Vancouver BC V6C 3S4

[5]West Coast Aquatic
4770 Johnston Road, Unit B
Port Alberni BC V9Y 5M3

[6]Tr'ondëk Hwëch'in
1242 Front Street
Dawson City YT Y0B 1G0

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Canadian-origin Yukon River Chinook salmon are in crisis. Recent declines have led to an unprecedented seven-year fishing moratorium between the United States and Canada. The declines have been devastating for many communities within the Yukon River basin. To assess the various factors contributing to the declines, a structured framework was applied to assign risk rankings and confidence levels to limiting factors across the Chinook life cycle within the Canadian portion of the Yukon watershed.

In freshwater and marine environments, Yukon River Chinook face multiple high-risk threats throughout their life cycle. Freshwater risks are greatest during adult migration and spawning, with elevated temperatures and *Ichthyophonus* infections potentially causing 'carry-over' effects on egg and alevin survival. Marine risks include warming ocean temperatures and prey shifts during the maturing adult stage, as well as predation during the early marine stage. Additional factors considered across habitats highlight how interacting stressors across life stages, ecosystems, and generations likely drive population declines. This report synthesizes the best available scientific, Indigenous, and community knowledge to inform future efforts to rebuild Yukon River Chinook populations.

Résumé

von Finster, A., Murdoch, A., Gill, J.A., Hawkins, T., Hodgson, J., and Knight, K. 2025. Summary of Issues Facing Canadian-Origin Yukon River Chinook Salmon: A Review of Limiting Ecosystem and Habitat Factors. Can. Tech. Rep. Fish. Aquat. Sci. 3717: vi + 116 p. https://doi.org/10.60825/h1pj-h896

Les saumons Chinook du fleuve Yukon d’origine canadienne sont en crise. Les déclins récents ont mené à un moratoire de pêche sans précédent de sept ans entre les États-Unis et le Canada. Ces déclins ont eu des conséquences dévastatrices pour de nombreuses communautés du bassin du fleuve Yukon. Afin d’évaluer les divers facteurs contribuant à ces déclins, un cadre structuré a été appliqué pour attribuer des niveaux de risque et de confiance aux facteurs limitants tout au long du cycle vital du Chinook dans la portion canadienne du bassin du Yukon.

Dans les environnements d’eau douce et marins, les saumons Chinook du Yukon sont confrontés à de multiples menaces à haut risque au cours de leur cycle de vie. Les risques en eau douce sont les plus élevés durant la migration et la fraie des adultes, les températures élevées et les infections à *Ichthyophonus* pouvant entraîner des effets de « report » sur la survie des œufs et des alevins. Les risques en milieu marin comprennent le réchauffement des températures océaniques et les changements dans les proies au stade de maturation des adultes, ainsi que la prédation au stade marin précoce. D’autres facteurs pris en compte dans différents habitats mettent en évidence la manière dont les stresseurs interagissant à travers les stades de vie, les écosystèmes et les générations sont probablement à l’origine du déclin des populations. Le présent rapport synthétise les meilleures connaissances scientifiques, autochtones et communautaires disponibles afin d’éclairer les efforts futurs visant à rétablir les populations de saumons Chinook du fleuve Yukon.

Executive Summary

Canadian-origin Yukon River Chinook salmon are in crisis. Recent declines have led to an unprecedented, seven-year transboundary moratorium on fishing by the United States and Canada. The loss of salmon has been devastating for numerous groups and communities residing within the Yukon River drainage basin, including Yukon First Nations and Alaskan Natives that rely on salmon for food, culture, and overall well-being. Yukon Chinook salmon rebuilding strategies are currently underway and include the development of this report to summarize the issues facing Canadian-origin Yukon River Chinook salmon. The main goal of this report is to provide an overview of the limiting factors that may have contributed to Canadian-origin Chinook salmon population declines, as well as to identify potentially important data gaps where more information could be useful to guide Chinook recovery and rebuilding decision making. The Risk Assessment Methodology for Salmon process was used to assign risk rankings and associated confidence to over 100 limiting factors spanning the entire Chinook salmon life cycle across their freshwater and marine habitats. Limiting factors and risk rankings were presented at workshops and further vetted by professionals and knowledge holders from Yukon First Nations, Government of Yukon (YG), Fisheries and Oceans Canada (DFO), and others.

In the freshwater environment, the highest risks to Canadian-origin Yukon River Chinook salmon populations were identified at the adult migration and spawning stages and included negative effects from warm water temperatures and *Ichthyophonus* infection. In particular, it was noted that *Ichthyophonus* may be contributing to discrepancies in run size estimates throughout the watershed and possible undocumented pre-spawning mortality occurring in recent years. Reduced health of returning adults may decrease the success of later life stages, including possible 'carry-over' effects on egg and alevin fitness or survival. Historical in-river fishing activities were also highlighted as an important limiting factor that provides context to the current state of these populations. Limiting factors during the egg/alevin and fry stages generally had low or very low rankings apart from thiamine deficiency and specific localized effects that were separately assessed as higher risk (e.g., Whitehorse Hydro Plant, Mayo River Hydro Plant, placer mining effects, permafrost thaw, Porcupine River). In addition, predation on the freshwater juvenile stages was noted as a moderate risk but with low confidence.

In the marine environment, the highest potential risks identified were warming temperatures and related diet shifts during the maturing adult stage, and predation during the early marine stage. There is some evidence to suggest that Chinook may be returning to spawn in poorer health, possibly due to recent major shifts in the Bering Sea ecosystem. However, diet of immature and maturing adults remains an important data gap, and more information is needed to understand the role of shifting diet patterns in response to a changing climate. Moderate risks identified included warming temperatures and related diet shifts during earlier life stages, as well as competition for food with wild pink salmon during the immature and maturing adult stages. Bycatch from U.S. groundfish fisheries was considered low based on the estimated annual impact on Canadian-origin Yukon River Chinook salmon run size (1%) and spawning escapement (1.8%) over the 1994–2021 period.

Several limiting factors were considered across all habitats and at the multi-generational level. The long-term trend of smaller and younger returning adults has been well documented and was ranked as a high risk factor potentially contributing to lower run sizes over multiple decades. Persistently low spawning population sizes were identified as high risk for genetic drift. However, genetic data remains limited for individual salmon spawning populations in the Yukon River, making this area of study a potentially

important data gap. Finally, workshop participants identified a new limiting factor, “mortality or fitness reduction due to the loss of respect or relationship with people” as being high risk. This limiting factor highlights the deep-rooted connections between salmon and people and how changes in this relationship over time may be related to salmon declines.

This report highlights how multiple limiting factors may have contributed to Canadian-origin Yukon River Chinook declines, with the adult freshwater migration and spawning stages identified as being some of the most vulnerable life stages. Further, important limiting factors are likely to combine and carry-over multiple habitats, life stages, and cohorts, emphasizing the need for a holistic approach that considers a broad view of these unique Chinook populations. In particular, conditions during marine life stages may be critical for determining the fate of adults once they return to the river, as well as how successful they are in producing the next generation. While many data gaps for Canadian-origin Yukon River Chinook remain, this report attempts to synthesize the best available evidence from multiple perspectives to help inform future Chinook population recovery and rebuilding actions.

1. Introduction

Canadian-origin Yukon River Chinook salmon exist at the northern edge of the distribution of Chinook in the eastern Pacific Ocean. They have the longest freshwater migration of any salmonid, approximately 3,200 kilometers (Eiler et al. 2015; Brown et al. 2017), and have one of the longest life histories among Chinook populations, with the oldest Chinook returning at age seven (Bradford et al. 2009) and even some at age eight.

These unique fish are of fundamental importance to Yukon First Nations, who have depended on Chinook for sustenance, culture, and overall well-being since time immemorial. They are also critical to the ecosystems of the Yukon River basin, providing nutrients throughout the food web. Substantial commercial fisheries existed on these populations in both the U.S. and Canada, though these fisheries have not occurred since roughly 2010 (JTC 2024). For years, Yukon First Nations have voluntarily limited harvest or stopped fishing due to low returns. Canadian-origin Chinook historically comprised one-third to half of the total Chinook production from the whole basin, including Alaska (1981–2019; Hamazaki 2021) and approximately half of the total annual Chinook in-river harvest (JTC 2024).

Drastic declines in abundance throughout the entire watershed, from the Porcupine River to the furthest headwaters in the Teslin River, have led to closures of fisheries and increasing disconnection of people, especially Yukon First Nations, from these Chinook. There is a pressing need to rebuild Chinook populations for the maintenance of culture, the preservation of Chinook salmon, and the larger ecosystem in the Yukon.

Rebuilding efforts must be informed by a comprehensive understanding of the issues and factors that are limiting the survival of Chinook populations and may hinder their rebuilding. This report outlines the state of knowledge about what is limiting the survival or rebuilding of these populations primarily from a technical and scientific lens, acknowledging that it does not provide a fulsome picture of Traditional Knowledge held within Yukon First Nations about the issues facing these salmon. Together with other bodies of knowledge, this report aims to inform the rebuilding of Chinook populations.

1.1 Use of This Report

Given the drastic declines in Chinook abundance over the last several decades, many Yukon First Nations governments and partners have established salmon plans and programs to help restore Chinook stocks, relationships, and habitats within their traditional territories. Building on these local efforts, various governments and partner organizations involved in salmon recovery in the Yukon have now embarked on a collective approach to rebuild Canadian-origin Yukon River Chinook salmon populations.

To address the need for multi-party collaboration, Fisheries and Oceans Canada (DFO) has committed to support the development of a collective *Canadian-Origin Yukon River Chinook Salmon Rebuilding and Ecosystem Strategy* (the Strategy). This opportunity is intended to enable Yukon First Nation governments, the Federal Government (through DFO), and the Government of Yukon (YG), as well as organizations such as the Yukon Salmon Sub-Committee (YSSC) and the Yukon First Nations Salmon Stewardship Alliance/Council of Yukon First Nations (YFNSSA/CYFN), and others, to identify and pursue informed, strategic, and coordinated action.

This report summarizes scientific and technical information about issues facing Canadian-origin Yukon River Chinook salmon using the limiting factor framework developed by DFO as a part of the Risk

Assessment Methodology for Salmon (RAMS) (Hyatt et al. 2017). The limiting factor framework is a systematic and comparative tool for assessing and comparing various issues facing all species of salmon throughout the Yukon and British Columbia. The summary of issues herein was compiled with the explicit purpose of informing actions by one or more governments or organizations to rebuild Chinook salmon populations and with the purpose of identifying key knowledge gaps that may require further investigation.

It is important to acknowledge that Canadian-origin Yukon River Chinook salmon spend most of their lives in the Bering Sea and migrate through the state of Alaska, where Chinook salmon returns have also declined dramatically. This report focuses on issues facing Canadian-origin Yukon River Chinook salmon when they are in Canadian waters, and briefly discusses issues faced while they are migrating through Alaska. Many of the freshwater and marine factors identified in this report fall under the jurisdiction of the Alaska state government (Alaska Department of Fish and Game) and the U.S. Federal Government (National Marine Fisheries Service and the U.S. Fish and Wildlife Service), or the North Pacific Anadromous Fish Commission. Throughout this report, Canadian-origin Yukon River Chinook salmon will be referred to as Chinook.

2. Watershed Overview

The headwaters of the Yukon River are located in Canada along with several major Canadian tributaries, including the Stewart, Pelly, White, and Teslin rivers and southern lakes. These tributaries join the mainstem Yukon River which then flows through Alaska and discharges into the Bering Sea. Additional tributaries join the Yukon River mainstem throughout the Alaskan portion of the watershed. This includes the Porcupine River, which is the largest Yukon River sub-drainage in Canada. The Yukon River watershed drains an area of approximately 850,000 km^2, with approximately 500,000 km^2 in Alaska and 350,000 km^2 in Canada. The U.S./Canada border is at approximate river kilometer 2,025. The mouth of the McNeil River, the furthest upstream Chinook spawning river, is at river kilometer 3,204 (Eiler et al. 2015; Brown et al. 2017; Figure 1). While much of the Yukon River watershed is sparsely populated, the southern lakes region is more densely populated around the city of Whitehorse (Figure 1).

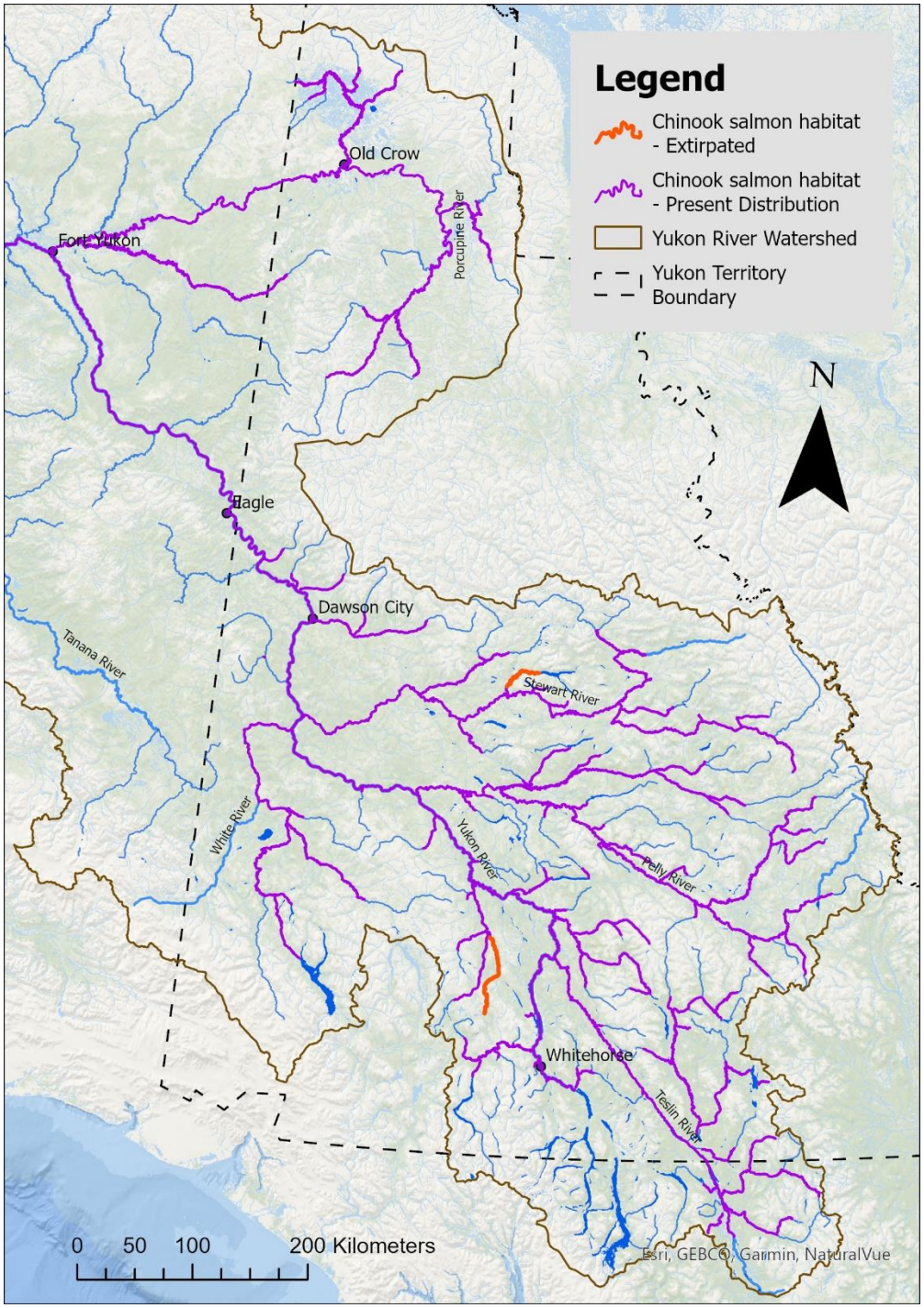

Figure 1. Map of Yukon River Chinook salmon distribution in Canada. Distribution based on extent from Brown et al. (2017) but may not encompass all known spawning and rearing locations throughout the watershed.

The Yukon River has a graded bed with few waterfalls or impassable rapids. In fact, only five of the over 100 Chinook spawning streams in the Canadian portion of the Yukon watershed are naturally obstructed at certain times of the year by waterfalls (von Finster 2022; Ogilvie et al. 2025). These are the

M'Clintock, Tay, and Lapie rivers and Squanga and Watson creeks. This high degree of accessibility to adult Chinook allows spawning populations to be widely distributed. There are two infrastructure barriers to passage: the Whitehorse Hydro Plant and the Mayo Hydro Plant. Completed in 1958 at river kilometer 2,820, the Whitehorse Hydro Plant fully obstructed Chinook from reaching their upstream spawning habitats until construction of a fish ladder allowed fish passage one year later, though passage was impacted well into the 1960s. A hydro facility exists on the Mayo River, a tributary to the Stewart River, which has fully obstructed fish passage since the early 1950s.

Temperature and precipitation regimes are variable across the watershed owing to coastal effects near the Bering Sea, a large continental interior, and significant topographic diversity. The large size of the Canadian portion of the watershed also allows for localized weather systems: one portion may be cool and wet, while another is hot and dry (Wahl 2004).

2.1 Yukon River Watershed Hydrological Characteristics

Groundwater is a major factor determining aquatic habitat quality within the Yukon River watershed. It plays an important role by providing water to rivers. This is a major issue in the southern part of the Canadian portion of the watershed, where important spawning and rearing streams may dry up during extended dry summer periods. In the Yukon, groundwater discharges contribute to under-ice flows in winter. Most rivers and streams have aquifers storing and transporting hyporheic (sub-surface) flows. Aquifers are underground layers or deposits of permeable sediment, including sand, gravel, rock or fractured bedrock, that allow the storage and movement of groundwater. Water enters the ground, passing through spaces between sediments or rocks, recharges the aquifer, and flows underground through the porous substrate, and may resurface downgradient in stream beds, springs or wetlands. In small streams, discharges of groundwater from these aquifers allow Chinook fry and invertebrates to survive winters. During winters, many of the smaller streams will have reaches covered by aufeis and other reaches fed by hyporheic groundwater. Aufeis, or icing, occur when water flows over the ice surface of the river and forms frozen sheets over the valley floor. These groundwater-fed areas may extend under the valley floor, where there are biological and chemical reactions that remove dissolved oxygen from the underground flow (Zhou et al. 2014). Some groundwater discharge zones with significant oxygen demands may not have sufficient concentrations of dissolved oxygen to support aquatic life.

Oxygen-rich groundwater discharge zones are important for Chinook. Some groundwater discharge zones can be found along the edges of rivers, while others discharge into the bottoms of rivers. The Klondike River near Dawson is the easiest place to see them. Hyporheic groundwater zones may also be found in tributary valleys, where they will join with the larger downstream river (Hynes 1983). McIntyre Creek is an excellent example as well. In Whitehorse, the clear water springs near the Pump House Pond below Yukon University are hyporheic, as are the springs that feed the hatchery on Mountainview Drive. An important attribute of hyporheic flows in northern environments is that most of the water enters the ground during the summer when air and water temperatures are warm. That warm water does not freeze underground and is released in the winter as warm, productive water, even causing some springs to be ice-free in the winter (von Finster 2011; Utting et al. 2012). These open areas assist in allowing the stream or river waters to re-oxygenate if dissolved oxygen levels are low.

Water temperatures during the open water period are influenced by air temperatures, length of day, and duration of sun exposure. The Yukon River is a high latitude river. The Canadian portion extends

from northern British Columbia northward to the Crow River (also known as Old Crow River or Crow Flats), a tributary to the Porcupine River. Constant or near-constant solar radiation decreases the period in which the stream can cool at night in mid-summer, resulting in relatively high summer temperatures for such a high-latitude river (von Finster 2014).

In the autumn when temperatures decline, frazil ice forms in the streams; these are strands of ice formed in turbulent flows. They drift downstream and may form aggregations known as slush or anchor ice (Brown et al. 2011). In rivers, slush ice may obstruct channels downstream of dams, rapids or falls. Slush ice is most easily seen from the White Pass train station lookout over the Yukon River in Whitehorse. The surface of most streams and rivers freezes as winter progresses. The slush ice in the channel beneath the ice may melt or remain as slush for much or most of the winter. A complete ice cover will limit oxygen transfer from air.

Shallow lakes, ponds, or wetlands that are underlain by vegetation may become anoxic under ice cover (Rabaey et al. 2021; Marshall et al. 2021). This is due to the high biological oxygen demand associated with the decomposing vegetation in wetlands. Taye Lake, the headwaters of the Mendenhall River, is a good example. It is shallow and warm and supports a nearly vegetated lake bottom and has populations of whitefish and northern pike. An almost complete fish kill in the lake that is attributed to anoxic conditions occurs on a roughly 10-year cycle. Support for this observation has been provided by Rene Rivard and Nick de Graff, who observed the winter kill in March 2019 and measured dissolved oxygen (DO) of less than 1.0 mg/L in lake water.

Flows of groundwater from aquifers will generally increase during periods of low barometric pressure, which occurs when winter weather becomes warmer (Spane 2002). This can cause overflow on lakes, ponds, streams or wetlands and a layer of water saturated snow will cover the ice. Frazil ice may clog under-ice channels in streams, and freeze. When this occurs, aufeis can be formed. The stream channel under the aufeis may dry (Bradford et al. 2001). These effects of low barometric pressure are most easily observed along highways, and particularly along the Alaska Highway between Whitehorse and Haines Junction.

Outlets of mid-size or larger lakes tend to remain open, or to freeze only when air temperatures are very cold. They will then re-open as the air temperatures moderate. The outlets of Bennett Lake in Carcross and the Teslin River at Johnsons Crossing are good examples. Outlets of some smaller, upper elevation lakes such as Coal Lake tributary to Wolf Creek may completely freeze in winter (Jasek and Ford 1998). Downstream organisms may be stressed or die unless groundwater discharges provide flow of sufficient quantity and quality to sustain life.

In late winter or early spring groundwater that discharges into frozen channels may melt the ice from underneath. The ice will generally deform downward, leaving a slump in the ice surface. The slump will usually open, and water or shoreline will be exposed, initiating the process of breakup. The ice covering many small to mid-size streams tends to melt thermally with increasing air temperatures. The ice remains in place until melted, with limited movement of loose ice sheets. Creeks such as McIntyre, Wolf, Fox (near Whitehorse), Squanga, Deadman, Fox (near Teslin), Klusha, Tatchun, Frenchman, Mica, Willow (near Pelly), Crooked, Janet, Moose, Flat (near Dawson), and Beaver Dam on the Klondike Highway are general examples of thermal melting in spring. Larger rivers tend to break up mechanically as ice is floated and pushed by rising volumes of flow. The ice moves downstream in a mass or in a series of masses. Ice jams often occur and can raise the mixture of water and ice several meters or more. Ice jams

can also cause mild to severe shoreline erosion and scour. New river channels may form with the rising flows and past river channels may be abandoned (Beltaos 2003). Ice in all the major tributaries of the Yukon River and the mainstem below Lake Lebarge break up mechanically. The breakup of the Yukon River at Dawson is a good example of a mechanical breakup.

A period of low water tends to follow ice breakup, prior to the beginning of the spring freshet. Snowmelt from elevated terrain tends to fuel the subsequent spring freshet. Lakes and ponds usually become ice free after river channels in the unglaciated and upper Porcupine River areas. During the summer, precipitation augments base flows in streams. In the absence of precipitation, flows may be very low. This may be exacerbated when a portion of the flow is absorbed in an aquifer recharge zone. Sections of some streams can become totally dry under prolonged drought conditions (Tiwari 2023).

Much of the Yukon River drainage basin is underlain by permafrost (Figure 2). Permafrost is ground that remains frozen throughout the year. The southern portion of the Canadian sub-basin of the Yukon River is within the discontinuous permafrost zone. The permafrost becomes increasingly continuous with distance travelled north and is virtually continuous in the Porcupine River watershed (Smith et al. 2004).

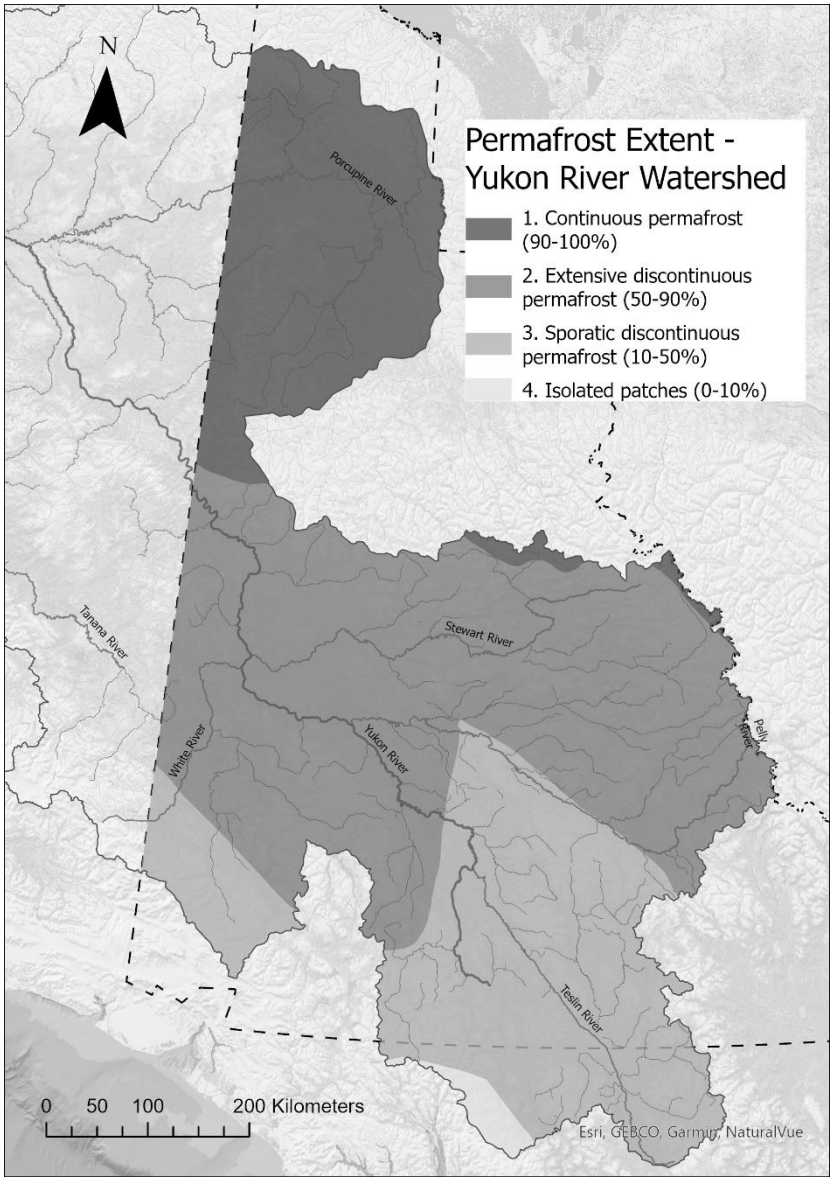

Figure 2. Permafrost extent for the Canadian portion of the Yukon River watershed.

There is a broad range of hydrological impacts associated with permafrost degradation because of the variable forms of permafrost. The effects of degradation are determined by gravity, slope, aspect, moisture content, location, overlying vegetation, or disturbances of the land surface, and other factors. Most noticeable degradations are landslides or slope failures near populated areas or infrastructure. The landslides into the Takhini River near Whitehorse that required the relocation of the Alaska Highway, and the slides from the north facing slopes beside the Klondike Highway near Dawson, are examples where permafrost thaw was a contributing factor in land failures. However, other effects are less likely to be noticed, including ground subsidence, non-retrogressive subsurface thaws, gullying, slumping, and many more (Lipovsky and Huscroft 2006). There is considerable potential for negative effects to aquatic environments when sediment from thawing permafrost is deposited into a waterbody or watercourse (Lipovsky et al. 2005). Very large permafrost thaw-induced slope failures can block or negatively affect

river channels for years or decades. The Ten Mile Slide in the hills east of the Klondike Highway near Carmacks occurred in 2001 and continues to release sediment into what was previously known to be Chinook spawning habitat in the Nordenskiöld River. This will reduce the quality of the downstream spawning habitat until sedimentation from the slide ends and spawning returns. In severe cases, a river may erode a new channel around the deposited material or form a new channel elsewhere on the flood plain. New channel formation following sedimentation is in the process of occurring in the Chandindu/Twelve Mile River near Dawson (Karlie Knight, personal communication), from a slide that occurred in August 2023.

An emerging issue related to permafrost degradation is discoloration or rusting of streams and potential negative effects on fish and fish habitats. As the underlying bedrock or soils thaw, they may form, or contribute to, acid rock drainage. The products of the acid rock drainage and associated dissolved substances may flow into streams. Events may be short-term, while others may persist for years or decades. This has been of interest to local residents and the scientific community in Alaska (Rozell 2024) and only recently has been identified in tributary streams to the South McQuesten and Beaver rivers, with pH levels as low as 3.25 (R. Slater pers. comm.). It is likely to become an increasing issue in the near future as interests rise and the degree of discoloration increases. Permafrost thaw may be associated with dewatering events around the Fishing Branch River, a tributary of the Porcupine River, but has not been confirmed. Additional sedimentation may come from other natural processes. Wildfires may result in releases of sediment until the land surface stabilizes several years later. Beaver dam failures, especially at lake outlets, can release large amounts of sediment and reshape stream channels. The beaver dam failure at Mud Lake, tributary to Horse Creek near Whitehorse, almost washed out the Klondike Highway and transformed the stream channel from the lake outlet downstream to Shallow Bay.

There are multiple anthropogenic factors contributing to sediment releases. They may be directly or indirectly associated with natural sediment releases. Placer mining, especially in creeks like Hunker or Bonanza near Dawson, is the main source of added sediment. Very high flows may result in turbidity, increases in suspended sediments, and increases in bed load in streams and rivers. Turbidity effects are greatest where suspended sediments particles are smallest: sand settles quickly, while suspended clay particles may be visible far downstream (Birtwell 1999). Hydropower ramping increases flows and erosion, releasing sediments from stress on banks and bed mobilizing. The southern portion of the glaciated area is within the discontinuous permafrost zone. Where permafrost is present, the effects of thawing noted above are seen.

2.2 Geomorphological Classification

The Canadian Yukon River Basin experienced recent glaciation events, roughly 20,000 years ago (Dyke 2004), in two different ways, leading to an ability to classify the watershed into three categories, each with different geomorphological characteristics (Table 1; Figure 3):

1. Glaciated – these areas were covered by ice during more recent glacial periods, and include areas still covered by mountain glaciers
2. Unglaciated – areas that escaped glaciation, or were glaciated only during the oldest glaciations (2.9 million years ago; (Duk-Rodkin 2004). In this category, two distinct areas emerge with differing characteristics based on other geological and climatic factors:

a) Porcupine River sub-basin, which is the most northerly portion of the Canadian Yukon River Basin and was not glaciated in the last ice age. It comprises plains, old lake beds, and mountain areas, and is characterized by continuous permafrost.
b) Unglaciated portions of the Yukon River Basin, especially around Dawson City, which are much less topographically variable than the landscapes of the Porcupine Basin, and consist mainly of river-carved valleys, and is characterized by discontinuous permafrost.

Table 1. Area of each geomorphological category for the Canadian portion of the Yukon River watershed.

Geomorphological Category	KM^2	Percentage
Glaciated	239,204	72%
Unglaciated	33,285	10%
Porcupine (Unglaciated)	59,521	18%
Total	*332,010*	*100%*

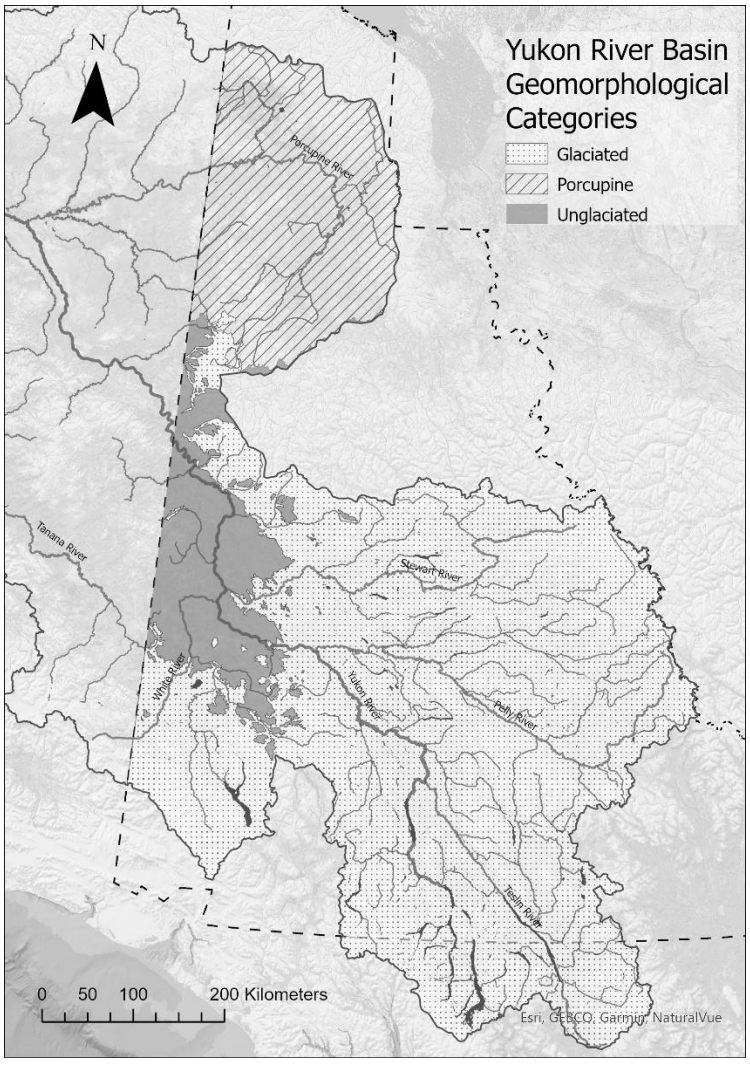

Figure 3. Map of geomorphological categories in the Canadian Yukon River Watershed.

2.2.1 Glaciated

This is the largest and most ecologically diverse area. Continental glaciation, which occurred roughly 20,000 years ago, generally covered the southern Canadian portion of the Yukon watershed and extended around the eastern margin to join the then active mountain glaciers of the southern Ogilvie Mountains (Dyke 2004). This area was covered by the Cordilleran Ice Sheet and extended westward to near the U.S./Canada border (Dyke 2004). Yukon Territory was largely unglaciated by 11,000 years ago (Dyke 2004).

The glaciated area includes lakes, wide U-shaped valleys, abandoned river channels, steep valley walls and other post-glacial features. Above the valley walls is a landscape dominated by rolling hills and ridges cut by the valleys carved by past glaciers. Valley bottoms and sides tend to be underlain by glaciofluvial or glaciolacustrine deposits. These deposits were left by rivers associated with glacial outwash and are composed mainly of cobble, gravel, and sand. Because of their porosity, glaciofluvial deposits provide storage and flow paths for significant volumes of hyporheic groundwater. Deposits above water level are now mined for gravel. The large gravel pits along Yukon highways and near developed areas demonstrate the use we make of glaciofluvial deposits.

Glaciolacustrine deposits were formed in glacial lakes and are generally composed of sand and silt. Due to this fine grain size, groundwater moving through these deposits moves slowly, dissolving fine materials along the way. This is in contrast to hyporheic water, which moves faster through shallow sediments. Water discharged from aquifers in glaciolacustrine substrate is usually stained, anoxic, and laden with dissolved substances. The “clay cliffs” of Whitehorse and the steep, bare hillsides are generally composed of glaciolacustrine material. They are the remains of lakes existing near the end of the glacial period. Discharges of groundwater from glaciolacustrine substrate may be found at the base of the escarpment on Mountainview Road. Upper elevation areas are underlain by bedrock and more mixed glacial deposits such as till and moraines. Lakes near tree level occupy depressions left by melting ice, or in areas excavated by glaciers that have now disappeared (Strahler 1969). Examples include Fish Lake near Whitehorse and Lapie Lake on the South Canol Road.

Streams with stepped profiles are common in glaciated areas. The headwaters are on elevated ground and have steep gradients. The flows enter upper altitude streams with gentle gradients flowing across the Yukon plateau. As they descend from the plateau to the floors of major valleys their gradient increases. These streams often form alluvial fans, where gentler gradients cause sediment to settle. Alluvial fans may store significant volumes of groundwater. Discharges of this groundwater from the bases of the alluvial fans may remain open during winter. In summer, groundwater discharges are much cooler than surface water flows (von Finster and Reid 2015). The South Klondike Highway from Twin Lakes to Minto Landing generally crosses streams near the apexes, or tops, of the alluvial fans. Driving northward, on the right side of the road is the high gradient section of the streams. On the left side are the developing alluvial fans.

2.2.2 Unglaciated

Much of what is referred to as the unglaciated area was glaciated over 740,000 years ago (Froese et al. 2008). Effects of earlier glaciations have largely been muted by time, although some deposits of glaciofluvial and other materials remain (Dud-Rodkin 2004; Lipovsky et al. 2005). Permafrost is common

in unglaciated areas and underlies most north facing slopes and some south facing slopes. Many valley bottoms are underlain by permafrost except for lands immediately beside or under river channels.

The land surface in much of the unglaciated area was originally composed of rolling hills. The Yukon River and its tributaries eroded valleys into the underlying bedrock, and as a result, most tributary valleys are narrow and have a V-shaped cross-section. Stream gradients are moderate to low for most of their lengths, then climb quickly to the divide with the adjoining basin. Streams in this system respond rapidly to precipitation. This discourages the establishment of beaver colonies, as their dams are usually swept away by sudden floods (von Finster 2012).

There are no large lakes in the unglaciated area, but smaller ponds are found in river valleys. Streams are generally clear in summer but become stained by tannins at low to moderate flows. Streams may be very turbid during high water events, and flow as a slurry with very high suspended sediment and bed loads. Valley walls tend to be steep and vulnerable to surface layer detachment when saturated or after wildfires, as the vegetation and underlying soil peel away from the slope.

Summer base flow in smaller streams tends to be moderate and cold, believed to be related to thawing permafrost (Woo 2012). Thaw continues under the snow in some locations. It can occur in the loosened bedrock of the valley walls or in thick deposits of organic material. Materials in the bedrock, such as sulfur, may dissolve and contribute to increased chemical oxygen demand, that will remove dissolved oxygen. Decomposing organic materials will increase the biological oxygen demand, with similar results (Woo 2012). In both cases, other substances, such as iron and other metals, may be dissolved and flow into surface waters (O'Donnell et al. 2024).

The Dawson City area is a good place to see unglaciated terrain. When driving northwest to Dawson one descends into the Klondike valley. The terrain on the left side of the road is unglaciated and the right side is glaciated near Flat Creek (i.e., Henderson Corner). The Top of the World Highway provides a better understanding of the land surface and the forces of nature that formed it, as one can look down deep into various valleys. Side trips from the Top of the World can be taken down the Clinton Creek Road, which also leads to the Yukon River near the old town of Fortymile.

2.2.3 Porcupine River

Much of the Porcupine River basin was not glaciated in the last glacial maximum (approximately 26,500 to 19,000 years ago; Clark et al. 2009) and exhibits distinct geomorphological characteristics. Permafrost is almost continuous in the Porcupine River watershed. Many of the banks and valley walls of the Porcupine River and tributaries such as the Crow River are failing due to thawing permafrost. Large areas of flat surface permafrost degradation have been noted.

The Canadian portion of the Porcupine River watershed comprises of a series of low-lying basins surrounded by mountains and high ground. The watershed has a northern/arctic interior climate, with short hot summers and long cold winters. In late June and July there may be little atmospheric cooling at night due to 24-hour daylight. High air temperature conditions may persist for a week or more. In concert with low water levels, this can result in elevated water temperatures in the Porcupine and Crow rivers (von Finster 2014). The extensive wetlands and standing water in the basins tend to have limited drainage areas and produce little surplus flow during low water conditions in the summer or the winter (Tondu et al. 2012). Water tends to remain in rather than flow through them.

Winter weather is cold in the Porcupine River watershed and temperatures below -40°C are common. Certain rivers draining the mountain valleys have open water areas where they enter the central basins, but the ice cover is continuous in the central basins. These open water areas in or near the mountains may persist through the winter. The most well-known open water area is the Fishing Branch of the Miner River (Schonewille and Dilling 2018).

River ice breakups in the Porcupine watershed can be very rapid, and river flows very high. Summer precipitation can result in flows of similar magnitude to the spring freshet but of shorter duration.

Most of the basins were filled by lakes during long-past glaciations. At times the Porcupine drained into the Mackenzie River basin through what has become the Eagle River valley. The existing hydrology of the basins include many shallow residual lakes. They are held in place by thermal aquicludes which stop the flow of ground water. In these areas, underlying permafrost has not allowed water to drain through the soil. The thermal aquicludes are increasingly failing due to permafrost thaw and are expected to continue failing. Many lakes in the Porcupine watershed are draining in part or entirely (Tondu et al. 2017).

3. Canadian-Origin Yukon River Chinook Salmon

3.1 Yukon Chinook Stock Distribution and Structure

In Canada, Yukon River Chinook are managed by DFO as two Stock Management Units (SMU), the Yukon Chinook SMU and the Porcupine Chinook SMU (Figure 4; Connors et al. in press) . The SMUs are further split into Conservation Units (CUs), which are a group of wild salmon sufficiently isolated from other groups that, if extirpated, is very unlikely to recolonize naturally within an acceptable time frame (DFO 2005). The Yukon Chinook SMU is comprised of nine CUs (numbered 68–76 in Figure 4) and the Porcupine Chinook SMU is comprised of three CUs (numbered 77–79 in Figure 4). Genetic assignment of Chinook to the CU level is in development, but categorization to similar stock aggregates (i.e., Lower, Middle and Upper/Canadian Yukon stocks) is achieved annually (JTC 2024). The Yukon Chinook SMU is largely populated by three stock aggregates, Teslin River, Mid-Mainstem and Carmacks Tributaries, which make up 23.9%, 23.5% and 17.9% of average annual returns, respectively (JTC 2024). In the Porcupine Chinook SMU, little is known about the Old Crow CU, though annual abundance estimates are captured for this CU and the Porcupine CU at an assessment site downstream of their spawning habitats. There is no population size information on Chinook salmon from the Salmon Fork CU.

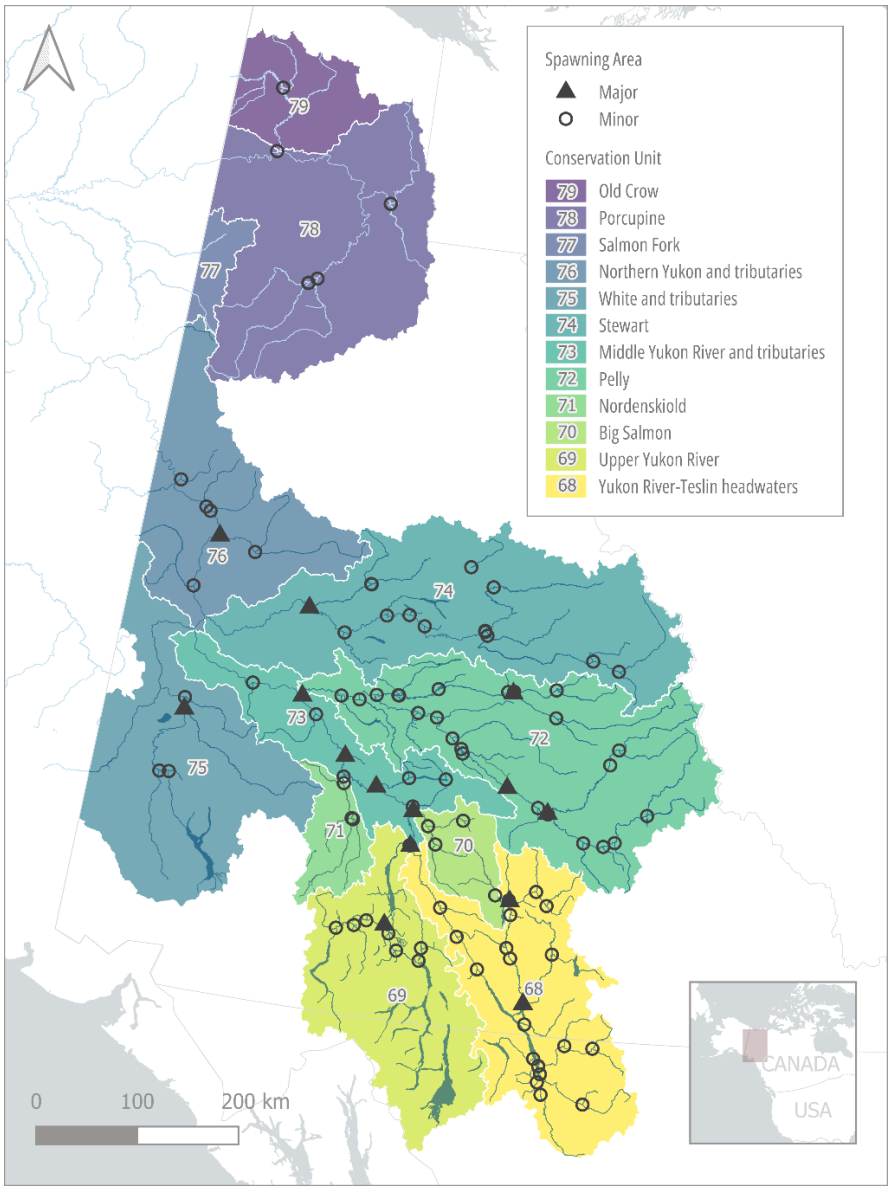

Figure 4. Canadian-origin Yukon Chinook salmon conservation units and "major" and "minor" spawning locations, as catalogued in Brown et al. (2017). Figure from Connors et al. (in press).

3.2 Yukon First Nations Relationship with and Respect for Salmon

Chinook have a unique relationship with Yukon First Nations people, and First Nations people understand Chinook to be their relatives and therefore maintain the utmost respect for Chinook. The following story, shared by elder Angela Sidney from Teslin Tlingit Council and documented in the August 1998 report, "The importance of fishing and fish harvesting to Yukon First Nations people: A summary" for the Yukon Fish and Wildlife Management Board (Muckenheim 1998), demonstrates how salmon are understood as relatives and discussed with respect. This story may be found across Yukon First Nations and is told in a variety of forms.

The Story of Moldy Head – Shaaláax
as told by Angela Sidney, Carcross/Tagish First Nation, recorded in Teslin:

One time there was a little boy who lived with his mother and father.
People dry fish – that's how they rustle for food.
If they do that, they don't have much hard time in winter when it's hard to rustle for game.

And so this little boy always cried for food in the evening,
Before he goes to bed his mother always gives him dry salmon, head part.
Here he tells his mother, "How come it's always moldy?"
He gets disappointed, throws it away.
"It's moldy."
Anyway, his mother gave him another one again, always.
Every now and then, like that, it's moldy.

But he said something wrong against the fish spirit

So the next year, they go to the same place – that's where they dry fish.
They were there again.
Here, his mother was cutting fish.
And you know how seagulls want fish guts all the time?
Here he set out a snare for that seagull.
Set out a snare to catch him.

Anyway, that toggle wasn't very strong or very big or very heavy.
And seagull started to drag it out.
That little boy started running after it.
He ran in the water to try to catch it.
Pretty soon, he fell in a hole.
He caught it, I guess, but they couldn't save him.

And here right away the fish spirit grabbed him – they saved him.
And when the fish went back to the ocean, they took him.
But for that boy, it seemed like right away he was amongst people.

They got a big boat, and they took him with them down to the fish country.
They came to a big city, big town – oh, lots of people run around, kids playing around.

One time they're playing outside and the little boys see fish eggs.
He starts to eat some.
He doesn't know what those people eat – he never sees them eat anything.
Here, he starts to eat fish eggs.

Here, someone called out Shaatláax, "Moldy Head."
They call him that because he used to call fish moldy.

"Moldy Head eats someone's poop," they said.
Here it was fish eggs.
Oh, by gosh, right away he gets shamed!
When the kids come home, they tell older people about it:
"Moldy Head eats people's poop."

Next morning, adults tell them,
"Why don't you kids go play around that point, play ball.
While you play, you catch fish.
But when you eat it and when you cook it,
Don't let anything fall in the hole, that cooking stick hole, where they put the stick in to roast fish."

So they make fire and one lady sees fish and clubs it and cooks it for him.
Now again when he gets hungry, they do that for him.
In the evening when they come home,
Here that boy never came home until last.

They told him,
"Throw the bone and skin and everything into the water,
But don't let anything fall in the cooking stick hole."
He threw everything in the water except that one eye.
It fell in the cooking stick hole.

They didn't see it – the lost eye.
So when they came home, that boy has got one eye missing.
He came back to life again and he's missing one eye.

The parents tell him to go back –
look in that cooking stick hole,
See if there's anything there.

So they went to the playground,
And sure enough there is fish eye there.
He picked it up and he threw it in the water.
And when he came back, all of a sudden
That boy has got both of his eyes back.

Finally, springtime started to come.
Everybody started to get ready to go up the river again.
That boy stays with those people that adopted him first and they all go up the river again.

They come to that same place – "Hee hut, hee hut," they pole upriver.
That's how come they know where to go:

They say when the fish go up the river
Their great-great-grandmother is at the head of the creek.
And that's why they go up to visit the great-great-grandmother, that fish –
They come back to the same place.

Here he sees his human mother –
His mother is cutting fish.
He goes close to his mother
Just the same, his mother never paid any attention to him –
It was just a fish to her.
I don't know how many times she tried to club that fish
But it always takes off.

So finally, she tells her husband about it.
"How come that one fish always comes to me and just stays right there all the time?
But after when I go back to see him, that fish is always gone.
Why is that?"

"I don't know why that is.
Let's try to kill it," he said.
"You know we lost our son last year.
Could be something. Must be something.
Let's try to catch it, okay?"
So they did. Anyway, they got it.

And here she started to cut that fish.
And here that fish had copper around his neck
Just like the one that boy used to wear all the time.
And that's the one when that lady started to cut his head off.
She couldn't cut the head off.
So she looked at it good.
Here she saw this copper ring on his head.
So she told her husband right away,
"Look at that. What's this here?"

And her husband said,
"Well, you know, our son used to wear a copper ring all the time around his neck."
Yes, they remembered that.
So they washed it good.

And then they took it home.
There's an Indian doctor there, too.
And the Indian doctor said,
"Put it in a nice clean white skin."

Old people used to have lots of that.
They put it in a nice clean skin,
Covered it with down feathers.

Then they tie it way up to where the smoke goes up,
Smokehole.
That Indian doctor told them to go fast for eight days.

So people fasted for eight days.
That Indian doctor said,
"If you see feathers blow up,
Then you take it down quick."

So they put the body up there,
Fasted for eight days.
That Indian doctor sang all the time.
They were singing, too, I guess –
Got to help the doctor sing.

Finally, on the eighth day, here they see the feathers blow up.
They take it down quick.
Here that little boy comes to life again, in human's body.
They brought him back to life.

That's how they know about fish.
That's why kids are told not to insult fish.
And kids are not to play with seagull because that happened.

3.3 Habitat Use by Life Stage

Most of the field work conducted on freshwater habitats used by juvenile Chinook has been documented in technical reports and memoranda. These observations reflect a limited period of time and place in a constantly changing and evolving watershed and by an ever-adapting species. Formal scientific enquiry into the life histories of Chinook has been scant, although there is a growing body of scientific research on Canadian Yukon River Chinook salmon. Traditional Knowledge which has been established through countless generations of relationships between Yukon First Nations and the land, water, and fish of the Yukon River watershed, provides a much more fulsome understanding of Chinook. However, opportunities persist to address data gaps and gaps of understanding through Traditional Knowledge, scientific research, and through cross-knowledge and cross-cultural collaboration.

Chinook life cycles are often depicted as being circular: life starts as an egg in the gravel. Upon emergence from the gravel Chinook swim through various freshwater and marine environments as they rear and grow. Finally, adults return to the streams of their birth, lay eggs, and life ends as new life begins. The following sections provide further detail within major life stages in that circular cycle.

3.3.4 Egg and Alevin

The fertilized Chinook egg is deposited in a redd which a spawning female digs with her tail. Egg deposition typically occurs in August in the Canadian portion of the Yukon River watershed (DFO 2023). The redd is usually composed of a mixture of cobbles, gravel, and a limited amount of finer materials. This mixture allows incubation, where oxygenated water passes over eggs kept secure in the riverbed. The egg absorbs dissolved oxygen and discharges metabolic byproducts. These eggs are at the mercy of any changes to their environment, and particularly changes in water quality or quantity and sedimentation, which can suffocate eggs.

The Accumulated Thermal Units (ATU) method, where each degree Celsius above 0°C for each day is equal to 1 ATU, is generally used to predict hatch timing of salmon eggs. In hatcheries, Chinook require approximately 500 ATUs to hatch from egg to alevin and an additional 825–1029 ATUs to develop from alevins to emergent fry (DFO 2003). The rate of development is temperature dependant and is not linear. Application of the ATU method to Yukon spawning areas has indicated that fry in Deadman Creek (tributary to Teslin Lake) may emerge just above 500 ATU with low emergence success (Schonewille 2020), with time to emergence requiring more ATUs in other rivers measured such as the Morely (tributary to Teslin Lake), Nisutlin (tributary to Teslin Lake), Klondike River and others (B. Schonewille, pers. comm.). The thermal regime of each spawning stream will determine the rate at which eggs hatch into alevins, or larval salmon and then emerge as fry. While developing, the alevins remain below the riverbed surface and absorb their yolk sack. As the sack depletes, they move upward toward the surface and after a short, transitional stage they emerge from the gravel to become a fry or 0+ juvenile Chinook salmon (Figure 5). Temperatures were measured hourly for thirteen calendar years with submerged data loggers. The coldest annual temperatures were in the North Klondike River which had an average annual sum of 995.1 ATU. The warmest temperatures measured was in Tatchun Creek, with an average annual sum of 2672.7 ATU (von Finster 2021). Although these ATUs were for the calendar year and not for the spawning and incubation life stages, the range of ATUs implies thermally diverse spawning and incubation habitats. This should factor into any planning or management processes for specific populations.

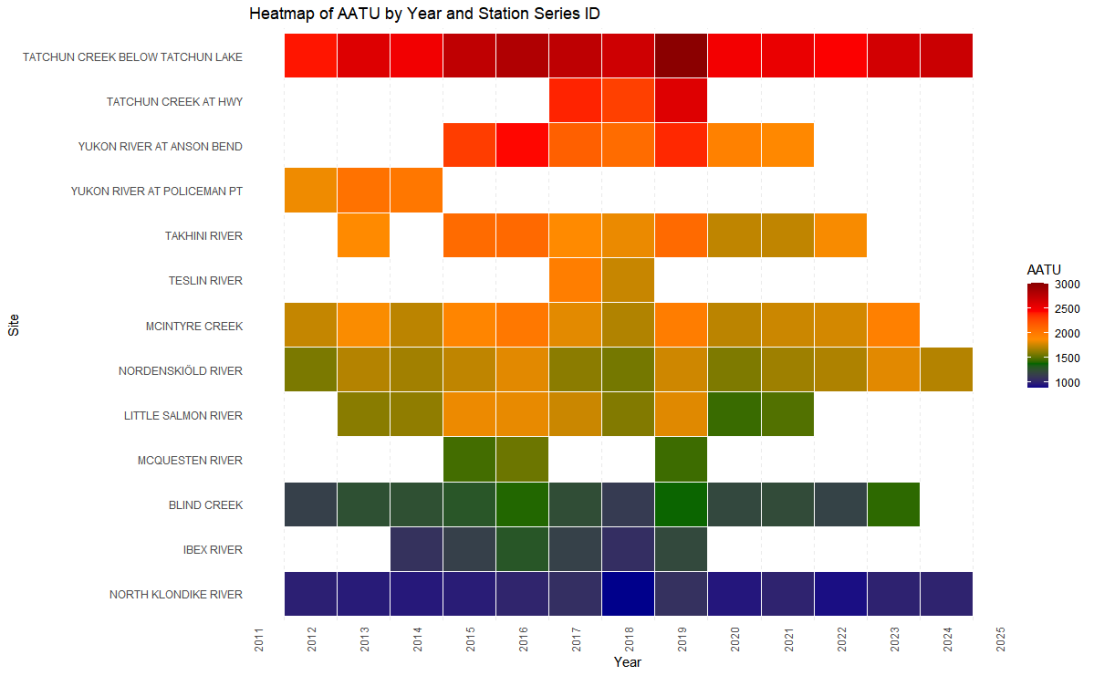

Figure 5. Annual accumulated thermal units (ATUs) for select streams across the Canadian portion of the Yukon River Watershed, from Milligan (2025).

3.3.5 Fry

Fry are fish that are less than a year old, having emerged in the spring, and become smolts the following spring when they begin their direct migration to the estuary. Single fry or loose schools of fry are generally visible in spring in still waters along the advancing margins of spawning rivers and streams. Emergent fry in the relatively warm Yukon River near Whitehorse have been observed in early May (von Finster 1996a). In the nearby but much colder Wolf Creek (Whitehorse area) emergent fry were captured in late June (von Finster 1996b). Emergent fry are about 35–38 mm in fork length (FL; Duncan and Bradford 2004). Juvenile Chinook are seldom found in completely still water except shortly after emergence or possibly in some overwintering areas.

Chinook on the west coast of North America may exhibit “stream-type” or “ocean-type” life histories. Stream-type fish spend at least one winter in fresh water after hatching, while ocean-type fish enter salt water during their first summer. All wild Canadian-origin Chinook were previously considered to be stream-type. Recently however, scientists at the U.S. National Oceanic and Atmospheric Administration captured Teslin River Chinook 0+ juveniles in research trawls off the mouth of the Yukon River (J. Murphy, pers. com.), and an adult female carcass was sampled on the Teslin River that had entered the ocean as a 0+ fry (W. Twardek, pers. comm.). This confirms that naturally propagated Chinook entering the ocean as 0+ fry may survive and return to spawn. This may signal a partial and perhaps developing transition toward an ocean-type Chinook life history for some populations or portions thereof.

Many stream-type Chinook remain in their natal spawning streams for the first summer and some presumably overwinter there (de Graff 2004). Densities of fry may be high and growth slow in natal streams in the first summer (von Finster 1989). It is likely that a considerable portion of the 0+ juveniles

disperse downstream from emergence locations (Daum and Flannery 2011; Bradford et al. 2008). The triggers for juveniles leaving the natal stream have not been determined. It may be related to the timing or severity of river flows, fry density, or other reasons. There may be opportunities to learn from Traditional Knowledge to explore this data gap.

The pattern of downstream dispersal of 0+ fry is distinct from migration of 1+ smolts. Young-of-year fry move downstream and stop in one or more intermediate locations to rear and overwinter. In contrast, 1+ smolts migrate directly to the Yukon River estuary (Bradford et al. 2001, 2009).

Fry disperse downstream to non-natal habitats via larger rivers. Which habitat they use to do so (e.g., the center of the river, the margins, or which/when) has been poorly investigated. Fry may enter and ascend non-natal streams and rivers (Bradford et al. 2009) or enter streams and rivers that support another spawning population (MacKenzie-Grieve 2016). The amount of available and usable habitat in these streams depends on the ability of fry to ascend them. A seemingly minor obstruction such as a beaver dam may restrict or deny use of the stream habitat upstream of it. Entrance to non-natal tributaries by 0+ Chinook juveniles in the Whitehorse area generally commences in early June (Moodie et al. 2000; von Finster and Mackenzie-Grieve 2007) and about a month later in the Dawson area (Duncan et al. 2004) at a fork length of 45–55 mm (Bradford et al. 2001). Fry can ascend streams or rivers more than 200 km downstream from spawning sites (Duncan et.al. 2004). Sampling in the U.S. has indicated that Canadian 0+ juveniles may ascend Alaskan tributaries 1,200 km from the rivers of their birth (Daum and Flannery 2009).

Rearing Chinook fry tend to be very widely dispersed. If the brood stock population was abundant in any given year, the fry will be in virtually every tributary downstream (Daum et al. 2001; Hunka et al. 1988). Fry have been captured in non-natal streams at locations more than 50 km upstream from known spawning or migration routes (Fisheries and Oceans Canada 1988a; 1988b). Genetic analysis (DNA) of fry captured from Clinton Creek over a 3-year period determined the fry were from 12 separate populations (Mackenzie-Grieve 2010, 2013, 2014). In small, moderate gradient non-natal streams the juveniles may be most numerous in small pools (Bradford et al. 2001). In larger streams, the juveniles may use in-channel analogues of pools (Lister et al. 1991). Juveniles (0+) that ascend further upstream in non-natal tributaries may achieve greater average fork lengths than those that remain closer to the mouth, as has been observed in Croucher Creek (Moodie et al. 2000). High densities of 0+ juveniles have been found immediately downstream of partial or total obstructions such as a beaver dam on Flat Creek tributary to the Takhini River (von Finster 1987) or perched roadway culvert crossing on Mickey Creek tributary to the Fortymile River (Smart 2006). Young-of-year may be present in low densities in waters with high turbidity, or where periods of high turbidity are frequent. Densities tend to be low in clear water streams after summer high water or high turbidity events in unglaciated terrain (Hunka et al. 1988). Fry displaced from streams may enter other non-natal streams located further downstream.

Feeding behavior of fry has not been comprehensively studied for rearing Yukon River Chinook salmon. The investigations conducted to date have identified true flies as contributing most to Chinook fry diets during the summer period (Gutierrez 2010; Mackenzie-Grieve 2005).

Aquatic predators of Chinook fry include lake trout, northern pike, burbot, and inconnu. Slimy sculpin may consume very small Chinook. Predation by Arctic grayling is rare, although emergent fry may be found in mature Arctic grayling stomachs where the two species spawn in the same locations but at different times (B. Schonewille, personal communication). Juvenile Chinook are almost absent in

streams or are found in limited numbers in deep cover after mergansers have passed through a section of stream (von Finster 2009). This infers significant predation of fry in streams and rivers large enough to be used by mergansers. Kingfishers, gulls, loons, and other birds predate on the juveniles. Mink have been observed to target overwintering Chinook habitats, and predation by otters is known to occur.

Successful overwintering of 0+ juveniles has been documented only in streams and smaller rivers (Bradford et al. 2001; Harder 1989) and in hyporheic groundwater fed off-channel habitats (von Finster 2001), though overwintering may also occur in mid-sized rivers. Overwintering in Croucher Creek, a small tributary to the Yukon River near Whitehorse appears to be related in part to local ice formation and groundwater sources (Bradford et al. 2001). Chinook have survived in areas fed by or downstream of ground water discharges but did not survive in areas overlain by aufeis. No overwintering Chinook have been documented in lakes. An investigation found that juvenile Chinook were absent from the stomachs of predatory fish (185 burbot, 21 lake trout, 4 inconnu and 9 northern pike) captured by gillnet in Lake Laberge during the winters of 1985 through 1989. The conclusion inferred from this analysis was that juvenile Chinook were not present in the lake during those winters (von Finster 1991).

Investigations by U.S. researchers determined that Canadian fry continue to enter non-natal streams on the Alaskan side of the border at least as far downstream as Circle (Daum et al. 2009). Sampling ceased at Circle, and it is likely that Canadian-origin fry use tributaries entering the Yukon River further downstream. American researchers have only documented summer rearing, but it is likely that overwintering also takes place.

3.3.6 Smolts

Smolts are understood to be juvenile salmon that have completed their first year of life and are on their way down to the estuary in their second spring/summer. Overwintered 1+ juveniles grow rapidly in spring if food resources and temperatures permit. For example, average body mass increased by more than 50% prior to outmigration from overwintering sites in Croucher Creek (Bradford et al. 2001). Outmigration may be delayed if the spring is cool or late (Moodie et al. 2000). Relatively few 1+ juveniles are captured in the Yukon River in Canada after July 15 of any given year and then usually only in spawning streams. These fish may become residual males and not migrate to sea. This is rare but larger numbers of residual males have recently been observed in the Teslin River basin (B. Schonewille, pers. comm.).

Overwintered Chinook begin the smolting process as they migrate downstream. They complete smolting as they enter the Yukon River estuary and the Bering Sea. The out-migration of Chinook smolts from different Yukon River tributaries in Canada is not well documented. The degree of synchronicity between populations of smolts remains unknown or undocumented. Nearly all Canadian-origin smolts except those from the Porcupine River must migrate past Dawson City. A rotary screw trap located there between 2002 and 2004 determined that the aggregate downstream smolt migration followed a downstream dispersal of 0+ juveniles from non-natal streams (Duncan et al. 2004). Smolt migration to the delta is understood to be direct (Bradford et al. 2009).

3.3.7 Marine Life Stage

Chinook typically begin to enter the Yukon River estuary in late May and early June following warming spring temperatures and increased river discharge (Howard et al. 2017; Miller and Weiss 2023). There is currently a limited understanding of the environmental and ecosystem factors influencing Chinook

smolts during their transient life stage between freshwater and marine habitats (but see Miller et al. 2016, 2020; Howard et al. 2017; Miller and Weiss 2023). However, for Pacific salmon generally, it is understood that this life stage is likely a critical stage for growth and survival, with potentially high vulnerability to size-selective predation (Beamish and Mahnken 2001).

After exiting the Yukon River estuary, juvenile Chinook spend one summer in the shallow waters of the northeastern Bering Sea (Figure 6). Most of the information about the early marine period for Chinook comes from the annual northern Bering Sea (NBS) pelagic trawl surveys that began in 2002 (Murphy et al. 2023). The survey generally occurs in September of each year and provides information about the size, relative abundance, diet, and body condition of juvenile Chinook, while also tracking other species and general ecosystem conditions over time.

One main takeaway from NBS surveys is that juvenile abundance at the end of the first summer at sea is strongly associated with the number of returning adults to the Yukon River in later years (Figure 7). Although relatively high mortality does occur after the first summer in the marine environment for Chinook (5–8% survival rates; Howard et al. 2019), stable survival rates over time suggest that environmental factors acting during these later marine life stages are not a likely source of the recent declines for Canadian-origin Yukon River Chinook salmon. However, changing conditions in the Bering Sea may still be influencing the health of returning Chinook which may be leading to a reduction in productivity via transgenerational effects and/or an increase in en-route mortality (Howard and von Biela 2023). In addition, long-term declines in Yukon River Chinook adult size (-6%) and reproductive potential (-28%) since the 1970s may be in part due to environmental and ecosystem factors influencing Chinook growth and maturity patterns during the marine period (Figure 8; Ohlberger et al. 2020; Oke et al. 2020; Schoen et al. 2023).

Following their first summer, Yukon River Chinook move south of the ice edge towards the vicinity of the Bering Sea shelf break for the winter period (Figure 6). They generally spend 1–3 years in the ocean as immature salmon, migrating from their winter habitats near the shelf break, to their offshore summer habitats in the Aleutian Basin of the central and western Bering Sea. During their final winter and spring at sea, maturing adults are believed to move east to stage in the eastern Bering Sea prior to entering the Yukon River.

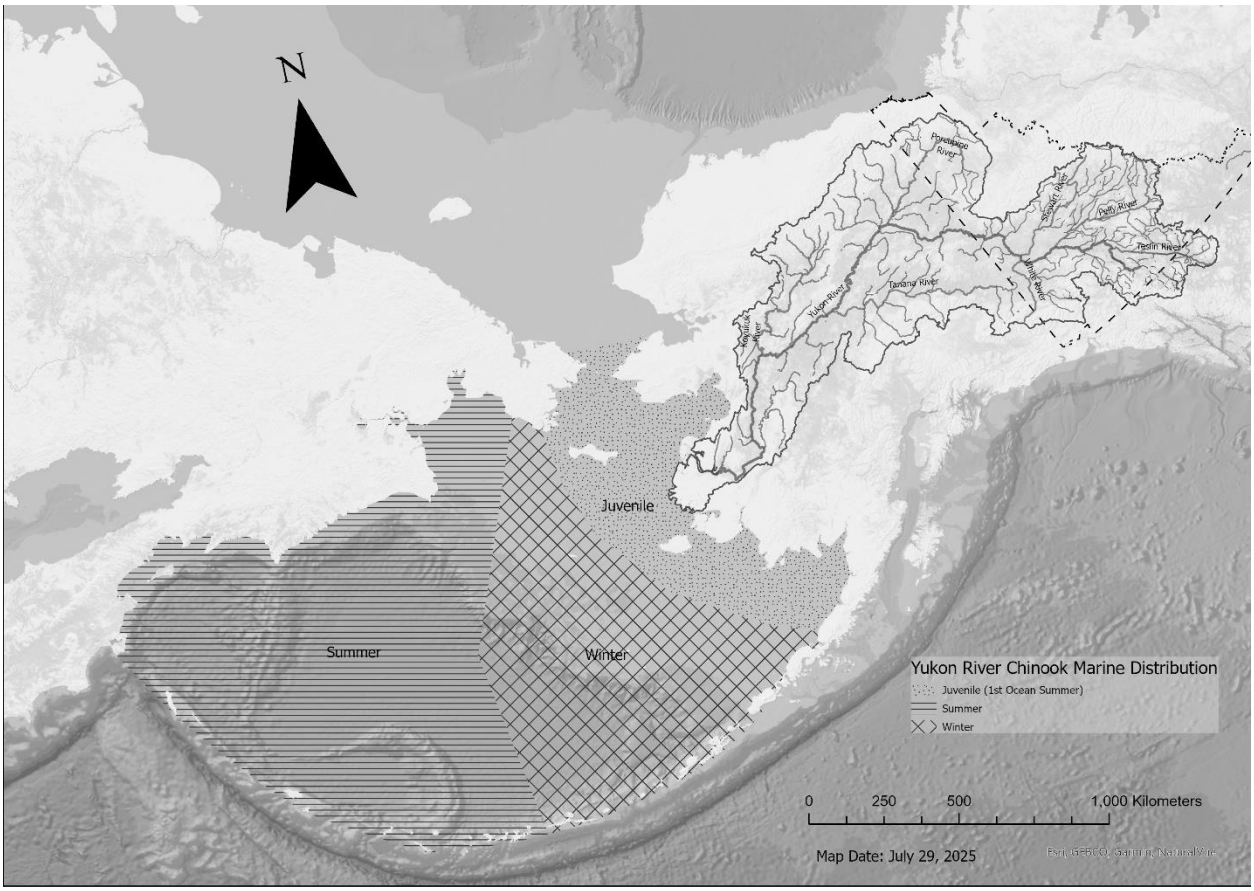

Figure 6. Conceptual map showing the distribution of Yukon River Chinook salmon in the Bering Sea, adapted from Meyers et al. (2010).

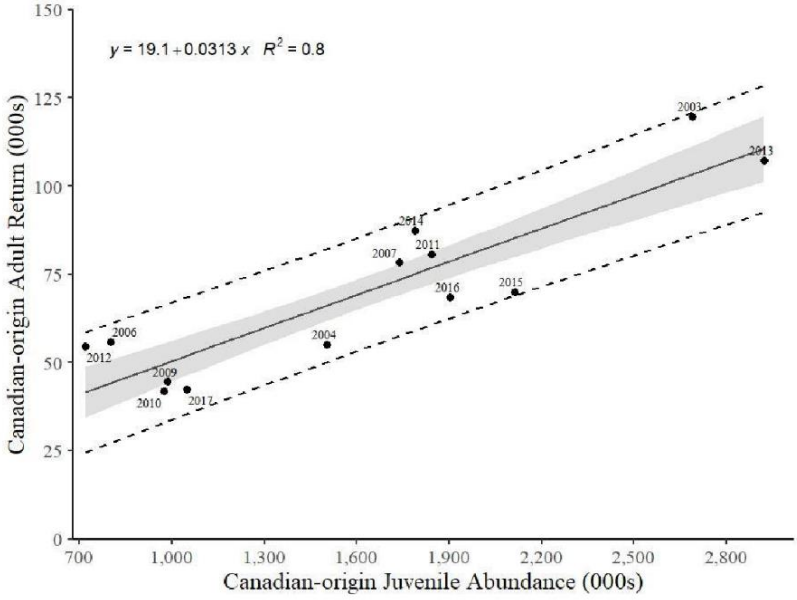

Figure 7. The number of returning adults to spawn is closely related to the abundance of juvenile Canadian-origin Yukon River Chinook salmon in the marine environment after their first summer at sea,

demonstrating very stable survival rates during later marine life stages over time (data from years 2003–2017). Figure from Murphy et al. (2023).

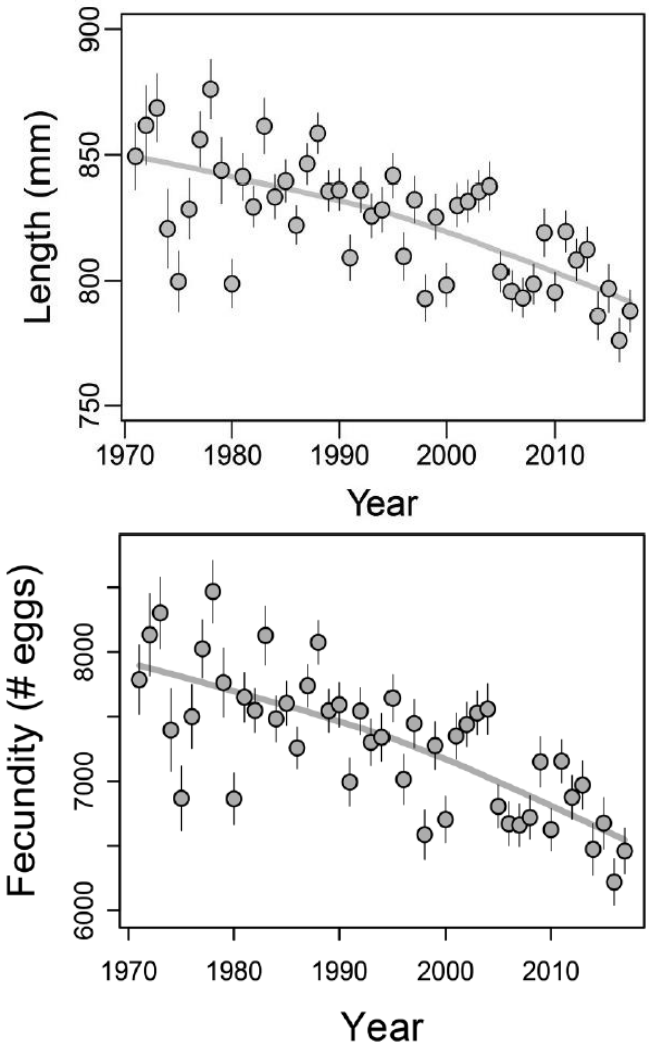

Figure 8. Yukon River Chinook salmon adult body size (length) and reproductive potential have greatly decreased over the past fifty years. Figure adapted Ohlberger et al. (2020). Both figures are presented for multiple Yukon River Chinook salmon populations.

3.3.8 Spawning Adults

Adult Chinook enter the Yukon River shortly after ice break up, in late May through July, with Canadian-origin Chinook returning earlier in the run on average compared to US-origin stocks (JTC 2024; Eiler et al. 2014). Observations from radio tagging data suggest that fish traveling to further tributaries (e.g., Teslin River) return later than fish returning to the lower portions (e.g., Klondike and Stewart rivers) of the Canadian portion of the watershed, though the migration window is still short for all populations (Eiler et al. 2014). Canadian-origin Yukon River Chinook migrate at a greater daily rate compared to other

stocks in the Alaska portion of the Yukon River, reaching the Canadian border in approximately 32–38 days (Eiler et al. 2015).

Some adult Chinook may migrate through Alaska during the period of potential maximum air and water temperatures. Water temperatures may meet or exceed the temperature threshold for inducing heat stress in migrating adult Chinook of 18°C (von Biela et al. 2020) in these waters. Chinook start to cross the U.S./Canada border in late June, and spawn in the 100+ spawning rivers or streams (Brown et al. 2017) by approximately September 15.

Most Chinook presently return as aged 5 and 6, with some returning as aged 7 and even fewer at aged 8 (O'Dell, pers. comm.). Aged 3 and 4 spawners return in low numbers and are predominately male, while near all of the older aged Chinook are female (Brown et al. 2017). An unknown number of residual males remain near the spawning areas instead of migrating to the marine environment and will participate in spawning.

Chinook enter the Porcupine River at Fort Yukon, Alaska about 1,570 km from the mouth of the Yukon River. The Porcupine River in Alaska tends to be slow moving. Flows may be very low in dry years, when there has been little seasonal precipitation. Several mountain rivers enter the Porcupine River in Alaska but the effects of these cold tributaries on water temperatures in the Porcupine River mainstem are not well understood. In Canada, temperatures of the Porcupine and Crow rivers at Old Crow can exceed thresholds for upstream migration during the adult Chinook run (von Finster 2021; von Biela et al. 2020). A maximum daily temperature of 21.7 degrees was recorded by data logger in the Porcupine River at Old Crow in 2012 (von Finster 2013). Subsequent sampling at the Porcupine Sonar confirmed this. In 2023 the Porcupine River at this site reached 22.9°C and remained above 22°C for five days. Longer periods above 21°C and 20°C were also measured (O'Dell, pers. comm.).

There is little spawning in the unglaciated area of the Yukon. A minor population exists in Matson Creek (tributary to Sixtymile River) and a somewhat larger population in the Klotassin River. The Klondike River flows along part of the northern margin of the unglaciated area. Most of the water in the river, however, comes from the glaciated foothills of the Ogilvie Mountains.

In the glaciated area of the Canadian Yukon River basin, Chinook spawn below lake outlets, in major rivers and in smaller streams. Many of the spawning areas are in waters with intermediate physical characteristics. The sheer size of larger rivers mitigates much of the risk of disruption of spawning habitats found within them. However, larger rivers pose other risks, particularly increased predation of juveniles. Lake-headed small streams may support relatively large populations of spawning Chinook. Lakes tend to moderate downstream water temperatures. Generally, lakes store thermal energy and release it later in the year which may result in temperatures exceeding desirable limits in the early portion of the spawning migration. Both lake headed and non-lake headed small streams are vulnerable to partial or total obstruction of adult Chinook by beaver dams. These dams also provide an opportunity for bears to feed on Chinook, which can be a major but localised source of adult Chinook mortality in low water conditions. Low water conditions also provide beavers with increased opportunity to build more dams and more effectively obstruct upstream migrating Chinook.

Spawning substrates, redd structure, and spawning behavior have not been specifically studied in the different habitats used by Chinook in the Canadian Yukon River drainage though Traditional Knowledge may include information about this. There is a general understanding that larger Chinook spawn in flows

of greater volume and velocity, and smaller Chinook spawn in flows of lesser volume and velocity. This principle has been extended to the spawning habitat, with larger fish spawning in swifter rivers with coarse substrate and smaller Chinook spawning in slower rivers with finer gravel and cobble substrate, and is seen throughout other salmon populations and species (Bjornn and Reiser, 1991). Spawning directly in ground water discharge areas is not known to occur.

During spawning, the female Chinook uses her tail to excavate a pocket in the underlying stream bottom, creating a redd. Most sands and silts are pushed downstream from the redd, while cobbles and gravels remain. She forms an egg pocket, deposits her eggs which are quickly fertilized, and the redd is filled by the female as spawning proceeds. In some locations only single redds are developed. In other locations two or more redds are joined or are closely adjacent to form compound redds. Chinook spawning below lake outlets results in the development of spawning dunes, which are ridges of gravel formed perpendicular to the direction of flow. These dunes can be prominent features in the substrate and visually identifiable in the right conditions, as they are at the outlet of Kusawa Lake. They were engineered by Chinook spawning over hundreds and possibly thousands of years through repeated spawning (Tutty 1986). Where salmon have recently spawned, “bright spots” are formed where algae has been removed from the front or top of the dune to create the redd. Groupings of spawning dunes are termed “dune complexes”.

4. Methods

4.1 Limiting Factor Assessment Framework

The following review of issues facing Canadian-origin Yukon River Chinook involved a systematic assessment of risks to the population using a list of potential limiting factors (LF) to Chinook survival (Table 2). This comprehensive list of LFs was developed as a part of the Risk Assessment Methodology for Salmon (RAMS) process (Hyatt et al. 2017), which has been used in the assessment of other Chinook populations on the Pacific Coast of Canada (e.g., Irvine et al. 2024). The LFs framework provides a method for ensuring that a broad range of potential issues facing these Chinook throughout their life cycle are considered.

The LFs framework provides an opportunity to assess risks facing a salmon population from the perspective of the salmon swimming through each stage of their life cycle rather than from the perspective of humans as managers. Each limiting factor describes a phenomenon that may be limiting the productivity of that population. This is a different approach than one that singles out potential impacts by human management category, such as mining, forestry, or different types of fishing. The life cycle approach enables results to be used in focused restoration or rebuilding actions.

Given the unique constraints of Chinook rebuilding planning efforts in the Yukon, including the lack of empirical data for key life stages, the size and diversity of the watershed, and time constraints of governments involved, the decision was made to use the LFs framework from RAMS, but not follow the entirety of the specific RAMS methodology. Specifically, multi-party scoring of LFs based on a function of exposure and impact was deemed to be not feasible, though the method was referenced for guidance where needed. Instead, an expert knowledge elicitation process was used whereby two experts reviewed the LFs framework, adapted it to the unique habitat and life cycle considerations for Yukon River Chinook, and provided qualitative recommended risk rankings and rationales for each of the LFs. This assessment and the resultant risk recommendations were first presented to a large workshop of

involved professionals and knowledge holders from Yukon First Nations, Government of Yukon, DFO, and others in Whitehorse in March 2024. During this workshop, participants provided initial feedback to experts and asked follow up and clarifying questions.

Table 2. List of limiting factors, with numerical ID. Marine refers to adult marine stage and migration refers to adult return migration stage.

LF ID	Life Stage	Limiting Factor Category	Limiting Factor
1	Egg / Alevin	Direct Anthropogenic Interactions	Redd disturbance by humans
2	Egg / Alevin	Biological Interactions	Redd overspawn
3	Egg / Alevin	Biological Interactions	Parasites, pathogens, or disease
4	Egg / Alevin	Biological Interactions	Predation
5	Egg / Alevin	Physical Habitat	Unfavourable bed material
6	Egg / Alevin	Hydrology and Oceanography	Altered timing, frequency, or magnitude of peak flows
7	Egg / Alevin	Hydrology and Oceanography	Altered timing, frequency, or magnitude of low flows or water levels
8	Egg / Alevin	Water Quality	Unfavourable water temperatures
9	Egg / Alevin	Water Quality	Low dissolved oxygen
10	Egg / Alevin	Water Quality	Unfavourable water chemistry
11	Egg / Alevin	Water Quality	Contaminants or deleterious substances
12	Fry	Direct Anthropogenic Interactions	Stress from anthropogenic activity
13	Fry	Biological Interactions	Competition
14	Fry	Biological Interactions	Parasites, pathogens, or disease
15	Fry	Biological Interactions	Predation
16	Fry	Biological Interactions	Lack of quality or quantity of appropriate food
17	Fry	Physical Habitat	Loss of access to rearing habitat
18	Fry	Physical Habitat	Unfavourable channel form and/or timing or duration of sediment loads
19	Fry	Hydrology and Oceanography	Altered timing or magnitude of peak flows causing flushing
20	Fry	Hydrology and Oceanography	Altered timing or magnitude of peak flows causing stranding
21	Fry	Water Quality	Unfavourable water temperatures
22	Fry	Water Quality	Low dissolved oxygen
23	Fry	Water Quality	Unfavourable water chemistry
24	Fry	Water Quality	Contaminants or deleterious substances
25	Smolt	Direct Anthropogenic Interactions	Stress from anthropogenic activity
26	Smolt	Biological Interactions	Competition
27	Smolt	Biological Interactions	Parasites, pathogens, disease, or algal blooms
28	Smolt	Biological Interactions	Predation

LF ID	Life Stage	Limiting Factor Category	Limiting Factor
29	Smolt	Biological Interactions	Lack of access and availability of appropriate food
30	Smolt	Physical Habitat	Loss of access to estuarine habitat
31	Smolt	Physical Habitat	Unfavourable channel form or sediment loads
32	Smolt	Hydrology and Oceanography	Altered timing or magnitude of peak flows causing flushing
33	Smolt	Hydrology and Oceanography	Altered timing or magnitude of low water levels causing stranding
34	Smolt	Hydrology and Oceanography	Oceanography, currents, or tides
35	Smolt	Water Quality	Unfavourable water temperatures
36	Smolt	Water Quality	Low dissolved oxygen
37	Smolt	Water Quality	Unfavourable water chemistry
38	Smolt	Water Quality	Contaminants or deleterious substances
39	Juvenile	Direct Anthropogenic Interactions	Stress from anthropogenic activity
40	Juvenile	Direct Anthropogenic Interactions	Fishing
41	Juvenile	Biological Interactions	Competition for prey
42	Juvenile	Biological Interactions	Parasites, pathogens, disease, or harmful algae
43	Juvenile	Biological Interactions	Predation
44	Juvenile	Biological Interactions	Lack of access and availability of appropriate food
45	Juvenile	Physical Habitat	Reduced habitat connectivity
46	Juvenile	Hydrology and Oceanography	Oceanography, currents, or tides
47	Juvenile	Water Quality	Direct impacts of water temperatures
48	Juvenile	Water Quality	Direct impacts of hypoxia or dissolved oxygen levels
49	Juvenile	Water Quality	Unfavourable water chemistry
50	Juvenile	Water Quality	Exposure to containments or deleterious substances
51	Immature	Direct Anthropogenic Interactions	Stress from anthropogenic activity
52	Immature	Direct Anthropogenic Interactions	Fishing
53	Immature	Biological Interactions	Competition for prey
54	Immature	Biological Interactions	Parasites, pathogens, disease, or harmful algae
55	Immature	Biological Interactions	Predation
56	Immature	Biological Interactions	Lack of access and availability of appropriate food
57	Immature	Physical Habitat	Reduced habitat connectivity
58	Immature	Physical Habitat	Reduction in habitat quality or quantity
59	Immature	Hydrology and Oceanography	Oceanography, currents, tides
60	Immature	Water Quality	Direct impacts of water temperatures
61	Immature	Water Quality	Direct impacts of hypoxia or dissolved oxygen levels
62	Immature	Water Quality	Unfavourable water chemistry
63	Immature	Water Quality	Exposure to containments or deleterious substances

LF ID	Life Stage	Limiting Factor Category	Limiting Factor
64	Marine	Direct Anthropogenic Interactions	Stress from anthropogenic activity
65	Marine	Direct Anthropogenic Interactions	Fishing
66	Marine	Biological Interactions	Competition for prey
67	Marine	Biological Interactions	Parasites, pathogens, disease, or harmful algae
68	Marine	Biological Interactions	Predation
69	Marine	Biological Interactions	Lack of access and availability of appropriate food
70	Marine	Physical Habitat	Reduced habitat connectivity
71	Marine	Physical Habitat	Reduction in habitat quality or quantity
72	Marine	Hydrology and Oceanography	Oceanography, currents, tides
73	Marine	Water Quality	Direct impacts of water temperatures
74	Marine	Water Quality	Direct impacts of hypoxia or dissolved oxygen levels
75	Marine	Water Quality	Unfavourable water chemistry
76	Marine	Water Quality	Exposure to containments or deleterious substances
77	Migration	Direct Anthropogenic Interactions	Mortality or fitness reduction as a result of stress due to anthropogenic activity
78	Migration	Direct Anthropogenic Interactions	Fishing
79	Migration	Biological Interactions	Competition
80	Migration	Biological Interactions	Parasites, pathogens, or disease
81	Migration	Biological Interactions	Predation
82	Migration	Physical Habitat	Migration barriers
83	Migration	Physical Habitat	Unfavourable channel form or sediment loads
84	Migration	Hydrology and Oceanography	Altered timing or magnitude of peak flows
85	Migration	Hydrology and Oceanography	Altered timing or magnitude of low water levels
86	Migration	Hydrology and Oceanography	Oceanography, currents, or tides
87	Migration	Water Quality	Mortality, fitness reduction, or delayed migration due to unfavourable water temperatures
88	Migration	Water Quality	Mortality or fitness reduction as a result of low dissolved oxygen
89	Migration	Water Quality	Unfavourable water chemistry
90	Migration	Water Quality	Contaminants or deleterious substances
91	Spawning	Direct Anthropogenic Interactions	Mortality or fitness reduction as a result of stress due to anthropogenic activity
92	Spawning	Direct Anthropogenic Interactions	Fishing
93	Spawning	Biological Interactions	Competition
94	Spawning	Biological Interactions	Parasites, pathogens, or disease
95	Spawning	Biological Interactions	Predation
96	Spawning	Physical Habitat	Unfavourable channel form or sediment loads
97	Spawning	Physical Habitat	Reduced quality and quantity of spawning habitat

LF ID	Life Stage	Limiting Factor Category	Limiting Factor
98	Spawning	Hydrology and Oceanography	Altered timing or magnitude of high flows
99	Spawning	Hydrology and Oceanography	Altered timing or magnitude of low water levels
100	Spawning	Water Quality	Delayed spawning or pre-spawn mortality due to unfavourable water temperatures
101	Spawning	Water Quality	Low dissolved oxygen
102	Spawning	Water Quality	Unfavourable water chemistry
103	Spawning	Water Quality	Contaminants or deleterious substances
104	N/A	Population	A reduction in natural genetic diversity
105	N/A	Population	Changes in biological characteristics such as fecundity, egg quality or quantity, maturation rate, sex ratios, size at age, etc.
106	N/A	Population	The loss of respect or relationship with people

4.2 Issues Facing Chinook Salmon Workshop (June 2024)

A small group of salmon biologists and management professionals from several Yukon First Nations, the Yukon Salmon Sub-Committee, the Yukon First Nations Salmon Stewardship Alliance, and DFO gathered in Whitehorse on June 12–13, 2024, for a facilitated workshop along with the two experts who had conducted the initial LF review. Two days were spent reviewing relevant LFs in detail and deliberating on an appropriate risk ranking for each LF using each participant's awareness of scientific, Traditional, technical, and local knowledge. Risk rankings were determined by consensus based on subjective assessment. The risk rankings that emerged from this workshop are presented in this report.

Workshop participants reviewed LFs with expected risk rankings of moderate or greater (moderate, high, or very high) to efficiently review top priority risks. Additionally, participants were welcomed to bring LFs not discussed (i.e., very low or low ranking) to the floor for discussion as well as propose new LFs if a gap was identified. A consensus risk ranking was required for each LF discussed.

The review workshop participants were:

Name	Organization
Bonnie Huebschwerlen	Fisheries and Oceans Canada
Cheyenne Bradley	Fisheries and Oceans Canada
Elizabeth MacDonald	Yukon First Nations Salmon Stewardship Alliance/Council of Yukon First Nations
Emma Hoogland	Kwanlin Dün First Nation
Huey O'Leary Baikie	Tr'ondëk Hwëch'in
Jeska Gagnon	Fisheries and Oceans Canada
Jessica Gill	Fisheries and Oceans Canada
Karlie Knight	Tr'ondëk Hwëch'in
Lars Jessup	Consultant to First Nation of Nacho Nyäk Dun

Marina Milligan	Yukon First Nations Salmon Stewardship Alliance/Council of Yukon First Nations
Morgan Gilmar	Fisheries and Oceans Canada
Stephanie Lyons	Yukon First Nations Salmon Stewardship Alliance/Council of Yukon First Nations
Steve Smith	Fisheries and Oceans Canada
Sebastian Jones	Yukon Salmon Sub-Committee
Gillian Rourke	Teslin Tlingit Council
Brittany Milner	Taku River Tlingit First Nation

Al von Finster and Alyssa Murdoch, consulting biologists who completed the initial expert review, were also present, and Tim Hawkins, from West Coast Aquatic, provided workshop facilitation.

Risk rankings were revised based on the outcomes of this workshop, and discussion was used to update risk ranking rationales where relevant. The findings of this workshop are summarized below.

4.3 Ranking Framework

Quantitative data demonstrating direct effects on survival and/or run size are generally lacking for Canadian-origin Yukon Chinook, requiring impacts to be considered in a broader context based on the available evidence and knowledge of potential mechanisms influencing salmon. Further, because direct evidence linking limiting factors to effects on Chinook populations is relatively sparse, relevant information was used from other salmon populations elsewhere on the Pacific coast to understand and qualify potential risk. Based on these limitations and the increasingly vulnerable population status of Canadian-origin Yukon River Chinook in recent years, the authors and workshop participants followed the recommended precautionary approach outlined in the RAMS guidelines to identify the appropriate score for each factor. To score each risk, the spatial and temporal exposure fish face to a given threat, as well as the potential impact to fish from exposure to that threat was considered. In general, risk was assessed for each limiting factor at the aggregate scale (i.e., for all Canadian-origin Yukon River Chinook salmon populations combined), except for select factors (e.g., mortality related to migration barriers caused by the construction of dams on the Mayo River) for streams facing a particular, known set of impacts. Any disagreement in opinion was captured in a confidence ranking (Table 3). Confidence is noted when assessed though was not considered for all LFs. When confidence was not considered or assessed, it is not noted.

Table 3. Ranking of confidence scores used in the assessment.

Confidence	**Rationale**
Low	● Data exist but are considered poor or conflicting, or ● No data exist, or ● Substantial disagreement among experts
Medium	● Data exist but some key gaps ● Some disagreement among experts
High	● Data exist and are considered sound, or ● Consensus between experts

The final biological risk ratings presented in this report integrated exposure and impact into a single metric ranging from very low to very high. A future risk ranking was determined based on the knowledge of each specific limiting factor and the expected change over the next 50 years.

The report provides a review of limiting factors to Chinook. All LFs considered are listed by life stage and numerical ID (Table 2; Appendix A. Limiting Factor Table for Canadian-origin Yukon River Chinook salmon), though factors ranked very low are not always presented in the text of this report for brevity. Knowledge of risks in freshwater habitats is substantially different in nature and availability than knowledge of risks in the marine environment, which led authors to structure the description of risks differently between freshwater and marine life sections, though efforts to ensure consistency between each stage were made.

At the Issues Facing Chinook salmon review workshop, participants highlighted the problem of scale in analysis of risks to these fish. When evaluating risk at an entire-watershed scale, one loses the ability to highlight risks facing select systems with well understood risks. For example, placer mining, beaver dam obstructions, or hydroelectric dam effects may be significant for populations in the tributaries they affect but may be a relatively small factor when evaluating risk at for all populations combined across the Yukon River drainage. To address the problem of the scale of evaluation, all limiting factors were evaluated for all populations at the watershed scale, but some limiting factors were also evaluated for select populations in systems with known effects.

5. Limiting Factors Assessment

During the limiting factor review workshop, LFs were reviewed based on their impact to the entire Canadian-origin Yukon River Chinook salmon population across their various freshwater and marine habitats (Table 4). There were multiple factors where localized risks were more apparent, which are presented after the initial broad population assessment (e.g., 12, 12a). Risk factors are presented in numerical order. Largely, factors that were ranked as very low or data gaps of lower importance are not presented in the text; therefore a gap in numbering might occur. A complete list of limiting factors and their rankings can be found in the table in Appendix A.

Table 4. Risk ranking summary by life stage for select limiting factors (LFs) considered for all Canadian-origin Yukon River Chinook populations combined. Specific ratings may differ for local effects (e.g., Whitehorse Rapids Dam, placer mining regions) which are described after the watershed-wide ranking. Impacts that were considered across life stages and generations of salmon are indicated under the population column. Not all limiting factors are presented in the table. Please refer to individual limiting factor text and Appendix A for a full description of each ranking and associated confidence.

Limiting Factor Category	LFs associated with category	Egg and Alevin	Fry	Smolt (Estuarine)	Juvenile (Ocean)	Immature (Ocean)	Adult (Ocean)	Returning Spawner	Population
Water temperature	8, 21, 35, 47, 60, 73, 87, 87a, 100, 100a	Very Low	Low	Moderate	Moderate	Data Gap	High	High[1]	N/A
Competition	2, 13, 26, 79, 93	Very Low	Very Low	Data Gap	Data Gap	Low[2] to Moderate[3]	Low[2] to Moderate[3]	Very Low	N/A
Food access / availability	16, 29, 41, 44, 53a, 53b, 53c, 56, 66b, 66c, 69	N/A	Low	Moderate	Moderate	Data Gap	Data Gap	N/A	N/A
Ichthyophonus	54a,67a, 80a, 94a	Very Low	Very Low	N/A	N/A	Data Gap	Data Gap	High	N/A
Thiamine deficiency	3a, 54b,67b, 80b, 94b	Moderate	Low	N/A	N/A	Data Gap	Data Gap	Moderate	N/A
Predation	4, 15, 28, 43, 55, 68, 81, 95	Very Low	Moderate	High / Data Gap[4]	High / Data Gap[4]	Moderate	Very Low	Low	N/A
Physical habitat degradation or loss	12, 12a, 17, 17a, 25, 30, 39, 45, 51, 57, 64, 70, 77, 77a, 82, 82a, 91	Low	Low	Data Gap	Very Low	Very Low	Very Low	Low	N/A
Water Quality (not including temperature)	9, 10, 11, 22, 23, 24, 36, 37, 38, 48, 49, 50, 61, 62, 63, 74, 75, 76, 88, 89, 90, 101, 102, 103	Very Low	Low	Very Low / Data Gap[5]	Very Low / Data Gap[5]	Low	Low	Very Low	N/A

Limiting Factor Category	LFs associated with category	Egg and Alevin	Fry	Smolt (Estuarine)	Juvenile (Ocean)	Immature (Ocean)	Adult (Ocean)	Returning Spawner	Population
Fishing (bycatch and targeted harvest)	40, 52, 52a, 52b, 65, 78, 92	N/A	N/A	N/A	Very Low	Low[6]	Low[6]	Moderate	N/A
Hydrology	6, 7, 19, 20, 20a, 32, 33, 34, 46, 59, 72, 84, 85, 86, 98, 99	Low	Very Low to Moderate [7]	N/A	N/A	N/A	N/A	Very Low to Low	N/A
Demographic / Escapement Quality	105	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High
Genetic diversity and drift	104, 104a	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Moderate to High / Data Gap
Relationship with people	106	N/A	N/A	N/A	N/A	N/A	N/A	N/A	High

[1]Water temperature ranking here excludes the Porcupine River, which is rated as very high
[2]Competition with hatchery-origin pink salmon or with chum salmon (hatchery-origin and wild combined)
[3]Competition with wild pink salmon
[4]Predation for these life stages expected to be high but also a noted data gap
[5]Data gap classification is due to the unknown potential for lowered oxygen following harmful algal blooms
[6]Only U.S. groundfish fisheries were considered in the review; it is recognized that other U.S. fisheries and countries catch Canadian-origin Yukon River Chinook salmon in the Bering Sea.
[7]Moderate risk ranking is for risk of low winter flows due to ice conditions and stranding in the early spring.

5.1 Egg and Alevin

This section pertains to the egg and alevin stage, which refers to when fertilized Chinook eggs are nestled in gravel riverbeds, where they incubate and later hatch into yolk-sac-bearing alevins. At this stage, they remain buried in the riverbed, highly sensitive to temperature and water quality, as they absorb oxygen and grow. Their development rate depends heavily on the thermal conditions of the specific spawning stream.

5.1.1 Direct Anthropogenic Interactions

LF 1: Mortality or fitness reduction due to redd disturbance by humans

Current Risk: Very low, high confidence

Future Risk: Very low, high confidence

Most redds are located in streams in isolated areas and most Chinook spawning habitat is untouched by humans. Recreational use in smaller, high density spawning streams that are readily accessible is limited in part due to potential conflict with bears. Instream development of infrastructure is regulated by DFO and YG. Timing windows for instream construction have been developed and instream work by heavy equipment that could disturb Chinook redds is not permitted during incubation periods. For these reasons, both current and future risk are considered very low with high confidence.

5.1.2 Biological Interactions

LF 2: Mortality or fitness reduction due to excess spawning

Current Risk: Very low

Future Risk: Very low, high confidence

Excess spawning is when numbers of returning adult salmon exceed the amount of preferred or available spawning area available. It is one of the few variables that is easily observed from the air and has opened new opportunities for application of drones. It is most visible when late migrating adults spawn on or over existing redds. Field observations are also relatively simple: if excess spawning has occurred there will be abundant loose eggs on the river bottom. If some eggs are present, it may have occurred; however, if eggs are abundant, excess spawning did occur. At current Chinook spawning population levels, the risk of excess spawning is very low. Of note, excess spawning has not been observed or recorded in the numerous Chinook populations surveyed or enumerated during periods where populations were more than three times greater than they are at present. The future risk is also understood to be very low with high confidence.

LF 3: Mortality or fitness reduction due to parasites, pathogens, or disease

Current Risk: Low, low confidence

Future Risk: Low

Note: Potential effects of thiamine deficiency on egg and alevin life stages are considered separately in LF 3a.

Disease scans have been done on broodstock at salmon hatcheries and community involvement projects, but results have not been communicated. Wider, systemic surveys of parasites or pathogens of salmon eggs in the natural environment have not been conducted on the Yukon River in Canada. A late 1980s pilot project captured Chinook fry from a number of spawning populations in the Canadian Yukon River subbasin to determine parasite levels. It was thought that parasites could be used as a proxy to estimate abundances of various Yukon River Chinook populations. Parasite levels in fry were found to be very low (Murray et al. 1990). By implication, parasite levels in eggs and alevins would also have been low. The proposed study was abandoned.

There has been increased international and Canadian attention to Yukon River water temperatures and heat stress on the presence and abundances of parasites, pathogens, and disease in Chinook. This has included eggs and estimation of possible carry-over effects to them. However, the current risk is evaluated to be low. Future risk is ranked as low.

LF 3a: Mortality of fitness reduction due to parasites, pathogens, or disease – Thiamine deficiency

Current Risk: Moderate, low confidence

Future Risk: Moderate

Thiamine is an essential dietary nutrient required by salmon that is obtained through their food and passed on to developing embryos. An exploratory study examining egg thiamine levels from returning adult Chinook revealed evidence for potential thiamine deficiency, particularly in Chinook with longer migrations (Larson and Howard 2019). Based on this work, it has been suggested that low egg thiamine levels may have contributed to lower run sizes in recent years (Larson and Howard 2019; Howard and von Biela 2023). Low thiamine levels have been linked to increased early life stage mortality, as well as potential secondary effects on fitness in salmonid populations from other systems, such as for Great Lakes lake trout (Larson and Howard 2019). Although this factor is acting during freshwater stages, it is likely linked to diet changes in the marine environment with implications for thiamine levels in developing eggs (see Limiting Factors 60 and 73 for further discussion). Thiamine deficiency in eggs may also be related to *Ichthyophonus* infection in the adult female who laid the eggs (K. Howard pers. comm.). However, the identified risk ranking of moderate is currently with low confidence, as more information is required to understand and validate how Yukon River Chinook respond to low thiamine levels.

LF 4: Mortality or fitness reduction due to predation

Current Risk: Very low, high confidence

Future Risk: Very low, high confidence

Predation of fertilized eggs and alevins in redds is expected to be minor or absent. This justifies a current and future risk of very low with high confidence. Fertilized Chinook eggs are deposited deep in redds. Yukon River freshwater fish species, such as lake trout, northern pike, inconnu and other whitefish, longnose suckers and slimy sculpin, cannot excavate the materials redds are composed of. Birds would likely have difficulty accessing eggs due to the depth of burial in redds. Chinook spawn in moving water. The velocity of water flow in the stream or river would further discourage predation by waterfowl.

5.1.3 Physical Habitat

LF 5: Mortality or fitness reduction due to unfavourable stream bed material

Current Risk: Low, medium confidence

Future Risk: Moderate

Sediment movement is a normal part of how a river functions, but the dynamics of sediment movement can be changed in ways that are unfavourable to Chinook , causing mortality or fitness reduction. In Yukon, four drivers of unfavourable change to stream bed sediment dynamics are: (1) permafrost thawing and slumping, (2) placer mining, (3) gravel starvation due to the presence of a dam, and (4) hydrological variability associated with a changing climate. This limiting factor is considered to be of low risk as the effects of sedimentation on the egg and alevin life stage is thought to be minimal at a watershed scale. However, some spawning streams have been negatively affected, such as Crooked Creek (tributary to Stewart River) and it is likely that there are others that are undocumented. It is expected to have an increasing probability of providing risk to eggs and alevins due to the increased permafrost thaw and other land surface failures expected as a result of climate change. Addition of sediment and high stream flows are primary mechanisms of disturbance to stream bed materials. Downstream dispersing, or attenuating, sediment may suffocate a redd or contribute to it being scoured away. Sources of sediment inputs in the watershed include permafrost thaw, placer mining, infrastructure development, hard rock mining, forest fire destabilization and others. Secondary contributions may occur when riverbanks downstream of the source of the sediment erode or the channel moves laterally.

Permafrost Thaw and Slumping

Sedimentation is commonly caused by instability of riparian slopes leading to mass slumps, caused in part by permafrost thaw and/or precipitation infiltration surpassing soil saturation and resulting in degradation at a landscape level. Sediment may be released through thawing or degrading permafrost adjacent to a stream or draining into it. This may contribute to a lack of lateral channel stability. This has been observed in some spawning streams such as the Klondike River, Chandindu River, Porcupine River and others. Rivers such as the Teslin, Pelly and Stewart are also becoming less laterally stable.

In the unglaciated area, permafrost degradation varies from small slope failures to surface layer displacements and rare but massive slides. In the glaciated area, sloped and steep terrain are the primary areas of degradation. Massive slides associated with permafrost degradation are also found, particularly in the Porcupine River basin where there are many large failures into valley bottoms and rivers. Permafrost degradation in the Porcupine basin is changing flat grasslands as the permafrost thaws from below. The land surface sinks into wetlands with standing water. Lakes on the Old Crow flats and smaller wetland complexes are draining as the thermal aquicludes that retained the water melts. The contribution of sediment that had been held together by permafrost into streams can lead to a variety of problems for egg incubation.

Placer Mining and Other Anthropogenic Activity

Anthropogenic sources of sediment are related to placer mining, river engineering, quartz mining, and various other land and water uses. In streams where beds, banks, and surrounding terrain have been disturbed by past and continuing placer mining activity, particularly acute impacts to redds may occur.

This may be directly on Chinook spawning habitat, or through upstream disturbance that results in downstream sediment aggradation and may present a moderate risk to incubating eggs. It is acknowledged that current regulation of placer mining generally results in a lower risk of direct disturbance to eggs by placer mining. However, historical placer mining activity may have de-stabilized streambeds and riverine geomorphological regimes. The effects of these historical practices will remain until the land surface becomes stable.

Examples of watersheds where this limiting factor is thought to be an issue include portions of the Klondike, McQuesten, South Big Salmon, Big Creek, Donjek, Nisling, and Fortymile River watersheds. In considering this impact, workshop participants emphasized a need to consider and develop an understanding of cumulative watershed impacts.

Another anthropogenic impact of note is wildfire. When climate change-induced or human caused wildfires disturb riparian vegetation, it can destabilize banks and result in sediment inputs. Though, wildfire disturbance is rare and not a high risk to salmon at a watershed scale.

Further justifying the future moderate risk ranking for this LF, releases of sediment into a stream may take years to entirely move downstream. Problems with sedimentation may just be increasing from impacts that were 10–20 years ago. Other sediment releases may enter the creek and compound the effect of the current sediment loading

Gravel Starvation

Participants raised the issue of gravel starvation caused by hydroelectric dam disturbance to downstream sediment regimes. An in-channel placement of gravel was made to meet the regulatory requirements of the Mayo “B” Hydroelectrical project. However, there is not enough knowledge on the impact of this potential effect on the Yukon River Watershed. We considered the risk ranking to be a data gap, and that an awareness of this issue will remain relevant. Traditional Knowledge may be able to inform an understanding of this factor.

Hydrologic Variability

When high water occurs after spawning and before ice-up, redds may fill with the fine sediment and destruction of eggs may occur. A series of post spawning high-water events may have additive effects. Extreme high water may result in the scour of the redd and destruction of the eggs. The increased climatic and meteorologic variability and severity of rainfall events will increase the risk of high and late water stream and river flows.

5.1.4 Hydrology

LF 6: Mortality or fitness reduction resulting from altered timing, frequency, or magnitude of peak flows

Current Risk: Low, low confidence

Future Risk: Moderate

This limiting factor is closely related to LF 5 (unsuitable bed material) and has a current risk of low and a future risk of moderate. The effects to eggs of unfavourable flows are most serious when the high flows (or series of high flows) occur post-spawning. Eggs may be washed away if redds are scoured. Redds may be covered or filled by downstream moving sediment or left dry if channels shift due to high water

levels or flood. The effects of high flows on incubation have been examined for Yukon Chinook in Alaska in several studies but with varying results (Neuswanger et al. 2015; Jones et al. 2020; Murdoch et al. 2024; Feddern et al. 2024). For Canadian-origin Yukon River Chinook specifically, there was weak evidence for a decline in productivity associated with higher streamflows or precipitation during the incubation stage (Murdoch et al. 2024; Feddern et al. 2024). More fine-scale knowledge would be useful to determine if specific watersheds may be more vulnerable to negative effects from high flows for this life stage. However, it is likely that eggs deposited in unbuffered small streams are most affected, versus eggs in rivers and mainstem areas being less affected, and with eggs in lake headed systems least affected. Flows are buffered in spawning locations downstream of lakes due to their water storage capacity. The major Chinook spawning area in the Takhini River downstream of Kusawa Lake and extending to the dunes above the confluence with the Mendenhall River is a good example. Effects from the buffered flows will be limited and will have the smallest impact on eggs. In the Porcupine River, effects on eggs may be most severe in smaller streams and rivers around the outside of the central basin due a lack of upstream lakes and the very rapid drainage from permafrost landscapes. Effects may be moderate in larger rivers such as the Miner which supports the greatest densities of spawning Chinook. This is a result of these rivers being a sum of their parts and not being subject to basin wide intensity of rainfall.

LF 7: Mortality or fitness reduction resulting from altered timing, frequency, or magnitude of low flows or water levels

Current Risk: Low

Future Risk: Moderate

Chinook redds are deeply excavated, therefore eggs and alevins will be generally safe over the winter from variable flows. Uncertainty in early spring flows supports a current risk ranking of low rather than very low. Future risk is ranked as moderate given the expected hydrological and precipitation variability that will come from climate change. Fry emergence and early utilization during low spring stream flows may be affected in the absence of precipitation to augment flows and allow access to rearing habitats.

LF 8: Mortality or fitness reduction due to unfavourable water temperatures

Current Risk: Very Low

Future Risk: Low

Incubation begins when the fertilized egg is deposited in the redd. Development of the egg is largely a function of water temperatures within the redd. Eggs in non-buffered streams and rivers develop at a slower rate due to cooler water temperatures. Eggs in buffered waters downstream of lakes will develop more swiftly. In more southern areas such as the U.S. Pacific Northwest there have been concerns that warming may speed up fry emergence in advance of available food items. This speculative concern does not change the very low current risk with high confidence. The timing of food availability versus emergence has not been studied in the Canadian portion of the watershed. The issue of water temperatures has been, and will continue to be, a field of interest. We have entered a period of increased climate volatility and variability, justifying an increase to a low future risk.

LF 9: Mortality or fitness reduction due to low dissolved oxygen

Current Risk: Very low, high confidence

Future Risk: Very low, high confidence

All Chinook life stages require adequate levels of dissolved oxygen (DO) to survive, including eggs and alevin. Chinook will choose optimal redd locations to account for sufficient DO presence in the water, and other non-stationary life stages will adapt behaviour or physiological processes in the presence of reduced DO. It is therefore unlikely that reduced DO will inhibit Chinook survival, unless there is an upstream point source contaminant or discharge of anoxic water from an aquifer or wetland complex. Current and future risk levels are considered to be very low with high confidence.

Chinook spawn in flowing water. Chinook do not spawn in anoxic ground water discharges; therefore, eggs and alevins are not limited by low DO levels. However, there may be risk if there is an unexpected, large, and probably transitory discharge of anoxic water from an upstream aquifer or wetland complex. This is possible but highly unlikely to occur. There is, therefore, a very low current and future risk with high confidence.

LF 10: Mortality or fitness reduction due to unfavourable water chemistry

Current Risk: Low, low confidence

Future Risk: Moderate

All water in the Yukon River and its tributaries naturally contains substances that are potentially deleterious to Chinook in sufficient concentrations. Additionally, there tend to be multiple relatively small and localized sources of human related contamination throughout the watershed including those from mines, landfills, agriculture, roads and other activities. However, these substances are seldom in concentrations likely to cause stress or mortality to Chinook eggs and alevins located in spawning areas, justifying a low current risk. Looking into the future, additional risks may include episodic releases or the chronic effects of treated effluents from the quartz mines or municipal wastewater, and of any seeps or other releases related to them. Increased population, development, agriculture and infrastructure will also pose some degree of risk and justify a future risk ranking of moderate.

A local example of this risk presented itself in 2024 when a large heap leach failure and landslide at the Eagle Gold Mine occurred. The mine drains to Haggart Creek, tributary to the South McQuesten River, the McQuesten River and then the Stewart River before joining the Yukon River. The mine used sodium cyanide for gold extraction from ore. It remains to be seen how much sodium cyanide and other deleterious substances has entered, or will enter, the groundwater and then discharge from it or the streams draining the mine site. Sodium cyanide at high doses can be lethal to aquatic organisms, including all Chinook life stages. This is raising concern regarding impacts to Chinook and their habitats. Additionally, other substances of potential concern, including mercury, have been released into the aquatic environment because of the slide. Sampling of ground and surface waters is being conducted to determine the extent and concentration of potentially deleterious substances. This is a work-in-progress and will depend heavily on the nature of the amount and rate of water released in the spring of 2025 and water treatment and restoration activities.

LF 11: Mortality or fitness reduction due to contaminants, or deleterious substances

Current Risk: Low, low confidence

Future Risk: Moderate

This LF was assessed in conjunction with LF 10. Please refer to LF 10 for full description and risk evaluation.

5.2 Fry

Fry refers to juveniles from when they become free swimming after emergence from the gravel, through any downstream dispersal, rearing, overwintering and early spring feeding. When they start their downstream migration to the river delta and ocean, they are called smolts. The terms fry and juvenile are used interchangeably in this section.

5.2.1 Direct Anthropogenic Interactions

LF 12: Mortality or fitness reduction due to stress from anthropogenic activity

Current Risk: Low

Future Risk: Moderate

Note: Potential effects of Whitehorse Rapids Hydro Plant on the fry life stage are considered separately in LF 12a.

Chinook fry use a very wide range of habitats, most of which are not stressed by anthropogenic activities. Much of the Canadian Yukon River basin is remote and overlap of Chinook fry with anthropogenic activities is generally brief and/or transitory. This is particularly the case for non-natal rearing and overwintering streams.

Some rearing streams are found in areas of the Yukon that are populated or otherwise used by humans. Human activities may affect rearing streams and rivers or cause stress directly to fry. These include roads, placer and quartz mining, hydroelectric facilities, boating, agriculture and related activities. An emerging agriculture industry may be of some concern due to the consumptive use of water for irrigation. Irrigation may cause entrainment or impingement from water extraction or pumps or dewater lower reaches of tributary streams used by rearing Chinook. The effect of individual stressors is generally small and current risk to fry fitness is considered low. As development continues, risks will be additive to those assessed in the current context, therefore future risk is moderate. It should be noted that there are some placer mines where reserves have been exhausted, mining has ceased, and reclamation is complete; however, potential risks from these mines and associated infrastructure may remain into the future.

LF12a: Mortality or fitness reduction due to stress from anthropogenic activity – select populations impacted by Whitehorse Rapids Hydro Plant

Current Risk: Very High, high confidence

Future Risk: Very High

The Whitehorse Rapids Hydroelectric Generating Station requires juvenile Chinook to pass downstream over the spillway, through the power generation turbines or through the fishway. Recent studies led by Yukon Energy and with the collaboration of the Kwanlin Dün First Nation, Ta'an Kwäch'än Council and Carcross/Tagish First Nation found that mortality rates of juvenile passage downstream may approach 30% (Twardek et al. 2023a). The scale of this mortality rate justifies a risk ranking of very high in the present and future for this system. Additionally, there are concerns about potential injury and stunning

of juveniles or smolts making them susceptible to downstream predation. This presents a potentially significant limiting factor for juvenile populations affected by this hydroelectric facility. Yukon Energy has retained consultants to conduct studies on the downstream migration of Chinook and determine mitigative strategies (Twardek et al. 2023a). Additional studies will be in progress under the planned oversight of Yukon Energy and the Whitehorse Rapids Generating Station (WRGS) Technical Working Group.

Obstructing access of mammalian predators to the Whitehorse Rapids dam site provided protected nesting sites for gulls and terns. The nesting birds joined others to feed on fry and smolts in the tailrace of the dam and in the water downstream. Suggestions to leave fox-sized holes in the fence to discourage nesting were made but may not have been implemented. Fry and smolts are stressed as they pass downstream through the Whitehorse Rapids Hydroelectric Generating Station turbines or spillway. Surviving fry and smolts may then be vulnerable to predation.

5.2.2 Biological Interactions

LF 13: Mortality or fitness reduction due to competition

Current Risk: Low

Future Risk: Low

Chinook fry may compete for food and space with each other and other fish. Sampling to date has identified dipterans (true flies) as comprising most of the diet of fry during summer months (Mackenzie-Grieve 2005; Gutierrez 2011). There are thousands of species of true flies, which include black flies, mosquitoes and chironomids (non-biting midges) for example. Dipterans typically overwinter in ice as an egg or larvae, develop in the stream as water temperatures increase and then pupate and emerge from the stream to mate during the latter parts of summer. True flies are generally abundant in Chinook rearing habitat, though migration barriers in rearing streams such as beaver dams or elevated culverts may artificially induce competition by restricting access of fry to areas of upstream rearing habitats where there is an abundance of food.

Salmonids form a social structure to exploit optimal foraging habitats, where larger or more aggressive individuals benefit most (Fausch 1984; Nakano 1995). Competition between Chinook fry is therefore influenced by prey availability and quality and the preferred access to these prey. Von Finster (1987) observed larger fry in lower abundance above a beaver dam compared to downstream of this partial barrier, suggesting potential competition below the dam.

Both current and future risk rankings of competition are therefore low.

LF 14: Mortality or fitness reduction due to parasites, pathogens, or disease

Current Risk: Very low

Future Risk: Very low

A targeted parasite, pathogen or disease sampling program or study has not been completed in the Canadian portion of the watershed on wild Chinook fry or smolts. A significant amount of salmon fry sampling was conducted by Yukon First Nations, DFO and consultants. This sampling included all areas of the watershed. A major portion of the drainage basin was sampled by DFO over a 25-year period. Although Chinook fry were not specifically sampled for parasites, pathogens or disease, gross external

abnormalities would have been noted. The only reported observations of externally visible cysts in fry resulting from parasites in fry were in the Mayo River by EDI and in Clinton Creek by DFO (von Finster 2005, 2007). The Clinton Creek samples were found to contain a species of *Triaenophorous* (tapeworm). Of note, water levels in streams and rivers were low in both years and water temperatures were elevated at the time and location of sampling. No dead fry were observed in any other investigation. The apparent low rate of parasitized or dead Chinook over the extended period of sampling justifies a current and future risk of very low. No parasites or pathogens have as yet been identified in migrating smolts.

LF 15: Mortality or fitness reduction due to predation

Current Risk: Moderate, low confidence

Future Risk: Moderate

Fry are predated upon as they emerge, disperse down river, enter and ascend tributaries, overwinter and feed as waters warm in the spring. It is assumed that fry remaining in larger spawning streams will face a greater degree of avian and fish predation than those dispersing, particularly in lake outlet spawning systems, due to increased concentration of fry in one area. The current risk is moderate, but with low confidence. Workshop participants noted that substantial local knowledge exists regarding predation. The future risk will likely remain at moderate, though an acknowledgement that greater agricultural, residential, recreational land development and other uses may alter the presence of predators. The present assessment only considers Canadian freshwater habitat, therefore predation in any freshwater habitat in Alaska used by Canadian-origin Chinook have not been considered and pose a limitation to this assessment.

Significant concern exists about predation on fry by freshwater resident fishes, especially pike. The Government of Yukon has encouraged the catch and release of predatory fish (i.e., pike, lake trout, inconnu) in the sport fishery. This may be at the expense of increasing predation on Chinook fry and out-migrating smolts. At least one Yukon First Nation and Renewable Resources Council have requested less restrictive sports fishing regulations expressly to protect Chinook juveniles. Traditional Knowledge also suggests the reduction in Indigenous fisheries on resident freshwater fishes as other food sources became more widely available may have led to increased abundances of predators of Chinook, such as pike (R. Chambers, pers. comm.; S. Njootli Sr., pers. comm.).

In non-natal streams predation on fry is greatest when they are concentrated, which occurs downstream of obstructions to their upstream migration. Kingfishers have been observed fishing downstream of a beaver dam in Croucher Creek near Whitehorse. During observations in Croucher Creek, about 1% of the fry sampled in minnow traps showed beak marks from unsuccessful feeding attempts (von Finster, personal observation). Overwintering fry in smaller creeks may be confined by ice and become vulnerable to predation by mink (von Finster 2005). Downstream migrating smolts will be predated on but the rate at which this occurs is unknown.

Specific dynamics regarding heightened predation downstream of the Whitehorse Rapids Hydroelectric Generating Station are described in LF 12a above.

LF 16: Mortality or fitness reduction due to lack of quality or quantity of appropriate food items

Current Risk: Very Low

Future Risk: Low

Within the Yukon River, preliminary (and scant) information on Canadian Chinook fry diets indicate that dipterans (true flies) make up most of the diet. High flows in northern streams and rivers remove benthic organisms through erosion of attached individuals and periphyton by sediment and displacement downstream. Although the stream substrate does recolonize, benthic organisms are largely at the mercy of the next high-water event. A series of high-water events can reduce the amount of food that the fry require to build up fat to overwinter.

5.2.3 Physical Habitats

LF 17: Mortality or fitness reduction due to loss of access to rearing habitat

Current Risk: Low

Future Risk: Low

Note: Potential effects of Mayo River Hydro Plant on the fry life stage are considered separately in LF 12a.

Lack of access to rearing habitats results from obstructions to fry passage to upstream rearing habitat. The current risk due to loss of access to upstream rearing habitat is low as these obstructions are possible but infrequent. Expanding land and water development in the Yukon carries with it the potential for additional obstructions along non-natal and some natal streams.

Chinook can be denied access to existing rearing habitat by acts of nature (waterfalls, chutes, or log jams), humans (improperly placed and/or maintained culverts, dams, etc.), or beavers (dams). Most natural falls and chutes are stable and do not move. Log jams are transitory and can cause passage obstructions for a short or longer time. There are a limited number of problem culverts that obstruct fry to some extent. Although there is no active list of hanging culverts (i.e. where the outlet of the culvert is above the stream surface), when there is a proposal for stream construction or renewal, DFO works with proponents to update crossings to allow fish passage. Beavers and their dams tend to be most problematic for fry to access habitat, particularly during periods of low flows, as dams are easily built and maintained during those conditions. As stream flows increase, the overall barrier effect of beaver dams decreases. Of importance, relatively few beaver dams are total obstructions to upstream moving fry, but each dam is a partial obstruction. The numbers of fry that can use upstream habitat declines with each dam encountered.

The Porcupine River basin has a single road that crosses its headwaters and has no waterfalls. Beaver generally do not dam non-natal rearing creeks in the Porcupine watershed. In the unglaciated area near Dawson City, many smaller streams go subsurface before reaching larger rivers. All streams experience very rapid responses to rainfall and snow melt due to underlying permafrost. These sudden floods tend to burst dams and displace beaver colonies using open channels. Beaver, however, can more effectively exploit ground water fed spring brooks in the flood plains of rivers. Placer mines have stream crossings which may obstruct juvenile access.

In the glaciated area many streams are utilized by beavers. Damming may be both intensive with repeated dams in a single stream and extensive where the beaver dams are located in the headwaters of many streams. Many of these intensely impacted streams can be observed from the Alaska Highway between the new road around the recent (2023) permafrost slide to the Takhini River crossing and the

Takhini River Bridge. The surface of each pond reaches the toe of the next dam upstream. Quantification of juvenile habitat impacted by beaver dams has not occurred, but is believed to be minimal across the entire watershed.

LF 17a: Mortality or fitness reduction due to loss of access to rearing habitat – on the select populations impacted by Mayo River Hydro Plant

Current Risk: Moderate

Future Risk: Moderate

Wareham Lake is the head pond of the Mayo River Generating Station. The Wareham Lake dam is a total obstruction to all upstream migrating adult Chinook. It also obstructs any fry that could have moved upstream from the Mayo River. Before the facility's construction in the early 1950s, Chinook adults spawned up to the outlet of Mayo Lake and beyond. Spawning also had been reported in tributary streams above the dam. Overall, the Mayo River Chinook population would have been a major stock as defined by Brown et al. (2017). Fry would have reared and overwintered in the now-obstructed river and dispersed into its tributaries. As there remains some rearing habitat below the dam, but much habitat was lost, the suggested risk ranking is moderate.

LF 18: Mortality or fitness reduction due to unfavourable channel form and/or timing or duration of sediment loads

Current Risk: Low

Future Risk: Moderate

Note: Potential effects of placer mining on juvenile life stages are considered separately in LF 18a.

The current risk for this limiting factor is low as unfavourable or unstable channel form is considered to be rare but present throughout the watershed. This risk is likely to increase until the amount of sediment added to the channel from permafrost thaw ends. Of note, the sediment may be of a wide range of sizes. The finest particles will pass through the system as total suspended sediment and will be visible as turbidity. As particle sizes increase, they will be suspended at high(er) flows and be stable or move downstream as bed load at low(er) flows. Particles larger still will move only at high flows as bed load. Climate change is predicted to increase the variability of weather and the severity of weather events. Greater sediment loads and/or greater flows will probably result in unstable alluvial channels.

Basin wide, the largest inputs of sediment are believed to be related to permafrost thaw/degradation. An important consideration is that some of the resulting landslides will be composed of a wide range of particle sizes. This can provide future structure to the beds and banks of streams, and in-channel sorted deposits of gravel or cobble. Wildfires and permafrost thaw often co-occur, as the overlying forest otherwise insulates the underlying frost (Lipovsky et al. 2005). The loss of the insulating vegetation results in ground instability, slides and gullying.

There have been increased stream and river flows over the last 15 years. Wildfires have a periodicity: that is, they burn, the land revegetates and then they burn again. Sediment input from permafrost degradation is expected to increase. Downstream effects will continue, in part as increased climatic variability may result in more- and greater high-water events.

LF18a: Mortality or fitness reduction due to unfavourable channel form and/or timing or duration of sediment loads – select systems with placer mining impacts

Current Risk: Moderate

Future Risk: Moderate

Much or most of the placer mining takes place on portions of creeks well upstream of salmon fry utilization (Figure 9), but effects to channel form may remain due to downstream sedimentation. Though the overall watershed risk of sedimentation on fry is understood to be low, in select systems with placer mining that occurs adjacent to or upstream of fry rearing habitat, sedimentation will be a more significant issue. This justifies an augmented risk ranking relative to LF 18. Research to understand where this effect is experienced and how placer related sediment impacts rearing fry in these locations is needed. Traditional Knowledge may be able to inform this understanding as well.

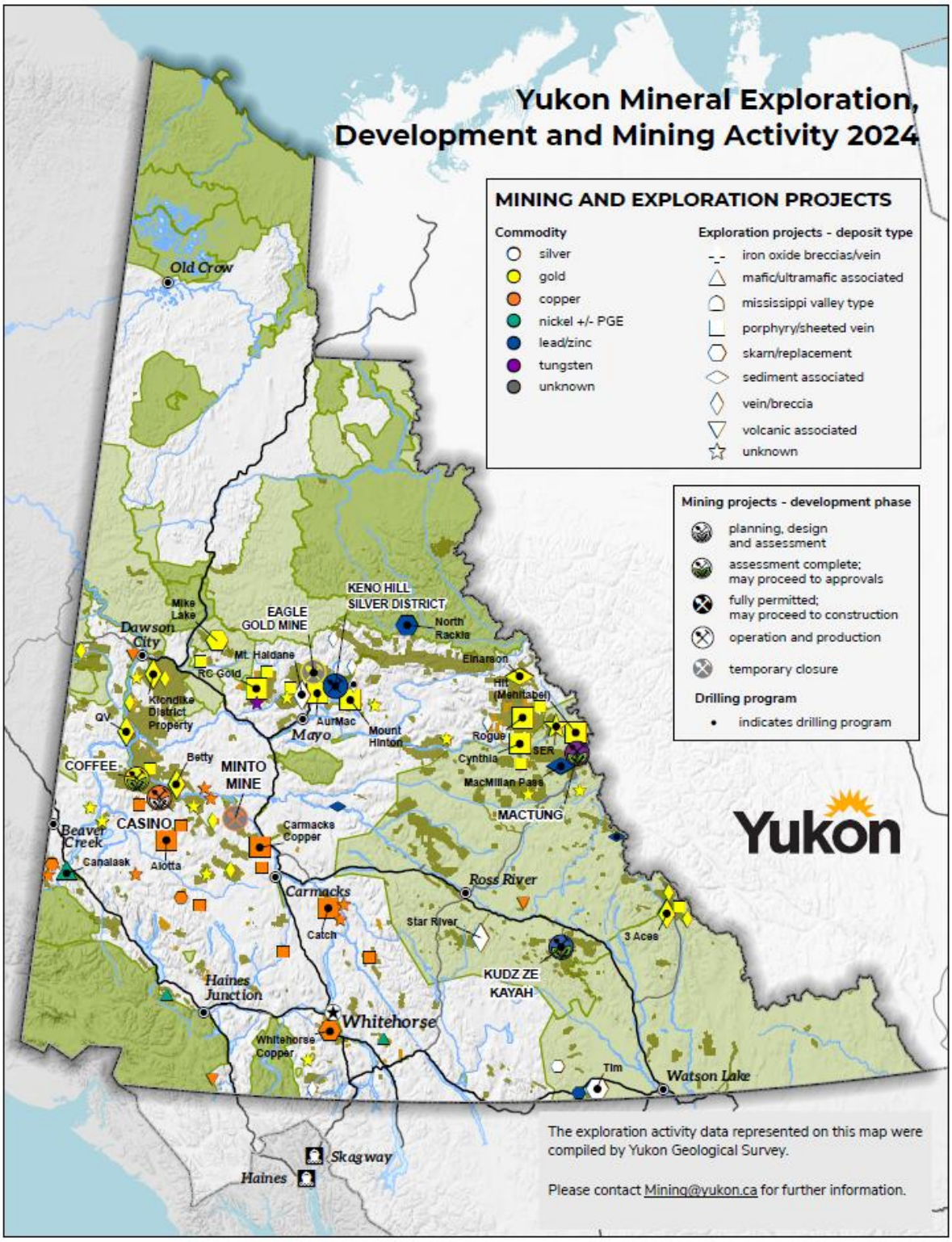

Figure 9. Yukon mineral exploration, development and mining activity in 2024, from Government of (2024).

5.2.4 Hydrology

LF 19: Mortality or fitness reduction due to altered timing or magnitude of peak flows causing flushing

Current Risk: Low, low confidence

Future Risk: Moderate

There is some evidence to suggest that high flows may negatively affect juvenile Chinook in Yukon and Alaska (Cunningham et al. 2018; Jones et al. 2020; Feddern et al. 2024, Murdoch et al. 2024). High flows have the potential to reduce juvenile feeding efficiency, cause displacement from optimal rearing habitats, and degrade habitat quality by increasing erosion and sedimentation. In particular, it was found that productivity of Canadian-origin Chinook decreased in years associated with higher precipitation during freshwater juvenile rearing from 1985–2012 (Murdoch et al. 2024). However, a similar study that examined estimated median stream flows during juvenile rearing did not find a relationship for Yukon River Chinook (Feddern et al. 2024). As summer precipitation is projected to increase in the Yukon (Bush and Lemmen 2019), the future risk is considered moderate.

More site-specific observations would be useful to understand the potential risk of high flows on the juvenile life stage, and how it may vary across drainages and years. In particular, it is possible that the juvenile Chinook residing in the unglaciated area may be more vulnerable due to a lack of buffering flows. In one example where this has been observed, after a prolonged dry period, heavy rains caused a sudden flood in a small stream underlain by permafrost. The creek was a tributary to the west bank of the Yukon River near Dawson and included Swede and Excelsior creeks. Exposed stream banks thawed, dried, and then eroded very quickly when challenged by the flood. The water in the creek came up very swiftly and flowed as a slurry which displaced fry downstream to the Yukon River. Sampling after the event captured very few Chinook fry.

As noted above, unbuffered or poorly buffered streams or rivers will be at the mercy of high water events. The highest impact will be seen with the very rapid hydrologic response of tributaries in the unglaciated and Porcupine River basins. Additionally, in areas where placer mining has occurred, there may be increased dislodging and transport of sediment. This may reduce the ability of the stream to produce food organisms. Higher risk is also possible on systems where dam-controlled flow is not managed with Chinook habitat impacts in consideration.

LF 20: Mortality or fitness reduction due to altered timing or magnitude of low water levels causing stranding

Current Risk: Low, low confidence

Future Risk: Moderate

Note: Potential effects of overwintering ice related effects on the fry life stage are considered separately in LF 20a.

Stranding of fry occurs but tends not to be attributable to altered timing or magnitude of low water. The stranding that does occur is most common in rivers with unstable beds. As water levels decline from spring freshet or high-water events, pools may remain in side channels stranding the fry within them. If this is identified the stranded fry can be salvaged with salmon egg baited minnow traps and returned to the stream. Overall, this is a transitory impact in some rivers in the Canadian portion of the watershed.

Stranded Chinook fry have not yet been documented in the Porcupine River. Stranding has been observed and fry salvaged in several locations along the Klondike River (Smart 2006). This is immediately north of the unglaciated area and receives most of its flow from the glaciated Ogilvie Mountains to the north. In the glaciated area, Chinook fry stranding has been reported from the Minto Flats area of the Yukon River, however, the fry may not have been Chinook as chum spawn (and emerge) in the same general area. There are reports of stranding from the mid-Pelly River in the Faro/Ross River area. All areas identified have unstable channels. In addition, during large flooding events, Little Salmon/Carmacks First Nation conducted fry salvages around the Nordenskiöld River and at least one Chinook was released back into the river. Smolts are unlikely to be affected.

LF 20a: Mortality or fitness reduction due to low water levels causing ice related mortality during overwintering

Current Risk: Moderate

Future Risk: High

Flows of groundwater from aquifers will generally increase during periods of low barometric/air pressure (Spane 2002) which can cause overflow on lakes, ponds, streams or wetlands. A layer of water saturated snow will cover the ice surface, and frazil ice may clog under-ice channels in streams and freeze. When this occurs, water will flow over the ice surface and form ice sheets over the valley floor; this is termed icing or aufeis. The stream channel under the aufeis may dry (Bradford et al. 2001). Groundwater discharge variability contributes to aufeis formation.

Croucher Creek near Whitehorse is representative of non-natal rearing and overwintering streams. Bradford (2001) found that the creek did not have continuous wetted habitat due to aufeis formation. Chinook did not survive under the areas overlain by aufeis but did survive in areas close to ground water releases that were not covered by aufeis. More Traditional Knowledge, local knowledge and overwintering habitat research is needed; however, participants identified this limiting factor as having a moderate current risk and potential for high future risk.

The increase in future risk for this limiting factor is due to the experienced and expected increase in winter temperature variability, which may increase variability in ice formation and groundwater flow, causing fish to experience unpredictable overwintering conditions.

5.2.5 Water Quality

LF 21: Mortality or fitness reduction due to unfavourable water temperatures

Current Risk: Low, medium confidence

Future Risk: Moderate

Rearing Chinook in the Yukon River basin have a general temperature range in which they can survive and grow. The USFWS (2005) consider a preferred daily temperature range for the freshwater stages of all juvenile salmon species to be between 10°C and 17°C. This range was determined for cold water fish (as the USFWS defined) in the Pacific Northwest of the continental United States. There is compelling evidence that the range for Chinook salmon may be wider in the Yukon River (von Finster 2021). Adherence to temperature ranges developed elsewhere for general groups of species should be considered carefully until Yukon specific ranges are determined. Chinook fry growth is slowed by cooler

water temperatures, and growth can halt during very cold conditions. In Yukon, growth is also slowed in cooler streams (Hunka et al. 1988).

Juveniles usually have access to cold groundwater discharges in unglaciated areas. If those groundwater discharges are low in oxygen or anoxic, juveniles can cool their bodies without passing the discharging ground water through their gills. After freshet fry may remain in spring brooks on the flood plains of rivers. The spring brooks in these floodplains tend to be cold, and the Chinook using them remain smaller than in those in warmer water. Little information has been collected in the Porcupine River basin for assessment. In the glaciated area of the Canadian portion of the watershed, the high diversity of habitats provides a wide range of water temperatures along and within creeks. High temperature effects to fry have only been observed in juveniles remaining in isolated pools following early season high flow events. Many streams have headwaters on the Yukon plateau and remain cold or cool throughout the summer. The streams that drain along river valleys tend to be warmer. In the absence of groundwater discharges into these streams they may approach or exceed temperature thresholds. The effects of cold water either under ice or as open water during winter have not been studied to determine effects to fry or their habitats. The future risk continues to be low.

Water temperatures are likely to be of sustained interest especially due to impacts on adult life stages (described in LF 87). It may justify examination of existing information held by Government of Canada, Yukon governments, Yukon First Nations and others to determine which streams are most vulnerable.

LF 22: Mortality or fitness reduction due to low dissolved oxygen

Current Risk: Low, with high confidence during the open water period and low confidence under ice

Future Risk: Low

Low dissolved oxygen (DO) does not pose risks to rearing Chinook during the summer open water period. Depressions in DO in the summer can be found in wetlands or in deeper lakes, though juveniles tend not to use these habitats. Low to absent DO may affect overwintering juveniles. This justifies the current risk of low rather than very low. Future risk is also low as the rationale given below will continue to apply.

Winter DO regimes have been poorly documented. This is in part due to the difficulty in conducting fieldwork. Insufficient information has been collected in the Porcupine River to allow assessment of low winter DO concentrations though Traditional Knowledge could inform an understanding of this phenomenon there. At the northern edge of the unglaciated area fry have been found that died from lack of oxygen. They were found in the Germaine Creek Avulsion area. Water had drained from a wetland and had entered an overwintering area which killed juveniles that could not escape the site. It is expected that spring brooks that are not augmented by hyporheic flows along major rivers in the unglaciated, glaciated and Porcupine areas of the Canadian portion of the watershed will pose the same risk to overwintering juveniles.

LF 23: Mortality or fitness reduction due to unfavourable water chemistry

Current Risk: Low, low confidence

Future Risk: Moderate

Most naturally existing water in the Yukon River and its tributaries contains substances that could be deleterious to Chinook. The existing concentrations of these substances are not likely to cause stress or mortality to juveniles, justifying a risk ranking of low. Substances that are acutely deleterious and used by humans are almost always stored, transported, used and disposed of appropriately and are unlikely to result in much risk. The wide range of substances that could be deleterious are not used in quantities that would support risks of mortality (i.e., insect repellent, soap, cooking oil, asphalt, etc.). The future risk of moderate is based on increased deleterious substances from larger human populations and associated land development, mining and other industrial establishments, the web of infrastructure that supports it, chemical spills, and other releases.

Permafrost thaw and resultant slumping have introduced sediment and suspended sediments that may include deleterious chemicals or substances. This is beginning to be observed at high latitudes and will likely increase in prevalence with climate change. Therefore, a moderate future risk is further justified.

There are some possible exceptions, however. They include the Faro Mine Complex, which discharges treated effluent into Rose Creek, tributary to Anvil Creek and then the Pelly River; the United Keno Hill Mining Complex, which discharges to Flat Creek, tributary to the South Mcquesten River, the Mcquesten River, and then the Stewart River; Mt Nansen, which discharges treated effluent to Dome Creek, tributary to Victoria Creek and then the Nisling River and others. Both Rose/Anvil Creeks and the South McQuesten have populations of rearing and possibly overwintering Chinook. Fry would be present in the Nisling River, but at some distance downstream from the mine. Effects of deleterious substances would be of most concern during the winter due to lower dilution and chronic effects may occur and reduce the fitness of overwintering Chinook. However, these effects are likely to impact very small portions of the population unless there was a major release.

LF 24: Mortality or fitness reduction due to contaminants or deleterious substances

Current Risk: Low, low confidence

Future Risk: Moderate

This LF was assessed in conjunction with LF 23. Please refer to LF 23 for full description and risk evaluation.

5.3 Smolt

This section pertains to the transient smolt stage within the estuarine environment. As they smolt, they undergo physiological changes to adapt to saltwater and head into the Yukon River estuary for a short period before entering the Bering Sea. This life stage marks a critical transition, where food access and availability, predation, and environmental conditions may heavily influence survival and future returns.

5.3.1 Biological Interactions

LF 26: Mortality or fitness reduction due to competition for prey

Current Risk: Data Gap

Future Risk: Data Gap

There is limited knowledge of competition during the marine smolt life stage. During one three-year study, Miller et al. (2016; 2020) reported substantial overlap of Chinook diet with coho salmon in the

Yukon River estuary. Both species preyed on fish, including chum and pink salmon, and insects. However, some differences in diet were apparent, with more diverse diets of Chinook suggesting more opportunistic feeding behaviour compared to coho. Future work may help explore the possibility of competition between these species occurring during the transient period spent in the estuary channels.

LF 28: Mortality or fitness reduction due to predation

(Please note that the following description is also relevant for the juvenile marine life stage under LF 43)

Current Risk: High / Data Gap, medium confidence

Future Risk: High / Data Gap

The early marine period is expected to be a critical life stage for growth and survival, with potentially high vulnerability to size-selective predation (Beamish and Mahnken 2001). Further, individuals that are able to reach larger sizes faster will have access to a wider variety of prey species, including larger fish prey, enabling increased growth and lowering the predation risk. It is expected that predation risk may decline as Chinook achieve larger sizes during their first summer in the estuarine and nearshore marine environments. However, there is currently no research examining the predation risk for young Chinook during their early marine period, making this issue a potentially important data gap. In particular, it will be important to understand if predation pressure is changing along with climate-related ecosystem shifts. For example, increased predation risk could be linked to warmer temperatures if predators adapted to warmer conditions are shifting their distributions further north over time.

LF 29: Mortality or fitness reduction due to lack of access and availability of appropriate food

Current Risk: Moderate, low confidence

Future Risk: High

This limiting factor is considered directly in conjunction with limiting factor 35 (mortality or fitness reduction due to direct impacts of water temperature for the smolt-estuarine life stage) below. Please see the section for further information.

5.3.2 Physical Habitat

LF 31: Mortality or fitness reduction due to unfavourable channel form or sediment loads

Current Risk: Data Gap

Future Risk: Data Gap

Permafrost thaw and coastal erosion in northern regions is increasing, with potential consequences for habitat quality and quantity in estuarine and nearshore environments. Local and Traditional knowledge available for communities located near the mouth of the Yukon River and on the nearby coast (e.g., St Mary's, Emmonak, Hooper's Bay) indicated that increased erosion, river widening, and more sandbars have been observed over time in the lower river (Moncrieff et al. 2009). However, more information is needed to understand the extent and severity of these changes in channel form and sedimentation, as well as how Chinook may be affected during their estuarine life stage.

5.3.3 Water Quality

LF 35: Mortality or fitness reduction due to direct impacts of water temperatures

(Please note that the following description is relevant for both the smolt-estuarine and juvenile marine life stage under LF 47 due to the inability to adequately distinguish potential effects of water temperature by life stage)

Current Risk: Moderate, medium confidence

Future Risk: High

A warming climate has the potential to affect juvenile Chinook growth and overall health due to increases in metabolic demand (i.e., more energy required at warmer temperatures) as well as potential changes in the quality and quantity of prey species. The U.S. National Marine Fisheries Service northern Bering Sea (NBS) surveys provide insight into how warming may be affecting Chinook diet and the amount of energy stored in their bodies (energy density) during their first summer at sea (Murphy et al. 2023). In warmer years, juvenile salmon experience changes in their feeding patterns resulting in lower stomach fullness and a decline in piscivory (i.e., eating fish). However, Chinook energy density does not show similar declines and instead appears to increase with warming to a point, after which there is some evidence for a slight decline in 2019, which was the hottest year on record (Figure 10; Murphy et al. 2023). Together, these results suggest that juvenile Chinook salmon have been able to adequately compensate for changing diet in warmer years over the 2009–2021 period (Garcia and Sewall 2021; Murphy et al. 2023). However, more frequent and longer future heatwaves may lead to greater disruptions in the Bering Sea ecosystem prey base with potentially negative implications for juvenile Chinook if they are unable to adapt to ongoing changes (Garcia and Sewall 2021; Murphy et al. 2023).

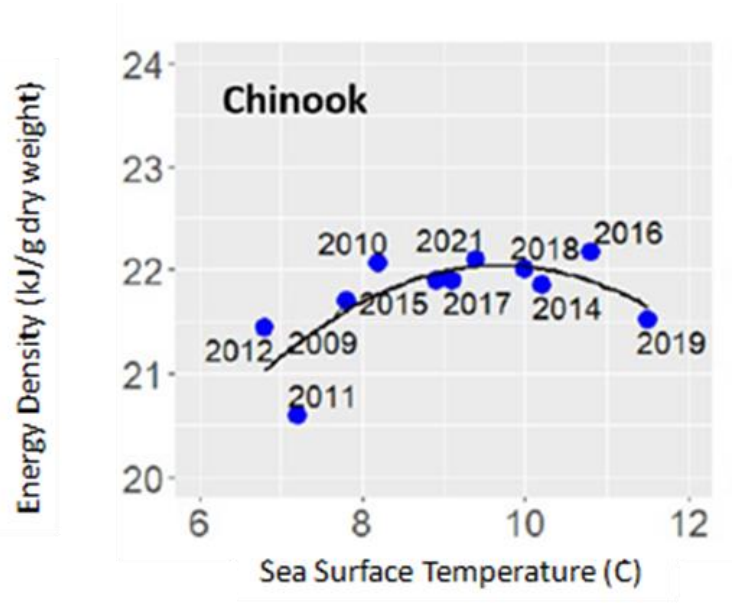

Figure 10. The relationship between juvenile Chinook energy density (kJ/g dry tissue mass) and sea surface temperature from samples obtained during the northern Bering Sea Ecosystem and surface trawl surveys 2009–2021. Adapted from Murphy et al. (2023).

The relationship between early marine temperature and the number of juvenile Chinook in the marine environment produced per spawner is not significant, suggesting that there is no strong direct influence of temperature on early marine survival during their first summer at sea (Murphy et al. 2021; Howard and von Biela 2023; Murdoch et al. 2024).

There are other potential pathways for limiting factors relating to the early marine stage that are being explored. For example, warmer winters and a decrease in ice cover in the estuary prior to smolt outmigration have been related to an increase in early marine survival, possibly due to an increase in food supply (Murphy et al. 2021). Recent years of relatively high ice cover in the Yukon River estuary may have been an important limiting factor for Canadian-origin Yukon River Chinook survival (Murphy et al. 2021), however Bering Sea ice coverage is expected to decline with climate change projections. In addition, warmer spring temperatures and earlier ice break up have been linked to earlier marine entry of outmigrating smolts (Bradford et al. 2008; Howard et al. 2017), which may allow for greater growth and survival during this critical early marine life stage (Cunningham et al. 2018; Murdoch et al. 2024). Warmer temperatures during the first spring and summer at sea may also benefit growth, as juvenile Chinook were found to be larger in warmer years during the NBS surveys (Howard et al. 2019). However, the influence of early marine temperature on growth may vary over time and depend on concurrent shifts in prey availability. For example, negative effects of warming on early marine growth were observed for Chinook during the 2002–2010 period, possibly owing to the decline of high quality prey fish species like capelin (Yasumiishi et al. 2020). Another study found that Yukon River Chinook stomach fullness was unrelated to water temperature during the smolt life stage in the delta over a three-year period (Miller et al. 2020). Finally, increasing temperatures during the early marine life stage have also been correlated with an increase in the number of early returning adult Chinook (i.e., “jacks”; Murphy et al. 2021). It is possible that warmer early temperatures may influence the maturation schedule of these Chinook, resulting in smaller sized returns (Siegel et al. 2017).

In summary, during the early marine period, Chinook are influenced both positively and negatively by warming temperatures and concurrent shifts in the available prey species. Importantly, juvenile Chinook salmon appear to shift their diets in response to warmer temperatures in the marine environment, consuming less fish and having emptier stomachs. There is also evidence that their body condition (energy density) may have declined during 2019 which was notably the warmest summer on record. It is possible that continued warming in the northern Bering Sea may negatively affect juvenile Chinook growth if they are unable to find enough high-quality prey to offset their growing energy demands. In contrast, there is some evidence that past warming has benefited Chinook during the early marine life stage, possibly due to earlier marine entry and/or greater food availability in spring and early summer. Based on the mixed results observed, the risk ranking is determined to be moderate at this time with the potential to move to higher risk following continued warming.

LF 37: Mortality or fitness reduction due to unfavourable water chemistry

(Please note that the following description is relevant for all marine life stages under LFs 49 (marine juvenile), 62 (immature), and 75 (adult))

Current Risk: Low, low confidence

Future Risk: Low, low confidence

The potential for ocean acidification to impact marine organisms is a growing concern with climate change. The Bering Sea ecosystem may be disproportionately vulnerable to ocean acidification due to its cold and carbon rich waters that are naturally more corrosive than other marine regions worldwide (Siddon et al. 2023). The risk of ocean acidification in the Eastern Bering Sea has been closely monitored and reported annually (Siddon et al. 2023), with the focus on deep waters where effects are expected to be greatest. There is some evidence to suggest that king crab species are already being negatively affected by ocean acidification in the Bristol Bay region (Litzow et al. 2025), due to their reliance on deep water habitats. Ocean acidification risks are expected to be greater for crabs and other species that use calcium carbonate for shells or skeletal structures.

In contrast, salmon species are relatively less likely to have experienced the effects of ocean acidification directly, however, indirect effects through changes in the food web may be more likely in the future with the growing risk of ocean acidification. Research examining the effects of acidification on salmon species is currently limited but suggests that more acidic waters may negatively impact prey detection and growth (Ou et al. 2015; Williams et al. 2018). In addition, there is evidence to suggest that salmon may have some ability to adapt to changes in acidification (Frommel et al. 2020, 2024). Given the potential for adaptation, the future risk is considered to remain low with low confidence due to the limited available information.

5.4 Juvenile (Marine)

This section pertains to the marine juvenile life stage, which refers to when Chinook salmon have left the estuarine environment and enter the shallow shelf of the Bering Sea (Figure 6). Their growth, migration, and survival during this period are shaped by ocean conditions, predation, and temperature. This stage typically lasts for one year, until the fish are old enough to move offshore.

5.4.1 Biological Interactions

LF 41: Mortality or fitness reduction due to competition for prey

Current Risk: Data Gap

Future Risk: Data Gap

Knowledge of juvenile Chinook diet and potential overlap with other species comes from the annual northern Bering Sea surveys (years 2003–present; Murphy et al. 2023). Although there may be some diet overlap of varying degrees between all juvenile salmon in the northern Bering Sea, coho appear to represent the species with the highest potential overlap with Chinook during this period (Murphy et al. 2023). Juvenile Chinook are also found to be in relatively shallower waters compared to pink and chum salmon during this period (Riddell et al. 2018) and are generally larger in size (Murphy et al. 2023) which likely reduces the potential for competition. It is also possible that Yukon River Chinook face more competition with other Chinook populations originating from rivers further south in warmer years (Murphy et al. 2023). However, the potential influence of competition during the juvenile marine life stage remains unknown as there are currently no studies that have focused on this topic.

LF 43: Mortality or fitness reduction due to predation

Current Risk: High / Data Gap, medium confidence

Future Risk: High / Data Gap

This limiting factor is considered directly in conjunction with limiting factor 28 (mortality or fitness reduction due to predation for the smolt-estuarine life stage). Please check LF 28 for further information.

LF 44: Mortality or fitness reduction due to lack of access and availability of appropriate food

Current Risk: Moderate, medium confidence

Future Risk: High

This limiting factor is considered directly in conjunction with limiting factors 35 (mortality or fitness reduction due to direct impacts of water temperatures for the smolt-estuarine life stage) and 47 (mortality or fitness reduction due to direct impacts of water temperatures for the marine juvenile life stage). Please see those sections for further information.

5.4.2 Water Quality

LF 47: Mortality or fitness reduction due to direct impacts of water temperatures

Current Risk: Moderate, high confidence

Future Risk: High

This LF is considered in conjunction with LF 35 (mortality or fitness reduction due to direct impacts of water temperatures for the smolt-estuarine life stage). Please see LF 35 for more information.

LF 49: Mortality or fitness reduction due to unfavourable water chemistry

Current Risk: Low, low confidence

Future Risk: Low, low confidence

This LF was assessed in conjunction with LF 37 (mortality or fitness reduction due to unfavourable water chemistry for the smolt-estuarine life stage). Please refer to LF 37 for full description and risk evaluation for all marine life stages.

5.5 Immature (Marine)

This section pertains to the immature life stage, which refers to the marine stage following the first summer spent in the Bering Sea when salmon begin to move away from nearshore habitats to pelagic (offshore) habitats (Figure 6). Their growth, migration, and survival during this period are influenced by ocean conditions, prey access and availability, and predation.

5.5.1 Direct Anthropogenic Interactions

LF 52: Mortality or fitness reduction due to fishing – direct effects of U.S. groundfish fisheries

Current Risk: Low, medium confidence

Future Risk: Low

Note: Potential additional effects of fishing on the immature marine stage are considered separately in LF 52a and 52b. Please note that the following descriptions in 52a and 52b are also relevant for the adult marine life stage under LF 65.

After their first summer at sea, immature and maturing adult (ages 3+) Canadian-origin Yukon River Chinook are vulnerable to incidental capture (i.e., bycatch) by groundfish fisheries in the Bering Sea (Ianelli and Stram 2018). The risk of Chinook bycatch in U.S. fisheries has been well documented, particularly for the U.S. Bering Sea-Aleutian Islands (BSAI) pollock fishery which makes up approximately 88% of the Chinook catch in this region (JTC 2024). The U.S. BSAI pollock fishery is considered one of the most regulated and monitored fisheries worldwide, with 100% observer coverage and abundance-based bycatch caps that are reduced in response to low run sizes of Alaskan and Canadian Chinook (JTC 2024). However, the potential impacts of Chinook bycatch by foreign fisheries in the Bering Sea outside of U.S. waters are currently unknown (Schindler et al. 2013). Notably, historical driftnet fisheries reported high catches of Chinook in the high seas outside of U.S. and Russian territorial waters (NPAFC 2017). However, the fishery was banned following the Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean in 1992 (NPAFC 2023).

The risk ranking of U.S. fishery bycatch on Canadian-origin Yukon River Chinook is considered to be low based on the available information and the assumptions described below. On average, 36,000 Chinook salmon were captured per year as bycatch in the Bering Sea by U.S. fisheries over the 1991–2024 period (JTC 2025), and most recently an estimated 10,458 Chinook salmon were caught as bycatch in 2024 (JTC 2025). Notably, this annual bycatch average includes Chinook salmon from multiple populations and not just Canadian-origin Yukon River Chinook. Further, because some natural mortality in the ocean is expected, many of these salmon would not have returned as mature adults. Therefore, in order to understand the impact of bycatch on returning adult in-river run sizes, information on marine survival rates, genetic and age stock composition, and salmon maturity schedules are used to produce an 'adult equivalents' bycatch value (Ianelli and Stram 2015). Using this method, it is estimated that bycatch from the U.S. pollock fisheries have resulted in an average annual loss of approximately 850 returning Canadian-origin Yukon River Chinook adult salmon over the 1994–2021 period (Ianelli and Stram 2018; JTC 2025; Figure 11). Bycatch-related mortality has fluctuated over the years, with more recent years (2010–2021) demonstrating lower than average impacts ranging from approximately 350–800 returning adult salmon. Further, new regulations instated in 2011 and 2016 to prevent higher bycatch are likely to maintain these lower impacts into the future (JTC 2025). When compared to adult spawning run sizes, bycatch-related mortality translates into an average annual loss of 1% of the overall run size for Canadian-origin Yukon River Chinook salmon and 1.8% of the estimated spawners (Figure 11; Ianelli and Stram 2018; JTC 2025). The most recent data available (2021 run year) estimated a bycatch of 493 Canadian-origin Chinook salmon (JTC 2025).

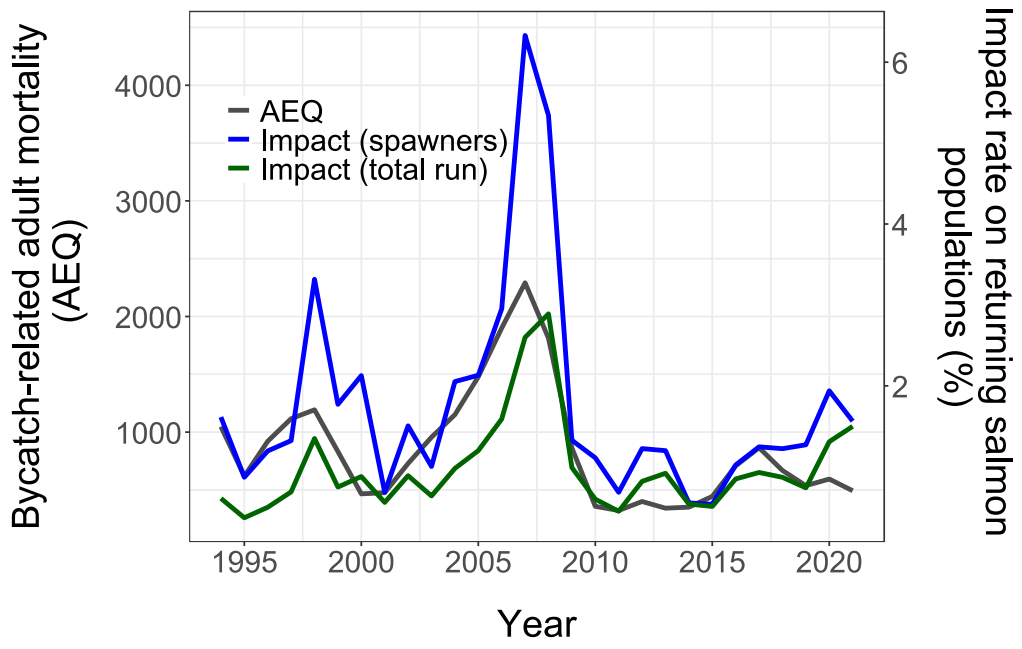

Figure 11. Impacts of U.S. BSAI pollock fishery bycatch on Canadian-origin Yukon River Chinook mortality at the mature adult stage (Adult Equivalents = AEQ; grey line) and resultant impacts (%) on the number of returning spawners (blue line) and annual run size (green line) over the 1994–2021 period. Adult Equivalents represent the number of salmon taken by the fishery that would have returned as adults to the Yukon River. Data from Ianelli and Stram (2018) and JTC (2025), and estimated number of spawners and total run size are derived from JTC (2025).

LF 52a: Mortality or fitness reduction due to fishing – indirect effects

Current Risk: Data Gap

Future Risk: Data Gap

Industrial-scale fisheries may influence the food web dynamics in the Bering Sea, including reducing prey fish for Chinook salmon (Schindler et al. 2013). For example, it is thought that historical overfishing of pollock by the foreign trawl fleet may have indirectly impacted Alaskan-origin salmon (Schindler et al. 2013). There is also some evidence that Chinook may feed on pollock offal from U.S. Bering Sea fisheries, which could be an important source of the *Ichthyophonus* parasite (Buser et al. 2009; refer to the *Ichthyophonus* section for more information). However, documented evidence of large-scale marine fishing effects via food web changes on Chinook remains limited.

Potential degradation of benthic habitat from bottom trawls is estimated in the annual Bering Sea Status Ecosystem reporting (Siddon 2023). Northern Bering Sea habitat degradation is very low (<2%). Southern Bering Sea habitat degradation is estimated higher but has declined over time (from approximately 10% to 6%) due to changes in fishing practices.

LF 52b: Mortality or fitness reduction due to fishing – Alaska Peninsula and Aleutian Islands Management Area ("Area M")

Current Risk: Low, medium confidence

Future Risk: Low

Area M is a commercial fishing management area surrounding the Alaskan Peninsula and Aleutian Islands that includes fisheries mainly targeting sockeye salmon (Russell 2023). There is increasing concern that fishing in this region could be contributing to chum declines in particular from the Arctic-Yukon-Kuskokwim region, as chum may use this region as a migratory corridor and large numbers of chum have been previously reported as catch (Russell 2023). Fisheries from the Area M North Alaska Peninsula within the southern Bering Sea report relatively minor incidental capture of Chinook (average of 1,879 Chinook per year over the 2012–2021 period; Russell 2023), however, the origins of these fish are currently unknown due to a lack of genetic testing. Although there are Chinook systems throughout the Alaskan Peninsula that many of these salmon are likely returning to, future work understanding the origin of Chinook caught incidentally in these fisheries would be useful to quantify the potential impact on other populations that may use southern Bering Sea habitats periodically. Canadian-origin Yukon Chinook are not known to use the Gulf of Alaska habitat, and are not expected to be impacted by fisheries in the Gulf of Alaska.

5.5.2 Biological Interactions

Pink salmon abundances in the North Pacific Ocean have steadily increased since the mid 1970s (Figure 12; Ruggerone et al. 2023; Connors et al. 2025). In addition to hatchery production, warming of the North Pacific Ocean is likely a contributing factor for increased pink salmon abundances, as they appear better suited to warmer temperatures in comparison to longer-lived and larger salmon such as Chinook (Davis et al. 1998). Of these salmon, approximately 16% are of hatchery origin from North America (e.g., Alaska, British Columbia) and Asia (e.g., Russia, Japan) based on data over the 2000–2015 period (Ruggerone and Irvine 2018). However, it is important to note that North American hatchery pink salmon are understood to not be present in the Bering Sea, leading to a lap of physical overlap between North American hatchery pink salmon and Yukon River Chinook.

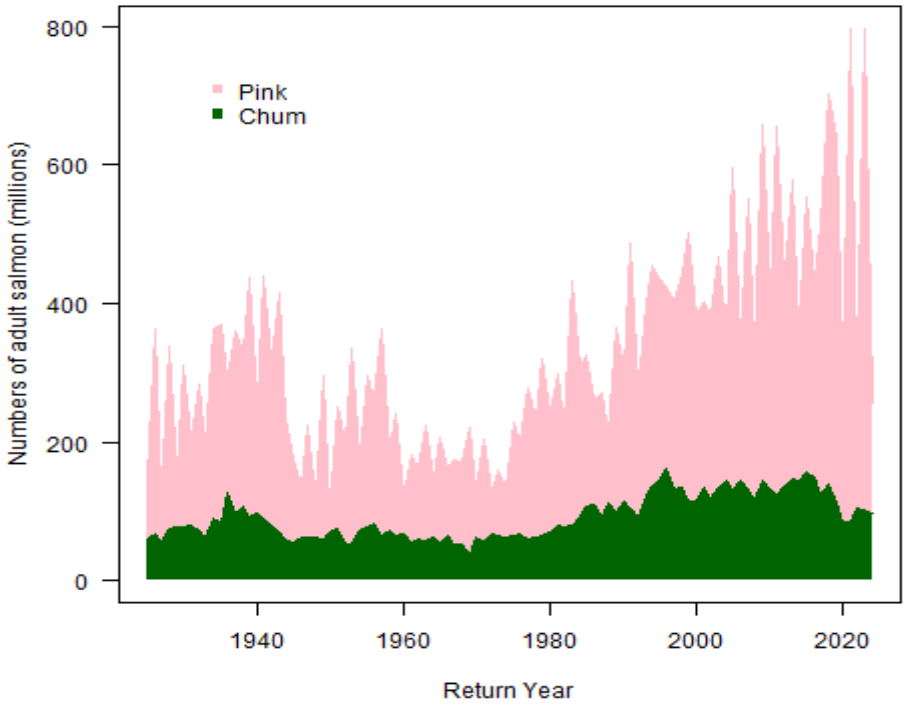

Figure 12. Annual abundances of pink and chum salmon (catch and spawners) returning to Asian and North American watersheds from 1925–2023. Reproduced from Connors et al. (2025)

LF 53a: Mortality or fitness reduction due to competition for prey – pink salmon, hatchery

Current Risk: Low, low confidence

Future Risk: Data Gap

Note: Potential additional effects of pink and chum salmon on the immature marine stage are considered separately in LF 53b and 53c. Please note that the following description is also relevant for the adult marine life stage under LF 66a, 66b, and 66c.

While hatchery production has substantially increased in the North Pacific Ocean (Figure 12), the limited, available evidence suggests that hatchery pink salmon are unlikely to be influencing Bering Sea ecosystems and the salmon that reside there, including Yukon River Chinook. All North American pink salmon hatcheries are located outside of the Bering Sea, predominantly in the Gulf of Alaska region. These hatchery-origin pink salmon are unlikely to enter the Bering Sea based on historical data of pink salmon migration patterns in the North Pacific Ocean (Radchenko et al. 2018; Langan et al. 2024). Pink salmon have been documented spending their winters south of the Aleutian chain and therefore outside of the extent where Chinook salmon are expected to winter in the Bering Sea (Radchenko et al. 2018; Langan et al. 2024). Pink salmon originating from the Gulf of Alaska region have demonstrated a counterclockwise migration pattern within the region, including southwest movements offshore as juveniles followed by a return to coastal areas the following spring and summer prior to spawning (Radchenko et al. 2018). In addition, it is possible that Russian pink salmon hatcheries could be

influencing Bering Sea ecosystems, however they represented a relatively small contribution to the overall North Pacific pink salmon abundance (5%) over the 2000–2015 period, as well as included populations from the Russian mainland which may not enter the Bering Sea (Radchenko et al. 2018; Ruggerone and Irvine 2018).

In summary, based on the limited, available evidence and general expert consensus of the potential effects of hatchery-origin pink salmon on Yukon River Chinook salmon the risk ranking is considered to be low, but with low confidence. More recent data for population-specific migrations, particularly in hatchery producing regions, would be very useful for validating historical findings and to examine if pink salmon may be shifting their distributions over time in response to warming and related ecosystem changes. Given this potential for future change in pink salmon distributions and the lack of current data, the future risk ranking is understood to be a data gap.

LF 53b: Mortality or fitness reduction due to competition for prey – pink salmon, wild

Current Risk: Moderate, medium confidence

Future Risk: High

Pink salmon have the potential to influence immature and maturing Chinook salmon in the Bering Sea through direct and indirect competition for food, with implications for their growth, reproduction, survival, and overall productivity (reviewed in Ruggerone et al. 2023). There is substantial evidence that pink salmon play an important, regulating role in the North Pacific pelagic food web (i.e., open water habitats), with other species displaying strong shifts in abundance and growth during 'odd' years when pink salmon abundances are higher. Although much of this work has focused on pink salmon from the broader North Pacific Ocean, there is also evidence specific to Bering Sea foodwebs with potential relevance to Yukon River Chinook (e.g., Davis 2003; Ruggerone et al. 2016; Batten et al. 2018).

For Yukon River Chinook, the effects of high pink salmon abundance, largely originating from Eastern Kamchatka in Russia, may occur in two ways. First, high numbers of pink salmon can have a cascading effect on the pelagic food web, resulting in major impacts on the base of the food web such as reduced plankton that may lower feeding opportunities for important, high-quality Chinook salmon prey species like fish and squid (Batten et al. 2018). Second, there is evidence that larger maturing pink salmon may directly compete for fish and squid species that are important food sources for Chinook salmon in the Bering Sea (e.g., Davis 2003; Myers et al. 2010). For example, Bering Sea Chinook salmon were shown to consume 56% less food, as well as less nutritionally valuable food in odd-numbered years when pink salmon abundances were high (Davis 2003). Several correlative studies have also linked increasing pink salmon abundances with declines in Bering Sea Chinook salmon survival, growth, and productivity over multiple decades (Ruggerone et al. 2016; Cunningham et al. 2018; Oke et al. 2020; Murdoch et al. 2024). For example, higher Russian pink salmon abundance was related to lower growth, decreased productivity, and a lower proportion of older returning adults for Yukon River Chinook salmon (Ruggerone et al. 2016).

Direct and/or indirect competition between pink and Chinook salmon may have contributed to long-term declines of average body size and age-at-maturity trends observed for Alaskan Chinook salmon, including Canadian-origin Yukon River Chinook (Ruggerone et al. 2016; Ohlberger et al. 2020; Oke et al. 2020). Additional possible explanations influencing these trends include warmer ocean temperatures, size-selective fishing-related mortality, and predation (Schindler et al. 2013; Oke et al. 2020; Manishin et

al. 2021; Ruggerone et al. 2023). Declines of Yukon River Chinook spawner body size have been well documented since the 1970s and have resulted in a major loss of reproductive potential (-28%; Ohlberger et al. 2020). It was estimated that declines of Chinook salmon across Alaska have resulted in a 26% reduction in meals per fish and a 25% reduction in commercial value overall (Oke et al. 2020).

In summary, there is a reasonable amount of evidence suggesting that increased pink salmon abundance in the Bering Sea may be negatively affecting Canadian-origin Yukon River Chinook, and that these effects may be enhanced by warming temperatures (reviewed in Ruggerone et al. 2023). Pink salmon have the ability to alter the pelagic food web in the Bering Sea with negative implications for Chinook growth and escapement quality. Decades of high pink salmon abundance may have contributed to smaller returning adults, and resultant negative effects on fecundity and overall productivity, along with other stressors (e.g., fishing, predation) selectively acting on older life stages. However, adequately quantifying effects of pink salmon competition on adult Chinook run sizes remains challenging, particularly as pink salmon competition may be acting cumulatively over multiple years of a Chinook's life, the effects of pink salmon may be carried over to future Chinook generations, and there remains relatively limited knowledge of how pink and Chinook may be overlapping and potentially interacting within the Bering Sea ecosystem. The risk ranking is therefore classified as moderate with medium confidence as more studies are needed to improve certainty of how pink salmon may be affecting spawner body size and reproductive potential, as well as potential long-term effects on run sizes. Finally, the future risk may be expected to increase if pink salmon become even more abundant in the northern Bering Sea owing to warming temperatures.

LF 53c: Mortality or fitness reduction due to competition for prey – with chum salmon

Current Risk: Low, medium confidence

Future Risk: Low

The potential for chum salmon competition with Yukon River Chinook has also been examined, in part due to rising numbers and total biomass of hatchery-origin chum salmon in the North Pacific Ocean (Ruggerone and Irvine 2018). Overall, there is limited support for chum salmon competition being an important influence on Canadian-origin Yukon River Chinook. During their subadult life stage when Chinook are expected to overlap in space with chum salmon, it appears that there is relatively low diet overlap between the two species (~30%), compared to pink salmon (60%; Davis et al. 2005). The potential competitive influence of chum salmon on Chinook has also been examined in correlative studies using multi-decadal data. There was no evidence for effects of chum salmon abundance on Canadian-origin Yukon River Chinook productivity over the 1985–2012 period (Murdoch et al. 2024), as well as no observed effect of chum salmon abundance on Alaskan Chinook growth over sixty years (years: 1957–2018; Oke et al. 2020). In contrast, one study found evidence for Japanese hatchery chum salmon having a potentially negative effect on Yukon River Chinook survival from the Chena and Salcha populations (Cunningham et al. 2018). Based on the above, it is likely that chum salmon have a low effect on Canadian-origin Yukon River Chinook spawner numbers, however, more work examining this potential link is needed to increase confidence in the low risk ranking.

LF 54a: Mortality or fitness reduction due to parasites, pathogens, disease, or harmful algae – *Ichthyophonus*

Current Risk: Data Gap

Future Risk: Data Gap

Note: Potential effects of Thiamine deficiency on the immature marine stage are considered separately in LF 54b. Please note that the following description is also relevant for the adult marine life stage under LF 67a.

Ichthyophonus disease remains a leading hypothesis for recent Chinook run discrepancies between Pilot and Eagle sonar assessments (in the adult freshwater life stage), however, the source of this parasite is expected to come from feeding on infected marine prey (JTC 2023). Further, it is possible that *Ichthyophonus* may also affect the growth and survival of immature and maturing adult life stages. Although *Ichthyophonus* has been documented in the Bering Sea ecosystem for several decades now (White et al. 2014), there is evidence that Yukon River Chinook may be disproportionately susceptible to infection compared to southern Chinook that have experienced longer exposure to *Ichthyophonus* and therefore greater potential for host adaptation (Elliott et al. 2021).

Research into the transmission and impacts of *Ichthyophonus* in the marine environment is ongoing. Most recently, the northern Bering Sea surveys have been testing Chinook salmon and prey fish for *Ichthyophonus* infection (Murphy et al. 2023; 2025). Three years of sampling (2021–2023) have supported the following conclusions: 1) *Ichthyophonus* does not occur at the juvenile life stage, 2) *Ichthyophonus* first occurs sometime during the immature life stage, and 3) the most likely infected prey fish source is pollock (Murphy et al. 2023; 2025). The proportion of infected immature fish varied over the three years. For example, in 2021, almost half of immature Chinook were infected with *Ichthyophonus*, with 25% considered to have 'high' infection levels.

There is also some evidence that *Ichthyophonus* infection may be occurring during the maturing adult stage prior to river entry. Small parasite sizes noted on infected return migrating individuals suggests a recent infection, as the parasite grows over time (Murphy et al. 2023).

Several possible sources of *Ichthyophonus* have been tested including Pacific herring, rainbow smelt, sand lance, capelin, and pollock (Murphy et al. 2025). To date, only age 1+ pollock have shown an indication of being the possible main source of *Ichthyophonus* in the marine environment. This finding agrees with prior research that identified infected pollock as a potential key source of the parasite in the Bering Sea (White et al. 2014). Although Chinook salmon naturally prey on pollock, there is also some concern that the risk of *Ichthyophonus* may be increased due to predation on pollock offal from the Bering Sea pollock fishery. Chinook salmon have been observed feeding on pollock offal in the past, particularly in the winter months when food availability may be lowered (Buser et al. 2009). However, the amount of offal consumed was considered low and more work is needed to understand the possible role of pollock fisheries in *Ichthyophonus* transmission in the marine environment (Riddell et al. 2018).

In summary, *Ichthyophonus* infection may be occurring during immature or maturing adult stages in the marine environment, with the most likely source being pollock. Unfortunately, there is no long-term data evaluating the prevalence of *Ichthyophonus* in the marine environment, which is needed to understand what the natural or 'baseline' rates of infection are over time. While it is possible that infection is leading to impacts on growth or marine survival, the strong relationship between marine juvenile abundance and the number of returning adults in recent decades demonstrated in Figure 7 (Murphy et al. 2023) suggests that direct mortality during these marine stages remains low. Instead, higher impacts are expected to occur during the upriver migration or be transgenerational, i.e., impacting the success of freshwater embryo development and survival (see Limiting Factor 80).

However, more research into how Chinook salmon are becoming infected in the marine environment is greatly needed for understanding and predicting future run sizes and productivity of Yukon River Chinook.

LF 54b: Mortality or fitness reduction due to parasites, pathogens, disease, or harmful algae – Thiamine deficiency

Current Risk: Data Gap

Future Risk: Data Gap

Please note that the following description is also relevant for the adult marine life stage under LF 67b.

Chinook salmon receive thiamine through their food, and recent shifts in prey availability associated with a strong warming period (2014–2019) may have contributed to thiamine deficiencies noted for Yukon River Chinook (Larson and Howard 2019). Low thiamine, along with potential other stressors (*Ichthyophonus*, heat stress), may have contributed to increased en-route mortality or resulted in lowered spawning and incubation success. Diets of maturing adults remains a potentially important data gap, and more information is needed to understand the role of shifting feeding patterns and whether or not thiamine deficiency could be negatively affecting Chinook during their marine life stages. However, the strong relationship between marine juvenile abundance and the number of returning adults in recent decades demonstrated in Figure 7 (Murphy et al. 2023) suggests that thiamine-related mortality in the marine environment is unlikely to be a main contributor to recent declines. Instead, higher impacts are expected to occur during the upriver migration or be transgenerational, i.e., impacting the success of freshwater embryo development and survival (see Limiting Factor 94).

LF 55: Mortality or fitness reduction due to predation

Current Risk: Moderate, low confidence

Future Risk: High

Please note that the following description is also relevant for the adult marine life stage under LF 68. However, the ranking for the adult marine life stage is considered very low, with low confidence.

The potential for late-stage mortality (i.e., after the first winter at sea) has been explored as a driver for observed declines in adult Chinook salmon body size and age over time (Manishin et al. 2021). In particular, ocean-age 3 individuals appeared to be the most vulnerable to predation, possibly due to their intermediate size which is greater than the average size of other prey species (Manishin et al. 2021). There is increasing evidence of predation on Chinook by apex predators including salmon sharks and killer whales in the Bering Sea (e.g., Seitz et al. 2019; Ohlberger et al. 2019). While there is currently little information for the trends of salmon sharks over time, killer whales have notably increased in the North Pacific Ocean over the past several decades and resident killer whales are known to have a strong preference for consuming Chinook (Ohlberger et al. 2019). However, trends of killer whale abundance over time specific to the Bering Sea ecosystem remain limited. The relative abundance of killer whales in the Bering Sea may be an area that could be informed by Traditional and local Knowledge.

In summary, there is some evidence that size-selective predation on immature Chinook may be increasing over time and contributing to smaller and younger returning adults (Ohlberger et al. 2019; Manishin et al. 2021). However, the relatively stable relationship between marine juvenile abundance

and returning adults (Figure 7; Murphy et al. 2023) suggests that this source of mortality is unlikely to be a main contributor to recent declines. Instead, selective predation on larger Chinook salmon may be impacting long-term trends in body size and resultant reproductive potential by contributing to an evolutionary shift towards earlier maturing salmon (Ohlberger et al. 2019). Understanding how predation pressure may be changing over time in response to environmental factors in the Bering Sea would be useful to understand future risk, which is ranked as high for immature Chinook, and as very low for maturing adult Chinook.

LF 56: Mortality or fitness reduction due to lack of access and availability of appropriate food

Current Risk: Data Gap

Future Risk: Data Gap

This limiting factor is considered directly in conjunction with limiting factor 60 (mortality or fitness reduction due to direct impacts of water temperatures in the immature life stage). Please see the following section for further information.

5.5.3 Water Quality

LF 60: Mortality or fitness reduction due to direct impacts of water temperatures

Current Risk: Data Gap

Future Risk: Data Gap

It is possible that immature Canadian-origin Yukon River Chinook are being negatively affected by rising temperatures and climate-related ecosystem shifts in the Bering Sea, and that these effects may be amplified by competitive interactions with other species such as pink salmon. Yukon River Chinook are returning at earlier ages and with smaller body sizes, with negative implications for reproductive potential and long-term productivity trends (Figure 8; Ohlberger et al. 2020; Oke et al. 2020; Schoen et al. 2023). However, there is currently limited information linking climate to changes occurring during the immature life stage, such as changes in food access and availability, making this multi-year period an important data gap.

LF 62: Mortality or fitness reduction due to unfavourable water chemistry

Current Risk: Low, low confidence

Future Risk: Low, low confidence

Please see LF 37 (mortality or fitness reduction due to unfavourable water chemistry for the smolt-estuarine life stage) for a description of how ocean acidification was considered as a limiting factor for all marine life stages.

5.6 Adult (Marine)

This section pertains to the marine maturing adult life stage, which refers to when Chinook salmon are in the pelagic and nearshore environments of the Bering Sea (Figure 6). Their survival during this period is shaped by ocean conditions, competition, and temperature. During their final months in the ocean, maturing adults will move closer to shore in the eastern Bering Sea prior to entering the Yukon River mouth.

5.6.1 Direct Anthropogenic Interactions

LF 65: Mortality or fitness reduction due to fishing – U.S. groundfish fisheries bycatch

Current Risk: Low, medium confidence

Future Risk: Low

This LF was assessed in conjunction with LF 52 (mortality or fitness reduction due to fishing during the immature life stage). Please refer to LF 52 for full description and risk evaluation.

5.6.2 Biological Interactions

LF 66a: Mortality or fitness reduction due to competition for prey – pink salmon, hatchery

Current Risk: Low, low confidence

Future Risk: Data Gap

This LF was assessed in conjunction with LF 53a (mortality or fitness reduction due to competition for prey – pink salmon, hatchery during the immature life stage). Please refer to LF 53a for full description and risk evaluation.

LF 66b: Mortality or fitness reduction due to competition for prey – pink salmon, wild

Current Risk: Moderate, medium confidence

Future Risk: High

This limiting factor is considered directly in conjunction with limiting factor 53b (mortality or fitness reduction due to competition for prey – pink salmon, wild during the immature life stage). Please refer to LF 53b for further information.

LF 66c: Mortality or fitness reduction due to competition for prey – with chum salmon

Current Risk: Low, medium confidence

Future Risk: Low

This LF was assessed in conjunction with LF 53c (mortality or fitness reduction due to competition for prey – chum salmon during the immature life stage). Please refer to LF 53c for full description and risk evaluation.

LF 67a: Mortality or fitness reduction due to parasites, pathogens, disease, or harmful algae – *Ichthyophonus*

Current Risk: Data Gap

Future Risk: Data Gap

This LF was assessed in conjunction with LF 54a (mortality or fitness reduction due to parasites, pathogens, disease, or harmful algae – *Ichthyophonus* during the immature life stage). Please refer to LF 54a for full description and risk evaluation.

LF 67b: Mortality or fitness reduction due to parasites, pathogens, disease, or harmful algae – Thiamine deficiency

Current Risk: Data Gap

Future Risk: Data Gap

This LF was assessed in conjunction with LF 54b (mortality or fitness reduction due to parasites, pathogens, disease, or harmful algae – thiamine deficiency during the immature life stage). Please refer to LF 54b for full description and risk evaluation.

LF 68: Mortality or fitness reduction due to predation

Current Risk: Very Low, low confidence

Future Risk: Very Low

This limiting factor is considered directly in conjunction with limiting factor 55 (mortality or fitness reduction due to predation). Please check LF 55 for further information.

LF 69: Mortality or fitness reduction due to lack of access and availability of appropriate food

Current Risk: Data Gap

Future Risk: Data Gap

This limiting factor is considered directly in conjunction with limiting factor 73 (mortality or fitness reduction due to direct impacts of water temperature during the adult marine life stage). Please see the following section for further information.

5.6.3 Water Quality

LF 73: Mortality or fitness reduction due to direct impacts of water temperatures

Current Risk: High, medium confidence

Future Risk: Very High

Prior to entering the river, maturing adults are expected to stage over the preceding winter and spring months in the southern Bering Sea. A possible explanation for the recent declines of Yukon River Chinook is that Chinook may be entering the river in poorer health than before, perhaps owing to recent heatwave conditions and differences in available food (Figure 10; Howard and von Biela 2023). In support of this hypothesis, the study authors found that Canadian-origin Yukon River Chinook productivity declined in association with warmer temperatures experienced during the maturing adult life stage in the Bering Sea (Howard and von Biela 2023). Together, their conceptual framework describes how both marine and freshwater effects may combine to reduce the overall health of individual Chinook salmon, impede their spawning migrations, and potentially lead to lowering spawning and incubation success (Figure 13). For example, shifting diets may result in Chinook salmon eating more prey infected by the *Ichthyophonus* parasite, or impact their thiamine uptake, which is an essential nutrient needed for successful spawning and egg development. The role of thiamine deficiency is another potential risk factor that is currently being explored. Chinook receive thiamine through their

food, and recent shifts in prey availability may have contributed to thiamine deficiencies noted for Yukon River Chinook (Larson and Howard 2019).

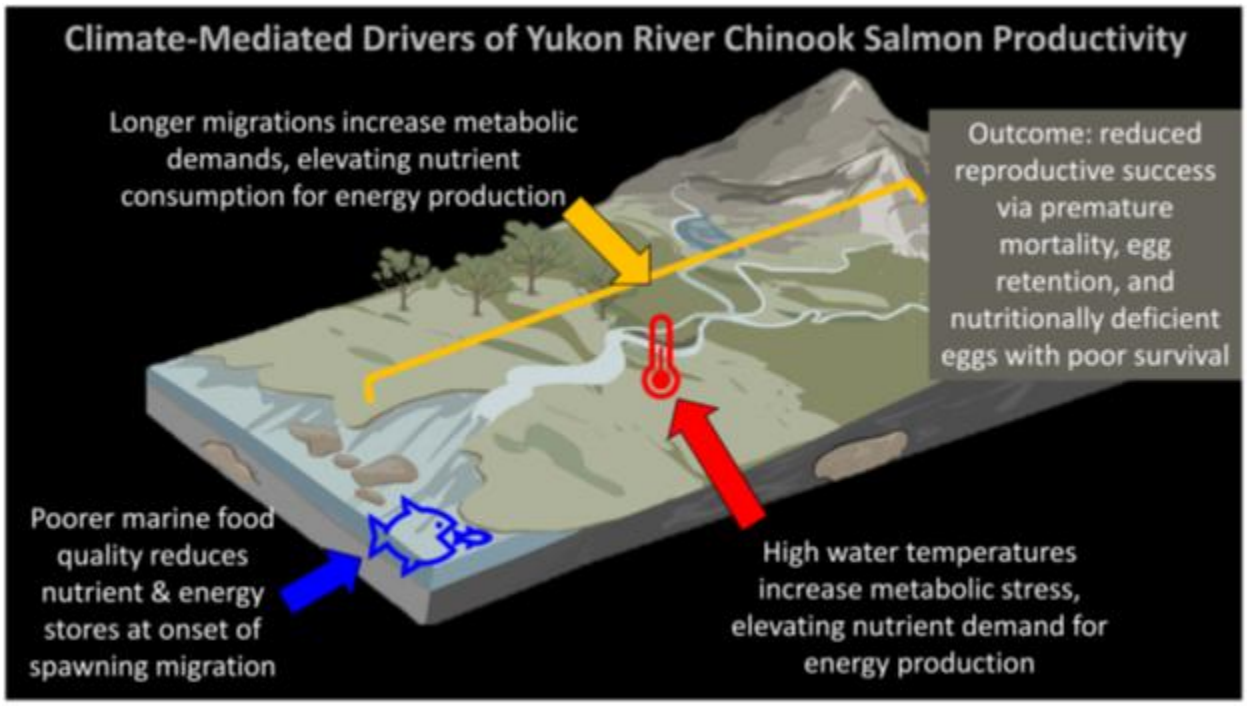

Figure 13. Conceptual diagram demonstrating the interrelated roles of marine and freshwater climate-related stressors influencing Yukon River Chinook salmon productivity. From Howard and von Biela (2023).

In summary, while there is limited information surrounding this life stage, climate-related risks during the maturing adult period have been identified as potentially playing an important role in the recent declines of Canadian-origin Yukon River Chinook salmon. Recent ecosystems shifts associated with a strong warming period (2014–2019) in the Bering Sea may be leading to poorer condition of returning adults, which in turn could put Chinook at higher risk for heat stress, *Ichthyophonus* disease, and/or thiamine deficiencies. Together, these impacts may have contributed to increased en-route mortality or resulted in lowered spawning and incubation success. Diet of maturing adults remains a potentially important data gap, and more information is needed to understand the role of shifting feeding patterns in response to a changing climate for this life stage.

LF 75: Mortality or fitness reduction due to unfavourable water chemistry

Current Risk: Low, low confidence

Future Risk: Low, low confidence

Please see LF 37 (mortality or fitness reduction due to unfavourable water chemistry during the smolt-estuarine life stage) for a description of how ocean acidification was considered as a limiting factor for all marine life stages.

5.7 Adult (Freshwater Migration)

This section pertains to the adult freshwater migration stage, which refers to when mature Chinook re-enter the Yukon River and migrate upstream to reach their spawning grounds. Mature adults re-enter the Yukon River in late spring, navigating thousands of kilometers upstream under increasing thermal stress to reach spawning habitats across the Canadian basin. These long-distance migrations expose Chinook to heat stress, physical barriers, and low water flows, particularly in smaller tributaries. Timing, temperature, and river conditions during this journey are critical for survival and successful reproduction.

5.7.1 Direct Anthropogenic Interactions

LF 77: Fitness reduction, migration delay or mortality as a result of stress due to anthropogenic activity

Current Risk: Low

Future Risk: Moderate

Note: Potential effects of Whitehorse Dam on the adult migration stage are considered separately in LF 77a.

As adult Chinook enter the Yukon River and migrate upstream through Alaska, they are subject to stress from natural and anthropogenic causes and activities. However, they are seldom directly disrupted by human activities upstream of the Canadian border. The risks associated with the Whitehorse Rapids Hydroelectrical Project and the Mayo River Hydroelectrical Project are addressed in sections 5.7.3, 5.8.1, and 5.8.3. Excluding the hydroelectric projects, the suggested current risk is considered to be low.

However, future risk must acknowledge the potentially poor health of returning adults. They may be suffering from the effects of heat stress, parasite infections, the distance travelled upstream in both Canada and Alaska, simple exhaustion, thiamine deficiency or other causes not yet identified. The direct effects of existing stressors during upstream migration can be expected to increase due to climate change. As such, the suggested ranking for future risk is moderate.

Returning adult Chinook avoid areas that may pose risks. There has been a reduction or removal of risks and stress to adult Chinook posed by enumeration and management activities. Use of mark-recapture methods for biological data collection at fish wheels has been replaced by sonar installations. The use of gillnets in test fisheries to capture adults to confirm readings at enumeration sonars remains a potential issue, particularly at low adult abundances.

Enumeration weirs or fences were generally used on streams and smaller rivers until the recent past, though one is still used on Tatchun Creek. Chinook would hold below the fence and at times some would not pass upstream through it. This was most apparent when stream flows were low. The reluctance or refusal to migrate through the gate in the weir or fence implied stress. Photo enumeration fences and smaller sonars are now used in spawning streams. This reduces or removes risk and stress to upstream migrating adults.

Fish ladders in the Yukon not associated with the Whitehorse Rapids hydro facility are limited in number. A fish ladder was placed on Wolf Creek in the early 2000s to allow adult Chinook passage through the Alaska Highway culvert. One of two culverts across McIntyre Creek at Mountainview Drive has adult Chinook passage structures to allow passage to upstream spawning areas.

The demand for electricity in the Yukon will continue to expand. Less than 10 years ago the Yukon Development Corporation proposed to build a major dam in one of seven locations on Chinook spawning rivers. There was considerable public concern due to the potential for disruption to Chinook populations and habitats (von Finster and Reid 2015). Although the utility's attempt to choose a project failed, future attempts are likely if the demand remains. Other projects impacting water access for salmon have been proposed, but the implementation schedule is unclear.

LF 77a: Fitness reduction, migration delay or mortality as a result of stress due to anthropogenic activity – Whitehorse Rapids Dam and Upstream

Current Risk: Very High, medium confidence

Future Risk: Very High

The Whitehorse Rapids power generation dam was constructed in the late 1950s. A navigation dam at the outlet of Marsh Lake was rebuilt to provide storage for the facility. Both the power generation dam and the storage dam included fish ladders. A study done from 2017–2020 indicates that passage success of the fishway was on average 31%, and particularly low for females (13%; Twardek et al. 2023b). Two of the study years (2017, 2020) recorded 0% passage rate, though sample sizes were small (Twardek et al. 2023b). Passage delays were also noted, with many Chinook (12%) falling back after passing the dam (Twardek et al. 2023b). Although it should be noted that some of these Chinook could have been exploring upstream of the spawning area just below the dam as the report also showed natural movement of several kilometers. There have also been inconsistent returns of adults from Whitehorse Rapids Chinook hatchery releases. The hatchery has operated since 1984. There has been backwatering of significant Chinook spawning areas upstream of the dam. There is a very high future risk ranking due to the unresolved issue of adult Chinook passage and the likelihood this contributes to pre-spawn mortality or reduced fitness.

LF 78: Mortality or fitness reduction due to fishing

Current Risk: Moderate

Future Risk: Moderate

Historically, targeted Chinook fisheries on the Yukon River harvested a significant proportion of the Canadian-origin Yukon River Chinook salmon population. There is broad consensus that this was a major driver of historical population decline. This assessment of issues facing Yukon River Chinook acknowledges that fishing was a very significant risk historically, however fishing has been drastically restricted and poses a much more limited risk than it once did. This assessment addresses the present reality that the risks posed by fishing have diminished significantly from what they once were.

Until a sudden decrease in the abundance of returning adults in the late 1990s, spawning populations supported commercial, domestic, recreational, and Yukon First Nations fisheries. For the past couple decades, fishing has steadily been restricted or voluntarily reduced, first on the Canadian side of the border, and eventually on the U.S. side as well. In 2024, a seven-year watershed-wide fishing moratorium agreement was reached by the U.S. and Canada. Any harvest that occurs, despite how small, presents a risk to the remaining small population size. For example, despite widespread management and conservation measures restricting all targeted Chinook salmon fisheries in U.S. and Canada from 2021 onwards, an average of 6% of the run size was still reported as incidental harvest

over the 2021–2024 period (Figure 14; JTC 2025). Further, following the seven-year fishing moratorium agreement instated in spring 2024, approximately 4% of the run size was harvested during 2025 (1,085 Chinook harvested out of a run size of 25,390 salmon; JTC 2025). This continued incidental harvest at low run sizes justifies a moderate risk ranking in both present and future risk categories.

Even in the present moment, the risk fishing presents to Chinook varies temporally and spatially. Social and political pressures continue to influence the rate of fishing during and will influence beyond the moratorium. Management regimes, however, reflect the uncertainty involved in future risk.

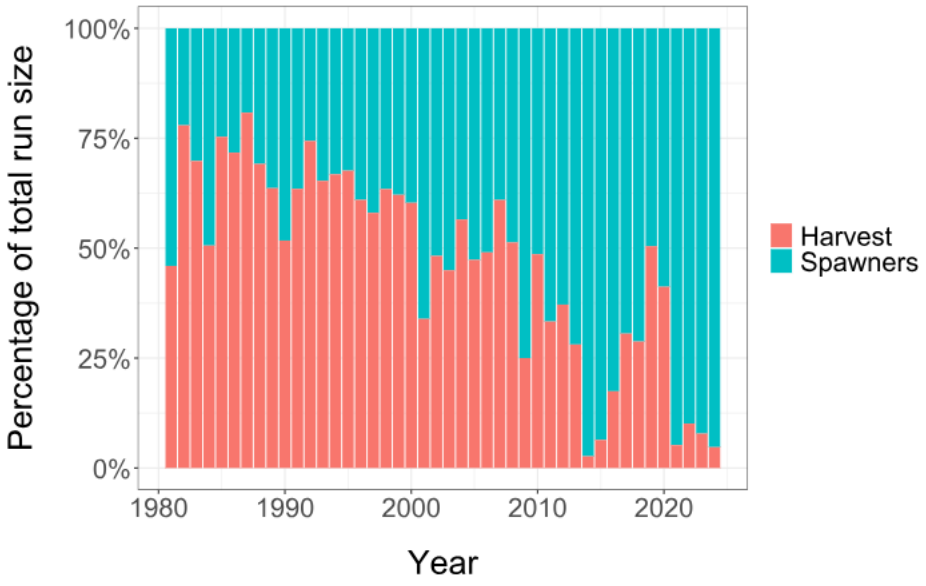

Figure 14. Estimated percentage of return spawners and harvested Canadian-origin Yukon Chinook salmon. Data from JTC (2025) and Zach Liller (ADF&G, pers. comm.).

5.7.2 Biological Interactions

LF 79: Mortality or fitness reduction due to competition

Current Risk: Very Low

Future Risk: Very Low

Competition is unlikely to be a concern at existing low spawner numbers unless the Chinook population abundance rebounds significantly. The current risk of competition is very low. Adult Chinook in small but highly productive creeks such as the Tatchun Creek may be obstructed from upstream migration by beaver dams or other structures and be forced to spawn in confined areas. This is particularly the case during years with low- to very low water levels. Even so, the future risk to the overall Yukon River population will be very low.

Of note, Yukon River Chinook tend to find spawning habitats in streams rather than directly compete for them. In Michie Creek, Chinook have spawned about 500 meters downstream of preferred habitat during very low water years when the gravels in the preferred spawning sites were dewatered. Chinook showed the same response in Glenlyon Creek, tributary to the Pelly River. Where flows in a spawning stream were low for too many years, such as in Klusha Creek tributary to the Nordenskiöld River, the Chinook have been extirpated.

LF 80a: Mortality or fitness reduction due to parasites, pathogens, or disease – *Ichthyophonus*

Current Risk: High

Future Risk: High

Note: Potential effects of Thiamine deficiency on the adult migration stage are considered separately in LF 80b.

Ichthyophonus hoferi has been a parasite of interest since the early 2000s. A greater understanding of the parasite and of its effect on Chinook is being developed. The effects of warm water temperature and heat stress and the development and prevalence of *Ichthyophonus* are under investigation. These support a suggested ranking of current and future risk as high. Further description of the mechanisms of *Ichthyophonus* infection can be found in the sections on LFs 54 and 67 above.

Ichthyophonus may persist in the population annually, with large increases in the prevalence of the parasite and severity of infection fluctuating over a long time series. Warm water temperatures in the Bering Sea and lower Yukon River may promote the disease progression of *Ichthyophoniasis* and effects of heat stress, potentially causing en-route mortality of migrating adult Chinook in the Yukon River (Kocan et al. 2004; von Biela et al. 2020). It is likely that given their longer migration, Canadian-origin Yukon River Chinook could be more susceptible and impacted by *Ichthyophonus* compared to lower river fish.

For adults migrating upstream, signs of visible infection tend to be greatest midway along the river near Rampart (Carroll and Liller 2023). Sampling done in this area found that infection rates (the percent of samples with the disease) were very high during the 1999–2004 period, ranging from 20–35% (Kocan et al. 2004; Carroll and Liller 2023). Infection rates decreased over the 2005–2013 period but high levels have been confirmed with recent sampling in 2020 (>25% infected at Rapids Research) and 2021 (>40% infected with samples from Pilot Station and near Rapids; Carroll and Liller 2023). Confirmation of infection in a fish requires lethal sampling. Sampling has shown that infection prevalence is significantly higher in females than in males (Kocan et al. 2004), which can result in female pre-spawn mortality or reduced egg fertilization or development.

In some recent years, expected abundances of Canadian Chinook based on captures at Pilot Station near the Yukon River mouth have not been reflected further upstream near the Canadian border at Eagle. There have been significant annual shortages of Canadian-origin Chinook. The current theory is that there is a significant die off of Canadian Chinook in part due to *Ichthyophonus* between the river mouth and Eagle. This causes a portion of the discrepancy in passage numbers calculated at Pilot Station and those counted at Eagle.

LF 80b: Mortality or fitness reduction due to parasites, pathogens, or disease – Thiamine deficiency

Current Risk: Moderate, low confidence

Future Risk: Moderate

Thiamine is an essential dietary nutrient required by Chinook that is obtained through their food and passed on to developing embryos. An exploratory study examining egg thiamine levels from returning adult Canadian-origin Chinook revealed evidence for potential thiamine deficiency, particularly in salmon with longer migrations (Larson and Howard 2019). Based on this work, it has been suggested

that low egg thiamine levels may have contributed to lower run sizes in recent years (Larson and Howard 2019; Howard and von Biela 2023). Low thiamine levels have the potential to negatively impact adult fish, reducing their ability to reach spawning areas as well as effectively carry out spawning activities (Larson and Howard 2019). Although this factor is acting during freshwater stages, it is likely linked to diet changes in the marine environment with implications for thiamine levels in developing eggs (see Limiting Factors 60 and 73 for further discussion). However, the identified risk ranking of moderate is currently with low confidence as more information is required to understand and validate how Canadian-origin Yukon River Chinook respond to low thiamine levels.

LF 81: Mortality or fitness reduction due to predation

Current Risk: Low

Future Risk: Moderate

Risk of predation of adults is very low in the mainstem and major tributaries, but rises as spawning areas are approached. Freshwater predators such as bears, wolves, and otters may capture and consume adults in creeks and smaller rivers. A current and future risk ranking of low is justified as a blanket risk for the entire watershed. Some highly productive lake headed small stream systems may require a higher, local ranking for management. As risks increase when stream flows decrease, there should be consideration of the possible effects of low stream flows immediately prior to or during the spawning period. If Chinook body size continues to decline, predation by eagles should be assessed as a risk.

Risks to the Chinook in small streams are greatest when non-permanent barriers to upstream migration are present. These are usually beaver dams, but occasionally log and debris jams. Chinook concentrate below these obstructions and become easier prey for bears. It is believed that high and perhaps significant numbers of adult Chinook may be killed in these situations.

5.7.3 Physical Habitat

LF 82: Mortality or fitness reduction due to migration barriers

Current Risk: Low

Future Risk: Moderate

Note: Potential effects of Mayo Hydro Plan on the adult migration stage are considered separately in LF 82a.

Other than isolated situations where major hydroelectric dams provide partial or complete barriers to fish passage, the Yukon River is largely unobstructed. In smaller tributaries returning adults may be restricted or obstructed by beaver dams (Jang, 2004; von Finster, 2009). Though beavers are fur bearers, they are currently seldom harvested as there is no market for their pelts. Low flows have the potential to exacerbate beaver-related barriers, particularly as warmer and drier conditions may increase further beaver activity.

Permafrost thaw can lead to situations where entire rivers are blocked by major landslides. This happened recently on the Chandindu River, north bank tributary of the Yukon River below Dawson. Although the river is re-establishing an accessible channel through the slide, similar failures are possible in any river flowing through a canyon or confined valley. The increasing risk of these events due to climate change justifies the elevated future risk ranking. Massive permafrost thawing, such as in the

upper Nordenskiöld River and Crooked Creek, may have caused local extirpation of adult Chinook populations (von Finster 2001, 2004). However, escapements are not monitored in either river.

LF82a: Mortality or fitness reduction due to migration barriers – Mayo Hydro Plant

Current Risk: Very High

Future Risk: Very High

The Wareham Lake dam has been a total obstruction to all upstream migrating adult Chinook to the upper river and tributaries above the lake since it was constructed in the early 1950s. This justifies the current risk of very high. Of concern, the upper Mayo River watershed once supported a large spawning population of Chinook. The Mayo Hydroelectrical project is licensed under the *Yukon Waters Act* which will expire in 2025. The new license application is being developed by Yukon Energy (YE) in collaboration with First Nation of Na-cho Nyäk Dun (FNNND) and Government of Yukon (YG). The application will be reviewed through the Yukon Environmental and Socio-Economic Act (YESSA) and applicable regulatory agencies of various governments. The future risk is considered very high. YE is currently proposing fish passage above the Wareham dam. The upper control structure is being replaced but this will not enable Chinook to pass the dam complex until fish passage is included at Wareham dam.

LF 83: Mortality or fitness reduction due to unfavourable channel form or high sediment loads

Current Risk: Low, low confidence

Future Risk: Moderate

Unfavorable channel form and high sediment loads are considered to pose an existing risk of low, and the increasing risks associated with permafrost thaw slumping justify a future risk of moderate. Though the effects of channel form disturbance or sedimentation may be significant, they are infrequent or distributed spatially across the watershed so as to be diffuse. Sediments from permafrost thawing or degradation may decrease channel stability. Very large landslides deposit coarse materials into the channel. This may result in aggressive bank erosion, or in the channel finding a new path on the valley bottom. Importantly, a major slide may take years or decades for deposited sediment to erode and therefore continue contributing significant sediment to the channel. Local and Traditional knowledge from communities near the mouth of the Yukon River have observed increased erosion and river widening, as well as more sandbars (Moncrieff et al. 2009). These changes have the potential to negatively impact the fitness of adults migrating upstream owing to poorer water quality and more challenging navigation.

Some spawning rivers have been channelized at road crossings, for flood control and along infrastructure corridors. Placer mining generates sediment. Most intentional sediment releases from this industry are settled to meet regulatory standards. Additionally, almost all placer mines are located a substantial distance upstream or away from spawning habitat.

Independent of human activity, many river channels have straightened and widened as a result of increased high flows and sediment input. These are generally associated with a changing climate. Rivers become shallower as their channels widen. At low flows, Chinook may have to abandon preferred spawning habitats that have insufficient water depth. Most will find alternate locations to spawn but perhaps will be less successful there.

The Porcupine River basin is affected by permafrost degradation and wildfire produced sediment in spawning areas. The unglaciated portion of the Yukon River basin has few spawning streams. It is bordered to the north by the Klondike River, which is a product of glaciation. The glaciated terrain contains most of the Chinook spawning habitat in this region. Effects of channelization are widespread but vary considerably between local areas. Crooked Creek has been heavily affected by multi-year sediment releases believed to be related to permafrost thawing. As a result, the Chinook population spawning in the creek may have been extirpated. No escapement monitoring takes place to track this. On the Nordenskiöld River, the Ten Mile Creek slide terminated immediately above the Klondike Highway in 2003. Drainage from the slide reached the river, and it continues to deposit sediment into it. Further up the Nordenskiöld River, a significant permafrost thaw just downstream of Hutshi Lake contributed sediment directly onto a spawning area for about five years. Active placer mining remains in Big Creek, Mt. Nansen, the South Big Salmon and Mayo areas and continues to contribute sediment to each river.

Given the vast scale of the assessment, the risk is understood to be low, though on select streams it may be much higher.

5.7.4 Hydrology and Oceanography

LF 84: Mortality or fitness reduction due to altered timing or magnitude of peak flows

Current Risk: Low

Future Risk: Moderate

Mortality and fitness reduction in adults due to alteration and magnitude of high flows is suggested to be a current risk of very low in all but extreme situations. Upstream migration may be delayed by high- or flood flows in major rivers, or may be more rapid in smaller rivers or streams. The main impact of high flows will be to the egg stage and is addressed in limiting factor 6 described above. This supports the future risk of low.

The effects of high water in different habitat types will not be equal. Lake outlet spawning areas will have buffered flows and the risk of lost year classes is minimal. Chinook in non-buffered larger streams and rivers may be more affected. There will probably be an abundant and diverse supply of sediment upstream of spawning areas that high flows could mobilize after spawning has occurred. Non-buffered small streams will probably suffer the greatest effect and are at greatest risk of knock-on effects from lost year classes.

LF 85: Mortality or fitness reduction due to altered timing or magnitude of low water levels

Current Risk: Low

Future Risk: Moderate

Lower water levels are generally associated with higher water temperatures. Returning adult Chinook may have been experiencing high water temperatures throughout their upstream migration. The effects of heat stress, possible infection with *Ichthyophonus* and thiamine deficiency may negatively affect the Chinook's ability to enter some spawning streams and to crest smaller obstructions. That aside, access can be indirectly or directly denied to spawning grounds by low water levels that precede and extend through the spawning period. A series of low water years may result in some populations being reduced

and, in time, extirpated. The current risk is considered to be low. Additionally, and based on the future likelihood of changing precipitation patterns and streamflow conditions, the suggested future risk is moderate.

Considering an ecosystem perspective, beavers may move into smaller streams during low flow periods. They may also dam much larger streams and rivers. Beaver dams in spawning streams can restrict or deny the upstream movement of adult Chinook. Chinook that reach the spawning grounds may have to relocate to less favorable habitats due to insufficient water cover over preferred habitats. Low water levels also tend to increase water temperatures within spawning streams, and particularly downstream of lakes.

During low water periods Chinook, particularly large females, may have difficulty swimming over the gravel apron along some larger rivers to enter smaller spawning streams. In the early 1990s Chinook were unsuccessfully attempting to cross the gravel bar at the mouth of Earn Creek, tributary to the Pelly River.

During a dry spell in the late 1990s on Michie Creek, a beaver dam was breached to allow upstream access of adults. Preferred spawning habitat was in an area of spawning dunes at the lake outlet. The tops of the spawning dunes were above the surface of the water. The Chinook spawned approximately 500 meters downstream. During the same period, a beaver dam across the Nordenskiöld River immediately above the mouth of Klusha Creek barred access to spawning sites in approximately 80km of the upper river.

In Klusha Creek what appears to have been a substantial population of Chinook has been extirpated due to low flows. The low flows are thought to have resulted from a wildfire that converted the forest from spruce to aspen in the 1960s and with the additive effects of climate change.

5.7.5 Water Quality

LF 87: Mortality, fitness reduction, delayed migration, or delayed spawning due to unfavourable water temperatures

Current Risk: High

Future Risk: Very High

Note: Porcupine River water temperatures are discussed in more detail under LF 87a below.

Water temperature effects on adult Chinook may start in the Bering Sea and continue until spawning ends. The upstream migration must pass through the lower Yukon River in Alaska near solstice, when virtual 24 hour daylight may elevate water temperatures. As the process of spawning to some extent affects the health and viability of the egg, there is a probability of carry-over effects into the next generation and beyond. On the basis of what is presently known, we suggest the current risk to be ranked as high. The future risk, assuming that the warm water temperatures persist in the Bering Sea and lower Yukon River for an extended period, is suggested to be very high.

As Chinook enter the Yukon River, they begin experiencing heat stress as they swim through water warmer than 18°C (von Biela et al. 2020), and average daily temperatures of 21°C or higher could result in mortality (U.S. EPA 2003; von Biela et al. 2020). As temperatures warm, Chinook with long migrations such as Yukon River Chinook are likely at a disadvantage as they will require more energy to offset

increasing metabolic demand. Another concern is that warming may also increase the virulence of pathogens, such as *Ichthyophonus* (Kocan et al. 2009), or increase oxygen demand beyond what Chinook are capable of during their 'marathon' migrations (Eliason et al. 2013). Temperatures above 18°C have been noted in many years over the past several decades, although temperatures above 21°C remain less common (von Biela et al. 2020). Warmer spawning migration temperatures have also been negatively linked to productivity for Canadian-origin Yukon River Chinook using multidecadal time-series data over the 1985–2012 period (Murdoch et al. 2024). Warmer migration temperatures may be negatively affecting productivity by directly reducing spawning success or via carryover effects on progeny fitness and survival (Howard and von Biela 2023; Murdoch et al. 2024; Feddern et al. 2024).

It is important to note that thermal refuges tend to exist in portions of most rivers. Thermal refuges for Chinook adults require a source of colder water and a riverbed configuration that reduces the risk of the colder and warmer water bodies mixing. Adults can cool themselves in these areas. Residual effects of heat stress will continue, to some extent, even if Chinook do use them.

Thermal refuges have been studied in southern rivers. Chinook and other salmon species rest in cold water plumes at the mouths of tributaries. This principle is expected to apply in both the un-glaciated and glaciated portions of the Yukon River and tributaries. Areas at the mouths of tributaries, and particularly the north bank mountain rivers draining south from the Ogilvie Mountains and entering the Yukon River downstream of and including the Klondike, may provide thermal refuges. Areas with strong hyporheic flows in the glaciated areas of the watershed may also offer thermal refuge. However, a recent report based on Chinook ascending the Yukon River between 2002 and 2004 and with temperature and depth tags indicated that the adult Chinook use of thermal refuges was either not occurring or was of very short duration (Eiler et al. 2023). Potential thermal refuges are being considered by managers but have not yet been mapped.

In an effort to identify thermal refuges, temperatures have been measured in a number of Canadian spawning rivers beginning in 2010. A wide range of temperatures were recorded in or immediately downstream of spawning areas. They were analysed against U.S. standards and Canadian thresholds for an assumed stream-specific spawning period. As of 2020, the coldest stream was the North Klondike River, which did not exceed either the U.S. 13°C spawning standard (maximum daily temperature) or the Canadian 18°C spawning threshold (mean daily temperature) (Van Wert et al. 2023, U.S. EPA 2003). Of note, the North Klondike River was the only station measured that fully met the American standard. The Tatchun Creek, a small, highly productive lake buffered spawning stream, was the warmest stream. It exceeded the U.S. standard on an average of 31.2 days of a 32 day assumed spawning period. 18°C was exceeded on an average of 7.1 days; 19°C on an average of 4 days; 20°C on an average of 1.6 days, and 21°C on an average of 0.2 days. It is believed that the Chinook returning to Tatchun Creek hold in the Yukon River near the mouth until the stream cools sufficiently and then ascend it to spawn once temperatures permit (Mathes et al. 2010). If any similar streams flow into a seasonally warm receiving river, and if there is not a thermal refuge at the mouth of the spawning stream, the Chinook holding there may be negatively affected.

LF87a: Mortality, fitness reduction, or delayed migration due to unfavourable water temperatures – Porcupine River

Current Risk: Very High

Future Risk: Very High

The Porcupine River watershed is the northernmost tributary to the Yukon River in Canada. In the summer, it receives 24 hours of sun each day, and in-stream water temperatures have reached among the highest observed throughout the broader Yukon River watershed. Due to this solar exposure, there may be an elevated risk of water temperatures to adult migrants in the Porcupine River watershed relative to the risk in the rest of the watershed.

LF 88: Mortality or fitness reduction as a result of low dissolved oxygen

Current Risk: Very Low

Future Risk: Very Low

There is a very low risk to migrating Chinook from low dissolved oxygen levels. Chinook migrate during the summer in moving water. This water is constantly exposed to air, and dissolved oxygen will be constantly renewed.

LF 89: Mortality or fitness reduction due to unfavourable water chemistry

Current Risk: Low

Future Risk: Moderate

Most water in the Yukon River and its tributaries contains substances that could be deleterious to fish. However, the expected concentrations of these substances are not likely to cause stress or mortality to adult Chinook. This supports a current risk of low. One risk to adult Chinook is if a significant discharge of deleterious substances is released directly into their spawning river as a result of a spill or equivalent but the likelihood of this occurring is low. The future risk of effects of deleterious materials to adult Chinook is therefore suggested as moderate.

There are some possible exceptions, which include the Faro Mine Complex, which discharges treated effluent to Rose Creek and Vangorda Creek, both tributaries of the Pelly River; the United Keno Hill Mining Complex, which discharges treated effluent to Flat Creek tributary to the South McQuesten River and then the Stewart River; and Mt. Nansen which discharges treated effluent to Dome Creek tributary to Victoria Creek, then the Nisling River, and finally the White River. All sites have migrating or spawning Chinook in downstream waters. Of note, the Chinook populations of Anvil Creek and the South McQuesten Rivers were extirpated by spills and effluents from quartz mining in the 1960s and 1940s, respectively (Cox 1999). As of 2014, the Chinook populations had partially re-established themselves.

The risk of a petrochemical spill occurring that would drain into Chinook spawning waters in such concentrations that would cause harm is extremely low. Since the June 2024 workshop, a large failure and landslide at the Eagle Gold Mine heap leach occurred. The mine uses sodium cyanide for gold extraction from ore. It remains to be seen how much of the sodium cyanide has entered or will enter the groundwater and eventually be released to Haggart Creek, a tributary of the Stewart River. Juvenile Chinook and adult grayling have been observed in Haggart Creek prior to this incident. Adult Chinook habitat use has been documented in the McQuesten River at and upstream of the mouth of Haggart Creek (Tobler et al. 2003). Sodium cyanide in high doses can be lethal to aquatic organisms. Additional substances potentially deleterious to fish, including mercury, have also been released. Monitoring and remediation of the site continues.

LF 90: Mortality or fitness reduction due to contaminants, or deleterious substances

Current Risk: Low

Future Risk: Moderate

This limiting factor is considered directly in conjunction with limiting factor 89 (mortality or fitness reduction due to unfavourable water chemistry). Please check LF 89 for further information.

5.8 Adult (Spawning)

This section pertains to the spawning portion of their life stage, which refers to when Chinook salmon have reached their natal streams (Figure 1), deposited their eggs, and die. Survival during this period is shaped by spawning stream temperatures, parasites, carryover effects from the conditions of the marine environment, and access to spawning grounds. This stage typically lasts for one month, until the fish have spawned and died.

5.8.1 Direct Anthropogenic Interactions

LF 91: Fitness reduction, migration delay or mortality as a result of stress due to anthropogenic activity

Current Risk: Low

Future Risk: Moderate

This LF was assessed in conjunction with LF 77 (mortality or fitness reduction as a result of stress due to anthropogenic activity for the adult freshwater migration stage). Please refer to LF 77 for full description and risk evaluation.

LF 92: Mortality or fitness reduction due to fishing

Current Risk: Moderate

Future Risk: Moderate

This LF was assessed in conjunction with LF 78 (mortality or fitness reduction due to fishing on the adult freshwater migration life stage). Please refer to LF 78 for full description and risk evaluation.

5.8.2 Biological Interactions

LF 93: Mortality or fitness reduction due to competition

Current Risk: Very Low

Future Risk: Very Low

This LF was assessed in conjunction with LF 79 (mortality or fitness reduction due to competition on the adult freshwater migration life stage). Please refer to LF 79 for more information.

LF 94a: Mortality or fitness reduction due to parasites, pathogens, or disease – *Ichthyophonus*

Current Risk: High

Future Risk: High

Note: Potential effects of Thiamine deficiency on the adult spawning stage are considered separately in LF 94b.

This LF was assessed in conjunction with LF 80 (mortality or fitness reduction due to parasites, pathogens, or disease – *Ichthyophonus* on the adult freshwater migration life stage). Please refer to LF 80 for full description and risk evaluation.

LF 94b: Mortality or fitness reduction due to parasites, pathogens, or disease – Thiamine deficiency

Current Risk: Moderate, low confidence

Future Risk: Moderate

This LF was assessed in conjunction with LF 80a (mortality or fitness reduction due to parasites, pathogens, or disease – Thiamine deficiency for the adult freshwater migration life stage). Please refer to LF 80a for full description and risk evaluation.

LF 95: Mortality or fitness reduction due to predation

Current Risk: Low

Future Risk: Moderate

This LF was assessed in conjunction with LF 81 (mortality or fitness reduction due to predation for the adult freshwater migration life stage). Please refer to LF 81 for full description and risk evaluation.

5.8.3 Physical Habitat

LF 96: Mortality or fitness reduction due to unfavourable channel form or high sediment loads

Current Risk: Low, low confidence

Future Risk: Moderate

This LF was assessed in conjunction with LF 83 (mortality or fitness reduction due to unfavourable channel form or high sediment loads for the adult freshwater migration life stage). Please refer to LF 83 for more information.

LF 97: Mortality or fitness reduction due to decreases in quality and quantity of spawning habitat

Current Risk: Low, low confidence

Future Risk: Moderate

Note: Potential effects of Mayo Hydro Plant on the adult spawning stage are considered separately in LF 97a.

Only the largest changes in spawning habitat quality and quantity are readily apparent. These generally support a current risk of low and future risk of moderate. The spawning habitat lost or degraded by the Mayo Hydroelectricity Project is described in limiting factors 97a below.

Decreases in spawning habitat quantity and quality can be roughly assessed by looking at stressors that could contribute to the degradation. These include the direct or indirect effects of large contributions of sediment, primarily through permafrost-related land failures. Subtle changes to the quality of spawning

habitat, such as determining the degree of compaction and subsurface composition of potential spawning beds require significant expertise and finances to conduct. The sampling tends to require excavation of stream beds or the use of ice core sampling or hand/heavy equipment.

Changes to spawning habitat in the Porcupine River watershed are anticipated. There have been, and continue to be, decreases in the quality of spawning habitat in the large tributaries of the Yukon River and perhaps in the river itself in the Minto Flats area. Lake outlets and large streams and small rivers seem not to have suffered greatly.

Beaver may dam a stream when Chinook have spawned upstream. This may effectively drown the eggs, as there will no longer be flows to deliver oxygen or remove metabolic waste. A relatively rare situation may occur when beaver dams restrain the outlet of a lake. When the dam breaks, a significant and potentially catastrophic flood can occur and alter downstream spawning habitats.

LF 97a: Mortality or fitness reduction due to reduced quality and quantity of spawning habitat – select populations impacted by Mayo River Hydro Plant

Current Risk: Very High, high confidence

Future Risk: Very High

As described above in LF 82a, the Wareham Lake Dam obstructs all passage of Chinook upstream into historically highly productive spawning habitat, including spawning dunes. Additionally, gravel starvation caused by the dam and channel works downstream of the Silver Trail bridge over the Mayo River likely contributes significantly to reduced quality of spawning habitat below the dam.

5.8.4 Hydrology and Oceanography

LF 98: Mortality or fitness reduction due to altered timing or magnitude of high flows

Current Risk: Low

Future Risk: Moderate

This LF was assessed in conjunction with LF 84 (mortality or fitness reduction due to altered timing or magnitude of peak flows on the adult freshwater migration life stage). Please refer to LF 84 for full description and risk evaluation.

LF 99: Mortality or fitness reduction due to altered timing or magnitude of low water levels

Current Risk: Low

Future Risk: Moderate

This LF was assessed in conjunction with LF 85 (mortality or fitness reduction due to altered timing or magnitude of low water levels on the adult freshwater migration life stage). Please refer to LF 85 for full description and risk evaluation.

5.8.5 Water Quality

LF 100: Mortality, fitness reduction, delayed migration, or delayed spawning due to unfavourable water temperatures

Current Risk: High

Future Risk: Very High

Note: Potential effects of the Porcupine River on the adult spawning stage are considered separately in LF 100a.

This LF was assessed in conjunction with LF 87 (mortality, fitness reduction, or delayed migration due to unfavourable water temperatures on the adult freshwater migration life stage). Please refer to LF 87 for full description and risk evaluation.

LF 100a: Mortality, fitness reduction, delayed spawning or pre-spawn mortality due to unfavourable water temperatures – Porcupine River

Current Risk: Very High

Future Risk: Very High

As described above in LF 87a, the Porcupine River basin is the most northerly Chinook spawning system in the Yukon River basin. Temperature data has been collected on the Porcupine and Crow rivers at Old Crow for a very limited period of time. Both rivers exceeded the average daily water temperature threshold (U.S. EPA 2003) of 18°C during periods when spawning Chinook were migrating through the area. Almost all Chinook in the basin pass the community of Old Crow when returning to either the Porcupine and Crow Rivers. High temperatures affect Chinook not only during migration but also as they are holding to spawn and spawning. This justifies the current risk of very high, and the future risk of very high.

LF 101: Mortality or fitness reduction as a result of low dissolved oxygen

Current Risk: Very Low

Future Risk: Very Low

There is a very low risk to spawning Chinook salmon from low dissolved oxygen levels. Chinook spawn during the summer in moving water. This water is constantly exposed to air, and dissolved oxygen will be constantly renewed.

LF 102: Mortality or fitness reduction due to unfavourable water chemistry

Current Risk: Low

Future Risk: Moderate

This LF was assessed in conjunction with LF 89 (mortality or fitness reduction due to unfavourable water quality for the adult freshwater migration life stage). Please refer to LF 89 and 90 for full description and risk evaluation.

LF 103: Mortality or fitness reduction due to contaminants or deleterious substances

Current Risk: Low

Future Risk: Moderate

This LF was assessed in conjunction with LF 89 and 90 (mortality or fitness reduction due to unfavourable water quality for the adult freshwater migration life stage freshwater migration stage). Please refer to LF 89 and 90 for full description and risk evaluation.

5.9 Population Level

LF 104: Mortality or fitness reduction due to a reduction in natural (wild) genetic diversity

Current Risk: Moderate, low confidence

Future Risk: Moderate, moderate confidence

Note: genetic drift was considered as a separate, but related limiting factor. See LF 104a below.

Given the very high number of spawning populations (>100) documented for Canadian-origin Yukon River Chinook (Brown et al. 2017), it is likely that less productive populations have experienced overfishing or even extirpation given high historical fishing pressure at the aggregate population level (Connors et al. 2022). Further, it is possible that reduced population diversity could help explain why Chinook from different major sub-basins had very similar responses to climate-related threats, with negative implications for regional fisheries stability in the face of ongoing environmental change (Murdoch et al. 2024). However, more information is required to understand the relative role of genetic diversity on productivity trends, making this issue a potentially important data gap. As Chinook populations decline, there may be an increasing risk for reduced gene diversity with negative implications for population fitness and survival in light of climate change (Garant et al. 2005). Future genetic studies may be useful to understand the potential decline in genetic characteristics over time with respect to population sizes and other potential contributing factors (van Doornik et al. 2011). It is possible that Traditional Knowledge could be used to inform an understanding of this limiting factor.

LF104a: Mortality or fitness reduction due to a loss in natural (wild) genetic diversity due to genetic drift effects on select small populations

Current Risk: High

Future Risk: Data Gap

Though not all populations throughout the Yukon River are expected to be experiencing small population genetic effects such as genetic drift, select, relatively small populations likely are. These populations are likely losing their diversity and key alleles found in the population that relate to local adaptation. In these scenarios, hatchery intervention may be a way to save select populations from extirpation, though many Yukon First Nations citizens and elders maintain that hatchery intervention may be culturally inappropriate. Workshop participants noted that the hatchery built to compensate for dam impacts to Chinook populations may provide its own risks to the population through domestication and other negative population effects.

There is a data gap for Yukon Chinook on how this dynamic will continue into the future as these select small populations exist in a tenuous state between rebuilding and extirpation.

LF 105: Mortality and fitness reduction due to changes in biological characteristics such as fecundity, egg quality or quantity, maturation rate, sex ratios, size at age, etc.

Current Risk: High, medium confidence

Future Risk: Very High

It is well understood that the size and age of Chinook has declined, with fewer seven-year-olds and smaller fish returning than were observed in past decades. This likely also influences fecundity for females (Ohlberger et al. 2020; Oke et al. 2020). Further information relating to changes in escapement quality are discussed in other limiting factors in relation to warming (sections 5.5.3 and 5.6.3), marine predation (sections 5.3.1 and 5.4.1), and pink salmon competition (sections 5.5.2 and 5.6.2).

LF 106: Mortality or fitness reduction due to the loss of respect or relationship with people

Current Risk: High

Future Risk: Very High

Workshop participants reflected concerns raised by knowledge holders that the loss of interactive relationships between people, the land and water, and salmon and the loss of customary practices and ceremony that showed respect for salmon that stems from that loss of relationship may directly impact salmon. Many First Nations in the Yukon have ceremonies for calling Chinook home to spawn or other practices that embody their relationship to these fish. With the changes associated with colonization, wage economy, and development, in tandem with reduced access to Chinook given the dwindling population, there is concern that the loss of these practices has a direct impact on Chinook. It is reasonable to expect that the relationship between people and Chinook may continue to dwindle if small population sizes persist, justifying an increased risk ranking in the future.

It should also be noted that the changes resulting from colonization have had secondary effects on Chinook habitat. Traditionally, people spent more time on the land, actively participating in maintaining the balance of the ecosystem. For example, people used to hunt beaver, which worked to keep streams and creeks clear of dams. Without those activities, we are seeing spawning and rearing habitat being affected.

6. Discussion

6.1 Summary of High Risks: Eggs, Alevins, Fry, and Freshwater Smolt Life Stages

There were no high risks identified in the egg/alevin and fry to smolt life stages. This may indicate that there are very large data gaps in our knowledge of the early freshwater life stages for Yukon Chinook salmon, or factors limiting the productivity of the population at these life stages has not measurably changed, or be due to a limited ability to observe or detect major impacts at these life stages. There are additional data gaps from carry over effects on factors affecting adult Chinook (e.g., thiamine deficiency, heat stress).

During the early freshwater life stages, moderate risk rankings included thiamine deficiency (LF 3a), predation on fry (LF 15), and mortality or fitness reduction due to low water levels causing ice related mortality during overwintering (LF 20a). It is understood that some degree of ice-related mortality has always been a natural cause of fry mortality in the Yukon River watershed at low water levels, when fry themselves are frozen, starved of oxygen, or killed by moving ice. This has likely been exacerbated by climate change and is expected to become an increasing problem because of climate change-induced hydrological variability.

6.2 Summary of High Risks: Marine Life Stages

In the marine life stages of Chinook, the highest risks are understood to be warming temperatures and related diet shifts during the maturing adult stage, and predation during the early marine stage.

Notably, Chinook are expected to face relatively high predation pressure during the early marine period based on knowledge of this life stage from other salmon systems in the Northeast Pacific Ocean. However, it is currently unknown if predation pressure may be relatively stable or linked to changing environmental processes over time, making it a potentially important data gap for Yukon River Chinook. Predation pressure may interact with demographic changes (LF 105) as there is some evidence that predation on older Chinook may be size-selective (Ohlberger et al. 2019; Manishin et al. 2021), providing an evolutionary pressure for smaller body sized fish.

Diet of maturing adults remains an important data gap, and more information is needed to understand the role of shifting feeding patterns in response to a changing climate for this life stage (LFs 56 and 69). For example, ecosystem changes in the Bering Sea could cause Chinook to shift their diets towards less optimal alternatives such as species infected by the *Ichthyophonus* parasite, or prey that is lower in essential dietary nutrients required for successful spawning and early incubation (Howard and von Biela 2023).

Moderate risks identified included warming temperatures and related diet shifts during earlier life stages, as well as competition for food with wild pink salmon during the immature and maturing adult stages. Notably, the early marine life stage may be experiencing both positive and negative effects in response to warmer temperatures and changes in prey availability, with potential implications for early marine growth and body condition (Murdoch et al. 2024; Feddern et al. 2024). It is possible that the risk of climate-related effects may increase in the future for these life stages from moderate to high.

6.3 Summary of High Risks: Adult Freshwater Migration and Spawning Life Stages

Disease, water temperatures, thiamine deficiency, and fishing are understood to be of primary concern in the generally observable adult freshwater life stages for these fish.

Ichthyophonus hoferi is a parasite that is transferred to Chinook through their prey with the potential for higher disease severity in warmer years during the marine stage. The effects of infection include visible lesions and direct reductions in a fish's cardiovascular output, which coupled with other stressors (i.e., warm water, poor body condition) can lead to mortality (Kocan et al. 2004). The discrepancy in estimates between Chinook entering the river at Pilot Station, Alaska, and crossing the Canadian border near Eagle, Alaska, is thought to be largely because of reduced fitness or mortality relating to *Ichthyophonus*. As such, impacts of *Ichthyophonus* was ranked as one of the highest risks to Chinook across their life stages.

Water temperatures in stress-inducing or lethal ranges are observed most years on the lower Yukon River, as summer sunlight provides close to or fully 24-hour thermal inputs to the watershed. Prolonged exposure to temperatures above 18°C has been demonstrated to cause heat stress for migrating adult Chinook. These thermal conditions have been observed frequently in portions of the watershed, highlighting risks of direct thermal mortality on the freshwater migration back to spawning grounds. It is expected that thermal refuges may exist along migration routes, providing respite for thermal-stressed Chinook, though the locations of these are not well understood and are a priority for mapping and protection.

Thiamine deficiency is another factor that could potentially reduce the condition of Yukon River Chinook and therefore their ability to effectively carry out their spawning activities. Directly related to the high risk of lack of access to appropriate food in the marine environment (LFs 44, 56, and 69), low levels of this key vitamin may be an acute driver of poor fish condition and lead to pre-spawn mortality or carryover effects on offspring in freshwater. Additional research is required to determine the threshold level of thiamine that may cause these effects in Canadian-origin Yukon River Chinook.

Fishing, though it has been almost completely curtailed because of fishery management decisions in recent years, still provides a direct, tangible risk to Chinook given the small numbers of returning fish each year. Workshop participants emphasized that any harvest, regardless of how small, will continue to pose a risk to the broader population at current run sizes (LFs 78 and 92).

A factor not captured in the limiting factor framework is an issue brought up by many Yukon First Nations representatives—that low return abundances and low Chinook densities may result in Chinook not being able to find a mate during spawning.

6.4 Risks Spanning All Life Stages

Two key factors emerged as limiting to Chinook populations that span life phases or generations: changes in demographic characteristics and the loss of respect or relationship with people.

Changes in demographic characteristics have been observed in the Yukon River Chinook salmon population. Fewer older (especially age 7) fish are represented in the returning spawners. This results in smaller fish size and lower female fecundity as age 7 Chinook are significantly larger and more fecund than age 6 or 5 (Ohlberger et al. 2020). Over time, the trend towards younger, smaller, and less fecund fish at a population scale may be a risk to population productivity though it may also be an adaptive strategy (Healey 1986). It does, however, constitute a change in the relationship between Chinook, the environment, and the people of the Yukon.

Chinook have held important social value to many Yukoners over generations. Importantly, Yukon First Nations have always had a respectful and caring relationship with Chinook. The loss of relationships between Chinook and people is understood to be a tangible limiting factor to the productivity of the population. As returning Chinook numbers drop, opportunities for continued relationships between people and Chinook are increasingly limited. Elders and knowledge holders from First Nations across the Yukon River watershed have emphasized that rebuilding the relationship and respect is vital to rebuilding the stock.

6.5 Limitations of This Approach

There are a variety of limitations with the limiting factor framework for assessing issues facing Yukon River Chinook. Firstly, the assessment of risk by limiting factors is intended to provide a way of understanding risk through the lens of the Chinook at various points across their life cycle. Though reducing complex life stages into 106 limiting factors allows for detailed consideration of many potential issues, the method provides limited opportunities for understanding the interactions between factors and cumulative effects of multiple limiting factors.

A paucity of data about these Chinook across their life cycle and geography limited the ability to comprehensively assess risk for many limiting factors. For much of their life cycle in fresh water, Chinook overwinter in remote or inaccessible habitat, limiting the ability of researchers to develop a robust

understanding of year-round population dynamics. Even in summer months, much of the Canadian portion of the Yukon River Watershed is extremely remote and difficult to study or observe Chinook within. Small population numbers and limited assessment data also limit quantitative analysis, particularly in the Porcupine drainage.

Potentially important data gaps relating to the main marine issues were identified including warming temperatures and related diet shifts during the immature stage, feeding patterns during the maturing adult stage, early marine competition and predation, and *Ichthyophonus* during the immature and maturing adult stages. In addition, there is currently no information estimating the potential impact of bycatch from foreign fisheries.

There are several other data gaps with potential risks to Chinook that represent emerging or understudied issues. For example, increasing permafrost thaw and sedimentation processes in the estuary or nearshore marine habitats have the ability to impact habitat access and quality for migrating Chinook. Further, climate-related changes in river flow such as more extreme high or low flows may lead to impacts on estuary habitat access and quality for smolts. Harmful algal blooms are increasing in the Bering Sea (Siddon 2023), with potential implications for marine ecosystem health including salmon (Esenkulova et al. 2022). There is also currently a limited understanding of how changes in ice cover, cold pool extent, or other broad oceanographic processes may be mechanistically linked to Chinook declines.

Traditional Knowledge is an important field of understanding generated through countless generations of relationships between Chinook and people and may be an important part of addressing the data gaps identified above. Efforts to braid Traditional Knowledge and technical or scientific knowledge about Chinook have been made in the development of this report. Although Traditional Knowledge informed aspects of this risk assessment, the scale of the assessment, as well as limited collaborative capacity, presented challenges to comprehensively weaving the diverse knowledges held by Yukon First Nations and others working on rebuilding Chinook.

Evaluating risks at a watershed scale presented a consistent challenge for the workshop participants as some risks affect only small sub-populations in certain tributaries. Workshop participants noted where risks are only faced by select populations, though the risk of the limiting factor across the entire population often was less severe than the risk for those select populations. Further, assessing impact of risks at a watershed scale was challenging as environmental and geophysical conditions vary substantially across the watershed. Finally, this assessment of issues was conducted over a relatively limited time span, and it is expected that knowledge on issues facing Chinook will expand as rebuilding work advances.

6.6 Recommendations on Future Work

Despite significant progress in identifying key limiting factors to Yukon River Chinook salmon, important data gaps remain that need attention to improve management and conservation. Recent capacity increases with DFO and Yukon First Nations have allowed many projects to begin in earnest, but longevity of programs are at risk due to upcoming budget constraints. Future research and monitoring are recommended to better understand and respond to growing environmental and ecological risks in the Yukon River watershed and marine ecosystem. In freshwater systems, the effects of gravel starvation, caused by changes in sediment flow downstream of hydroelectric dams like the Mayo River Hydro Plant, are not well understood and need further study. Using Traditional Knowledge can also help

build a better understanding of this issue and how the landscape has changed. Another concern is the impact of more frequent high stream flows on juvenile Chinook salmon. These high flows, expected to increase with climate change (Bush and Lemmen 2019), can reduce feeding, push young Chinook out of suitable habitats, and damage those habitats through erosion and sediment buildup (Cunningham et al. 2018; Jones et al. 2020; Feddern et al. 2024; Murdoch et al. 2024). Site-specific monitoring is especially important in unglaciated areas, where there is less natural protection from rapid water level changes. Some streams affected by past placer mining activity may also be more vulnerable, making them a priority for study. As permafrost continues to thaw, acid rock drainage (ARD) is expected to become more common. This can lead to stream discoloration and harm fish and their habitats (Rozell 2024). Monitoring programs should be put in place to detect early signs of ARD, such as staining in aufeis, and to study how thawing soils and bedrock contribute to these chemical changes. Although Engineer Creek is outside the Yukon River basin, it is a useful location for observing ARD and could help predict what might happen elsewhere. Additionally, triggers for juvenile Chinook leaving their natal streams are also unknown and may relate to various ecological or hydrological factors. Integrating Traditional Knowledge with scientific methods offers a strong opportunity to better understand migrating smolt behavior.

In the marine environment, a critical research need involves competition among juvenile salmon species during early marine stages as some diet overlap between Chinook and coho salmon smolts in the estuary environment is known, but the broader patterns of competition remain unexplored. There is also a clear need for more research on how pink salmon may be contributing to the long term decline in Chinook salmon size, age-at-maturity, and reproductive success, especially as warming ocean temperatures may allow pink salmon to become even more abundant (Ruggerone et al. 2016; Ohlberger et al. 2020; Oke et al. 2020; Ruggerone et al. 2023). Ocean acidification is progressing quickly in the eastern Bering Sea, which may affect Chinook salmon indirectly by changing the food web (Siddon et al. 2023; Litzow et al. 2025; Ou et al. 2015; Williams et al. 2018; Frommel et al. 2020, 2024). Although salmon may be somewhat adaptable, more research is needed to understand the long term effects on their food sources.

In the river, returning adult Chinook are increasingly affected by stress from warming water, parasites, exhaustion, thiamine deficiency, and other unknown causes. These risks are expected to grow over time, and future studies should include monitoring the health and condition of returning adults. While fish counting methods have improved by replacing fences and fishwheels with sonar, some practices like gillnetting, radio-tagging, and helicopter surveys still cause stress and should be reviewed and improved. Maintaining and improving fish passage infrastructure, such as culverts and fish ladders at dam sites, will be essential as human development and energy demands continue to grow (von Finster and Reid 2015). Finally, genetic diversity loss at regional and subpopulation levels remains a pressing concern. While Yukon River Chinook form a large management group, smaller populations may be losing genetic variation, threatening local adaptations and resilience, and continued investigation into the genetics of Yukon River Chinook is warranted.

6.7 Conclusion

As documented in the limiting factor summary table (Appendix A) there is no singular risk limiting the rebuilding of Canadian-origin Yukon River Chinook salmon or “smoking gun.” Best efforts were made to convene experts and gather available information from Traditional, western, and local knowledge systems. This evidence base informs a multi-factorial understanding of factors limiting Chinook populations, including warming temperatures, competition, disease, predation, habitat degradation or

loss, hydrological and geomorphological changes, and carry-over effects from marine life stages on migrating adults and spawners. Though fishing is not presently understood as a driver of population decline, nor a limiting factor to population rebuilding, given the low levels of current harvest (2024 harvest estimated at 1,875; JTC 2025), it is widely understood to have played a significant role in creating the present situation for Chinook, and any removals presently or into the future could have significant impacts. This report synthesizes perspectives from multiple partners with responsibility and expertise at different scales, supporting a better understanding of the relative impact of localized risks on the whole watershed.

This summary of limiting factors to Chinook is intended to reflect the state of knowledge at the time of publication and is compiled with the intent of informing the development of a collaborative *Canadian-Origin Yukon River Chinook Salmon Rebuilding and Ecosystem Strategy* (the Strategy). The Strategy includes objectives and actions that may be pursued by individuals, communities, and governments to ensure a continued presence of Chinook throughout the waters of the Canadian Yukon River Basin. In tandem with the development of the Strategy, working groups have been established to pursue priority rebuilding work. Short and long-term rebuilding work must address the variety of limiting factors outlined in this report and be mindful of how they impact Chinook in the context of their complex life cycle and the diversity of habitats they migrate through, spawn in, rear in, and mature in. Potential rebuilding actions should be assessed on their ability to address factors known to be limiting survival or rebuilding of Chinook. Recognizing that many data gaps exist, this report is intended to support ongoing dialogue as knowledge and rebuilding work advances.

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Personal communication

- Jim Murphy, National Marine Fisheries Service
- William Twardek, Ecofish Research Ltd.
- Ben Schonewille, Ecosystem Dynamics Inc.

- Ron Chambers, Champagne Aishihik First Nation
- Nick DeGraff, Can-nic-a-nick Environmental Services
- Karlie Knight, Tr'ondëk Hwëch'in
- Adam O’Dell, Fisheries and Oceans Canada
- Katie Howard, National Marine Fisheries Service
- Rasheeda Slater, First Nation of Na-cho Nyäk Dun

Appendix A. Limiting Factor Table for Canadian-origin Yukon River Chinook salmon

Ecosystem Unit	Life Stage	Limiting Factor Category	Limiting Factor Subcategory	LF ID	Limiting Factor	Confidence (If Noted)	Current Risk	Future Risk	Page
Freshwater	Egg / Alevin	Direct Anthropogenic Interactions	Harassment and Disturbance	1	Mortality or fitness reduction due to redd disturbance by humans	High	Very Low	Very Low	37
Freshwater	Egg / Alevin	Biological Interactions	Competition	2	Mortality or fitness reduction due to redd overspawn	High	Very Low	Very Low	37
Freshwater	Egg / Alevin	Biological Interactions	Parasites, Pathogens, Disease, and Harmful Algae	3	Mortality or fitness reduction due to parasites, pathogens, or disease	Low	Low	Low	37
Freshwater	Egg / Alevin	Biological Interactions	Parasites, Pathogens, Disease, and Harmful Algae	3a	Mortality or fitness reduction due to parasites, pathogens, or disease - Thiamine deficiency	Low	Moderate	Moderate	38
Freshwater	Egg / Alevin	Biological Interactions	Predation	4	Mortality or fitness reduction due to predation	High	Very Low	Very Low	38
Freshwater	Egg / Alevin	Physical Habitat	Channel Stability and Form	5	Mortality or fitness reduction due to unfavourable bed material	Medium	Low	Moderate	39
Freshwater	Egg / Alevin	Hydrology and Oceanography	High Flows	6	Mortality or fitness reduction resulting from altered timing, frequency, or magnitude of peak flows	Low	Low	Moderate	40
Freshwater	Egg / Alevin	Hydrology and Oceanography	Low Flows	7	Mortality or fitness reduction resulting from altered timing, frequency, or magnitude of low flows or water levels		Low	Moderate	41
Freshwater	Egg / Alevin	Water Quality	Temperature	8	Mortality or fitness reduction due to unfavourable water temperatures		Very Low	Low	41
Freshwater	Egg / Alevin	Water Quality	Dissolved Oxygen	9	Mortality or fitness reduction due to low dissolved oxygen	High	Very Low	Very Low	41
Freshwater	Egg / Alevin	Water Quality	Chemistry	10	Mortality or fitness reduction due to unfavourable water chemistry	Low	Low	Moderate	42
Freshwater	Egg / Alevin	Water Quality	Contaminants and Deleterious Substances	11	Mortality or fitness reduction due to contaminants or deleterious substances	Low	Low	Moderate	42
Freshwater	Fry	Direct Anthropogenic Interactions	Harassment and Disturbance	12	Mortality or fitness reduction due to stress from anthropogenic activity		Low	Moderate	43

Ecosystem Unit	Life Stage	Limiting Factor Category	Limiting Factor Subcategory	LF ID	Limiting Factor	Confidence (If Noted)	Current Risk	Future Risk	Page
Freshwater	Fry	Direct Anthropogenic Interactions	Harassment and Disturbance – Whitehorse dam	12a	Mortality or fitness reduction due to stress from anthropogenic activity – select populations impacted by Whitehorse Rapids Hydro Plant	High	Very High	Very High	43
Freshwater	Fry	Biological Interactions	Competition	13	Mortality or fitness reduction due to competition		Low	Low	44
Freshwater	Fry	Biological Interactions	Parasites, Pathogens, Disease, and Harmful Algae	14	Mortality or fitness reduction due to parasites, pathogens, or disease		Very Low	Very Low	44
Freshwater	Fry	Biological Interactions	Predation	15	Mortality or fitness reduction due to predation	Low	Moderate	Moderate	45
Freshwater	Fry	Biological Interactions	Prey and Food	16	Mortality or fitness reduction due to lack of quality or quantity of appropriate food		Very Low	Low	45
Freshwater	Fry	Physical Habitat	Barriers	17	Mortality or fitness reduction due to loss of access to rearing habitat		Low	Low	46
Freshwater	Fry	Physical Habitat	Barriers – Mayo Dam	17a	Mortality or fitness reduction due to loss of access to rearing habitat – specific populations impacted by Mayo River Hydro Plant		Moderate	Moderate	47
Freshwater	Fry	Physical Habitat	Channel Stability and Form	18	Mortality or fitness reduction due to unfavourable channel form and/or timing or duration of sediment loads		Low	Moderate	47
Freshwater	Fry	Physical Habitat	Channel Stability and Form – Placer Mining	18a	Mortality or fitness reduction due to unfavourable channel form and/or timing or duration of sediment loads – select systems with placer mining impacts		Moderate	Moderate	48
Freshwater	Fry	Hydrology and Oceanography	High Flows	19	Mortality or fitness reduction due to altered timing or magnitude of peak flows causing flushing	Low	Low	Moderate	50
Freshwater	Fry	Hydrology and Oceanography	Low Flows	20	Mortality or fitness reduction due to altered timing or magnitude of low water levels causing stranding	Low	Low	Moderate	50
Freshwater	Fry	Hydrology & Oceanography	Low Flows	20a	Mortality or fitness reduction due to low water levels causing ice related mortality during overwintering		Moderate	High	51

Ecosystem Unit	Life Stage	Limiting Factor Category	Limiting Factor Subcategory	LF ID	Limiting Factor	Confidence (If Noted)	Current Risk	Future Risk	Page
Freshwater	Fry	Water Quality	Temperature	21	Mortality or fitness reduction due to unfavourable water temperatures	Medium	Low	Moderate	51
Freshwater	Fry	Water Quality	Dissolved Oxygen	22	Mortality or fitness reduction due to low dissolved oxygen	High / Low	Low	Low	52
Freshwater	Fry	Water Quality	Chemistry	23	Mortality or fitness reduction due to unfavourable water chemistry	Low	Low	Moderate	52
Freshwater	Fry	Water Quality	Contaminants and Deleterious Substances	24	Mortality or fitness reduction due to contaminants or deleterious substances	Low	Low	Moderate	53
Estuarine	Smolt	Direct Anthropogenic Interactions	Harassment and Disturbance	25	Mortality or fitness reduction due to stress from anthropogenic activity	Medium	Very Low	Very Low	53
Estuarine	Smolt	Biological Interactions	Competition	26	Mortality or fitness reduction due to competition		Data Gap	Data Gap	53
Estuarine	Smolt	Biological Interactions	Parasites, Pathogens, Disease, and Harmful Algae	27	Mortality or fitness reduction due to parasites, pathogens, disease, or algal blooms	High	Very Low	Very Low	N/A
Estuarine	Smolt	Biological Interactions	Predation	28	Mortality or fitness reduction due to predation	Medium	High / Data Gap	High / Data Gap	54
Estuarine	Smolt	Biological Interactions	Prey and Food	29	Mortality or fitness reduction due to lack of access and availability of appropriate food	Low	Moderate	High	54
Estuarine	Smolt	Physical Habitat	Barriers	30	Mortality or fitness reduction due to loss of access to estuarine habitat		Data Gap	Data Gap	N/A
Estuarine	Smolt	Physical Habitat	Chanel Stability and Flow	31	Mortality or fitness reduction due to unfavourable channel form or sediment loads		Data Gap	Data Gap	54
Estuarine	Smolt	Hydrology and Oceanography	High Flows	32	Mortality or fitness reduction due to altered timing or magnitude of peak flows causing flushing		Data Gap	Data Gap	N/A
Estuarine	Smolt	Hydrology and Oceanography	Low Flows	33	Mortality or fitness reduction due to altered timing or magnitude of low water levels causing stranding		Data Gap	Data Gap	N/A
Estuarine	Smolt	Hydrology and Oceanography	Physical Oceanography	34	Mortality or fitness reduction due to oceanography, currents, or tides		Data Gap	Data Gap	N/A

Ecosystem Unit	Life Stage	Limiting Factor Category	Limiting Factor Subcategory	LF ID	Limiting Factor	Confidence (If Noted)	Current Risk	Future Risk	Page
Estuarine	Smolt	Water Quality	Temperature	35	Mortality or fitness reduction due to unfavourable water temperatures	Medium	Moderate	High	55
Estuarine	Smolt	Water Quality	Dissolved Oxygen	36	Mortality or fitness reduction due to low dissolved oxygen		Data Gap	Data Gap	N/A
Estuarine	Smolt	Water Quality	Chemistry	37	Mortality or fitness reduction due to unfavourable water chemistry	Low	Low	Low	56
Estuarine	Smolt	Water Quality	Contaminants and Deleterious Substances	38	Mortality or fitness reduction due to contaminants or deleterious substances	Medium	Very Low	Very Low	N/A
Marine (nearshore)	Juvenile	Direct Anthropogenic Interactions	Harassment and Disturbance	39	Mortality or fitness reduction due to stress from anthropogenic activity	Medium	Very Low	Very Low	N/A
Marine (nearshore)	Juvenile	Direct Anthropogenic Interactions	Fishing	40	Mortality or fitness reduction due to fishing	High	Very Low	Very Low	N/A
Marine (nearshore)	Juvenile	Biological Interactions	Competition	41	Mortality or fitness reduction due to competition for prey		Data Gap	Data Gap	57
Marine (nearshore)	Juvenile	Biological Interactions	Parasites, Pathogens, Disease, and Harmful Algae	42	Mortality or fitness reduction due to parasites, pathogens, disease, or harmful algae	High	Very Low	Very Low	N/A
Marine (nearshore)	Juvenile	Biological Interactions	Predation	43	Mortality or fitness reduction due to predation	Medium	High / Data Gap	High / Data Gap	57
Marine (nearshore)	Juvenile	Biological Interactions	Prey and Food	44	Mortality or fitness reduction due to lack of access and availability of appropriate food	Medium	Moderate	High	58
Marine (nearshore)	Juvenile	Physical Habitat	Barriers	45	Mortality or fitness reduction due to reduced habitat connectivity	Medium	Very Low	Very Low	N/A
Marine (nearshore)	Juvenile	Hydrology and Oceanography	Physical Oceanography	46	Mortality or fitness reduction due to oceanography, currents, or tides		Data Gap	Data Gap	N/A
Marine (nearshore)	Juvenile	Water Quality	Temperature	47	Mortality or fitness reduction due to direct impacts of water temperatures	High	Moderate	High	58
Marine (nearshore)	Juvenile	Water Quality	Dissolved Oxygen	48	Mortality or fitness reduction due to direct impacts of hypoxia or dissolved oxygen levels		Data Gap	Data Gap	N/A
Marine (nearshore)	Juvenile	Water Quality	Chemistry	49	Mortality or fitness reduction due to unfavourable water chemistry	Low	Low	Low	58

Ecosystem Unit	Life Stage	Limiting Factor Category	Limiting Factor Subcategory	LF ID	Limiting Factor	Confidence (If Noted)	Current Risk	Future Risk	Page
Marine (nearshore)	Juvenile	Water Quality	Contaminants and Deleterious Substances	50	Mortality or fitness reduction due to exposure to containments or deleterious substances	Medium	Very Low	Very Low	N/A
Marine (pelagic)	Immature	Direct Anthropogenic Interactions	Harassment and Disturbance	51	Mortality or fitness reduction due to stress from anthropogenic activity	Medium	Very Low	Very Low	N/A
Marine (pelagic)	Immature	Direct Anthropogenic Interactions	Fishing	52	Mortality or fitness reduction due to fishing	Medium	Low	Low	58
Marine (pelagic)	Immature	Direct Anthropogenic Interactions	Fishing	52a	Mortality or fitness reduction due to fishing – indirect effects		Data Gap	Data Gap	60
Marine (pelagic)	Immature	Direct Anthropogenic Interactions	Fishing	52b	Mortality or fitness reduction due to fishing – Alaska Peninsula and Aleutian Islands Management Area ("Area M")	Medium	Low	Low	60
Marine (pelagic)	Immature	Biological Interactions	Competition	53a	Mortality or fitness reduction due to competition for prey – pink salmon, hatchery	Low	Low	Data Gap	62
Marine (pelagic)	Immature	Biological Interactions	Competition	53b	Mortality or fitness reduction due to competition for prey – pink salmon, wild	Medium	Moderate	High	63
Marine (pelagic)	Immature	Biological Interactions	Competition	53c	Mortality or fitness reduction due to competition for prey – with chum salmon	Medium	Low	Low	64
Marine (pelagic)	Immature	Biological Interactions	Parasites, Pathogens, Disease, and Harmful Algae	54a	Mortality or fitness reduction due to parasites, pathogens, disease, or harmful algae – *Ichthyophonus*		Data Gap	Data Gap	64
Marine (pelagic)	Immature	Biological Interactions	Parasites, Pathogens, Disease, and Harmful Algae	54b	Mortality or fitness reduction due to parasites, pathogens, disease, or harmful algae – Thiamine deficiency		Data Gap	Data Gap	66
Marine (pelagic)	Immature	Biological Interactions	Predation	55	Mortality or fitness reduction due to predation	Low	Moderate	High	66
Marine (pelagic)	Immature	Biological Interactions	Prey and Food	56	Mortality or fitness reduction due to lack of access and availability of appropriate food		Data Gap	Data Gap	67
Marine (pelagic)	Immature	Physical Habitat	Barriers	57	Mortality or fitness reduction due to reduced habitat connectivity	Medium	Very Low	Very Low	N/A

Ecosystem Unit	Life Stage	Limiting Factor Category	Limiting Factor Subcategory	LF ID	Limiting Factor	Confidence (If Noted)	Current Risk	Future Risk	Page
Marine (pelagic)	Immature	Physical Habitat	Habitat Quality and Quantity	58	Mortality or fitness reduction due to reduction in habitat quality or quantity	Medium	Very Low	Very Low	N/A
Marine (pelagic)	Immature	Hydrology and Oceanography	Physical Oceanography	59	Mortality or fitness reduction due to oceanography, currents, tides		Data Gap	Data Gap	N/A
Marine (pelagic)	Immature	Water Quality	Temperature	60	Mortality or fitness reduction due to direct impacts of water temperatures	Medium	Data Gap	Data Gap	67
Marine (pelagic)	Immature	Water Quality	Dissolved Oxygen	61	Mortality or fitness reduction due to direct impacts of hypoxia or dissolved oxygen levels	Medium	Very Low	Very Low	N/A
Marine (pelagic)	Immature	Water Quality	Chemistry	62	Mortality or fitness reduction due to unfavourable water chemistry	Low	Low	Low	67
Marine (pelagic)	Immature	Water Quality	Contaminants and Deleterious Substances	63	Mortality or fitness reduction due to exposure to containments or deleterious substances	Medium	Very Low	Very Low	N/A
Marine (pelagic and nearshore)	Adult	Direct Anthropogenic Interactions	Harassment and Disturbance	64	Mortality or fitness reduction due to stress from anthropogenic activity	Medium	Very Low	Very Low	N/A
Marine (pelagic and nearshore)	Adult	Direct Anthropogenic Interactions	Fishing	65	Mortality or fitness reduction due to fishing – U.S. groundfish fisheries bycatch	Medium	Low	Low	68
Marine (pelagic and nearshore)	Adult	Biological Interactions	Competition	66a	Mortality or fitness reduction due to competition for prey – pink salmon, hatchery	Low	Low	Data Gap	68
Marine (pelagic and nearshore)	Adult	Biological Interactions	Competition	66b	Mortality or fitness reduction due to competition for prey – pink salmon, wild	Medium	Moderate	High	68
Marine (pelagic and nearshore)	Adult	Biological Interactions	Competition	66c	Mortality or fitness reduction due to competition for prey – chum salmon	Medium	Low	Low	68
Marine (pelagic and nearshore)	Adult	Biological Interactions	Parasites, Pathogens, Disease, and Harmful Algae	67a	Mortality or fitness reduction due to parasites, pathogens, disease, or harmful algae – *Ichthyophonus*		Data Gap	Data Gap	68
Marine (pelagic and nearshore)	Adult	Biological Interactions	Parasites, Pathogens, Disease, and Harmful Algae	67b	Mortality or fitness reduction due to parasites, pathogens, disease, or harmful algae – Thiamine deficiency		Data Gap	Data Gap	69

Ecosystem Unit	Life Stage	Limiting Factor Category	Limiting Factor Subcategory	LF ID	Limiting Factor	Confidence (If Noted)	Current Risk	Future Risk	Page
Marine (pelagic and nearshore)	Adult	Biological Interactions	Predation	68	Mortality or fitness reduction due to predation	Low	Very Low	Very Low	69
Marine (pelagic and nearshore)	Adult	Biological Interactions	Prey and Food	69	Mortality or fitness reduction due to lack of access and availability of appropriate food		Data Gap	Data Gap	69
Marine (pelagic and nearshore)	Adult	Physical Habitat	Barriers	70	Mortality or fitness reduction due to reduced habitat connectivity	Medium	Very Low	Very Low	N/A
Marine (pelagic and nearshore)	Adult	Physical Habitat	Habitat Quality and Quantity	71	Mortality or fitness reduction due to reduction in habitat quality or quantity	Medium	Very Low	Very Low	N/A
Marine (pelagic and nearshore)	Adult	Hydrology and Oceanography	Physical Oceanography	72	Mortality or fitness reduction due to oceanography, currents, tides		Data Gap	Data Gap	N/A
Marine (pelagic and nearshore)	Adult	Water Quality	Temperature	73	Mortality or fitness reduction due to direct impacts of water temperatures	Medium	High	Very High	69
Marine (pelagic and nearshore)	Adult	Water Quality	Dissolved Oxygen	74	Mortality or fitness reduction due to direct impacts of hypoxia or dissolved oxygen levels	Medium	Very Low	Very Low	N/A
Marine (pelagic and nearshore)	Adult	Water Quality	Chemistry	75	Mortality or fitness reduction due to unfavourable water chemistry	Low	Low	Low	70
Marine (pelagic and nearshore)	Adult	Water Quality	Contaminants and Deleterious Substances	76	Mortality or fitness reduction due to exposure to containments or deleterious substances	Medium	Very Low	Very Low	N/A
Freshwater (Migration)	Adult	Direct Anthropogenic Interactions	Harassment and Disturbance	77	Mortality or fitness reduction as a result of stress due to anthropogenic activity		Low	Moderate	71
Freshwater (Spawning)	Adult	Direct Anthropogenic Interactions	Harassment and Disturbance	77a	Mortality or fitness reduction as a result of stress due to anthropogenic activity – Whitehorse Rapids Dam and upstream	Medium	Very High	Very High	72
Freshwater (Migration)	Adult	Direct Anthropogenic Interactions	Fishing	78	Mortality or fitness reduction due to fishing		Moderate	Moderate	72

Ecosystem Unit	Life Stage	Limiting Factor Category	Limiting Factor Subcategory	LF ID	Limiting Factor	Confidence (If Noted)	Current Risk	Future Risk	Page
Freshwater (Migration)	Adult	Biological Interactions	Competition	79	Mortality or fitness reduction due to competition		Very Low	Very Low	73
Freshwater (Migration)	Adult	Biological Interactions	Parasites, Pathogens, Disease, and Harmful Algae	80a	Mortality or fitness reduction due to parasites, pathogens, or disease – *Ichthyophonus*		High	High	74
Freshwater (Migration)	Adult	Biological Interactions	Parasites, Pathogens, Disease, and Harmful Algae	80b	Mortality or fitness reduction due to parasites, pathogens, or disease – Thiamine deficiency	Low	Moderate	Moderate	74
Freshwater (Migration)	Adult	Biological Interactions	Predation	81	Mortality or fitness reduction due to predation		Low	Moderate	75
Freshwater (Migration)	Adult	Physical Habitat	Barriers	82	Mortality or fitness reduction due to migration barriers		Low	Moderate	75
Freshwater (Migration)	Adult	Physical Habitat	Barriers – Mayo dam	82a	Mortality or fitness reduction due to migration barriers – Mayo River Hydro Plant		Very High	Very High	76
Freshwater (Migration)	Adult	Physical Habitat	Channel Stability and Form	83	Mortality or fitness reduction due to unfavourable channel form or sediment loads	Low	Low	Moderate	76
Freshwater (Migration)	Adult	Hydrology and Oceanography	High Flows	84	Mortality or fitness reduction due to altered timing or magnitude of peak flows		Low	Moderate	77
Freshwater (Migration)	Adult	Hydrology and Oceanography	Low Flows	85	Mortality or fitness reduction due to altered timing or magnitude of low water levels		Low	Moderate	77
Freshwater (Migration)	Adult	Hydrology and Oceanography	Physical Oceanography	86	Mortality or fitness reduction due to oceanography, currents, or tides		N/A	N/A	N/A
Freshwater (Migration)	Adult	Water Quality	Temperature	87	Mortality, fitness reduction, or delayed migration due to unfavourable water temperatures		High	Very High	78
Freshwater (Migration)	Adult	Water Quality	Temperature	87a	Mortality, fitness reduction, or delayed migration due to unfavourable water temperatures – Porcupine River		Very High	Very High	79
Freshwater (Migration)	Adult	Water Quality	Dissolved Oxygen	88	Mortality or fitness reduction as a result of low dissolved oxygen		Very Low	Very Low	80
Freshwater (Migration)	Adult	Water Quality	Chemistry	89	Mortality or fitness reductions due to unfavourable water chemistry		Low	Moderate	80

Ecosystem Unit	Life Stage	Limiting Factor Category	Limiting Factor Subcategory	LF ID	Limiting Factor	Confidence (If Noted)	Current Risk	Future Risk	Page
Freshwater (Migration)	Adult	Water Quality	Contaminants and Deleterious Substances	90	Mortality or fitness reduction due to contaminants or deleterious substances		Low	Moderate	81
Freshwater (Spawning)	Adult	Direct Anthropogenic Interactions	Harassment and Disturbance	91	Mortality or fitness reduction as a result of stress due to anthropogenic activity		Low	Moderate	81
Freshwater (Spawning)	Adult	Direct Anthropogenic Interactions	Fishing	92	Mortality or fitness reduction due to fishing		Moderate	Moderate	81
Freshwater (Spawning)	Adult	Biological Interactions	Competition	93	Mortality or fitness reduction due to competition		Very Low	Very Low	81
Freshwater (Spawning)	Adult	Biological Interactions	Parasites, Pathogens, Disease, and Harmful Algae	94a	Mortality or fitness reduction due to parasites, pathogens, or disease – *Ichthyophonus*		High	High	81
Freshwater (Spawning)	Adult	Biological Interactions	Parasites, Pathogens, Disease, and Harmful Algae	94b	Mortality or fitness reduction due to parasites, pathogens, or disease – Thiamine deficiency	Low	Moderate	Moderate	82
Freshwater (Spawning)	Adult	Biological Interactions	Predation	95	Mortality or fitness reduction due to predation		Low	Moderate	82
Freshwater (Spawning)	Adult	Physical Habitat	Channel Stability and Form	96	Mortality or fitness reduction due to unfavourable channel form or sediment loads	Low	Low	Moderate	82
Freshwater (Spawning)	Adult	Physical Habitat	Aquatic Habitat Quality and Quantity	97	Mortality or fitness reduction due to reduced quality and quantity of spawning habitat	Low	Moderate	Moderate	82
Freshwater (Spawning)	Adult	Physical Habitat	Aquatic Habitat Quality and Quantity	97a	Mortality or fitness reduction due to reduced quality and quantity of spawning habitat – select populations impacted by Mayo River Hydro Plant	High	Very High	Very High	83
Freshwater (Spawning)	Adult	Hydrology and Oceanography	High Flows	98	Mortality or fitness reduction due to altered timing or magnitude of high flows		Low	Moderate	83
Freshwater (Spawning)	Adult	Hydrology and Oceanography	Low Flows	99	Mortality or fitness reduction due to altered timing or magnitude of low water levels		Low	Moderate	83
Freshwater (Spawning)	Adult	Water Quality	Temperature	100	Mortality, fitness reduction, delayed spawning or pre-spawn mortality due to unfavourable water temperatures		High	Very High	83

Ecosystem Unit	Life Stage	Limiting Factor Category	Limiting Factor Subcategory	LF ID	Limiting Factor	Confidence (If Noted)	Current Risk	Future Risk	Page
Freshwater (Spawning)	Adult	Water Quality	Temperature – Porcupine River	100a	Mortality, fitness reduction, or delayed spawning due to unfavourable water temperatures – Porcupine River		Very High	Very High	84
Freshwater (Spawning)	Adult	Water Quality	Dissolved Oxygen	101	Mortality or fitness reduction as a result of low dissolved oxygen		Very Low	Very Low	84
Freshwater (Spawning)	Adult	Water Quality	Chemistry	102	Mortality or fitness reduction due to unfavourable water chemistry		Low	Moderate	84
Freshwater (Spawning)	Adult	Water Quality	Contaminants and Deleterious Substances	103	Mortality or fitness reduction due to contaminants or deleterious substances		Low	Moderate	84
N/A	N/A	Population	Genotypic Effects	104	Mortality or fitness reduction due to a reduction in natural (wild) genetic diversity	Low / Medium	Moderate	Moderate	85
N/A	N/A	Population	Genotypic Effects	104a	Mortality or fitness reduction due to a reduction in natural (wild) genetic diversity due to genetic drift effects on select small populations		High	Data Gap	85
N/A	N/A	Population	Phenotypic Effects	105	Mortality or fitness reduction due changes in biological characteristics such as fecundity, egg quality or quantity, maturation rate, sex ratios, size at age, etc.	Medium	High	Very High	85
N/A	N/A	Population	Traditional Knowledge	106	Mortality or fitness reduction due to the loss of respect or relationship with people		High	Very High	86